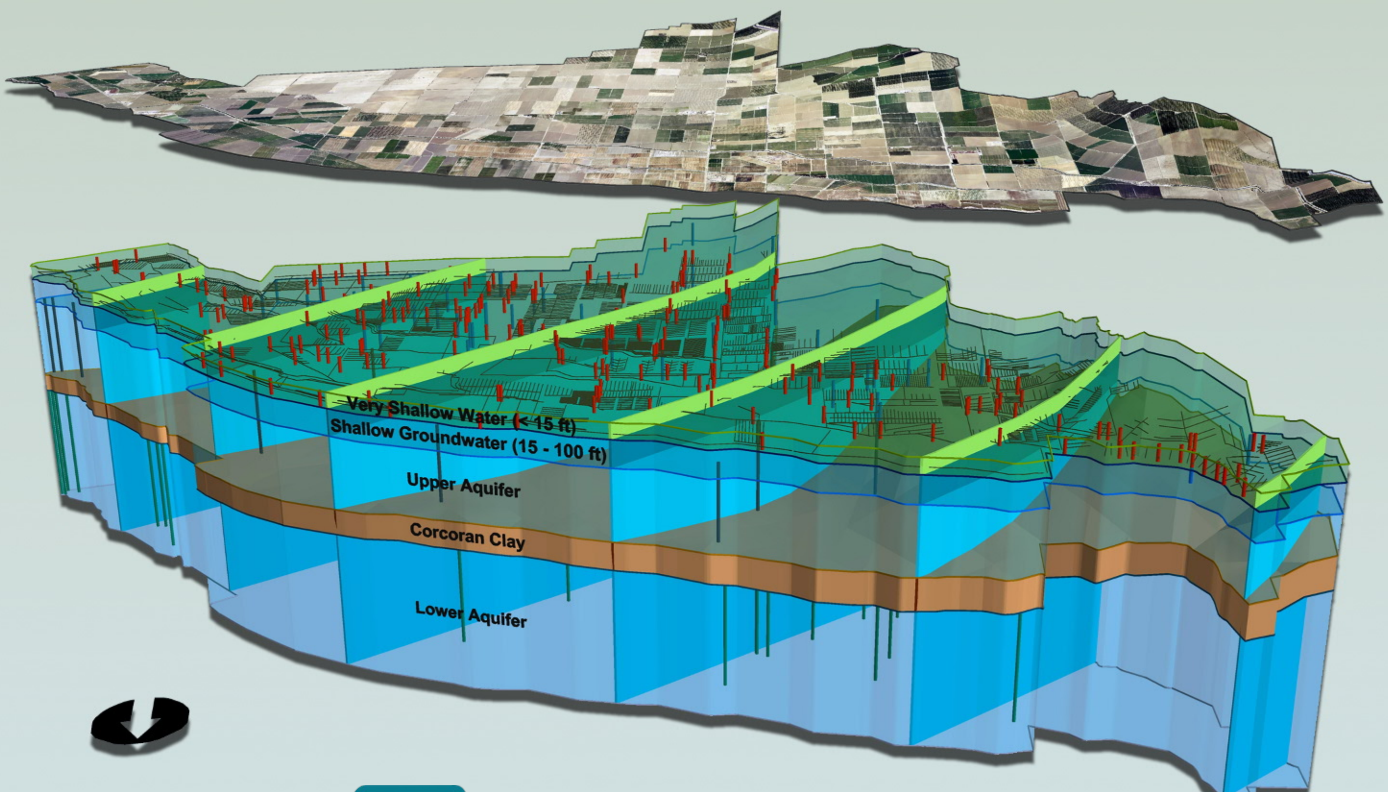


Grassland Drainage Area
Groundwater Quality Assessment Report

July 2016



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Prepared For

Grassland Basin Drainage Steering Committee

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LIST OF ABBREVIATIONS & ACRONYMS

af	Acre-feet
as N	As nitrogen
Bgs	Below Ground Surface
Regional Board	Central Valley Regional Water Quality Control Board
CALVUL	California Vulnerability approach
CASGEM	California Statewide Groundwater Elevation Monitoring
CDP	Census Designated Place
CDPH	California Department of Public Health
CVHM	Central Valley Hydrologic Model
CVPIA	Central Valley Project Improvement Act
DAC	Disadvantaged Community
DDW	Division of Drinking Water, State Water Resources Control Board
DEM	Digital elevation model
DPR	California Department of Pesticide Regulation
dS/m	Decisiemens per meter
DUC	Disadvantaged Unincorporated Community
DWP	California Department of Public Health Drinking Water Program
DWR	California Department of Water Resources
EC	Electrical conductivity
EHIB	Environmental Health Investigations Branch
ft/day	Feet per year
GAMA	Groundwater Ambient Monitoring Assessment program
GAR	Groundwater Quality Assessment Report
GDA	Grassland Drainage Area
GIS	Geographic Information Systems
GDA HVA	High Vulnerability Area defined for the GDA
GWPA	Groundwater Protection Area
HHVA	Hydrogeologic High Vulnerability Area
HWVA	High Well Vulnerability Area
IAZ	Initial Analysis Zones

ILP	Irrigated Lands Program
ILRP	Irrigated Lands Regulatory Program
lbs/ac	Pounds per acre
LSCE	Luhdorff & Scalmanini, Consulting Engineers, Inc.
LTILRP	Long-Term Irrigated Lands Regulatory Program
MCL	Maximum Contaminant Level
mg/L	Milligrams per liter
mg/L/yr	Milligrams per liter per year
MRP	Monitoring and Reporting Program
N_2	Nitrogen
NED	National Elevation Dataset
NH_3	Ammonia
NH_4	Inorganic nitrogen
NHI	Nitrate Groundwater Pollution Hazard Index
NO_2	Nitrite
NO_3	Nitrate
NRCS	Natural Resource Conservation Service
NWIS	National Water Information System
PCPA	Pesticide Contamination Prevention Act
PLSS	Public Land Survey System
p-value	Corresponding Probability
PWS	Public Drinking Water System
QA/QC	Quality assurance/quality control
$R\text{-}HN_2$	Organic nitrogen
RWQCB	Central Valley Regional Water Quality Control Board
SJRIP	San Joaquin River Improvement Project
SMCL	Secondary MCL
Steering Committee	Grassland Basin Drainage Steering Committee
SWRCB	California State Water Resources Control Board
TDS	Total dissolved solids
µg/L	Micrograms per liter
UCD	University of California at Davis

USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WDR	Waste Discharge Requirement
Westside Coalition	Westside San Joaquin River Watershed Coalition
Westlands Coalition	Westlands Water Quality Coalition
WQM	CDPH Water Quality Monitoring

EXECUTIVE SUMMARY

This Groundwater Quality Assessment Report (GAR) has been prepared on behalf of the Grassland Basin Drainage Steering Committee (Steering Committee). The Steering Committee serves as the third-party group for growers within the Grassland Drainage Area (GDA). The Waste Discharge Requirements (WDR), General Order R5-2015-0095, which applies to growers within the GDA, were adopted by the Central Valley Regional Water Quality Control Board (Regional Board or RWQCB) on July 31, 2015. The GDA is bordered to the north by the Westside San Joaquin River Watershed Coalition (Westside Coalition) and to the south by the Westlands Water Quality Coalition (Westlands Coalition).

ES 1 Grassland Drainage Area

The Steering Committee serves as the third-party group for the growers within the GDA and associated member districts, although some growers in the area may elect to be regulated as individuals. The GDA encompasses a total area of approximately 104,000 acres, including approximately 98,000 acres[1] of agricultural cropland, of which about 86,500 acres are irrigated land, and about 5,500 acres are non-agricultural land.

Subsurface tile drains have been installed in considerable portions of the GDA and are used to capture water percolating below the root zone. The Grassland Bypass Project routes this drainage water out of the GDA through the Grassland Bypass Channel. The water captured by tile drain systems and the discharges from tile drains are covered under separate WDRs relating to the Grassland Bypass Project. The WDRs for irrigated agriculture within the GDA, only pertain to discharges to groundwater that are not captured by tile drainage systems.

The San Joaquin River Improvement Project (SJRIP) located within the GDA reuses drainage water on an area of about 6,000 acres. More than 5,000 acres within the SJRIP are planted with salt-tolerant crops for reuse of drainage water. The WDRs governing irrigated lands apply only to drainage water that is used to irrigate cropland with the GDA, including on the SJRIP.

ES 2 WDR Timelines Related to the GAR

The Regional Board's adoption of the WDR on July 31, 2015 starts the timeline for several requirements, including the requirement in the WDR Order (Section IV. A.) that, three months after adoption of the WDRs by the Regional Board, "the third-party will provide a proposed outline of the GAR to the Executive Officer that describes the data sources and references that will be considered in developing the GAR". Accordingly, the due date for submittal of the GAR outline was October 29, 2015. The GAR outline was submitted by the Steering Committee to the Regional Board on October 20, 2015, and the Regional Board sent a letter on November 12, 2015 approving the GAR outline. The RWQCB noted that the GAR outline met all requirements in the WDRs, Attachment B. In accordance with the WDRs, the due date for the GAR is set at one calendar year after adoption of the WDRs, which for the GDA is July 31, 2016.

[1] The acreages included here are based on data for 2014.

ES 3 Overview of the GAR

This GAR has been prepared in accordance with the outline submitted by the Steering Committed to the RWQCB on October 20, 2015. The GAR documents current groundwater quality in the GDA, including nitrate and salinity concentrations and trends, evaluates the influence of irrigated agriculture on groundwater quality, and provides a scientifically based classification system for evaluating and determining the relative groundwater vulnerability (higher or lower) for the GDA. Key components of the GDA GAR involved:

- Developing a representation of a physical conceptual model describing the hydrogeology and groundwater quality conditions (salinity and nitrate) in multiple depth zones and the relationships with Coast Range sediments to the west and Sierran Sands on the east side conceptualized as follows
    - Very Shallow Water zone of tile drains dominated by drainage water within 15 feet of ground surface,
    - Shallow Groundwater zone below very shallow water between 15 and 100 feet deep,
    - Semi-confined Upper Aquifer zone extending from 100 feet to the top of the Corcoran Clay,
    - Corcoran Clay (E Clay) member of the Tulare Formation from 40 to 140 feet thick, and
    - Confined Lower Aquifer below the Corcoran Clay;
- Evaluating the hydrogeologic sensitivity of the groundwater to naturally occurring salts and conditions related to the concentration of those salts;
- Evaluating the trends in nitrate and salinity, particularly in the Shallow Groundwater and the Upper Aquifer;
- Determining the physical factors associated with confinement of the Lower Aquifer that serves to lower the vulnerability of the Lower Aquifer to nitrate effects;
- Identifying the presence of saline groundwater in the Lower Aquifer associated with Coast Range sediments and/or from leakage through the Corcoran Clay, where it is thinner; and
- Identifying existing wells (currently monitored by GDA districts or others) that can potentially be used to fill data gaps and/or to meet future trend monitoring needs for the Steering Committee while avoiding expenses associated with constructing new monitoring wells.

The relative vulnerability of groundwater to irrigated land agricultural impacts is assessed based on: (1) hydrogeologic sensitivity, (2) overlying land uses and practices, and (3) groundwater quality observations (particularly nitrate but also salt and pesticide concentrations). Hydrogeologic sensitivity is a factor that is tied to the inherent physical characteristics of the geology and soils and underlying hydrogeologic and geologic conditions. Land use (location of cropping and management systems on the landscape, and locations of other non-agricultural land uses) is an indicator of potential groundwater quality stressors. The spatial relationship between the hydrogeologic sensitivity of an area, the overlying land use, and the proximity of groundwater serving urban and rural communities (particularly recharge areas upgradient of communities that rely on groundwater) is assessed.

This GAR outlines the different methods for assessing groundwater vulnerability that have been used to evaluate groundwater vulnerability, including approaches applied to assess vulnerability in California (e.g., California State Water Resources Control Board [SWRCB], California Department of Pesticide Regulation [DPR], Nolan et al., 2002, Dzurella et al., 2012), and presents the method developed for determining high vulnerability areas within the GDA. To determine high vulnerability areas, select statistical analyses and index overlay approaches were used based on observed groundwater quality, soil parameters, and hydrogeologic characteristics of the aquifer system beneath the GDA. The results from the groundwater vulnerability assessment were evaluated with respect to locations of observed exceedances of groundwater quality drinking water standards for nitrate, total dissolved solids (TDS), and pesticide detections. The method of determining groundwater vulnerability also attempts to account for differences in land use among the observations in order to decipher differences in groundwater quality that are related to hydrogeologic variables as opposed to differences in groundwater quality that are related to land use. Spatial data representing land use mapped at different snapshots in time, including the mid-1990s, early-2000s, 2008, and 2014, were utilized in the analyses described in the GAR to account for different land use conditions.

High vulnerability areas, where irrigated agriculture operations have impacted or are more likely to impact groundwater quality, are identified and prioritized in the GAR, and existing wells are identified that may satisfy future requirements to develop a Groundwater Quality Trend Monitoring network to track groundwater quality and its response to agricultural practices.

Following are summaries of key findings:

ES 4 Summary of Findings

ES 4.1 Hydrogeologic Setting

The GDA is located within the San Joaquin Groundwater Basin and in the Delta-Mendota Subbasin, extending from Merced County to Fresno County in the southeast direction (**Figure ES-1**). The primary groundwater bearing units consist of Tertiary and Quaternary-aged unconsolidated continental deposits and older alluvium, including geologic units of the Tulare Formation. The continental and alluvial deposits consist of layers of sand, gravel, silt, and clay that increase in thickness away from the margins of the valley. The hydrogeologic system within the GDA is characterized by four distinct zones, including a Very Shallow Water zone (0 to 15 feet below ground surface), a Shallow Groundwater zone (15 to 100 feet below ground surface), an Upper Semi-Confined zone (Upper Aquifer) (100 feet to the top of the Corcoran Clay), and a Lower Confined zone (Lower Aquifer) starting at the bottom of the Corcoran Clay to the base of fresh water.

The Tulare Formation is hydrologically the most important geologic formation in the GDA because it contains many fresh water-bearing deposits. The Tulare Formation extends to the base of freshwater throughout most of the area and is comprised of stratigraphic layers of clays, silts, sands, and gravels and includes the Corcoran Clay (E-Clay) member, a diatomaceous clay or silty clay of lake bed origin which is a prominent aquitard and impediment to vertical hydraulic communication between the Upper Aquifer from the Lower Aquifer. The depth to the Corcoran Clay varies from 200 to 500 feet below ground surface, generally deepening toward the southeast and thickening up to 140 feet towards the northwest center of the GDA. The Corcoran Clay pinches out (does not exist) just west of Interstate-5 located along the GDA, which means that recharge of high TDS Diablo Range groundwater is not impeded by the Corcoran Clay most notably in the vicinity of the upper Little Panoche Creek fan head. The Lower Aquifer is the portion of the Tulare Formation that is confined beneath the Corcoran Clay extending downward to the underlying San Joaquin Formation and the interface of salty water of marine origin within its uppermost beds. The Upper and Lower Aquifers represent the primary sources of supply for groundwater used for agricultural and drinking water purposes within the GDA.

Most of the natural recharge that occurs in the GDA is in the alluvial fan apex areas along the intermittent Coast Range streams, although deep percolation of applied irrigation water is also a source of recharge. Changing irrigation technologies are reducing deep percolation from irrigation water. Secondary recharge to areas near the valley axis occurs from subsurface flow from the east (DWR, 2003). Groundwater quality within the GDA is variable and commonly reflects the chemical composition of the contributing streams and the subsurface sediments through which groundwater has flowed. Naturally high concentrations of TDS in groundwater within the GDA have existed historically due to the geochemistry of the Coast Range rocks, the resulting naturally high TDS of recharge derived from Coast Range streams, the dissolvable materials within the alluvial fan complexes, and the naturally poor draining conditions which tend to concentrate salts in the system.

Soils of low hydraulic conductivity, corresponding with extensive floodplain deposits, blanket much of the GDA, although higher hydraulic conductivity soils occur along modern and ancient surface watercourses and in association with alluvial fan features. The Shallow Groundwater and Upper Aquifer zones have relatively higher vertical hydraulic conductivity in the vicinity of the Little Panoche Creek alluvial fan and along the east side of the GDA. Alluvium within the Upper Aquifer associated with the San Joaquin River system, where Sierran alluvial fan materials sourced from the east side of the valley have extended into the GDA, are also evident in the cross-sections. Higher quality groundwater can be associated with these Sierran sediments that are generally coarser-grained and composed of relatively less dissolvable minerals compared to other sediments derived from Coast Range sources.

The Very Shallow Water constitutes drainage water within the zone of subsurface tile drainage systems and does not represent a supply of water for drinking uses within the GDA. Shallow Groundwater and the Upper Aquifer zones include geologic units of younger and older alluvium and upper parts of the Tulare Formation. The Corcoran Clay is a notable hydrogeologic feature throughout most of the GDA that acts as an aquitard and impediment to vertical hydraulic communication between the Upper and Lower Aquifers. The Corcoran Clay is present at depths ranging between approximately 200 and 500 feet with a general spatial pattern of deepening to the south with the thickest areas in the northern central parts of the GDA. The thickness of the Corcoran Clay, which is greater than 50 feet in most areas of the GDA, but ranges from 40 feet to more than 140 feet thick, is believed to provide some degree of hydraulic separation between the Upper and Lower Aquifers. The Lower Aquifer is the portion of the Tulare Formation that is confined beneath the Corcoran Clay extending downward to the underlying San Joaquin Formation and the interface of salty water of marine origin within its uppermost beds. The Upper and Lower Aquifers represent the primary sources of supply for groundwater used for agricultural and drinking water purposes within the GDA.

ES 4.2 Groundwater Hydrology

Characterization of groundwater conditions within the GDA requires understanding groundwater depths and elevations. Data on groundwater depth/elevation provide important information with which to interpret hydrogeologic conditions, including spatial and temporal patterns in flow direction, groundwater level trends, potential groundwater recharge and discharge areas, and other conditions. Groundwater level data from within and around the GDA were compiled into a water level database.

For the purposes of differentiating and evaluating water level trends within the depth zones of the hydrogeologic system, all wells were categorized by depth as interpreted from available information in the database. Groundwater level data were grouped into four depth categories (Very Shallow Water, Shallow Groundwater, Upper Aquifer, and Lower Aquifer) according to the zone which they are interpreted to represent in terms of hydraulics.

ES 4.2.1 Groundwater Levels

Regionally, groundwater elevation decreases from the valley perimeter to the valley axis – in the GDA this translates to a northeast decrease in groundwater elevation for depth zones above the Corcoran Clay. The recent depth to water in the Very Shallow Water zone ranges from less than 5 to more than 15 feet below ground surface, generally deepening in the fan head areas of the western side of the GDA and a shallower depth toward the northeast GDA. The elevation of water in the Very Shallow Water zone generally follows the land surface decreasing towards the northeast.

Depth to groundwater within the Shallow Groundwater zone ranges from more than 50 to less than 10 feet below ground surface and groundwater flow is generally toward the northeast.

The recent depth to the groundwater within the Upper Aquifer ranges from 30 to 140 feet below the ground surface with deeper areas toward the Coast Ranges and along the Delta-Mendota Canal in the vicinity of the SJRIP with generally northeast groundwater flow directions and an area of lower groundwater in the vicinity of the SJRIP that could correspond to groundwater pumping.

The recent depth to the groundwater potentiometric surface within the Lower Aquifer generally deepens toward the southeast of the GDA**,** corresponding to a trough-like depression indicated by the Lower Aquifer groundwater elevation surface throughout the central GDA. Within the Lower Aquifer groundwater flows in a southwestern direction from the valley axis toward the central GDA in addition to northeastern groundwater flows originating from the Coast Ranges.

Calculated head differences between depth zones suggests that there are heads are generally lower with depth across much of the GDA suggesting there may be potential for downward vertical movement of water between depth zones in the GDA. However, upward gradients in some areas are apparent within the Shallow Groundwater zone from comparison of hydrographs for select well pairs.

ES 4.2.2 Recharge Upgradient of Communities Reliant on Groundwater

Areas with higher relative potential for groundwater recharge are identified from soil and sediment properties and primarily include areas on the western margins of the GDA where coarser sediments associated with alluvial fan deposits exist. To inform the prioritization of groundwater management and monitoring efforts, communities reliant on groundwater within the GDA were identified based on Census Designated Places (CDP), Disadvantaged Communities (DACs), Disadvantaged Unincorporated Communities (DUCs) from Policylink (2012), and Public Drinking Water System (PWS) wells from DDW. These communities were evaluated with respect to reliance on groundwater using the DDW DRINC web portal and queries with wells identified in the DDW WQM dataset. Upgradient areas contributing groundwater to these communities were calculated from the recent spring groundwater elevation surfaces for the Shallow Groundwater, Upper Aquifer, and Lower Aquifer zones.

ES 4.3 Land Use

Characterizing changes in land use, irrigation, and fertilization practices over time supports understanding of past, current, and potential future groundwater quality, as these practices have the potential to affect groundwater quality. Quantitative and qualitative assessment of the spatial distribution of agricultural cropping and practices and assessing the intensity of effects on groundwater quality support the development of effective groundwater quality monitoring and management strategies. Additionally, documenting past and present land use and practices is critical in assessing groundwater vulnerability. In 2014, the irrigated crop area was approximately 86,500 acres based on data from U.S. Department of Agriculture (USDA) and provided by the GDA districts. Idle agricultural land was the top agricultural land use by acreage in 2014 with approximately 86,500 acres. Vegetables were the top agricultural crop category in 2014 with just over 17,000, closely followed by pasture and alfalfa with an estimated 14,321 acres. Grain, nut trees, and field crops are the next most common crops by acreage. Together these crops represent over 90 percent of the irrigated crop area within the GDA in 2014. California Department of Water Resources (DWR) and USDA data suggest a decrease in cultivated agricultural land of approximately 26,700 acres between the 1990s and 2014, although some of this decrease is likely a result of temporary idling of land in 2014 caused by drought conditions. Primary changes in agricultural cropping between the 1990s and 2014, based on DWR and USDA data, include an increase in idle cropland of 28,300 acres (400 percent), an increase in nut trees by 10,000 acres (220 percent), and a decrease in field crops by 44,900 acres (83 percent).

Available irrigation method data from the circa-2000 DWR land use surveys and additional data obtained from GDA districts were used to characterize changes in irrigation technology over time. Between approximately 2000 and 2015, the use of microirrigation increased nearly 80 percent less than 4 percent to more than 83 percent of the irrigated crop area. This likely reflects a combination of a shift to microirrigation for crops traditionally irrigated using gravity techniques and a shift from crops commonly irrigated via gravity (e.g., field crops) to crops typically irrigated using microirrigation (e.g., nut trees).

Nitrogen use by crop category is summarized based on data from literature for 1973 and 2005. These data indicate that vegetables have the greatest typical application rate with reported typical application rates for 2005 of 177 to 182 pounds per acre (lbs/ac) for tomatoes, 179 lbs/ac for almonds, and 177 lbs/ac for grain (Rosenstock et al., 2013). Viers et al. (2012) report a typical nitrogen application rate for alfalfa for 2005 of 12 lb/ac. Typical application rates increased between 1973 and 2005 for vegetables, nut trees, grain, field crops, seeds and beans, and rice. In contrast, nitrogen application rates appear to have decreased for alfalfa and vineyards. Typical rates for fruit trees appear to have remained about the same over this period, on average.

ES 4.4 Groundwater Quality

ES 4.4.1 Historical Presence of High Salinity in Shallow Groundwater

The presence of natural salinity conditions in groundwater throughout the GDA has existed historically as a result of the natural hydrogeologic setting. Natural conditions of groundwater salinity exist throughout all zones of the groundwater system as a result of the contribution of salts from recharge off of the Coast Range mountains. Areas of the GDA are underlain by low-permeability, fine-grained floodplain sediments and clays which impede vertical movement of groundwater, often resulting in poor drainage conditions, shallow groundwater stagnation, and associated accumulation of salts.

ES 4.4.2 Nitrate and TDS Concentrations

To characterize groundwater quality within the GDA, as it relates to impacts from irrigated agriculture, water quality data were gathered from a variety of different sources including GDA districts, U.S. Geological Survey (USGS), DDW, DWR, SWRCB, and RWQCB. Over 700 nitrate test results were compiled from 260 tile drains and wells and nearly 45,000 TDS test results were compiled from more than 600 tile drains and wells distributed throughout the GDA. Pesticide data were provided by DPR although the locations for the wells provided by DPR are specified only to the public land survey system (PLSS) section. Additional data for selenium and boron concentrations were also acquired and evaluated.

About one third of the sites for which nitrate data are available represent the Very Shallow Water zone. The maximum nitrate concentrations for most of the Very Shallow sites are above 10 milligrams per liter (mg/L). Comparison of the maximum and most recent nitrate concentrations suggests that there are minimal differences between these concentrations. The Shallow Groundwater also exhibits elevated nitrate concentrations in areas, although a mixture of sites with low nitrate concentrations is also apparent. Within the Shallow Groundwater zone, recent nitrate concentrations suggest there are slight improvements relative to maximum concentrations. Nitrate data for both the Very Shallow Water zone and the Shallow Groundwater zones have spatial data gaps and are particularly scarce near the town of Mendota. Data representing nitrate concentrations in deeper zones including the Upper Aquifer and Lower Aquifer suggest that concentrations are notably lower than in the Very Shallow Water and Shallow Groundwater. Although few wells with nitrate data are available for the Upper and Lower Aquifers (20 wells combined), they exhibit considerably reduced nitrate concentrations with most below 2.5 mg/L. Statistical analysis conducted on data indicate few sites with statistically significant temporal trends in nitrate concentrations. The few significant trends indicated suggest a mixture of decreasing and increasing nitrate concentrations within different depth zones although few notable patterns in these temporal trends are evident because of the limited number of sites with statistically significant trends.

Approximately half of the wells with TDS data are located in the Very Shallow Water zone. The majority of these sites have maximum historical concentrations exceeding 3,000 mg/L, but some improvement is indicated in the most recent concentrations. Such improvements are indicated in the area bounded by the Delta-Mendota Canal, Merced-Fresno county line, and W. Nees Avenue. In the Shallow Groundwater zone, a pattern of increasing TDS values to the east is evident with a majority of the wells located to the east N Russell Avenue exceeding 3,000 mg/L in contrast with the high number of wells to the west of N Russell Avenue with concentrations below 1,000 mg/L. Few wells in the Upper Aquifer have TDS concentration data and all available data points exceed 1,000 mg/L. The majority of the wells in the Lower Aquifer with TDS concentrations also have values above 1,000 mg/L. Most of the wells with TDS data in the Lower Aquifer are in the central part of the GDA. The most recent TDS concentrations in the Lower Aquifer also indicate values above. 1,000 mg/L.

Statistical analyses of temporal trends in TDS concentrations indicate a mixture of increasing and decreasing TDS concentrations in sites in the Very Shallow Water. Increasing trends exist in the northwestern-most tip of GDA although sites with decreasing trends slightly more common than increasing trends in the rest of the GDA. The Shallow Groundwater and Lower Aquifer zones have wells with generally increasing TDS concentrations along the Merced-Fresno county line; however, one well in the Lower Aquifer zone in this area has a decreasing TDS concentration trend.

ES 4.4.3 Pesticide Detections

Pesticide data from DPR indicate that three PLSS sections overlapping the GDA had a well with a historical pesticide detection. Of these sections, one section had a single well with historical pesticide concentrations that exceeded the water quality objectives.

ES 4.4.4 Selenium and Boron Concentrations

In addition to nitrate, TDS, and pesticides, data for selenium and boron concentrations were also evaluated. In the zone of Very Shallow Water, the majority of data indicate historical maximum selenium concentrations above 50 micrograms per liter (µg/L), although many of the sampled sites have recent selenium concentrations that are lower than the maximum values. This trend is most apparent in the area bounded roughly by the Merced-Fresno county line, W. Nees Avenue, and N. Russell Avenue where the majority of Very Shallow Water sites have concentrations below 20 µg/L. Selenium concentrations in the Shallow Groundwater zone exhibit lower maximum concentrations compared to the Very Shallow Water. Although many Shallow Groundwater wells have selenium concentrations above 50 µg/L, concentrations appear to be considerably lower in the western parts of the GDA where about one half of the wells have concentrations below 20 µg/L. The most recent concentrations in selenium suggest a decreasing trend as many of the wells have concentrations below 20 µg/L. Very limited data are available for selenium concentrations in the Upper Aquifer zone; of the available data, most of the wells indicate concentrations below 20 µg/L. Data for selenium concentrations in the Lower Aquifer zone are also very limited although the available selenium data suggest that maximum concentrations are much lower in the Lower Aquifer than in shallower zones with the majority of concentrations below 5 µg/L.

For boron, there are sparse data available for Very Shallow Water and nearly all observed boron concentrations in Very Shallow Water have maximum historical concentrations exceeding 5 mg/L. Most of the Shallow Groundwater data are located in the area between the Merced-Fresno county line and N. Fairfax Avenue. All of the Shallow Groundwater wells have maximum historical boron concentrations above 1 mg/L, with the majority of wells showing concentrations above 2 mg/L. The most recent boron concentrations in Shallow Groundwater include a greater number of wells with values below 1 mg/L. The sparse available boron data in the Upper Aquifer suggest boron concentrations generally in the range of 2 to 5 mg/L. A majority of the wells in the Lower Aquifer with boron data have concentrations between 2 and 5 mg/L although nearly an equal number of wells have concentrations between 1 and 2 mg/L. Notably decreased boron concentrations are apparent in the more eastern parts of the GDA whereas the highest concentrations of boron in the Lower Aquifer are apparent near the Merced-Fresno county line.

Statistical analyses of temporal trends in selenium and boron concentrations. The majority of the Very Shallow Water sites with statistically significant trends exhibit decreasing trends. The only well with a significant trend in the Lower Aquifer zone also has a decreasing trend.

Boron concentrations in the Very Shallow Water, Shallow Groundwater, and Lower Aquifer zones appear to be somewhat lower in the most recent testing than the historical maximum. However, due to the scarce amount of data, few statistically significant temporal trends in boron concentrations were identified. Only two wells in the Lower Aquifer have significant trends but both suggest that boron concentrations have changed very little.

ES 4.4.5 Other Water Quality Constituents

The focus of this GAR was on acquiring and summarizing general groundwater quality in the GDA based on chemical constituent data that are widely available and most commonly associated with impacts from irrigated agricultural practices. As a result, the acquisition and summary of groundwater quality data for this GAR focused on nitrate, TDS, pesticides, and to a lesser extent selenium and boron. Other published reports were reviewed to document regional groundwater quality characteristics other than nitrate, TDS, pesticides, selenium, and boron within the GDA. Concentrations of trace metals and numerous chemical constituents in groundwater were investigated across the Delta-Mendota Subbasin region by the USGS in 2010 as part of the SWRCB Groundwater Ambient Monitoring Assessment (GAMA) Program's Priority Basin Project and the results as summarized by Mathany et al. (2013) are included in this GAR. Water quality analyses conducted on samples from 45 wells within the Delta-Mendota Subbasin area indicate that most inorganic constituents in groundwater in the region are present at concentrations below Primary and Secondary maximum contaminant levels (MCLs), although many of wells sampled by Mathany et al. (2013) are not directly located within the GDA.

ES 4.5 Groundwater Vulnerability and Prioritization

ES 4.5.1 Approach

The approach for determining groundwater vulnerability in this GAR is modeled after the definition of *intrinsic vulnerability* as defined and discussed above and focuses on determining the vulnerability of groundwater to contaminants based on the intrinsic physical properties of the area. Intrinsic physical properties remain relatively static over time and represent conditions that are generally beyond control from management decisions. In contrast, influences from human activities as a result of land use are subject to major changes in trends over short periods of time. Consequently, a measure of groundwater vulnerability that is based on intrinsic physical properties independent of land use conditions is advantageous because physical characteristics of the watershed are less likely to undergo such rapid and major shifts in characteristics. From a practical standpoint, an assessment of groundwater vulnerability that is tied to land use would need to be adjusted in response to changes in land use. Land use considerations were incorporated throughout the process of determining high vulnerability areas.

ES 4.5.2 Conceptual Model

The groundwater vulnerability assessment for the GAR is grounded on a conceptual model in which the observed groundwater quality is the result of interactions between land use practices at the surface and the presence of physical hydrogeologic characteristics and processes occurring at a location. Under this conceptual model, the presence of hydrogeologic characteristics that enable potential contaminants to reach groundwater surface faster make a location more vulnerable to groundwater contamination than a location with hydrogeologic characteristics that impede the ability of contaminants to reach groundwater or attenuate the contamination. Accordingly, hydrogeologic processes and characteristics such as soil properties, the ability of subsurface materials to transmit water, lack of barriers (clay layers) to vertical movement of water, and depth to groundwater are expected to influence the vulnerability of a location to groundwater contamination.

Nitrate is a widespread contaminant in groundwater in the United States which has been primarily associated with anthropogenic influences, including agricultural fertilization activities, leaching from septic tanks and sewer facilities, confined animal feeding operations, discharge to land of wastewater, food processor waste, unprotected wellheads, improperly abandoned wells, and lack of backflow prevention on wells. Nitrate contamination is also one of the primary groundwater quality concerns in areas of irrigated agriculture in the Westside Coalition region. As an essential nutrient for plant growth, nitrogen is a component in many fertilizers that has been applied in agricultural areas for many decades. Nitrate is the dominant form of nitrogen in groundwater, and nitrate concentrations are regulated throughout the State of California. Naturally-occurring concentrations of nitrate in groundwater are typically very low, although research in the western San Joaquin Valley suggests that naturally occurring nitrogen and nitrate can be high in soils derived from some Coast Range rocks. Despite this recognition, because the locations and degree to which naturally occurring soil nitrogen may influence nitrate concentrations in the groundwater is not well documented, for the purposes of the vulnerability assessment conducted for this GAR, observations of nitrate in the groundwater are considered to be primarily a function of the application of nitrogen through fertilization practices (where applicable) at the surface and subsequent processes of transporting the contaminant through the subsurface into the groundwater. Nitrate concentrations are a more useful indicator of influence from irrigated agriculture than some other more commonly available groundwater quality measures such as TDS or electrical conductivity (EC), which indicate general water salinity and are known to occur naturally in high concentrations throughout many parts of the GDA.

ES 4.5.3 Methods

The approach to determining groundwater vulnerability developed in this GAR is based on adaptations to index- and overlay-based methods and incorporates identification of important physical variables based on the results from statistical analyses and comparisons conducted for the GDA and also for the Western San Joaquin River Watershed GAR. Bivariate comparisons were used to evaluate potential relationships between physical characteristics and groundwater quality. Results from multiple regression analyses for the Western San Joaquin River Watershed GAR were used to identify significant relationships between hydrogeologic characteristics and observed groundwater quality conditions across the greater GDA region, while controlling for different land use types. Analyses were conducted to identify relationships between physical characteristics and vulnerability within the context of the hydrogeologic system present within the GDA consisting of four depth zones (a zone of Very Shallow Water, a Shallow Groundwater zone, a semi-confined Upper Aquifer, and a confined Lower Aquifer below the Corcoran Clay). Hydrogeologic variables investigated focused on soil drainage class, soil hydraulic conductivity, and deeper subsurface sediment texture. Only hydrogeologic variables that could be evaluated in a manner consistent with the conceptual model were considered in the vulnerability assessment. Evaluating vulnerability within the GDA was challenging due to the complex hydrogeologic setting and data limitations. Considerable area within the GDA has subsurface tile drain systems which effectively intercept percolating water and other water in the zone of Very Shallow Water. These drains were installed mainly in the 1960s and 1970s, and their existence and timing of installation made quantitative approaches to assessing groundwater vulnerability within the GDA very difficult.

ES 4.5.4 High Vulnerability Area for the Grassland Drainage Area

Considering mechanisms and processes relating to vulnerability based on quantitative and qualitative comparisons, thresholds indicating high vulnerability for physical factors believed to be important for groundwater vulnerability were determined and adjusted using qualitative assessments based on professional judgment and using comparisons of areas relative to observed nitrate concentrations, especially exceedances. Following this process, a Hydrogeologic High Vulnerability Area (HHVA) was defined and represented largely by soils with high hydraulic conductivity and relatively well draining characteristics. Minor adjustments to the HHVA were made in the vicinity of nitrate exceedances and in select areas along the western edge of the GDA where available data relating to groundwater and hydrogeologic conditions are limited. In the southwestern part of the GDA, additional information relating to more local groundwater and subsurface conditions were reviewed and an area west of the

California Aqueduct was excluded from the HHVA based on this review. The HHVA encompasses most wells with elevated nitrate concentrations. The locations of wells with maximum historical nitrate concentrations of 10 mg/L as nitrogen (as N) or greater were incorporated through delineation of high well vulnerability areas (HWVAs) through inclusion of a 0.5-mile radius around outlier wells when they are located away from the HHVA.

Areas with subsurface tile drains exist to intercept percolating water from applied irrigation and other Very Shallow Water and act to effectively limit downward vertical movement of water quality constituents from irrigated agriculture. These areas are considered lower vulnerability areas, including where they are in soils of higher hydraulic conductivity and drainage characteristics, except where they are within 0.5 miles of an observed nitrate exceedance. HWVAs were defined around nitrate exceedance wells located away from the HHVA.

The high vulnerability area defined for the GDA (GDA HVA) includes the combined HHVA and HWVA areas and totals 27,794 acres, of which 24,659 acres are irrigated land. The GDA HVA and associated acreages are presented in **Figure ES-2** and **Table ES-1**.

ES 4.5.5 Prioritization of GDA HVA

All areas within the GDA HVA were prioritized for planning of future monitoring and management efforts. In accordance with factors identified in the WDR, prioritization incorporated many considerations including, but not limited to, the following:

- Identified exceedances of water quality objectives,
- Proximity to communities reliant on groundwater,
- Existing land uses, and
- Legacy or ambient groundwater conditions.

Additional factors were included to incorporate the vulnerability of areas. To objectively incorporate the many factors to be considered, a prioritization system was developed with which to calculate priority values across the high vulnerability area. From these priority calculations, priority areas ranging from priority 1 (high priority) to priority 4 (low priority) were identified to inform groundwater monitoring and management efforts. The results of the prioritization of the GDA HVA are presented in **Figure ES-3** and summarized in **Table ES-1**.

ES 4.6 Groundwater Monitoring Programs

A variety of different agencies have historically monitored groundwater conditions in the GDA. DWR, DDW, USGS, and the GDA districts maintain data which are updated somewhat regularly with new information. DWR and USGS have the largest data sets available for the study area for both groundwater levels and groundwater quality parameters, although the GDA districts and the Steering Committee have been monitoring Very Shallow Water with regularity.

An extensive data collection effort was conducted for this GAR. However, despite all the data collected, supporting information regarding samples was often times incomplete or non-existent. Many wells are lacking well depths and perforation data and recent data for some groundwater quality parameters are scarce. In particular, data are lacking for nitrate concentrations, especially in the Upper Aquifer.

Many of the wells for which data are available were assigned to a depth zone based on their use type, when well depth information is not known. Identification of well construction information will be important for any wells chosen as part of a future monitoring program to ensure the program is properly designed to meet its objectives. If depth or other construction information is not readily known, it may be advantageous to obtain this information through construction logs or other well records, in order to consider a well for inclusion as part of a monitoring program.

Recent water quality samples consist of TDS and selenium data more than other constituents. Only 33 samples were collected for nitrate since 2010. Additional monitoring for nitrate will be needed for future monitoring programs in the GDA. In addition, the majority of the wells with nitrate samples are located in the Very Shallow Water and Shallow Groundwater zones with much less data in the Upper Aquifer and Lower Aquifer.

Spatial data gaps exist in recent monitoring along the California Aqueduct and southeast of the N. Fairfax Avenue and W. Nees Avenue for water quality in the Very Shallow Water zone. Only a small area southeast of the N. Fairfax Avenue and W. Nees Avenue intersection has monitoring in the Shallow Groundwater since 2010. Similarly, the majority of the recent groundwater monitoring in the Upper Aquifer is limited to areas along the canals in the northern portion of the GDA. Recent monitoring of the Shallow Groundwater and Upper Aquifer are limited in the GDA HVA. Relatively few wells in the Lower Aquifer that have been monitored recently with few wells in the GDA HVA. Recently monitored wells of unknown depth provide addition future monitoring opportunities for consideration if depth information can be obtained.

Wells in the Shallow Groundwater and Upper Aquifer zones within the GDA HVA will be important for monitoring networks as these wells will be best suited for characterizing the impact of changing irrigation practices; however, as described above, there is a lack of recently monitored wells, particularly for the Upper Aquifer in the GDA. Further investigation of historically, but not recently, monitored wells may increase the coverage of wells for monitoring the Upper Aquifer zone.

Table ES-1
Summary of Acreages for the GDA High Vulnerability Area

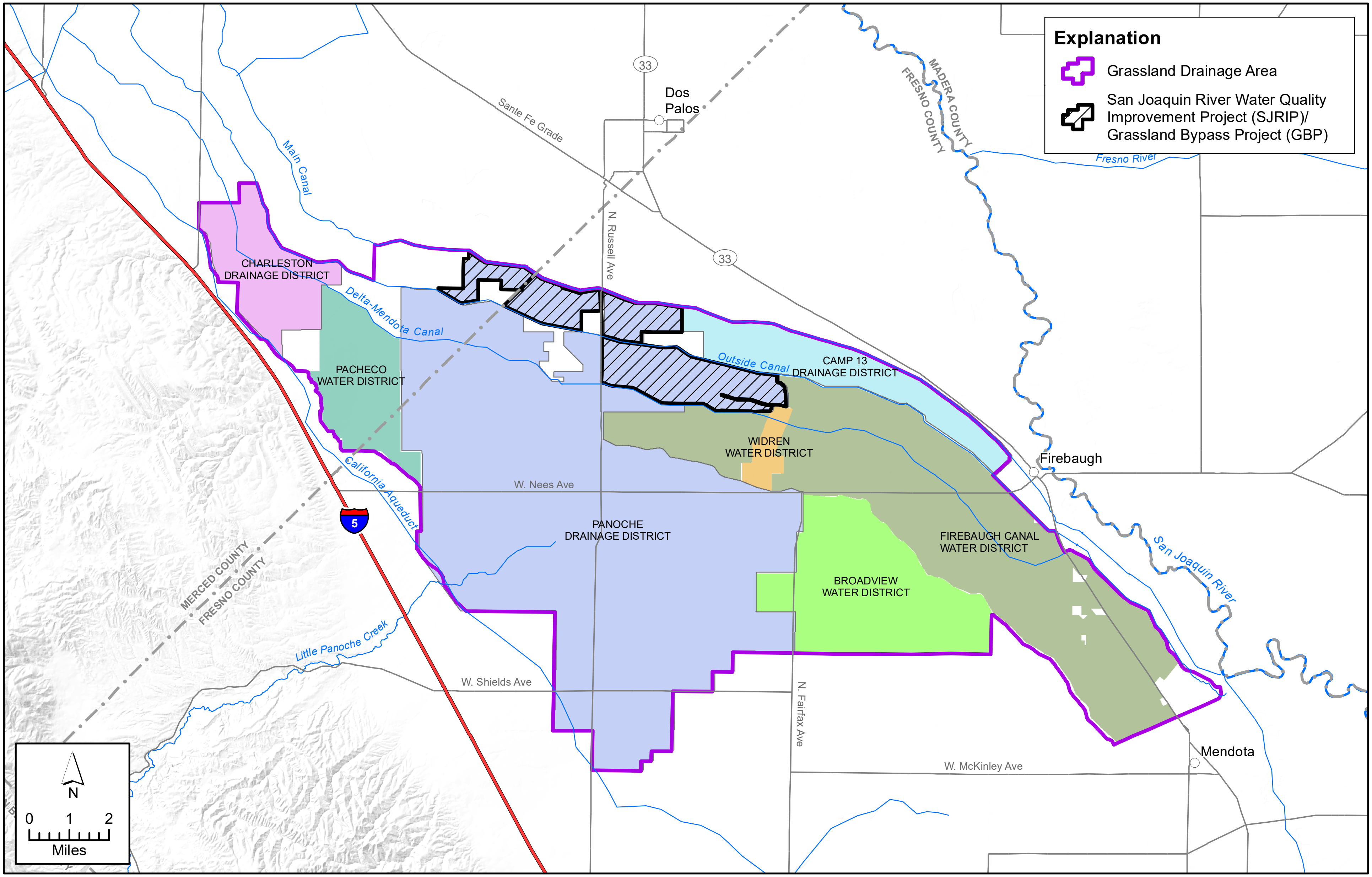
Area Description	Total Within GDA (Acres)	Within Irrigated Area* (Acres)
High Vulnerability Area (GDA HVA)[1]	**27,794**	**24,659**
Prioritization of High Vulnerability Area (GDA HVA)[2,3]	**27,512**	**24,412**
Priority 1	6,229	5,898
Priority 2	6,628	6,042
Priority 3	7,219	6,301
Priority 4	7,437	6,170

* Includes irrigated land as identified from 2014 USDA and GDA districts data.

[1] Acreage values for GDA HVA as reported on Table 6-3.

[2] Acreage values reported for prioritized areas differ from those on Table 6-3 because of gridding used during the prioritization process.

[3] Priority areas are in order from highest (1) to lowest (4).



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure ES-1 Grassland Drainage Area Member Districts.mxd

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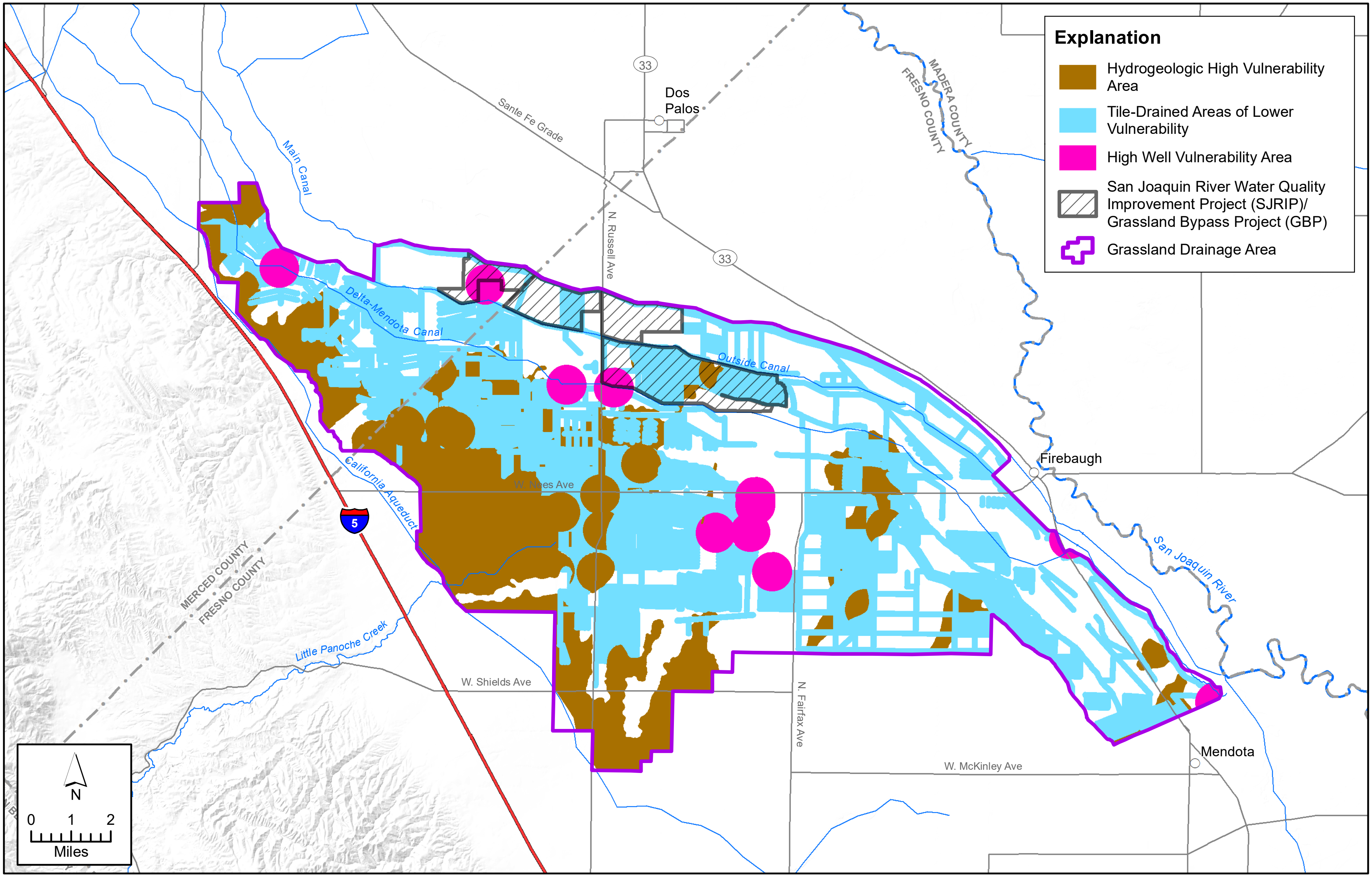
FIGURE ES-1
Map of Grassland Drainage Area Coalition Member Districts
Grassland Drainage Area Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure ES-2 High Vulnerability Area Components.mxd

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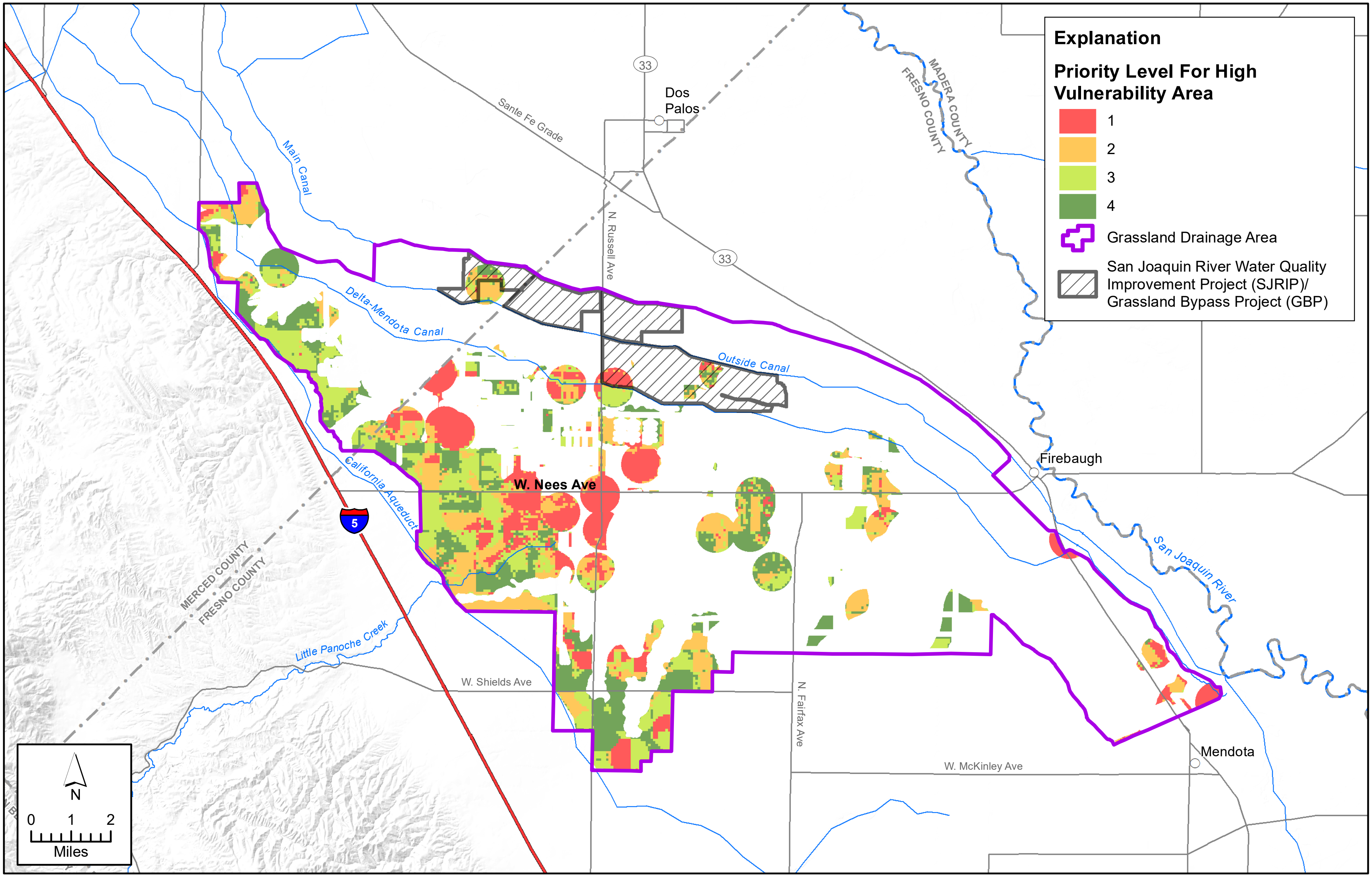
FIGURE ES-2

Map of High Vulnerability Area Components

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure ES-3 Map of Prioritization of the GDA High Vulnerability Area.mxd

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FIGURE ES-3
Map of Prioritization of the GDA High Vulnerability Area
Grassland Drainage Area
Groundwater Quality Assessment Report

1 INTRODUCTION

This Groundwater Quality Assessment Report (GAR) has been prepared on behalf of the Grassland Basin Drainage Steering Committee (Steering Committee). The Steering Committee serves as the third-party group for growers within the Grassland Drainage Area (GDA) (**Figure 1-1**). The Waste Discharge Requirements (WDR), General Order R5-2015-0095, which applies to growers within the GDA, were adopted by the Central Valley Regional Water Quality Control Board (Regional Board or RWQCB) on July 31, 2015. The GDA is bordered to the north by the Westside San Joaquin River Watershed Coalition (Westside Coalition) and to the south by the Westlands Water Quality Coalition (Westlands Coalition).

1.1 Background

California is known for the wide range of agricultural commodities the state produces and distributes worldwide. In 2003, the Irrigated Lands Program (ILP) was initiated to regulate discharges from irrigated agriculture to surface waters. Upon the adoption of the Conditional Waiver of Waste Discharge Requirements for discharges from irrigated lands, the ILP became known as the Irrigated Lands Regulatory Program (ILRP). An expansion of the ILRP, the Long-Term Irrigated Lands Regulatory Program (LTILRP) is underway and being developed to protect both surface water and groundwater.

The RWQCB has coordinated with growers to encourage them to combine resources by forming water quality coalitions. Currently, there are 14[2] coalition groups that work directly with their member growers to assist in complying with RWQCB requirements. Of the estimated 35,000 growers in the Central Valley, there are about 25,000 landowners / operators[3] who are part of one of these 14 coalition groups. The Steering Committee is one of the 14 coalition groups. The

1.1.1 Grassland Drainage Area

The Steering Committee serves as the third-party group for the growers within the GDA and associated member districts (**Figure 1-2**), although some growers in the area may elect to be regulated as individuals. The GDA encompasses a total area of approximately 104,000 acres, including approximately 98,000 acres[4] of agricultural cropland, of which about 86,500 acres are irrigated land, and about 5,500 acres are non-agricultural land.

Subsurface tile drains have been installed in considerable portions of the GDA and are used to capture water percolating below the root zone. The Grassland Bypass Project routes this drainage water out of the GDA through the Grassland Bypass Channel. The water captured by tile drain systems and the discharges from tile drains are covered under separate WDRs relating to the Grassland Bypass Project. The WDRs for irrigated agriculture within the GDA, only pertain to discharges to groundwater that are not captured by tile drainage systems.

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[2] There are 14 Coalition groups shown for the Central Valley, Region 5; http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/app_approval/index.shtml, accessed December 18, 2014.

[3] This number is included in the RWQCB ILRP Frequently Asked Questions as of November 2013; the number of enrolled growers has increased since that time.

[4] The acreages included here are based on data for 2014.

The San Joaquin River Improvement Project (SJRIP) located within the GDA reuses drainage water on an area of about 6,000 acres. More than 5,000 acres within the SJRIP are planted with salt-tolerant crops for reuse of drainage water. The WDRs governing irrigated lands apply only to drainage water that is used to irrigate cropland with the GDA, including on the SJRIP.

1.1.2 Waste Discharge Requirements and Other Timelines

The Regional Board's adoption of the WDR on July 31, 2015 starts the timeline for several requirements, including the requirement in the WDR Order (Section IV. A.) that, three months after adoption of the WDRs by the Regional Board, "the third-party will provide a proposed outline of the GAR to the Executive Officer that describes the data sources and references that will be considered in developing the GAR". Accordingly, the due date for submittal of the GAR outline was October 29, 2015. The GAR outline was submitted by the Steering Committee to the Regional Board on October 20, 2015, and the Regional Board sent a letter on November 12, 2015 approving the GAR outline. The RWQCB noted that the GAR outline met all requirements in the WDRs, Attachment B. In accordance with the WDRs, the due date for the GAR is set at one calendar year after adoption of the WDRs, which for the GDA is July 31, 2016.

1.2 Purpose of Groundwater Quality Assessment Report

The water resources of the GDA are essential to the livelihood and prosperity of the area. The GDA has experienced challenges related to saline soils and shallow groundwater, which are largely a result of the naturally occurring conditions including salts in Coastal marine geologic deposits of the Coast Range, low permeability water logged soils, a very shallow water table, and accompanying poor natural drainage. These historical conditions prompted installation of subsurface tile drains to capture shallow water including applied irrigation water percolating below the root zone and shallow groundwater. Accordingly, growers within the GDA have also been moving towards increased irrigation efficiency through management of applied water and drainage water reuse. Some of these unique hydrogeologic conditions in the GDA have necessitated consideration of complicated confounding factors to evaluate the relative vulnerability in the GDA.

The GAR is a foundational element that outlines much of the framework for the Westside Coalition to navigate other requirements in its LTILRP WDRs, with an emphasis on assessment of groundwater conditions and long-term protection of regional groundwater quality. **Table 1-1** summarizes major requirements of the GAR as identified in the WDRs and where they are addressed within this GAR document.

The GAR documents current groundwater quality in the GDA, including nitrate and salinity concentrations and trends, evaluates the influence of irrigated agriculture on groundwater quality, and provides a scientifically based classification system for evaluating and determining the relative groundwater vulnerability (higher or lower) for the GDA. Key approaches for the GDA have involved:

- Developing a representation of a physical conceptual model describing the hydrogeology and groundwater quality conditions (salinity and nitrate) in multiple depth zones including Very Shallow Water within approximately 15 feet of the ground surface where tile drains are constructed, Shallow Groundwater from 15 feet to 100 feet, a semi-confined Upper Aquifer zone extending from 100 feet to the top of the Corcoran Clay, the extent and thickness of the Corcoran Clay, and the confined Lower Aquifer of the Coalition area and the relationships with Coast Range sediments to the west and Sierran Sands on the east side.

- Evaluating the hydrogeologic sensitivity of the groundwater to naturally occurring salts and conditions related to the concentration of those salts;
- Evaluating the trends in nitrate and salinity, particularly in the Shallow Groundwater and the Upper Aquifer;
- Determining the physical factors associated with confinement of the Lower Aquifer that serves to lower the vulnerability of the Lower Aquifer to nitrate effects;
- Identifying the presence of saline groundwater in the Lower Aquifer associated with Coast Range sediments and/or from leakage through the Corcoran Clay, where it is thinner; and
- Identifying existing wells (currently monitored by GDA districts or others) that can potentially be used to fill data gaps and/or to meet future trend monitoring needs for the Steering Committee while avoiding expenses associated with constructing new monitoring wells.

The relative vulnerability of groundwater to irrigated land agricultural impacts is assessed based on: (1) hydrogeologic sensitivity, (2) overlying land uses and practices, and (3) groundwater quality observations (particularly nitrate but also salt and pesticide concentrations). Hydrogeologic sensitivity is a factor that is tied to the inherent physical characteristics of the geology and soils and underlying hydrogeologic and geologic conditions. Land use (location of cropping and management systems on the landscape, and locations of other non-agricultural land uses) is an indicator of potential groundwater quality stressors. The spatial relationship between the hydrogeologic sensitivity of an area, the overlying land use, and the proximity of groundwater serving urban and rural communities (particularly recharge areas upgradient of communities that rely on groundwater) is assessed.

This GAR outlines the different methods for assessing groundwater vulnerability that have been used to evaluate groundwater vulnerability, including approaches applied to assess vulnerability in California (e.g., California State Water Resources Control Board [SWRCB], California Department of Pesticide Regulation [DPR], Nolan et al., 2002, Dzurella et al., 2012), and presents the method developed for determining high vulnerability areas within the GDA. To determine high vulnerability areas, select statistical analyses and index overlay approaches were used based on observed groundwater quality, soil parameters, and hydrogeologic characteristics of the aquifer system beneath the GDA. The results from the groundwater vulnerability assessment were evaluated with respect to locations of observed exceedances of groundwater quality drinking water standards for nitrate, TDS, and pesticide detections. The method of determining groundwater vulnerability also attempts to account for differences in land use among the observations in order to decipher differences in groundwater quality that are related to hydrogeologic variables as opposed to differences in groundwater quality that are related to land use. Spatial data representing land use mapped at three different snapshots in time, including the mid-1990s, early-2000s, 2008, and 2014, were utilized in the analyses described in the GAR to account for different land use conditions.

High vulnerability areas, where irrigated agriculture operations have impacted or are more likely to impact groundwater quality, are identified and prioritized in the GAR, and existing wells are identified that may satisfy future requirements to develop a Groundwater Quality Trend Monitoring network to track groundwater quality and its response to agricultural practices.

The study area for the GAR includes the entire GDA, which is located at the southern end of the Delta-Mendota Groundwater Subbasin within the San Joaquin Valley Groundwater Basin (**Figure 1-3**).

2 PHYSICAL SETTING

2.1 Location

The Grassland Basin Drainage Steering Committee is comprised of seven different water districts (Charleston Drainage District, Pacheco Water District, Panoche Drainage District, Camp 13 Drainage District, Widren Water District, Firebaugh Canal Water District, and Broadview Water District) (**Figure 1-2**). The Grassland Drainage Area is located within the San Joaquin Groundwater Basin and in the Delta-Mendota Subbasin (**Figure 1-3**), extending from Merced County to Fresno County in the southeast direction (**Figure 1-1**). The Main Canal bounds the area in the north and east and the California aqueduct bounds the area in the west with the Outside and Delta-Mendota Canals running through northeastern portion of the study area (**Figure 1-1**). Three cities are located in the vicinity of the drainage area with Dos Palos in the north, Firebaugh in the east, and Mendota in the south **(Figure 2-1)**.

2.1.1 Topography

The GDA area lies between the Coastal Mountain Range and the San Joaquin River. Ground surface elevation increases away from the valley towards the Coastal Mountain Range. Within the GDA, the northeastern half sits at 100-199 ft above mean sea level. The remainder of the GDA is 200-399 feet above mean sea level. The Coastal Mountain Ranges reaches well above 1,000 feet **(Figure 2-1)**. The topographic slope map (**Figure 2-2**) is reflective of the ground surface elevations. The topographic slope is less than 1 to 2 percent for the majority of the GDA. Increases in slope are seen towards the vicinity of Interstate 5 with some northwestern areas having slopes in the range of 5 to 10 percent.

2.1.2 Climate

Three CIMIS stations were used to examine average monthly and annual precipitation in the GDA. The Mendota Dam Station (045528) contained data from 1948 to 1984, the Los Banos Station (045118) provided data from 1906-2015, and lastly the Little Panoche Det Dam Station (044979) had data ranging from 1968 to 1975. Based on these stations, the average annual precipitation was 7.98 inches **(Figure 2-4)**. During most months, the Los Banos Station registered more rainfall than the other two stations. The majority of the precipitation occurs during late fall to early spring with little to no precipitation during the summer months **(Figure 2-4).** The PRISM model was used to construct a spatial distribution of average annual precipitation over the study area (PRISM Climate Group, 2014) **(Figure 2-3)**. The GDA receives 8 to 10 inches of precipitation annually with the areas north of West Nees Avenue receiving slightly higher amounts of precipitation than the southern portion.

2.1.3 Surface Water

The majority of surface water that exists in the GDA is in minor and major canals such as the Delta-Mendota Canal **(Figure 2-1)**. Little Panoche Creek flows from an eastern slope of the Diablo Range east-northeast ephemerally due to storm events or releases from the Little Panoche Reservoir towards the California Aqueduct, which skirts the southwestern edge of the GDA. Historically the surface waters of Little Panoche Creek flowed towards the slough of the San Joaquin River, building an alluvial fan that is apparent as a discrete lobe of 2 to 5 percent slopes on **Figure 2-2**. Additionally, **Figures 2-1 and 2-2** show numerous Coast Range surface water flow pathways for ephemeral streams and several lobes that comprise the merged alluvial fan complexed of the western San Joaquin Valley in the vicinity of the GDA.

2.1.4 Tile Drains in Relation to Shallow Groundwater

Tile drains within the GDA occur within the zone of Very Shallow Water (0 to 15 feet below ground surface) **(Figure 3-5)**. If groundwater within the Shallow Groundwater zone (15 to 100 feet below ground surface) rises into the Very Shallow Water zone, tile drains can intercept and route such groundwater to sump pumps for removal via surface drainage networks. Perched groundwater conditions could exist within the GDA if unsaturated conditions below the groundwater table within the Very Shallow or Shallow Groundwater zones are observed by water level measurements in nested wells. In this scenario, the Very Shallow or Shallow perched groundwater would infiltrate due to both gravitational gradients and pore pressure gradients (capillary suction) at the interface between the wetted sediments over sediments with residual saturation. Under fully saturated conditions where the Upper, Shallow, and Very Shallow Water zones are fully saturated in a hydraulic continuum, vertical infiltration rates will be dominated by regional head gradients and the saturated hydraulic conductivity of formation layers. In both fully saturated and unsaturated scenarios, tile drains within the GDA can intercept and re-route groundwater rising within the Very Shallow Water zone for pumping and removal into surface water drainage networks. Quinn et al. (1998) reported the presence of fallowed field tile drains actively flowing in the GDA, providing short circuited lateral hydraulic connections towards downslope areas even though neither those fields nor adjacent fields were irrigated at that time. Tile drains intercept vertical water infiltration within the Very Shallow Water zone; decreasing recharge and mass transport into the Shallow Groundwater zone while enhancing lateral groundwater flow and mass transport of constituents toward downslope areas.

2.1.5 San Joaquin River Water Quality Improvement Project and Grassland Bypass Project

The San Joaquin River Water Quality Improvement Project (SJRIP) and Grassland Bypass Project conjunctively involve reuse of tile drainage water to irrigate salt tolerant plants and transport subsurface agricultural drain water in the Grassland Bypass Channel to the San Luis Drain, bypassing sensitive wetland habitat areas. Tailwater return systems were designed and constructed to blend tailwater returns with surface water deliveries. In water year 2015, more than 33,000 acre-feet of drainage water was reused on the SJRIP. Collectively, between water years 1995 and 2014 the SJRIP and the Grassland Bypass Project have reduced the discharge of selenium from the GDA by about 97 percent while also reducing salt and boron discharges by 83 percent and 79 percent, respectively (SLDMWA, 2015).

2.2 Geologic Setting

The geologic setting of the GDA was assessed with data sources including geologic and hydrogeologic data from published reports, the USGS Central Valley Hydrologic Model (CVHM) (Faunt et al., 2009; Faunt et al., 2010), existing maps and relevant cross-sections, and DWR Bulletin 118 basin/subbasin information (DWR, 2003).

2.2.1 General Hydrogeologic Setting

The San Joaquin Valley is at the southern end of the Central Valley of California in the Great Valley Geomorphic Province. The Central Valley is a large structural trough that has been filled with interlayered sediments of sand, gravel, silt, and clay derived from erosion of the Sierra Nevada and Coast Range mountains. **Figure 2-5** shows the geology within the GDA region as generalized by the USGS and published as digital data by Ludington et al., (2007). **Figure 2-6** shows more detailed geologic mapping of the GDA region. Approximately three million years ago, tectonic movement of the oceanic and continental plates associated with the San Andreas Fault system gave rise to the Coast Range, which sealed off the Central Valley from the Pacific Ocean. As this occurred, the floor of the San Joaquin Valley began to transition from a marine depositional environment to a freshwater system, where ancestral rivers brought alluvium to saltwater bodies (Mendenhall et al., 1916). The Coast Ranges on the western side of the San Joaquin Valley consist mostly of complexly folded and faulted consolidated marine and nonmarine sedimentary and crystalline rocks ranging from Jurassic to Tertiary age **(Figure 2-6)**, which dip eastward and overlie the basement complex in the region (Croft, 1972; Hotchkiss and Balding, 1971). The Central Valley Floor within the GDA region consists of Tertiary and Quaternary-aged alluvial and basin fill deposits **(Figures 2-5 and 2-6)**. The fill deposits mapped throughout much of the valley extend vertically for thousands of feet, and the texture of sediments varies in the east-west direction across the valley. Coalescing alluvial fans have formed along the sides of the valley created by the continuous shifting of distributary stream channels over time. This process has led to the development of thick fans of generally coarse texture along the margins of the valley and a generally fining texture towards the axis of the valley (Faunt et al., 2009; Faunt et al., 2010). Steeper fan surfaces, with slopes as high as 80 feet per mile, exist proximal to the Coast Range whereas more distal fan surfaces consist of more gentle slopes of 20 feet per mile (Hotchkiss and Balding, 1971). In contrast to the east side of the valley, the more irregular and ephemeral streams on the western periphery of the Central Valley Floor have less energy and transport smaller volumes of sediment resulting in less-developed alluvial features, including alluvial fans, which are less extensive, although steeper, than alluvial fan features on the east side of the valley (Bertoldi et al., 1991). Lacustrine and floodplain deposits also exist closer to the valley axis as thick silt and clay layers. Lakes present during the Pleistocene epoch in parts of the San Joaquin Valley deposited great thicknesses of clay sediments.

Figure 2-6 shows the different geomorphic units, defining areas of unique hydrogeologic environments, in the GDA and surrounding areas. Alluvial fans and plains can be found in areas north of the GDA, overflow lands to the southeast, and alluvial fans and plains and diablo range towards the west. The alluvial fans and plains geomorphic unit is characterized by relatively better drainage conditions, with sediments comprised of coalescing and somewhat coarser-grained alluvial fan materials deposited by higher-energy streams flowing out of the Coast Range (Hotchkiss and Balding, 1971). Overflow lands are defined as areas of relatively poorly draining soils with a shallow water table and is dominated by finer-grained floodplain deposits that are the result of historical episodic flooding of this low-land area.

The hydrogeologic system within the GDA is into four distinct groundwater zones used to characterize the groundwater conditions. These include a Very Shallow Water zone (0 to 15 feet below ground surface), a Shallow Groundwater zone (15 to 100 feet below ground surface), a semi-confined Upper Aquifer zone (100 feet to the top of the Corcoran Clay), the Corcoran Clay, and a confined Lower Aquifer zone starting at the bottom of the Corcoran Clay to the base of fresh water **(Figure 2-7)**. The primary groundwater bearing units within the GDA consist of Tertiary and Quaternary-aged unconsolidated continental deposits and older alluvium of the Tulare Formation. Subsurface hydrogeologic materials covering the Central Valley Floor consist of lenticular and generally poorly sorted clay, silt, sand, and gravel that make up the alluvium and Tulare Formation. These deposits are thickest along the axis of the valley with thinning along the margins towards the Coast Range Mountains (DWR, 2003; Hotchkiss and Balding, 1971). Hotchkiss and Balding, 1971, estimated the zone of Very Shallow Water to generally have very shallow depths to groundwater of less than 10 feet. Under predevelopment conditions, the Very Shallow Water zone would be in direct connection and recharge the naturally swampy lands adjacent to the San Joaquin River within the San Joaquin Valley axial trough. The Tulare Formation extends to several thousand feet deep and to the base of freshwater throughout most of the area and consists of interfingered sediments ranging in texture from clay to gravel of both Sierra Nevadan and Coast Range origin. The Tulare Formation also includes the Corcoran Clay (E-Clay) member, a diatomaceous clay or silty clay of lake bed origin, which is a prominent aquitard in the region hydraulically separating the Upper Aquifer from the Lower Aquifer (Hotchkiss and Balding, 1971). The depth and thickness of the Corcoran Clay is variable within the Central Valley Floor and is not present in peripheral areas (outside the Central Valley Floor). Within the Upper Aquifer, additional clay layers exist within the upper zone and also provide varying degrees of confinement, including other clay members of the Tulare Formation and layers of white clay identified by Hotchkiss and Balding (1971). These clays are variable in extent and thickness, but the white clay is noted to be as much as 100 feet thick in areas providing very effective confinement of underlying zones (Croft, 1972; Hotchkiss and Balding, 1971).

The Tulare Formation is hydrologically the most important geologic formation in the GDA region because it contains most of the fresh water-bearing deposits. Most of the natural recharge that occurs in the region is in the alluvial fan apex areas along Coast Range stream channels (Hotchkiss and Balding, 1971). More recently, a source of recharge to the groundwater system within the Coalition region has been from deep percolation of applied irrigation water, although changing irrigation technologies are reducing deep percolation of irrigation water.

Under natural (pre-development) conditions, the prevailing groundwater flow within the Upper and Lower Aquifer systems of the western San Joaquin Valley was predominantly in a general northeasterly direction from the Coast Range towards the San Joaquin River and Sacramento and San Joaquin Rivers Delta. Historically, numerous flowing artesian wells within the Lower Aquifer existed throughout the western San Joaquin Valley (Mendenhall et al., 1916). These flowing artesian conditions have disappeared in many areas as a result of increased development of groundwater resources within the Tulare Formation also changing the vertical flow gradient between groundwater zones (Hotchkiss and Balding, 1971). Under pre-development conditions the pressure gradient for groundwater flow was upward from the Lower Aquifer to the Upper Aquifer. Despite the presence of local pumping depressions within the western San Joaquin Valley, the prevailing northeastward flow direction for groundwater within the region has remained (AECOM, 2011; DWR, 2010; Hotchkiss and Balding, 1971). However, the combined effect of pumping above and below the Corcoran Clay and increased vertical leakage from the Very Shallow Water zone to the Shallow Groundwater zone/Upper Aquifer and a generally downward hydraulic gradient within in the Tulare Formation, which changes with variable pumping and irrigation over time (Bertoldi et al., 1991). Accordingly, historical conditions have indicated higher pressure heads in the Upper Aquifer than in the Lower Aquifer (Hotchkiss and Balding, 1971).

Periods of great groundwater level declines have also resulted in inelastic compaction of fine-grained materials in some locations, particularly between Los Banos and Mendota, potentially resulting in considerable decreases (between 1.5 and 6 times) in permeability of clay members within the Tulare Formation, including the Corcoran Clay (Bertoldi et al., 1991). Wells penetrating and screen above and below the Corcoran Clay may enable vertical hydraulic communication across the Corcoran Clay aquitard and other clay layers (Davis et al., 1959; Davis et al., 1964).

2.2.2 Natural Surface Water and Groundwater Chemistry

The west and east side of the San Joaquin Valley differ in the composition of alluvial sedimentation due to its different sources; Sierra granitic rocks in the east and Coastal Ranges in the west. The sediments from the west side streams have material derived from serpentine, shale, and sandstone parent rock. The GDA is located in the western portion of the Valley and therefore the sedimentation found here comes from sulfate and carbonate shales and sandstones which are more susceptible to dissolution processes. Some soils and sediments within the western San Joaquin Valley that are derived from marine rocks of the Coast Range, have notably high concentrations of naturally occurring nitrogen, with particularly higher nitrate concentrations in younger alluvial sediments (Strathouse and Sposito, 1980; Sullivan et al., 1979; DWR, 1971). These naturally occurring nitrogen sources may contribute to nitrate concentrations in groundwater within the GDA, although it is not well known where this may occur and to what degree.

The chemical quality of waters in the Coast Range streams can be closely correlated with the geologic units within their respective catchments. Groundwater flows discharging from these marine and non-marine rocks into streams introduce a variety of dissolved constituents, resulting in variable groundwater types. The water quality and chemical makeup in Coast Range streams flowing into the San Joaquin Valley can be highly saline, especially in more northern streams where historical base flow TDS concentrations have typically exceeded 1,000 mg/L with measured concentrations as high as 1,790 mg/L (Hotchkiss and Balding, 1971). This is in contrast with TDS concentrations typically below 175 mg/L in streams draining from the Sierras. The contribution of water associated with these Coast Range sediments has resulted in naturally high salinity in the groundwater within and around the GDA, which has long been recognized, including documentation of these conditions since the early 1900s (Mendenhall et al., 1916). Groundwater in some areas within the immediate vicinity of the San Joaquin River is influenced by lower salinity surface water discharging from the east side of the San Joaquin Valley Groundwater Basin (Davis et al., 1957) **(Figure 2-8)**. **Figure 2-8** depicts historical TDS concentrations based on data from Mendenhall et al. (1916) and these concentrations pre-date 1916. High salinity was observed in the GDA, with TDS concentrations measured above 2,000 mg/L within the Upper Aquifer and less than 500 mg/L east of the GDA in the vicinity of the San Joaquin River within the Shallow Groundwater zone **(Figure 2-8)**.

2.2.3 Physical Conceptual Model

The GDA hydrogeologic conceptual model **(Figure 2-7)** was developed by analyzing well log and water quality information alongside available literature on stratigraphy and fluvial geomorphologic setting and history of sediment deposition in the GDA vicinity. The Corcoran Clay provides a simplified conceptual model constraint as it is relatively thick and extensive throughout the GDA **(Figure 2-9 and 2-10)** as well as being the primary separation between the Upper and Lower Aquifers. Groundwater flow and mass transport from the Shallow Groundwater zone into the Upper Aquifer becomes more complex because there are no continuous discrete layers or primary stratigraphic features to separate them at a specific depth. For this reason, well logs and stratigraphy data were reviewed in parallel with groundwater elevation and quality data to provide insight on Shallow Zone interactions with the Upper Aquifer.

2.2.3.1 Very Shallow Water (drainage water and very shallow wells)

The Very Shallow Water zone is located in the upper 15 feet of the land surface within the GDA. Groundwater that is perched or regionally rising into this zone during wet periods can be intercepted and removed by the extensive tile drain networks (**Figure 3-5**). Some dissolved constituents intercepted by tile drainage systems within the Very Shallow Water zone are eventually transported to the San Joaquin River and therefore removed from the GDA. As discussed later in **Section 3.1.6**, there is some potential for upwelling of Shallow Groundwater into the Very Shallow Water zone based on observed vertical head differences (Deverel and Fio, 1991; Fio and Deverel, 1991), which indicate potential for upward mixing and constituent mass transport within the Shallow Groundwater and into the Very

Shallow Water zone in some areas of the GDA. A fraction of the dissolved constituents intercepted by tile drains within the Very Shallow Water zone are cycled within the GDA when drainage water is blended with fresh water and reapplied to land where they can re-accumulate and re-leach in the Very Shallow Water and Shallow Groundwater zones. Deeper pumping of groundwater from the Shallow Groundwater and Upper and Lower Aquifer zones also acts as a source for salts derived from the native Coast Range sediments that are applied to land and leached into the Very Shallow Water zone. Natural sediment weathering, recharge, and lateral mass transport in the form of regional groundwater flow, or enhanced underflow during wet periods within the Little Panoche Creek alluvial fan, will continue to act as a natural source for dissolved constituents in groundwater within the Very Shallow Water zone.

2.2.3.2 Shallow Groundwater

The Shallow Groundwater zone is located from 15 feet to 100 feet below the land surface within the GDA. Under the fully saturated scenario, where groundwater within the Very Shallow Groundwater Zone is hydraulically connected with the fully saturated Shallow and Upper Aquifer Zones, hydraulic residence time, dissolved constituent gradients, and regional flow will induce mixing and mass transport from the Very Shallow into the Shallow Groundwater Zone even though active tile drains (with sump pumping) may intercept large portions of groundwater infiltrating towards the Shallow Groundwater Zone.

2.2.3.3 Semi-Confined Upper Aquifer (above Corcoran Clay)

The Upper Aquifer consists of the materials between the Shallow Groundwater and the Corcoran Clay layer. The Corcoran Clay thickness and depth varies throughout the GDA area and therefore so does the thickness of the Upper Aquifer. The Upper Aquifer thins to less than 100 feet thick along the southwestern edge of the GDA and thickens to generally 300 feet towards the east-southeast of the GDA area.

2.2.3.4 Corcoran Clay

As discussed above, the Corcoran Clay is a notable hydrogeologic feature throughout the GDA that acts as an aquitard and impediment to vertical flow between the Upper and Lower Aquifers. The depth to the Corcoran Clay varies from 200 to 500 feet below ground surface **(Figure 2-9)** generally deepening toward the southeast. The thickness of the Corcoran Clay, which likely influences the degree of hydraulic separation between the Upper and Lower Aquifers, ranges between approximately 40 and 140 feet, thickening towards the northwest center of the GDA **(Figure 2-10)**. The Corcoran Clay pinches out (does not exist) just west of Interstate-5 located along the GDA (**Figure 2-10**), which means that recharge of high TDS Diablo Range groundwater is not impeded by the Corcoran Clay most notably in the vicinity of the Little Panoche Creek fan head. **Figure 2-11** shows other major clay layers (A and C) do not extend far enough northwest to impede vertical infiltration within the GDA.

2.2.3.5 Confined Lower Aquifer (below Corcoran Clay)

The Lower Aquifer refers to the materials below the Corcoran Clay extending down to the San Joaquin formation. The majority of the wells in this aquifer are utilized for agricultural purposes and yield groundwater with naturally occurring high levels of dissolved solids associated with marine-type Coast Range sediments prone to dissolution. There is also potential for agricultural wells to act as localized conduits that short circuit the Corcoran Clay for enhanced hydraulic communication and mass transport between the Upper and Lower Aquifer. Confinement of the Lower Aquifer suggests that head pressure within the Lower Aquifer is greater than the Shallow and Upper Aquifer Zones, resulting in an upward hydraulic gradient.

2.2.3.6 Hydrogeologic Conceptualization

Figure 2-12 shows the locations of geologic cross-sections created from the sediment texture model for the Central Valley generated by (Faunt et al., 2009 and 2010) for visualization of the vertical relationships between the three groundwater zones across the GDA. As described above, the Corcoran Clay divides the Upper and Lower Aquifers. In **Figures 2-14 through 2-20**, characteristics of subsurface materials are presented in 50-foot intervals by percent coarse with darker green areas indicating relatively lower percent coarseness corresponding with finer-grained sediments of lower hydraulic conductivity and lighter tan to orange colors indicating higher percentages of coarse-textured materials corresponding with coarser-grained sediments of generally greater hydraulic conductivity. The presence of fan materials is apparent in some sections transecting alluvial fans by the presence of coarse materials on the eastern side of the GDA (**Figures 2-14 and 2-22**), associated with the San Joaquin River. Cross section C **(Figure 2-15)** captures coarse materials just east of Interstate-5 within the Shallow and Upper Aquifer Zones associated with the fan head area of the Little Panoche Creek. **Figure 2-16** (cross section D) also similarly captures coarse Coast Range fan head alluvium correspondingly apparent as a discrete lobe on **Figure 2-2** in the vicinity of W. Shields Avenue where ephemeral Coast Range streams deposited coarser sediments along steeper slopes. Extensive alluvium within the Upper Aquifer associated with the San Joaquin River system and also sandier zones representing areas where Sierran alluvial fan materials sourced from the east side of the valley have extended into the GDA are also evident in the cross-sections. A pattern of increase in coarse subsurface sediments to the south is apparent from these cross-sections, with notably contrasting sediment texture compositions between the Upper Aquifer and the Lower Aquifer.

Additional notable cross-sections presented by Miller et al. (1971) and Hotchkiss and Balding (1971) that overlap with the GDA, are located on **Figure 2-12** and presented in **Figures 2-23, 2-24** and **2-25** respectively. These cross-sections provide additional information relating to the vertical and lateral extent and continuity of subsurface geologic features throughout the GDA, including indications of the geologic source and depositional environment that are not depicted in the cross-sections based on CVHM sediment texture data. Similarly, cross-section B constructed by Miller et al. (1971) (**Figure 2-24**) depicts an encroachment of micaceous Sierran sands above the Corcoran Clay that is not as apparent in the geologic cross-section F constructed using CVHM sediment texture data (**Figures 2-18**). Higher quality groundwater can be associated with these Sierran sediments that are generally coarser-grained and composed of relatively less dissolvable minerals compared to other sediments derived from Coast Range sources (Davis et al., 1957).

2.3 Surface and Subsurface Sediments Characterization

2.3.1 Surficial Soils

Data from the Natural Resource Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) were used to characterize surficial soils within the GDA in terms of permeability and chemistry. In mapping soils, ranges of properties are assigned to different map units by statistically aggregating observed data. As part of the NRCS soil surveys, soil map units are defined to express similarities between soils within similar landform and landscape positions.

2.3.1.1 Soil Hydraulic Conductivity

Figure 2-26 shows representative C-horizon vertical saturated hydraulic conductivity values of map unit soil-type areas within the GDA based on the NRCS, SSURGO, soil survey dataset. Saturated hydraulic conductivity and layer thickness values were used to compute the weighted harmonic mean of vertical saturated hydraulic conductivity of each SSURGO major soil component within each map unit. The major C-horizon soil components occupy known percentages of a given map unit's total area, so the component values were weighted by their percent of the total map unit area to estimate a representative map unit C-horizon vertical saturated hydraulic conductivity. The soil profile represented by each map unit is variable but commonly extends to a depth of 6 or more feet **(Figure 2-26)**.

Surficial floodplain deposits are evident as soils with relatively low hydraulic conductivity (less than 0.5 feet/day) within northeast areas of the GDA more proximal to the valley trough, although localized areas of soils with higher hydraulic conductivity are evident in association with modern and ancient surface waterways and alluvial fan features that splay northeast from the Coast Ranges **(Figure 2-26)**. Coarse soils of alluvial fan sediments deposited by historic Little Panoche Creek and other ephemeral northeasterly creek flows off the Coast Ranges are notably apparent as areas of soils of higher hydraulic conductivity (greater than 4 feet/day) located along historic/inactive stream channels extending northeast from the fan apex areas along the Valley Floor margins towards the current alignment of the San Joaquin River in the valley axis **(Figure 2-26)**.

2.3.1.2 Soil Drainage

The main soil drainage classes for each NRCS map unit are shown on **Figure 2-27** in the GDA. These drainage classes correspond strongly to the prior map of vertical saturated hydraulic conductivities **(Figure 2-26)**, where areas of higher hydraulic conductivity tend to be more well drained near the ground surface. Map units within the vicinity of the Little Panoche Creek alluvial fan and other paleochannel deposits that splay northeast from the Coast Ranges into the GDA are mostly well drained primarily due to higher soil hydraulic conductivity. These naturally well-drained areas **(Figure 2-27)** correspond strongly with the extent of areas without tile drains **(Figure 3-23)**, where tile drains are generally needed in areas with soil hydraulic conductivity less than 4 feet/day **(Figure 2-26)**.

2.3.1.3 Soil Chemistry

Soil salinity (dS/m) and alkalinity (pH) within the GDA were calculated for each NRCS-SSURGO soil map unit by averaging the salinity and alkalinity data values weighted C-horizon layer thicknesses for soil components and then averaging the soil components weighted by their respective areas within map units. The representative map unit soil salinities and alkalinities are shown on **Figures 2-28** and **2-29** respectively. The salinity of GDA soils varies from non-saline soils (less than 4 dS/m) to saline/very-saline soils (greater than 4 dS/m) **(Figure 2-28)** (a saline soil with an electrical conductivity of 4 dS/m corresponds to approximately 40 mmol salts per liter). The eastern half of the GDA has generally saline soil, the western half has generally less saline soils, and the northern area in the vicinity of the SJRIP has very saline soils **(Figure 2-28)**. The salinity of soils in the GDA **(Figure 2-28)** corresponds well with the drainage class **(Figure 2-27)** because salts that are not leached (in soils that are not well drained) to tile drains and/or the Shallow Groundwater Zone are accumulated near the ground surface via evapotranspiration, capillary action and sorption processes. The alkalinity of soils within the GDA **(Figure 2-29)** ranges from neutral to alkaline (7.5 to greater than 8.5 pH). The spatial patterns of soil alkalinity **(Figure 2-29)** within the GDA generally correspond with soil drainage characteristics **(Figure 2-27)** and soil salinity **(Figure 2-28)**, where less drained soils with higher salinity tend to be more alkaline;

however, pH variability is complex due to natural differences in sodium adsorption ratios that may link to slight differences in source rock alluvium minerology, weathering characteristics, and soil pore-water chemistry.

2.3.2 Hydraulic Properties of Subsurface Sediments

USGS CVHM layer data (originally developed by the USGS from numerous driller's logs) were used to calculate and map the lateral and vertical extent and saturated (lateral and vertical) hydraulic conductivities of the Shallow, Upper, Corcoran, and Lower Aquifer Zones.

2.3.2.1 Shallow Groundwater Zone

The vertical saturated hydraulic conductivity of the Shallow Groundwater Zone **(Figure 2-30)** is relatively low (similar to a semi-pervious very fine sand) and has relatively low variability in terms of absolute magnitude (ranging from about 0.25 to 0.30 feet/day) considering the hydraulic conductivities of gravel to clay naturally range over twelve orders of magnitude. This is a result of how the USGS originally factored discrete features from driller's logs into CVHM layer data, which was then used to calculate the layer-weighted vertical harmonic mean of saturated hydraulic conductivity within the Shallow Groundwater Zone. **Figure 2-30** shows that the Shallow Groundwater Zone has relatively higher vertical hydraulic conductivity in the vicinity of the Little Panoche Creek alluvial fan and east side of the GDA. The lateral hydraulic conductivity of the Shallow Groundwater Zone **(Figure 2-31)** plays an important role regarding lateral groundwater flow and mass transport towards the valley axis where mixing with fresh groundwater can occur. Similar to the relatively narrow (one order of magnitude) range of average vertical hydraulic conductivity values, lateral hydraulic conductivity within the Shallow Groundwater Zone ranges from less than 175 to over 390 feet per day **(Figure 2-31)**. The main vertical and lateral infiltration and mass transport pathways that exist in the GDA in terms of hydraulic conductivity are in the vicinity of the Little Panoche Creek fan head area and the minor fan just to the southeast. Higher vertical and lateral hydraulic conductivity areas within the Shallow Groundwater Zone near the San Joaquin River show the effect of Sierran sand encroachments within the valley axis.

2.3.2.2 Upper Aquifer

The vertical and horizontal hydraulic conductivities of the Upper Aquifer **(Figure 2-32** and **2-33)** are very similar to the Shallow Groundwater Zone **(Figure 2-30** and **2-31)** in terms of both spatial distribution and magnitude within the GDA. Slightly lower vertical and horizontal hydraulic conductivity values within the Upper Aquifer (compared to the Shallow Groundwater Zone) are likely due to compaction (subsidence) and collapse of pore spaces and/or a depositional environment with historically less energetic surface water flows splaying less-coarse Coast Range sediments towards the northeast. Based on the CVHM hydraulic conductivity data, the Shallow and Upper Aquifer zones are likely to exist in a saturated hydraulic connection in terms of both vertical and lateral recharge and mass transport within the GDA. The potential pathway for groundwater flow and lateral mass transport towards the valley axis within the Shallow and Upper Aquifer Zones in terms of hydraulic conductivity extends from southernmost GDA area north-northeast towards the eastern portion of the SJRIP **(Figures 2-31** and **2-33)**.

2.3.2.3 Corcoran Clay

The vertical hydraulic conductivity of the Corcoran Clay is approximately 4.8×10^{-4} feet/day. Spatial variation of the vertical hydraulic conductivity of the Corcoran Clay **(Figure 2-34)** is negligible with differences only apparent at the 10^{-5} feet/day decimal place. The depth, thickness, and western extent of the Corcoran Clay provides a much more important role in terms of groundwater flow and mass transport within the GDA than apparent spatial variations in its vertical hydraulic conductivity.

2.3.2.4 Lower Aquifer

The horizontal hydraulic conductivity of the Lower Aquifer **(Figure 2-35)** is generally increasing towards the northwest of the GDA and ranges from about 12 to 18 feet/day, one order of magnitude less than the horizontal hydraulic conductivity of the Shallow and Upper Aquifer zones. The vertical hydraulic conductivity of the Lower Aquifer ranges from about 0.032 to 0.037 feet/day, also one order of magnitude less than the vertical hydraulic conductivity of the Shallow and Upper Aquifer zones.

2.3.2.5 Subsurface Sediment Texture

Figures 2-34A and **2-34B** maps subsurface sediment texture from the CVHM sediment texture model. Depths of 0 to 250 feet exhibit large amounts of coarse sediment along and to the west of the San Joaquin River. These coarse materials extend into the eastern side of the GDA. Coarse sediment can also be seen in the southwest corner of the study area from depths of 0 to 250 feet after which it becomes sparse and disappears altogether. Depths 450 to 500 feet and 550 to 650 feet also show coarse materials concentrated on the western edge of the drainage area extending east from Interstate 5. By 650 to 700 feet, the entire GDA has less than 25 percent coarse materials.

2.4 Summary of Physical Setting

The Grassland Drainage Area is located within the San Joaquin Groundwater Basin and in the Delta-Mendota Subbasin (**Figure 1-3**), extending from Merced County to Fresno County in the southeast direction (**Figure 1-1**). The primary groundwater bearing units consist of Tertiary and Quaternary-aged unconsolidated continental deposits and older alluvium, including geologic units of the Tulare Formation. The continental and alluvial deposits consist of layers of sand, gravel, silt, and clay that increase in thickness away from the margins of the valley. The hydrogeologic system within the GDA is characterized by four distinct groundwater zones, including a Very Shallow Water zone (0 to 15 feet below ground surface), a Shallow Groundwater zone (15 to 100 feet below ground surface), an Upper Semi-Confined zone (Upper Aquifer) (100 feet to the top of the Corcoran Clay), and a Lower Confined zone (Lower Aquifer) starting at the bottom of the Corcoran Clay to depth **(Figure 2-7)**.

The Tulare Formation is hydrologically the most important geologic formation in the Westside Coalition region because it contains many fresh water-bearing deposits. The Tulare Formation extends to the base of freshwater throughout most of the area and is comprised of stratigraphic layers of clays, silts, sands, and gravels and includes the Corcoran Clay (E-Clay) member, a diatomaceous clay or silty clay of lake bed origin which is a prominent aquitard and impediment to vertical hydraulic communication between the Upper Aquifer from the Lower Aquifer. The depth to the Corcoran Clay varies from 200 to 500 feet below ground surface, generally deepening toward the southeast and thickening up to 140 feet towards the northwest center of the GDA **(Figure 2-10)**. The Corcoran Clay pinches out (does not exist) just west of Interstate-5 located along the GDA (**Figure 2-10**), which means that recharge of high TDS Diablo Range groundwater is not impeded by the Corcoran Clay most notably in the vicinity of the upper Little Panoche Creek fan head. The Lower Aquifer is the portion of the Tulare Formation that is confined beneath the Corcoran Clay extending downward to the underlying San Joaquin Formation and the interface of salty water of marine origin within its uppermost beds. The Upper and Lower Aquifers represent the primary sources of supply for groundwater used for agricultural and drinking water purposes within the GDA.

Most of the natural recharge that occurs in the GDA is in the alluvial fan apex areas along the intermittent Coast Range streams, although deep percolation of applied irrigation water is also a source of recharge. Changing irrigation technologies are reducing deep percolation from irrigation water. Secondary recharge to areas near the valley axis occurs from subsurface flow from the east (DWR, 2003). Groundwater quality within the GDA is variable and commonly reflects the chemical composition of the contributing streams and the subsurface sediments through which groundwater has flowed. Naturally high concentrations of TDS in groundwater within the GDA have existed historically due to the geochemistry of the Coast Range rocks, the resulting naturally high TDS of recharge derived from Coast Range streams, the dissolvable materials within the alluvial fan complexes, and the naturally poor draining conditions which tend to concentrate salts in the system.

Soils of low hydraulic conductivity, corresponding with extensive floodplain deposits, blanket much of the GDA, although higher hydraulic conductivity soils occur along modern and ancient surface watercourses and in association with alluvial fan features. The Shallow Groundwater and Upper Aquifer zones have relatively higher vertical hydraulic conductivity in the vicinity of the Little Panoche Creek alluvial fan and along the east side of the GDA. Alluvium within the Upper Aquifer associated with the San Joaquin River system, where Sierran alluvial fan materials sourced from the east side of the valley have extended into the GDA, are also evident in the cross-sections. Higher quality groundwater can be associated with these Sierran sediments that are generally coarser-grained and composed of relatively less dissolvable minerals compared to other sediments derived from Coast Range sources.

3 GROUNDWATER HYDROLOGY

3.1 Groundwater Levels

Characterization of groundwater conditions within the GDA requires understanding groundwater levels. Groundwater level data provide information with which to interpret hydrogeologic conditions, including spatial and temporal patterns in flow direction, groundwater level trends, potential groundwater recharge and discharge areas, and other conditions. Publically and readily available groundwater level data for the GDA were gathered from the USGS and DWR databases.

3.1.1 Groundwater Level Dataset

Available groundwater level data within three miles of the GDA were acquired for interpretation of regional groundwater level conditions. Within and around the GDA vicinity, more than 16,000 depth-to-groundwater measurements from the DWR and USGS were available and acquired. DWR data consisted of 836 wells with 14,928 measurements, and USGS data consisted of 80 wells with 1,218 measurements. Of these assembled data, 680 wells have available information on well construction such as depth or screened interval. The groundwater level data acquired for this GAR are summarized in **Table 3-1**.

All data received were processed and underwent quality assurance/quality control (QA/QC) procedures. During the QA/QC process, to the degree possible, duplicate well records and measurements and erroneous data were detected and eliminated. Additionally, clusters of variable water level data associated with multiple wells in very close proximity require some degree of filtering for improved spatiotemporal groundwater level interpolations.

Groundwater level and associated well data were grouped into the four depth categories they best represent in terms of hydraulics based on their construction. The depth categories correspond to the Very Shallow Water (shallow monitoring wells less than 15 feet deep), Shallow Groundwater (monitoring wells and wells 15 to 100 feet deep), Upper Aquifer (domestic wells and wells greater than 100 feet deep but above the top of the Corcoran Clay), and Lower Aquifer (irrigation or public supply wells below the Corcoran) zones.

Wells with a known well type that did not have screened depth or other construction information available were assigned a depth class in accordance with the typical depths for different well types in the area. Monitoring wells without construction information were assigned to the Shallow Groundwater zone, domestic wells were assigned to the Upper Aquifer, and irrigation and public water supply wells were assigned to the Lower Aquifer. Wells lacking any information that could be used to classify them in the above categories, either by well type or construction information, were designated as unknown depth.

Figure 3-1 shows the spatial distribution of groundwater level datasets by source in and around the GDA. Consistent and continuous representations of groundwater depths and elevations in the groundwater zones were interpolated for delineating general groundwater flow directions and vertical head differences between zones.

The spatial distribution of groundwater level data by year of the most recent measurement for each well is shown in **Figure 3-2**. Water level data from the 2000s to present are available throughout and around the GDA (**Figure 3-2**). **Figure 3-3** shows the frequency distribution of the acquired water level measurements data through time, and indicates that water level measurement efforts went through several periods of increased intensity, first in the early 1960s, then in the late 1980s and early 1990s, and most recently in the early 2000s.

3.1.2 Development of Groundwater Level Contours

As a foundational element of the GAR, a spatially complete representation of recent groundwater levels across the GAR was needed. Groundwater levels can fluctuate greatly through time due to numerous natural and anthropogenic factors, including long-term climatic conditions, adjacent well pumping, nearby surface water flows, and seasonal groundwater recharge/depletion. All of these factors can contribute to groundwater levels changing on short- and long-term temporal scales. Recent spring groundwater levels, prior to the onset of increased summer pumping, best represent current ambient groundwater conditions during which seasonal groundwater levels are expected to be highest.

Spatially continuous recent spring depth to groundwater and elevation surfaces were developed from the assembled water level data using Geographic Information System (GIS) spatial analysis tools and capabilities provided within ArcGIS (ESRI, ArcGIS 10.4). Recent spring groundwater surface elevation values were digitally interpolated between data (well) locations within the GDA using the nearest neighbor method. For each depth zone, the most recent spring groundwater elevation values were subtracted from corresponding land surface elevations (digital elevation model) to produce the depth to water (Shallow Groundwater and Upper Aquifer) and depth to potentiometric surfaces (Lower Aquifer). Contours of depth to water for the Very Shallow Water zone in 2012 created by DWR (DWR, 2012) were used to represent Very Shallow Water conditions. These depth-to-water contours were digitized and interpolated and then subtracted from land surface to generate a water surface elevation within the Very Shallow Water zone.

3.1.3 Spatial Patterns in Depth to Groundwater

Regionally, depth to groundwater decreases from the valley perimeter to the valley axis – in the GDA this generally translates to a west-to-east decrease in depth to water. Depth to groundwater is influenced by local elevation of the land surface and does not indicate flow direction; it is important to recognize that although depth to water decreases in the eastward direction, this does not imply that the groundwater gradient is from east to west. **Figure 3-4** shows that recent depth to water in the Very Shallow Water zone ranges from less than 5 to more than 20 feet below ground surface (BGS). Deeper water in the Very Shallow Water zone generally corresponds to the fan head areas along the southwest of the GDA where there is more unsaturated space and potential for vertical percolation (**Figure 3-4**). A discrete area of slightly deeper water in the Very Shallow Water zone (up to 15 feet BGS) in the eastern central portion of the GDA (near N. Fairfax Ave) could correspond with enhanced vertical drainage through coarser paleochannel deposits detected in this vicinity (**Figures 2-26** and **2-27**).

Subsurface tile drains and associated sump pumps are notable features within the GDA and play a considerable role in lateral and vertical water movement within the Very Shallow Water and Shallow Groundwater zones at localized (field) and regional (GDA-wide) scales. **Figure 3-5** shows the locations of tile drain systems within the GDA.

Figure 3-6 shows that the depth to groundwater within the Shallow Groundwater zone ranges from more than 50 to less than 10 feet below ground surface. Similar to the Very Shallow zone, the depth to groundwater in the Shallow Groundwater zone is deeper in the primary fan head areas (particularly the Little Panoche Creek alluvium) due to a combination of increased vertical drainage, land surface elevation, and unsaturated space (**Figure 3-6**). **Figure 3-7** shows that the depth to the groundwater potentiometric surface within the Upper Aquifer ranges from 30 to 140 feet below the ground surface with deeper areas toward the Coast Ranges and along the Delta Mendota Canal in the vicinity of the SJRIP. The deeper areas toward the Coast Ranges may correspond with increased land surface elevation and unsaturated space while the deeper area in the vicinity of the SJRIP may correspond with groundwater pumping/depletion (**Figure 3-7**). **Figure 3-8** shows that the recent depth to the groundwater potentiometric surface within the Lower Aquifer generally deepens toward the southeast of the GDA.

3.1.4 Subsurface Tile Drain Systems

The presence of naturally occurring ambient very shallow groundwater conditions in parts of the San Joaquin Valley and soil conditions that limit the ability of applied irrigation water to infiltrate has led to the installation of subsurface tile drainage systems in some areas. These features affect the lateral and vertical water movement within the Very Shallow Water and Shallow Groundwater zones at localized (field) and regional (GDA-wide) scales. In research by the USGS, in tile-drained fields, shallow water in the vicinity of tile drain lines flowed towards the drains from all directions including upward from depths considerably below the bottom of the tile drain (Deverel and Fio, 1991; Fio and Deverel, 1991). Data on the locations of tile drain lines within the GDA were provided by GDA Districts and the Steering Committee. The locations of tile drainage systems are presented in **Figure 3-5** and shows the presence of known tile drain locations across most of the GDA. The areas with tile drains correspond closely with areas where depth to water is less than 10 feet (**Figure 3-4**) and also areas of somewhat to very poorly drained soils (**Figure 2-27**).

3.1.5 Groundwater Elevations and Lateral Flow Directions

Figure 3-9 shows some of the observed variability in groundwater elevation data from various depth zones over time within the GDA. As discussed above, recent spring groundwater level data were used to construct groundwater elevation surfaces within individual depth zones to represent current groundwater conditions during the season when groundwater levels are expected to be highest. Lateral groundwater flow direction vectors within the GDA's aquifer zones were delineated from the recent spring groundwater elevation maps. The overall hydraulic gradient for the Very Shallow Water zone generally follows the land surface, which slopes downward towards the northeast within the GDA (**Figure 3-10**). Groundwater flow direction vectors are not plotted in the Very Shallow Water zone because the extensive network of tile drains (**Figure 3-5**) are believed to intercept and route the flow of water within this zone. Individual fields may act as local sinks drawing water from all directions during sump pump operations. **Figure 3-11** shows the groundwater elevation flow and direction vectors for the Shallow Groundwater zone. Groundwater flow in the Shallow Groundwater zone is generally toward the northeast (**Figure 3-11**) primarily due to naturally occurring shallow ambient groundwater conditions that follow the land surface with gentle slopes toward the northeast. Groundwater elevation mapping within the Upper Aquifer zone shows generally northeast groundwater flow directions and an area of lower groundwater elevation in the vicinity of the SJRIP that could correspond with areas of groundwater pumping (**Figure 3-12**). The effects of pumping and the resulting depression in groundwater within the Upper Aquifer in the SJRIP vicinity may draw water in a more northern direction instead of the natural northeastern flow direction (**Figure 3-12**). **Figure 3-13** shows the elevation of the Lower Aquifer groundwater potentiometric surface with groundwater flow direction vectors. There is a distinct trough-like depression in the Lower Aquifer's groundwater elevation indicative of groundwater pumping/depletion throughout the central GDA, which could induce deep southwestern direction groundwater flows from the valley axis toward the central GDA as indicated by the flow direction vectors (**Figure 3-13**). There is also deep northeast groundwater flows within the Lower Aquifer from the Coast Ranges towards the central GDA, which could result in deep, pumping-enhanced, mixing of different quality groundwater within the GDA's Lower Aquifer groundwater trough (**Figure 3-13**).

3.1.6 Vertical Head Differences Between Depth Zones

Recent hydraulic head differences between the depth zones were calculated in order to delineate vertical hydraulic gradients and potential for vertical groundwater flows throughout the GDA. **Figure 3-14** shows that the vertical head differences between the Very Shallow Water and Shallow Groundwater zones produces a generally downward hydraulic gradient resulting in potential for downward groundwater flow and mass transport throughout the central and northeastern portions of the GDA; most notably in the fan head areas. There are two areas (in the south and northwest GDA) of negative head differences where there is potential for upwelling groundwater flow as a result of semi-confined conditions within the Shallow Groundwater (**Figure 3-14**). The northwestern area of potential upward groundwater flow from the Shallow Groundwater to the Very Shallow Water zone could be a result of tile drain operations in that vicinity, where very shallow monitoring well data would reflect an artificially low (sump-pumping induced) depth to water while shallow monitoring wells would reflect the higher naturally occurring groundwater elevation surface (**Figure 3-14** and **Figure 3-5**). There are no tile drains mapped in the southern area where negative head differences are observed, which could indicate that there is potential for naturally occurring semi-confined conditions in the Shallow Groundwater zone with upward groundwater flow in this area of the GDA (**Figure 3-14** and **Figure 3-5**).

Figure 3-15 shows that the vertical head difference between the Shallow Groundwater and Upper Aquifer zones results in the potential for downward groundwater flow between these zones throughout all the GDA. This head difference is enhanced in areas along the Delta-Mendota Canal, which is suggestive of relatively more groundwater pumping within the Upper Aquifer than the Shallow Groundwater zone and increased potential for downward groundwater flow/recharge from the Shallow to the Upper Aquifer in these areas (**Figure 3-15**). Groundwater pumping within the Lower Aquifer zone and the resulting trough-like depression drives the large observed head difference (up to 300 feet) observed between the Upper and Lower Aquifer zones shown on **Figure 3-16**. The large observed head difference between the Upper and Lower Aquifer zones suggests that the Corcoran Clay provides a significant hydraulic separation between the two zones where groundwater within the Upper Aquifer could be perched on top of the Corcoran Clay while drawdown within the Lower Aquifer occurs (**Figure 3-16**). Wells that are screened both above and below the Corcoran Clay (within the Upper and Lower Aquifers), could therefore act as potential conduits for downward groundwater flow and mass transport from the Upper Aquifer into the Lower Aquifer throughout most of the GDA given the observed recent head difference between these zones (**Figure 3-16**). **Figure 3-17** shows water level hydrograph pairs (for wells within immediate vicinity of each other and different screened intervals) to illustrate changes in head differences between various depth zones over time and across the GDA. Graphs in **Figure 3-17** suggest some potential for semi-confined conditions and upward gradient within the Shallow Groundwater zone in the central GDA, groundwater pumping and stresses to the groundwater system during summer and fall months, and a downward hydraulic gradient from the Upper Aquifer zone to the Lower Aquifer zone along the Delta-Mendota Canal.

3.1.7 Areas with Higher Potential for Groundwater Recharge

The primary process for groundwater recharge within the GDA is from percolation of applied irrigation water. Groundwater recharge estimates made by DWR (2006) for the Delta-Mendota Subbasin region indicate that historically natural groundwater recharge has represented a relatively small fraction of total recharge when compared with estimates of recharge from applied water.

From DWR (2006), in the Delta-Mendota Subbasin of the San Joaquin Valley Groundwater Basin,

> "Natural recharge is estimated to be 8,000 af. Artificial recharge and subsurface inflow are not determined. Applied water recharge is approximately 74,000 af. Annual urban and agricultural extractions estimated to be 17,000 af and 491,000 af, respectively. Other extractions are approximately 3,000 af, and subsurface outflow is not determined."

Figure 3-18 shows areas within the GDA that have higher potential for groundwater recharge in terms of percentage of coarse sediments and soil hydraulic conductivity. Areas of higher soil hydraulic conductivity, as represented by shallow (top 6 feet) subsurface materials, are shown in **Figure 3-18** based on NRCS SSURGO data. CVHM data within the upper 100 feet with more coarse-grained sediments occur in the Little Panoche Creek fan head area as well as the eastern edge of the GAR (**Figure 3-18**). These areas (**Figure 3-18**) correspond well with the areas of greater vertical head difference between the Very Shallow and Shallow Groundwater zones (**Figure 3-15**), which suggests that vertical groundwater percolation/recharge could occur relatively more in these areas compared to the rest of the GDA.

3.1.8 Recharge Areas Upgradient of Communities Reliant on Groundwater

For purposes of understanding and prioritizing areas for monitoring and management of groundwater, the groundwater elevation datasets developed for the GDA were used to calculate contributing areas of groundwater upgradient from communities reliant on groundwater (**Figure 3-19** and **3-20**). All communities, including DACs, within the GDA were identified based on Census Designated Places (CDPs) from the 2010 United States Census data (Census, 2014). These communities were investigated through the SWRCB Division of Drinking Water (DDW) DRINC web portal (SWRCB, 2016) to identify any water systems serving those CDPs. The DRINC portal identifies which systems include groundwater wells as part or all of their water supply. Additionally, public drinking water systems (PWSs) from DDW Environmental Health Investigations Branch (EHIB) database (CDPH, 2015) were evaluated with respect to reliance on groundwater through queries with wells identified in the DDW Water Quality Monitoring (WQM) dataset. The CDPs found to be reliant on groundwater were further investigated with aerial imagery to identify the populated areas within each boundary. Only two PWS wells from the available DDW data are identified within the GDA. An area corresponding to the extent of developed land in the vicinity of these wells was delineated as reliant on groundwater for this GAR.

DUCs, delineated by PolicyLink (2013) and based on parcel data and year 2000 Census data, were also identified. **Table 3-2** lists all the communities, including DUCs, located within the GDA and the status with respect to reliance on groundwater, as determined through the procedure outlined above. The resulting community areas identified to be reliant on groundwater are shown on **Figure 3-19**.

Contributing areas to communities reliant on groundwater (**Figure 3-20**) were developed for groundwater zones above the Corcoran Clay. To do this, polygons representing communities reliant on groundwater were buffered by 200 meters to provide enough starting area to capture flow in a modeling environment. The recent groundwater elevation surfaces for the Shallow Groundwater and Upper Aquifer zones were separately processed to produce flow direction grids for each zone based on slope direction. These flow direction grids were then used to independently determine the contributing area for each buffered community polygon for each depth zone. The resulting sets of contributing areas were then merged to produce a single combined representation of potential groundwater contributing areas within the Shallow Groundwater and Upper Aquifer zones for all communities identified to be reliant on groundwater within the GDA.

It should be noted that these contributing areas are sensitive to changes in the input datasets used in their calculation. Small changes in the groundwater elevation datasets or in extent of communities reliant on groundwater can result in considerable change in contributing areas. The analysis used in the GAR incorporated groundwater elevation datasets representative of recent spring conditions in an attempt to most accurately identify potential source areas under ambient groundwater level conditions.

3.1.9 Areas of Potential Evapoconcentration

Figure 3-21 shows the areas with water table depth less than 10 feet within the GDA, indicating areas where potential evapoconcentration is most likely to occur in the Very Shallow Water zone. The areas of potential evapoconcentration (**Figure 3-21**) generally coincide with areas of lower vertical soil hydraulic conductivity (**Figure 2-26**), where vertical drainage becomes challenging despite tile drain coverage and sump pumping efforts (**Figure 3-5**). The fan head areas along the southwestern portion of the GDA with soils of higher vertical hydraulic conductivity, higher land surface elevations, steeper slopes, and increased unsaturated space result in increased vertical drainage, relatively lower ambient depth to water, less potential for evapoconcentration, and less need for tile drains.

3.2 Summary of Groundwater Hydrology

Characterization of groundwater conditions within the GDA requires understanding groundwater depths and elevations. Data on groundwater depth/elevation provide important information with which to interpret hydrogeologic conditions, including spatial and temporal patterns in flow direction, groundwater level trends, potential groundwater recharge and discharge areas, and other conditions. Groundwater level data from within and around the GDA were compiled into a water level database.

For the purposes of differentiating and evaluating water level trends within the depth zones of the hydrogeologic system, all wells were categorized by depth as interpreted from available information in the database. Groundwater level data were grouped into four depth categories (Very Shallow Water, Shallow Groundwater, Upper Aquifer, and Lower Aquifer) according to the zone which they are interpreted to represent in terms of hydraulics. Regionally, groundwater elevation decreases from the valley perimeter to the valley axis – in the GDA this translates to a northeast decrease in groundwater elevation for depth zones above the Corcoran Clay.

The recent depth to water in the Very Shallow Water zone ranges from less than 5 to more than 15 feet below ground surface, generally deepening in the fan head areas of the western side of the GDA and a shallower depth toward the northeast GDA (**Figure 3-4**). The elevation of water in the Very Shallow Water zone generally follows the land surface decreasing towards the northeast (**Figure 3-10**).

Depth to groundwater within the Shallow Groundwater zone ranges from more than 50 to less than 10 feet below ground surface and groundwater flow is generally toward the northeast (**Figure 3-6** and **3-11**).

The recent depth to the groundwater within the Upper Aquifer ranges from 30 to 140 feet below the ground surface with deeper areas toward the Coast Ranges and along the Delta-Mendota Canal in the vicinity of the SJRIP (**Figure 3-7**) with generally northeast groundwater flow directions and an area of lower groundwater in the vicinity of the SJRIP that could correspond to groundwater pumping (**Figure 3-12**).

The recent depth to the groundwater potentiometric surface within the Lower Aquifer generally deepens toward the southeast of the GDA (**Figure 3-8**)**,** corresponding to a trough-like depression indicated by the Lower Aquifer groundwater elevation surface throughout the central GDA. Within the Lower Aquifer groundwater flows in a southwestern direction from the valley axis toward the central GDA in addition to northeastern groundwater flows originating from the Coast Ranges (**Figure 3-13**).

Calculated head differences between depth zones suggests that there are heads are generally lower with depth across much of the GDA suggesting there may be potential for downward vertical movement of water between depth zones in the GDA (**Figures 3-14 through 3-16**). However, upward gradients in some areas are apparent within the Shallow Groundwater zone from comparison of hydrographs for select well pairs (**Figure 3-17**).

Areas with higher relative potential for groundwater recharge are identified from soil and sediment properties (**Figure 3-18**) and primarily include areas on the western margins of the GDA where coarser sediments associated with alluvial fan deposits exist. To inform the prioritization of groundwater management and monitoring efforts, communities reliant on groundwater within the GDA were identified based on CDP DACs, DUCs from Policylink (2012), and PWS wells from DDW (**Figure 3-19**). These communities were evaluated with respect to reliance on groundwater using the DDW DRINC web portal and queries with wells identified in the DDW WQM dataset. Upgradient areas contributing groundwater to these communities were calculated from the recent spring groundwater elevation surfaces for depth zones above the Corcoran Clay (**Figure 3-20**).

4 LAND USE

Characterizing changes in land use, irrigation, and fertilization practices over time supports understanding of past, current, and potential future groundwater quality, as these practices have the potential to affect groundwater quality. Quantitative and qualitative assessment of the spatial distribution of agricultural cropping and practices and assessing the intensity of effects on groundwater quality support the development of effective groundwater quality monitoring and management strategies. Additionally, documenting past and present land use and practices is critical in assessing groundwater vulnerability and prioritization, which are discussed in detail in **Section 6**.

The GDA consists of approximately 104,000 acres of land including approximately a total of about 86,500 acres of irrigated crop and grazing land (83 percent of the GDA) and about 17,000 acres of other lands, as presented in **Table 4-1** and described in this section. Some agricultural lands within the GDA are dry-farmed without use of irrigation. This section discusses available sources of data documenting historical and current land use and extent of irrigated lands and provides a description of land use characterization for purposes of the GAR. It details the extent and types of land uses in the GDA and describes land use changes over time, predominant agricultural commodities, irrigation practices, and fertilization practices.

4.1 Available Data Describing Land Use and Extent of Irrigated Lands

4.1.1 DWR Land Use Data

DWR has conducted land use surveys for agricultural counties approximately every ten years in California since the late 1980s or early 1990s. These data are provided in GIS format, allowing for evaluation of the spatial distribution of land use and irrigated area over time. Additionally, beginning in the late 1990s or early 2000s, detailed information describing irrigation methods has been included. The surveys are highly detailed and include over 70 categories of crop type and other land uses. The following surveys were used to quantify land use and irrigated area for circa-1990 (mid-1990s) and for circa-2000 (early-2000s):

- Fresno County: 1986, 2000
- Merced County: 1995, 2002

Detailed irrigation method information is additionally available for each of the circa-2000 surveys and summarized later in this section.

4.1.2 USDA Land Use Data

DWR land use surveys are only conducted periodically for each county, and the surveys are not available for recent years for most counties comprising the Grasslands Drainage area. In order to characterize current land use, land use data from the 2008 and 2014 U.S. Department of Agriculture (USDA) California Cropland Data Layer were also used. The USDA land use data are produced in a different way from the DWR land use surveys. These data are developed using supervised classification techniques using remotely-sensed multispectral satellite imagery. The classification technique combines ground-based cropping data for individual fields with the multispectral imagery to identify spectral signatures for individual crop types. Then, areas without available ground-data are classified based on their spectral characteristics. Through this process, crop or other land use type are assigned to individual pixels from the satellite imagery at a spatial resolution of 30 meters, or 0.22 acres. The accuracy of the classification analysis and results are evaluated through comparison of assigned land use to additional ground-based data. The overall accuracy of the 2008 and 2014 datasets are reported to be approximately 85 percent for over 70 categories of crop type and other land uses. When specific land uses are combined into more general classes (e.g., wheat and oats reclassified as grain crops, or almonds and pistachios reclassified as nut trees), the overall accuracy is improved.

4.1.3 GDA Districts Data

In addition to publicly available land use data from DWR and USDA, additional data from GDA Districts were available defining areas considered non-irrigated areas based on existing land uses or agreements that preclude future irrigated agricultural uses.

4.2 San Joaquin River Improvement Project

The SJRIP is a project designed to assist in management of subsurface drainage water high in selenium and other salts that is generated within the GDA as part of the Grassland Bypass Project. The SJRIP covers about 6,000 acres located with the GDA and includes more than 5,000 acres of salt-tolerant crops as displayed on **Figure 4-1**. The reuse of drainage water on the SJRIP, provides a management alternative to mitigate discharges through the Grassland Bypass Channel during times and in accordance with regulations pertaining to discharges for the Grassland Bypass Project. Drainage water discharged through the Grassland Bypass Channel are not covered by the irrigated lands WDRs for the GDA. However, the reuse of drainage water for irrigation of crops on the SJRIP is covered by the GDA WDRs.

4.3 Land Use Categorization

Because of the large number of unique land uses and crop types reported in the land use survey data from DWR and USDA, it was necessary to group similar land uses into categories for purposes of evaluating spatial and temporal patterns and also for the groundwater vulnerability assessment. Over 70 crop types and land uses contained in the land use survey data were grouped into 13 main categories based on general similarities in agricultural and irrigation practices and estimated typical nitrogen application rates. **Table 4-2** illustrates the land use category grouping system that was used for the DWR and USDA land use survey data and highlights the major commodities within each land use category.

4.4 Irrigated Agriculture

Agriculture is one of the main industries in the GDA and most agriculture in the area relies on irrigation. The extent of the irrigated lands is defined by land uses identified from the 2014 USDA data coupled with areas indicated by GDA Districts and the Steering Committee to be non-irrigated. In some cases, areas indicated by the 2014 USDA data as an agricultural land use are actually non-irrigated land based on information from GDA Districts. This occurs primarily in areas that are dry-farmed, including most notably areas within the Broadview Water District in the southeastern part of the GDA. The extent of the irrigated area within the GDA is displayed on **Figure 4-1** and includes approximately 86,500 acres, which includes lands identified as idle agricultural lands in the 2014 USDA land use dataset.

The spatial distributions of land use within the GDA for circa-1990, circa-2000, 2008, and 2014 are shown in **Figures 4-2 through 4-5**. As discussed above, there are differences in methodology and land use identification systems between the DWR and USDA land use surveys used to develop the data shown in these figures. Acreages for individual land use categories within the GDA are summarized in

Table 4-2. Within the GDA, the largest land use category in 2014 is idle cropland representing over 29,000 acres (28 percent) of the GDA. The number of acres of idle agricultural land in 2014 is in part caused by the limited availability of surface water for irrigation as a result of drought conditions throughout much of California. In 2014, vegetables (17,091 acres or 16.5 percent), pasture and alfalfa (14,321 acres or 14 percent), and grain (12,237 acres or 12 percent) were the most common agricultural crops followed by nut trees (10,488 acres) and field crops (9,291 acres) (**Table 4-3, Figure 4-6**). Together these crops comprise greater than 90 percent of the total agricultural crops grown in 2014 as shown on **Table 4-4**. **Table 4-4** summarizes the top crop categories by acreage and highlights the categories composing the top 80 percent, which are of particular interest in the prioritization of high vulnerability areas discussed in **Section 6**. Permanent crops such as nut trees, vineyards, and to a lesser degree fruit trees, represent an increased fraction of the agricultural area in 2014 (**Table 4-3**), especially in the western part of the GDA (**Figure 4-5**). Non-irrigated lands within the GDA consist of developed lands (5,100 acres) based on 2014 USDA land use data with some open water and wetlands (**Table 4-3**).

4.5 Land Use Change

Despite differences in the methodologies used to develop land use data by DWR and USDA, differences in land use have clearly occurred in the region. A summary of land uses within the GDA for four different historical snapshots since the 1990s (circa-1990, circa-2000, 2008, and 2014) based on data from DWR and USDA is provided in **Table 4-3** and illustrated in **Figure 4-7**. As noted above, differences in methodologies used for each of the land use snapshots may affect acreage values reported for land uses for different time periods although this is not likely to greatly alter the general trends and patterns indicated in land uses within the GDA.

Primary changes in agricultural cropping between 1990 and 2014 include the following:

- Idle cropland increased by 28,300 acres (400 percent)
- Nut Trees increased by 10,000 acres (220 percent)
- Field crops decreased by 44,900 acres (83 percent)

Table 4-3 shows that irrigated cropland has decreased by 29 percent whereas idle cropland has grown by 400 percent. Non-agricultural lands also have not experienced much change in acreage from circa-1990 to 2014. Some of the more notable changes in land use are most evident in **Figure 4-7** including the shifts to grain, pasture and alfalfa, and nut trees that occurred in the early 2000s. The dramatic increase in idle agricultural land in 2014 is also clearly apparent in **Figure 4-7**, although a steady increase in idle agricultural land also occurred from the 1990s through 2008.

4.6 Irrigation Practices

Available irrigation method data were acquired from the circa-2000 DWR land use surveys and also 2015 data from GDA Districts. These data were used to characterize typical irrigation method for different agricultural crop categories and also to evaluate changes in use of irrigation technologies over time. The circa-2000 DWR land use surveys provide spatially referenced irrigation method data. Irrigation method data available from the GDA Districts were provided only as the total number of acres for each irrigation method. The spatial distribution of irrigation application methods (i.e., microirrigation, sprinkler, or gravity) from the circa-2000 DWR land use data for irrigated lands is shown in **Figure 4-8**. **Table 4-5** and **Figure 4-9** summarize irrigation method by crop group based on the circa-2000 DWR data. Irrigation method data available from the GDA Districts were provided only as the total number of acres for each irrigation method.

In the early 2000s, approximately 87 percent of cropland was irrigated using gravity techniques (e.g., furrow, graded border, or level basin). Microirrigation and sprinkler technologies were used to irrigate approximately 4 percent and 6 percent of the crop area, respectively. Unknown irrigation methods were used on 2.5 percent of irrigated lands and 0.7 percent of the land was not irrigated. Many crops relied almost exclusively on gravity techniques, including fruit trees, rice, pasture/alfalfa, field crops, seeds/beans, grain, and vegetables (**Table 4-5, Figure 4-9**). Microirrigation systems were employed for irrigation of grapes and sprinklers were used to irrigate small amounts of vegetables, seeds/beans, field crops, grasses, and grain.

Irrigation method data for circa-2000 are compared with data from the GDA Districts for 2015 in **Figure 4-10**. Although the spatial distribution and method by crop type are not available for the 2015 irrigation data, the notable shift towards increasingly efficient irrigation methods between the early 2000s and 2015 is very apparent in **Figure 4-10**. In 2015, more than 83 percent of the cropped acreage was irrigated by microirrigation with about 12 percent irrigated by gravity (**Table 4-5**).

Tomatoes, alfalfa, almonds, cotton, and wheat are the five most common commodities grown in the GDA in 2014. Tomatoes are the most abundant commodity in the GDA and are typically irrigated using furrow or drip irrigation. When furrow irrigation is used, fields are watered infrequently to prevent root rot disease and help with weed control. On average, 2.5-3 acre feet of water are applied to furrow irrigated fields. Irrigation may become more frequent as the plant increases in fruit growth (Le Strange et al., 2000). During drip irrigation, fields are kept at field capacity for the entire season and soil moisture is continuously monitored. Anywhere from 20-36 acre inches are applied using drip irrigation during a growing season. Sprinklers can be used to establish young plants before switching them to other forms of irrigation (Le Strange et al., 2000).

Alfalfa is predominantly irrigated via border or check flood (gravity flow) irrigation systems. These irrigation methods are difficult to manage because they are dependent on a variety of factors (Meyer et al., 2007). Soil infiltration rate, slope, surface roughness, and border design all contribute to the effectiveness of these systems.

The most common method of irrigation used for almonds is microirrigation. Almonds tend to use the most water during the middle of the season with needs tapering off towards the end. Efficient irrigation can be accomplished by monitoring soil water moisture and tree growth stage (Sonke et al., 2010)

Furrow irrigation is the most dominant form of irrigation for cotton in California. Cotton is usually irrigated five times during the growing season with irrigation tapering off as the plant ages (Snyder et al., 2002).

Winter wheat, when harvested for grain, can require up to 22 inches of water per acre. Most commonly, wheat is gravity irrigated or rain-fed during the winter growing season (Munier et al., 2006). Gravity irrigation includes furrow or border check methods. More water is applied at the head of the field to prevent lack of irrigation in the middle or tail end of the field (Munier et al., 2006).

4.7 Cultivation and Fertilization Practices

4.7.1 Nitrogen Cycle

Nitrogen is a critical element for life on Earth and is found in air, water, soil, and organic matter. The nitrogen cycle is illustrated in **Figure 4-11** (Rosenstock et al., 2013). Fixation of nitrogen from the atmosphere converts gaseous nitrogen (N_2) in the atmosphere to ammonia (NH_3), which is then transformed into organic nitrogen (R-HN_2). Through the process of mineralization, organic nitrogen is transformed to inorganic nitrogen (NH_4^+). In the presence of air, inorganic nitrogen is then transformed by microbes into nitrite (NO_2^-) and nitrate (NO_3^-), which is the preferred source of nitrogen for most plants (Viers et al., 2012). This process is reversed when plants and other organisms take up mineralized nitrogen and convert it back to organic nitrogen. Ultimately, nitrogen returns to the atmosphere in its gaseous form. See Rosenstock et al. (2013) and Viers et al. (2012) for additional information describing the nitrogen cycle.

4.7.2 Crop Cultivation

In the Central Valley, tomatoes are transplanted and planted on raised beds with 17-18 inches between each plant. Tomato beds are prepared in the fall which allows for proper planting times and decreases soil compaction (Le Strange et al., 2000). Sub-soiling, disking, and land planning are used to prepare the ground in the case of furrow irrigation. Throughout the season, furrows are kept deep and smooth. In the case of drip irrigation, special equipment is used for cultivation and disking so as to not damage buried equipment. Although loam and clay loam soils are highly productive for tomato plants, sandy soils are preferred because of the ease of planting during wet seasons and rapid warming in the spring (Le Strange et al., 2000).

In addition to nitrogen, fertilizing also includes phosphorus and potassium applications. For phosphorus, typical application rates range from 80-160 pounds per acre. In the case of potassium, 0-120 pounds per acre are generally applied (Le Strange et al., 2000).

When establishing an alfalfa crop, farmers often use deep chisel plows to conduct deep tillage. Gypsum or sulfur is added to soils if they are affected by salt or lime is added to soils that are too acidic. Although alfalfa can be grown on many different soils, good drainage and lack of subsoil impediments are important (Meyer et al., 2007).

Because alfalfa roots have nodules with nitrogen-fixing bacteria, nitrogen application is rarely needed or recommended. Phosphorus is the nutrient alfalfa most commonly lacks. A maximum of two years supply of phosphorus is added to the soil pre-planting via double disking. In the case of potassium deficits, potash or potassium sulfate (in the case of both potassium and sulfur soil deficits) can be applied during pre-planting or after the second or third cutting. Additional nutrients that may be applied when deficiencies are observed are iron, boron, and molybdenum (Meyer et al., 2007).

The most common nutrients applied to almond trees consist of nitrogen, potassium, boron, and zinc. Applications are made in the spring when growth is the highest and then smaller amounts throughout the season and after harvesting (Doll and DeBuse, 1996).

Cotton is an annual crop, planted in April and harvested in October. During the growing season, cotton requires nitrogen application in most cases. In some situations, phosphorus and potassium are applied at average rates of 64 and 68 pounds per acre (Geisseler and Horwath, 2013).

In order to prepare the seedbed for wheat planting, soil is plowed as deep as possible to dispose of residual debris and herbicides. Soil types for winter wheat can vary from gravelly soils to clay soils. In addition to nitrogen applications, soils are augmented with phosphorus, sulfur, potassium, and zinc (Munier et al., 2006).

4.7.3 Common Fertilization Application Methods and Use for Primary Commodities

Nitrogen fertilization application methods and amounts differ depending on crop type, irrigation method, soil characteristics, and other factors. Nitrogen management practices for the primary crops in the GDA are summarized below. Typical nitrogen management practices for the region were gathered and summarized based on recent and archived cost and return studies developed by the University of California at Davis (UCD) Department of Agricultural and Resource Economics (UCD, 2015) and ANR Publications. Unique physical characteristics of the GDA may require different fertilization practices. For this report, the following cost and return studies were reviewed and are summarized below:

- Alfalfa: San Joaquin Valley – 50 Acre Planting, 2008.
- Almonds: San Joaquin Valley North – Micro Sprinkler Irrigation, 2011; San Joaquin Valley North – Flood Irrigation, 2011; and Northern San Joaquin Valley – Flood Irrigation, 1998.
- Cotton (Pima Variety): San Joaquin Valley, 2012.
- Tomatoes: San Joaquin Valley – Furrow Irrigated, 2007; and Sacramento Valley and Northern Delta – Sub-Surface, Drip Irrigated, 2014.
- Winter wheat: ANR Publication 8208 – Small Grain Production Manual, 2006

Tomatoes are the largest commodity covering approximately 13,900 acres in 2014. For fresh market, furrow-irrigated tomatoes, approximately 164 pounds of nitrogen per acre are applied each season from all nitrogen applications. About half of the nitrogen (i.e., 84 lbs/acre) is applied prior to planting. Seventy pounds of nitrogen is sidedressed in May, and another ten pounds is water-run in June.

Tomato growers have been rapidly transitioning to drip irrigation in the San Joaquin Valley over the last decade in many areas. A cost study for tomatoes using drip irrigation in the San Joaquin Valley has not been developed by UCD at this time. To approximate nitrogen management practices for tomatoes with drip irrigation, a cost study from the Sacramento Valley/Northern Delta was reviewed and is summarized herein. Before transplanting, liquid fertilizer containing 8 pounds of nitrogen per acre is commonly applied with a tractor and implement. Approximately 200 pounds of nitrogen fertilizer per acre is then applied through the drip irrigation system over the growing season via fertigation. Since fertigation is used, smaller nitrogen applications can be made on a frequent basis to match application to crop uptake.

Alfalfa is the second largest commodity in the GDA, accounting for 9,400 acres in 2014. Alfalfa is a legume. Legumes grow with nitrogen fixing bacteria attached to the roots, resulting in almost all nitrogen for growth being obtained from the atmosphere through the process of fixation. A small amount of nitrogen may be applied to alfalfa fields prior to the final discing before planting and germination to help establish a strong crop. It is not recommended or common to apply nitrogen to established alfalfa as little benefit is seen. Nitrogen is typically applied through broadcasting. Broadcasting involves uniformly distributing fertilizer over the soil surface. The fertilizer is then either mechanically mixed into the soil by discing or worked into the soil by rainfall or irrigation.

Almonds are the third largest commodity grown in the GDA totaling approximately 8,800 acres in 2014. To develop an almond orchard with micro-sprinklers, nitrogen is commonly broadcast by hand near the base of each tree for the first year in split applications. Approximately 20 pounds per acre of nitrogen is needed the first year with equal applications occurring during spring (March or April), early summer (June), and late summer (August). Starting the second year until the orchard reaches maturity, nitrogen applications increase and are applied in dissolved form directly through the irrigation system via fertigation. In following years, fertigation occurs monthly from April through August. Nitrogen application peaks starting in the sixth year at up to 200 pounds per acre.

Fertigation can be an effective method of applying small quantities of nitrogen over time to minimize nutrient leaching below the crop's root zone. This is done by timing nutrient applications to match crop consumption. Growers have seen benefits of switching to microirrigation (i.e., drip or microsprinklers) due to better nutrient management and irrigation scheduling practices, which often increase yields and may decrease overhead costs.

For almond orchards that remain flood-irrigated, the nitrogen requirement does not change per acre for a mature orchard relative to microirrigation, but the amount of nitrogen per application increases. Instead of monthly applications, nitrogen is often applied via spraying three times each growing season in larger quantities. According to the 1998 and 2011 cost studies for flood-irrigated almonds, the nitrogen application rate is approximately 20 pounds per acre less per growing season for mature orchards.

Cotton is the fourth largest commodity accounting for approximately 8,800 acres in 2014. Nitrogen is the primary nutrient applied to cotton during the growing season. For a furrow-irrigated cotton field, most nitrogen is applied using a method called sidedressing. Sidedressing is the application of fertilizer along the sides of bed rows. Applications can be timed to match the crop's peak nutrient demand to minimize nutrient leaching. For cotton, sidedressing commonly occurs in May. Approximately 150 pounds of nitrogen per acre is typically sidedressed at this time. In July, an additional 30 pounds of nitrogen is water run, meaning that the nitrogen is mixed with the irrigation water and carried through the furrows.

Winter wheat is the fifth largest commodity representing almost 6,900 acres in 2014. Although a host of nutrients may be required for winter wheat depending on soil quality, nitrogen is the most important nutrient for plant growth. Nitrogen requirements depend on the type of soil, yield potential, and the crop the winter wheat is following. For example, winter wheat planted after vegetables will require less Nitrogen than wheat planted after corn or cotton. Nitrogen can also be lost through leaching in sandy or gravelly soils.

Split applications of nitrogen are recommended for irrigated wheat however, where soils are not subject to leaching, all of the nitrogen can be applied during sowing. Topdressing can also be used as an application method after planting. During topdressing, fertilizer is applied directly to the soil surface during the growing season and usually one or two applications of 30 to 50 pounds per acre are applied.

4.7.4 Trends in Nitrogen Fertilization

Historical trends in nitrogen fertilizer use for the region, including the GDA, are presented in Figure 4-11 based on data compiled by the USGS describing county fertilizer sales from the late 1980s to the mid-2000s (Gronberg and Spahr, 2012). The GDA is within the counties of Fresno and Merced. Totals for each county are displayed to indicate the relative regional trends in farm nitrogen fertilizer use during the period from 1987 to 2006, although these values are not representative of the toral amount of nitrogen fertilizer applied on farms within the GDA. As indicated in **Figure 4-12**, nitrogen fertilizer use at a county level was relatively stable between 1986 through around 2000, with a trend of elevated use from 2002 to 2004 followed by somewhat reduced nitrogen use since 2004.

Nitrogen use by crop category is summarized in **Table 4-1** based on data from literature for 1973 and 2005 (Rosenstock et al., 2013; Viers et al., 2012). These data indicate that vegetables have the greatest typical application rate. For the main commodities grown in the GDA, Rosenstock et al. (2013) report typical nitrogen application rates for 2005 of 177 to 182 lbs/ac for tomatoes, 179 lbs/ac for almonds, and 177 lb/ac for grain while Viers et al. (2012) report a typical nitrogen application rate for alfalfa for 2005 of 12 lb/ac. Typical application rates increased between 1973 and 2005 for vegetables, nut trees, grain, field crops, seeds and beans, and rice. In contrast, nitrogen application rates appear to have decreased for alfalfa and vineyards. Typical rates for fruit trees appear to have remained about the same over this period, on average.

5 GROUNDWATER QUALITY

An essential part of this GAR is to understanding natural groundwater quality and assessing impacts on groundwater from past agricultural practices. For the purposes of this characterization, the focus is on nitrate, salinity (TDS and EC), selenium, boron, and pesticides. Readily available groundwater quality data were collected from a number of different sources in the characterization effort. Of the parameters examined, nitrate is the most common and is typically of greatest concern and relevance to influences from irrigated agriculture. Natural concentrations of nitrate in groundwater are typically believed to be low, but fertilization of irrigated lands can result in elevated levels. Although as noted in **Section 2.2.2**, some soils and sediments within the western San Joaquin Valley have high concentrations of naturally occurring nitrogen (Strathouse and Sposito, 1980; Sullivan et al., 1979; DWR, 1971) that may contribute to nitrate concentrations in groundwater within the GDA, although it is not well known where this may occur and to what degree. High concentrations of nitrate in drinking water can present health concerns and therefore are regulated. The U.S. Environmental Protection Agency (USEPA) has established an MCL level for nitrate (as nitrogen) of 10 mg/L under its National Primary Drinking Water Regulations; this MCL standard is established for public health reasons and is a requirement of all public drinking water systems.

EC and TDS are used to judge the overall water quality and salinity. Because EC is directly related to TDS, it also is helpful in characterizing the salinity of groundwater and drainage water. Agricultural practices have the potential to increase salinity in groundwater; however, due to the hydrogeologic setting consisting of extensive marine sediments in the GDA, salinity is naturally very high in the area. Selenium and boron are additional water quality constituents that are commonly present in high concentrations in the GDA as a result of dissolution from marine sediments high in soluble forms of selenium and boron. Although selenium and boron also occur naturally in high concentrations, they too represent important considerations for agricultural practices in the area. Because of its toxicity for wildlife, selenium is a particular concern in drainage water that is discharged to surface waterways, although such discharges are regulated separately under the WDRs for the Grassland Bypass Project. Many agricultural crops are sensitive to high concentrations of boron in irrigation water. Pesticide data was also gathered from DPR as their presence is indicative of groundwater quality impacts, sometimes resulting from agricultural activities.

5.1 Groundwater Quality Dataset

The GAR aims to characterize groundwater quality within the GDA and understand relationships between groundwater quality and land use practices. Data were gathered from GDA districts and through additional readily available public data sources including the USGS, DWR, DDW, and DPR. The water quality data collection efforts focused on nitrate, TDS, selenium, boron, and pesticide data for wells and tile drain sumps in the GDA.

Water quality data relating to tile drain sample points were provided by GDA Districts for inclusion in the GAR although tile drainage water is regulated separately by WDRs for the Grasslands Bypass Project. Although tile drains are distinct from wells in their construction and representation of groundwater, because of the existence of very shallow groundwater across the areas where the tile drains samples are located and the depth ranges indicated for the drains, the tile drain water quality sample data provided were included in the summary and analyses of groundwater quality in this report.

As part of initial processing and preparation of the assembled data, several steps of quality control and assurance were conducted. This included elimination of duplicates and erroneous data. Water quality results were reported as non-detectable concentrations were assigned a value equal to half of the detection level was used. If no laboratory detection limit was reported, a value of 0.225 mg/L was used for nitrate and 10 mg/L was used for TDS. For selenium and boron, which typically have lower laboratory detection limits, values of zero mg/L were assigned when no detection limit was reported for non-detectable results.

Nitrate data was provided as either nitrate as nitrate or nitrate as nitrogen (N). Nitrate reported as nitrate was converted to nitrate as N by dividing the value by a conversion factor of 4.427. This conversion factor is based on atomic weight. All nitrate values in this GAR are therefore reported as nitrate as N. In the case of EC, there is a direct relationship between TDS and EC. For the purposes of this GAR, all EC values have been converted to TDS by multiplying by a factor of 0.64. All water quality concentrations are reported as mg/L unless otherwise indicated.

Using the same procedure employed with the groundwater level data, groundwater quality data were categorized into four different depth zones described in **Sections 2 and 3**. Water quality in a Very Shallow Water zone included samples from tile drain sumps and from wells less than 15 feet deep. Below the Very Shallow Water zone within which subsurface drains exist, three additional depth zones were defined for the characterization of groundwater quality in this GAR. These depth zones include the Shallow Groundwater zone which includes wells with depths between 15 and 100 feet, the Upper Aquifer which extends below 100 feet to the top of the Corcoran Clay, and the Lower Aquifer which includes all wells deeper than the bottom of the Corcoran Clay. Wells for which depth information was not available were classified based on well type and related depth associations that have been observed in the area from previous experience. If no such information was available, the wells were classified as unknown depth.

Table 5-1a summarizes the entire water quality dataset utilized for this GAR, including water quality for drainage water as measured from tile drain sumps and very shallow wells in the Very Shallow Water zone. Of the unique sample locations for nitrate, 89 represent the zone of Very Shallow Water as measured in drainage water from tile drain sumps and from very shallow wells (less than 15 feet deep), 69 are for the Shallow Groundwater, six in the Upper Aquifer, 14 in the Lower Aquifer, and 82 were classified as unknown because not enough information was present to categorize them in a depth zone. The majority of the nitrate samples were taken in the 1980s, representing roughly 85 percent of the total number of samples (479 out of 563) (**Figure 5-5**) (**Table 5-1a**). The majority of these samples came from data provided by the USGS. Of the 260 total sample points with nitrate data, 57 percent exceeded the MCL of 10 mg/L and 41.5 percent exceeded 20 mg/L.

For the sample points with TDS data, 315 are in the Very Shallow Water zone as measured from tile drain sumps and from very shallow wells, 101 are in the Shallow Groundwater, 8 in the Upper Aquifer, 82 in the Lower Aquifer and 122 were from an unknown depth zone (**Table 5-1a**). Over half of the TDS samples were taken in the 2000s with 26,602 of the 44,999 samples being taken in this decade. The frequency distribution of data provided by different sources was relatively evenly distributed between USGS, GDA districts, and DWR with a few wells from DDW. Of the 628 sample points with TDS data, 99 percent of the locations had concentrations exceeding the Secondary Drinking Water Standard level of 500 mg/L; 93 percent exceeded 1,000 mg/L and 76 percent had concentrations above the short-term level of 1,500 mg/L.

For sites with selenium data, 242 sites were representative of the Very Shallow Water zone, 72 were in the Shallow Groundwater, 5 were located in the Upper Aquifer, 6 were in the Lower Aquifer, and 4 were classified as unknown. More than half (55 percent) of the total selenium samples were taken in the 2000s (**Figure 5-7**). The majority of the selenium data was provided by USGS (187) and GDA districts (136) (**Figure 5-3**). Selenium data was obtained from a total of 329 sample sites and 83 percent of these had concentrations above 0.02 mg/L of selenium (20 µg/L). Selenium is an essential nutrient for humans; however, high concentrations can present health concerns. Selenium has a Primary MCL for drinking water of 50 µg/L and a California Public Health Goal of 30 µg/L.

Boron has no drinking water MCL although it has a California Action Level of 1.0 mg/L and an agricultural goal of 0.7 mg/L. Many agricultural crops are sensitive to high boron concentrations. For the sites with boron results, 89 represent Very Shallow Water, 66 are in Shallow Groundwater, 8 in the Upper Aquifer, 58 in the Lower Aquifer, and 107 are in the unknown depth zone. The majority of the boron samples were taken in the 1980s (48 percent) or pre-1970s (45 percent) (**Figure 5-8**). All the sites with boron data were provided by USGS (216) and DWR (112) (**Figure 5-4**). Of the 328 sites with boron data, 97 percent had concentrations above the California Action Level of 1.0 mg/L.

5.2 Historical Presence of High Salinity in Shallow Groundwater

As discussed in **Section 2**, the presence of natural high salinity conditions in groundwater throughout much of the GDA has existed historically as a result of the hydrogeologic setting. Early documentation of the salinity conditions in the vicinity includes groundwater quality data collected and summarized in the early 1900s by Mendenhall (1916) (**Figure 2-9**). Natural conditions of groundwater salinity exist throughout all zones of the groundwater system as a result of the contribution of salts from recharge off of the Coast Range mountains. Surface water and groundwater flowing over and through Coast Range sediments of marine origin have dissolved naturally occurring salts contributing to the historical and current presence of salinity in the groundwater within the GDA.

In addition to natural salinity contributed from the Coast Range sediments, a number of other mechanisms are believed to further contribute to increased salinity in the groundwater in the region. As noted in **Section 2**, poorly draining soil conditions are extensive within the GDA. Often associated with poorly draining soils is a zone of Very Shallow Water and a build-up of soil salinity. High levels of salinity are clearly evident in all depth zones in the GDA as indicated by nearly all samples (99 percent) having TDS concentrations above the MCL of 500 mg/L and about 76 percent having concentrations above the short-term MCL of 1,500 mg/L.

5.3 Spatial Patterns in Groundwater Quality

Figures 5-10 through **5-57** depict concentrations by depth zone and agency for nitrate, TDS, selenium, and boron. Two separate figures were created for each depth zone and water quality constituent with one showing the maximum observed concentration for the constituent for each well and the other figure displaying the most recent concentration reported.

5.3.1 Nitrate Concentrations

Figures 5-10 and **5-11** display the maximum and most recent nitrate concentrations for all the wells throughout the study area. The data for maximum nitrate concentrations exhibit a mixture of wells with concentrations higher than 10 mg/L and lower concentrations interspersed across most of the GDA as seen in **Figure 5-10**. A similar mixture of high and low nitrate concentrations is apparent in **Figure 5-11**

showing the most recent nitrate data at each sample location. However, there is a notable sparsity of nitrate concentration data in the southeastern part of the GDA near the town of Mendota. Additionally, most of the nitrate data is relatively old with only 13 of the 260 nitrate sample sites having data since 2005 (**Table 5-1b**).

5.3.1.1 Very Shallow Water

Data for the maximum nitrate concentrations in the Very Shallow zone are displayed in **Figure 5-12**. As this figure highlights, the majority of the drainage water in the Very Shallow Zone has maximum concentrations exceeding the MCL of 10 mg/L. Similarly, **Figure 5-13** also shows that the most recent nitrate concentrations are also above 10 mg/L in almost every instance. However, the spatial distribution of data for this depth zone is limited in some parts of the GDA particularly in the central areas and also near the town of Mendota. The tile drains in the Very Shallow zone are designed to capture applied water that percolates below the root zone and to drain the water table in areas where it is very shallow. Consequently, it is expected that water sampled from tile drains and from very shallow wells (<15 feet) would exhibit higher concentrations of nitrate resulting from land use practices. As noted above, water drained from fields and discharged through the tile drain system is not regulated as part of this Order, but instead falls under the WDRs for the Grassland Bypass Project.

5.3.1.2 Shallow Groundwater

The Shallow Groundwater zone show different spatial patterns in terms of nitrate concentration than Very Shallow Water. As see in **Figure 5-14**, just slightly over half of the wells show maximum nitrate concentrations above 10 mg/L. The majority of these wells are located near the center of the GDA or in the vicinity of the northern portion of the Delta-Mendota Canal. Similar to the Very Shallow Water zone, no data is available near the town of Mendota.

The most recent nitrate concentrations appear to be slight improved relative to the maximum concentrations as fewer wells show most recent values above 10 mg/L compared to the maximum nitrate concentrations. Nevertheless, the spatial patterns in the most recent nitrate concentrations shown in **Figure 5-15** are similar to the maximum concentrations evident in **Figure 5-14**.

5.3.1.3 Upper Aquifer

The Upper Aquifer zone has the fewest number of wells with nitrate data including only six of the 260 total wells with nitrate data. Of these six wells, only one well has a maximum nitrate concentration above 10 mg/L with all other wells registering maximum values below 2.5 mg/L (**Figure 5-16**).

The most recent concentrations in **Figure 5-17** illustrate a similar pattern with only one location having a most recent nitrate concentration above 10 mg/L and all other locations below 2.5 mg/L.

5.3.1.4 Lower Aquifer

Similar to the Upper Aquifer, limited nitrate data are available in the Lower Aquifer including only the 14 wells shown in **Figures 5-18 and 5-19.** Of these available data, most of the wells are located in the vicinity of the Delta-Mendota Canal or south of W Nees Avenue and east of N Fairfax Avenue. All nitrate concentrations observed in the Lower Aquifer are below 10 mg/L with only two wells with maximum nitrate concentrations greater than 2.5 mg/L (**Figure 5-18**). Both the maximum and most recent nitrate concentrations in the Lower Aquifer exhibit generally low values mostly below 2.5 mg/L with nearly identical spatial patterns (**Figures 5-18 and 5-19**).

5.3.1.5 Unknown Depth Zone

The maximum nitrate concentrations for wells of unknown depth are displayed in **Figure 5-20**. The majority of these wells have maximum nitrate concentrations below 5 mg/L with more than half of the values under 2.5 mg/L. The available data are distributed throughout most of the GDA with few data gaps. **Figure 5-21** shows a similar pattern in concentrations and distribution as **Figure 5-20**. The majority of the recent concentrations for nitrate are below 5 mg/L with more than half being below 2.5 mg/L. These concentrations are similar to those in the Upper and Lower Aquifers whereas most of the available data for the Very Shallow Water and Shallow Groundwater zones exceeds 10 mg/L.

5.3.2 TDS Concentrations

As previously mentioned, TDS is indicative of the general salinity of groundwater. **Figures 5-22** through **Figure 5-33** highlight the maximum historical and most recent TDS concentrations found in the different depth zones. All drain and well data are depicted in **Figure 5-22** and nearly all the observations exceed the upper level of the Secondary MCL of 1,000 mg/L with the exception of a few locations near the intersection of W. Nees Avenue and N. Fairfax Avenue which have concentrations below 1,000 mg/L. Drinking water standards for TDS are in place for aesthetic reasons as opposed to health concerns. Four ranges apply to the Secondary MCLs (SMCL) with 500 mg/L being equivalent to the SMCL; 1,000 mg/L is equivalent to the upper level of the SMCL; 1,500 mg/L represents the short-term level of the SMCL.

TDS concentration data are dispersed across the study area as seen if **Figures 5-22** and **5-23**. Data for recent TDS concentrations for all drains and wells shown in **Figure 5-23** exhibit patterns similar to the historical maximum concentration data with most data exceeding 1,000 mg/L. Roughly 31 percent of the wells with TDS sample data have results since 2005 **(Table 5-1b).**

5.3.2.1 Very Shallow Water

Maximum historical values for TDS in the Very Shallow Water are depicted in **Figure 5-24.** The majority of these wells have concentrations exceeding 3,000 mg/L. Wells to the south of W. Nees Avenue and east of N. Fairfax Avenue have relatively lower TDS values concentrated. There is a lack of data in the proximity of the California Aqueduct.

Figure 5-25 depicts most recent values for TDS in the Very Shallow Water zone. A clear trend of decreased TDS values can be seen when comparing the most recent TDS concentrations with the historical maximum values (**Figure 5-24**). The area with the greatest number of wells with decreased TDS values is the area bounded by the Delta-Mendota Canal, Merced-Fresno county line, and W. Nees Avenue.

5.3.2.2 Shallow Groundwater

Approximately 16 percent of the wells with TDS data are located in the Shallow Groundwater zone as depicted in **Figure 5-26**. There is a gap in data to the north of the Delta-Mendota Canal and the majority of the data are located in the center of the GDA. A clear trend of increasing TDS values to the east is evident in **Figure 5-26** with a majority of the wells located to the east N Russell Avenue exceeding 3,000 mg/L in contrast with a considerably high number of wells to the west of N Russell Avenue having concentrations below 1,000 mg/L.

Although data distribution in **Figures 5-26** and **5-27** is similar, TDS concentrations seem to be improving. Specifically, the most prevalent reductions in TDS concentrations can be observed in the area enclosed by the Delta-Mendota Canal, Merced-Fresno County line, W Nees Avenue and N Russell Avenue.

5.3.2.3 Upper Aquifer

Of all the wells with TDS data, less than 2 percent were classified as being part of the Upper Aquifer depth zone. **Figure 5-28** reflects the sparse distribution of data and highlights that all available data points exceed 1,000 mg/L. **Figure 5-29** paints a similar picture with sparse data throughout the study area and recent concentrations also exceeding 1,000 mg/L.

5.3.2.4 Lower Aquifer

Figure 5-30 depicts wells categorized in the Lower Aquifer zone. The majority of the samples in this zone exceed 1,000 mg/L. The wells here are dispersed through the center of the study area with very little data available north of the Delta-Mendota Canal. A similar data distribution is seen in **Figure 5-31** with very little data available north of the Delta-Mendota Canal. Most recent TDS concentrations also reflect historic maximums with most samples exceeding 1,000 mg/L.

5.3.2.5 Unknown Depth Zone

Data for wells of unknown depth were distributed across the study area with the exception of the area in the vicinity of the intersection of W. Nees Avenue and N Fairfax (**Figure 5-32**). All the wells have historical maximum TDS concentrations below 3,000mg/L. **Figure 5-33** shows improvements in TDS concentrations in the area between the Delta-Mendota Canal and W. Nees Avenue. Wells of unknown depth in this area have lower TDS concentrations than their maximum historical values.

5.3.3 Pesticides

Pesticide concentration data for this GAR were limited to data obtained from DPR. Pesticide data available from DPR are for wells, but locations are only provided at the spatial resolution of the PLSS section in which the well is located. **Figure 5-58** shows the locations of sections where wells have been sampled for pesticides and where pesticide test results are reported by DPR and include sections that may only be partially within the GDA. Because well locations are not provided with these pesticide data, it is possible that wells in sections that are only partly within the GDA actually fall outside of the GDA. Sections with detected concentrations of pesticides exceeding levels provided in the SWRCB Water Quality Goals Online Database (http://www.waterboards.ca.gov/water_issues/programs/water_quality_goals/#data_downloads) are symbolized red in **Figure 5-58**, sections where pesticide detections have occurred at concentrations below the identified exceedance threshold are symbolized as orange, and green sections signify areas where pesticides were not detected. **Figure 5-58** shows all available pesticide sample data from DPR within the GDA. **Table 5-2** summarizes pesticides that have been detected in wells that are in sections that overlap with the GDA completely or partially, as reported in the DPR database. The threshold values used as a basis for identifying pesticide exceedances are also included in **Table 5-2**. The thresholds used to define pesticide exceedances were based first on a California Primary MCL, and otherwise the California Notification (action) Level and U.S. EPA Health and Water Quality advisory concentrations were used, as available.

Data for a total of 23 wells (in 18 PLSS sections) tested for pesticides in the study area were available from DPR. Of the 23 wells tested, 3 unique wells had detectable concentrations of a pesticide (**Table 5-2**). As shown in **Table 5-2**, 214 instances of pesticide detections were recorded within the GDA; however, some wells had detectable concentrations of multiple pesticides and multiple detections of the same pesticide. Of the 18 sections that had wells tested, three sections had wells with detectable concentrations of a pesticide and only one section had a well with exceedances. As shown in **Figure 5-**

58, few sections within the GDA had historical detections or exceedances for pesticides and there is little apparent pattern in the locations of pesticide detections and exceedances.

5.3.4 Selenium and Boron

Although both selenium and boron are naturally occurring in the GDA and are not necessarily a product of impacts from irrigated agriculture, understanding patterns and trends in their concentrations within the GDA is helpful for management of irrigated agriculture, particularly as it relates to sources of selenium in drainage water and boron concentrations in groundwater used for irrigation. Selenium is a natural element commonly found in soils in the GDA and also occur in groundwater. High selenium concentrations in groundwater and drainage water in the GDA have been a persistent issue in the GDA. Selenium is an essential nutrient for humans; however, high concentrations can present health concerns. Selenium has a Primary MCL for drinking water of 50 µg/L and a California Public Health Goal of 30 µg/L. Selenium can be toxic for aquatic wildlife at considerably lower levels and selenium concentrations in discharges of drainage water to surface waterways regulated under the Grassland Bypass Project WDRs have thresholds below the MCL and Public Health Goal.

Boron has no drinking water MCL although it has a California Action Level of 1.0 mg/L and an agricultural goal of 0.7 mg/L. Many agricultural crops are sensitive to high boron concentrations and its presence in groundwater in the GDA is a consideration for use of groundwater for irrigation purposes.

Figures 5-34 through **5-57** depicts the historical maximum and most recent concentrations for selenium and boron. These figures are also divided by depth zone for each of the constituents. The units for selenium concentrations displayed on the figures are in micrograms per liter (µg/L) whereas boron concentrations are presented in mg/L. **Figure 5-34** highlights the maximum concentrations of selenium observed historically within the GDA. The majority of the datapoints show maximum historical concentrations exceeding the MCL of 50 µg/L, but an improvement is evident in the most recent concentrations of selenium in **Figure 5-35**. Although most locations exhibit concentrations above 50 µg/L, some pockets of lower selenium concentrations exist, most notably in the area to the northwest of the W. Nees Avenue and N Russell Avenue intersection where concentrations are below 20 µg/L.

Historical maximum concentration data for boron for all depth zones is shown in **Figure 5-46** and the most recent data are presented in **Figure 5-47**. Most of these data show historical boron concentrations above 2 mg/L, a level which is considerably above the agricultural goal of 0.7 mg/L.

5.3.4.1 Very Shallow Water

In the zone of Very Shallow Water, the majority of data indicate historical maximum selenium concentrations above 50 µg/L (**Figure 5-36**). Although many of the sampled sites in **Figure 5-36** exceeded 50 µg/L, a greater number of the recent selenium concentrations in the Very Shallow zone are lower than the maximum values. This trend is most apparent in the area bounded roughly by the Merced-Fresno county line, W. Nees Avenue, and N. Russell Avenue. The majority of the sites in this part of the GDA have concentrations below 20 µg/L (**Figure 5-37**). Data for selenium in Very Shallow Water are limited or non-existing in areas southeast of the W. Nees Avenue and N. Fairfax Avenue intersection and also along the California Aqueduct near the western edge of the GDA.

There are sparse data available for boron concentrations in Very Shallow Water. The data that are available are concentrated in the center of the GDA, south of the Delta-Mendota Canal. Nearly all observed boron concentrations in Very Shallow Water have maximum historical concentrations exceeding 5 mg/L (**Figure 5-48**). A displayed in **Figure 5-49**, the most recent concentrations of boron do not suggest any notable change in concentrations and the spatial pattern in the concentrations of boron is similar to that of maximum values (**Figure 5-48)**.

5.3.4.2 Shallow Groundwater

Selenium concentrations in the Shallow Groundwater zone exhibit lower maximum concentrations compared to the Very Shallow Water. Although many wells have values above 50 µg/L, concentrations of selenium in Shallow Groundwater appear to be considerably lower in the western parts of the GDA. Approximately half of the wells to the west of N. Russell Avenue have concentrations below 20 µg/L (**Figure 5-38**). The most recent concentrations in selenium shown in **Figure 5-39** suggest a decreasing trend as many of the wells have concentrations below 20 µg/L. No selenium data are available for wells to the north of the Delta-Mendota canal and in the vicinity of the town of Mendota.

For boron, most of the Shallow Groundwater data are located in the area between the Merced-Fresno county line and N. Fairfax Avenue. All of the Shallow Groundwater wells have maximum historical boron concentrations above 1 mg/L, with the majority of wells showing concentrations above 2 mg/L (**Figure 5-50**). **Figure 5-51** highlights the most recent concentrations of boron in these wells with some most recent concentrations decreased relative to the maximum values. The most recent boron concentrations in Shallow Groundwater include a greater number of wells with values below 1 mg/L.

5.3.4.3 Upper Aquifer

Very limited data are available for selenium concentrations in the Upper Aquifer zone. Of the data that are available, most of the wells show concentrations below 20 µg/L. Wells along the Outside Canal show higher concentrations than other parts of the GDA, with concentrations above 50 µg/L in this area (**Figure 5-40**). No differences in selenium concentrations are apparent between the historical maximum concentrations and the most recent concentrations of selenium in the Upper Aquifer (**Figure 5-41**).

Figure 5-52 and 5-53 show the maximum and most recent boron concentrations in the Upper Aquifer zone. The available boron data in the Upper Aquifer are also sparse with only seven datapoints. All but one of the wells in the Upper Aquifer with boron concentrations have values between 2 and 5 mg/L with the other well slightly lower (1 to 2 mg/L). The maps of the maximum and most recent boron concentrations in the Upper Aquifer are identical.

5.3.4.4 Lower Aquifer

Data for selenium concentrations in the Lower Aquifer zone are also very limited. Most of the data are for wells in the vicinity of the Merced-Fresno county line, N. Russell Avenue, and W. Nees Avenue. The available selenium data suggest that maximum concentrations are much lower in the Lower Aquifer than in shallower zones with the majority of concentrations below 5 µg/L (**Figure 5-42**). **Figure 5-43** presents the most recent concentrations of selenium in the Lower Aquifer in the GDA. The patterns in the most recent selenium concentrations in the Lower Aquifer mimic those evident from the maximum concentrations presented in **Figure 5-42.**

A majority of the wells in the Lower Aquifer with boron data have concentrations between 2 and 5 mg/L although nearly an equal number of wells have concentrations between 1 and 2 mg/L (**Figures 5-54 and 5-55**). A notable decrease in boron concentrations is apparent in the more eastern parts of the GDA (east of N. Fairfax Avenue) and towards Mendota. The highest concentrations of boron in the Lower Aquifer are apparent near the Merced-Fresno county line. There are no major differences in the most recent boron concentrations and the maximum concentrations although several wells scattered across the GDA exhibit most recent concentrations that are lower than the maximum values.

5.3.4.5 Unknown Depth Zone

All the wells of unknown depth with selenium data are located in the northern-most parts of the GDA around the Delta-Mendota canal. About half of these wells have selenium concentrations exceeding 50 µg/L (**Figure 5-44**). Similarly, **Figure 5-45** shows data only in the northern most tip with similar concentrations as the maximum values.

Figure 5-56 displays those sites of unknown depth by historical maximum concentrations of boron. Relatively lower boron concentrations are evident in these wells in the areas east of N. Fairfax Avenue and increasing to the west of N. Russell Avenue. The majority of the boron concentrations are between 2 and 5 mg/L. The most recent concentrations of boron for sites without depth information displayed in **Figure 5-57** show values similar to the maximum concentrations.

5.4 Temporal Trends in Groundwater Quality

Evaluating historical temporal trends in groundwater quality is an important part of understanding the natural and anthropogenic influences on water quality. Temporal trends in groundwater quality were evaluated through plotting and comparison of graphs of time-series data for concentrations of nitrate, TDS, selenium, and boron. Select graphs of time-series concentration data for sites within the GDA are presented in **Figures 5-64 through 5-66, Figure 5-72, and Figure 5-78**. These figures graphical time-series concentration data for sites with relatively longer periods of record for evaluating historical changes and variability in groundwater quality conditions. Not all water quality constituents and depth zones have sufficient data for meaningful presentation in this format.

Basic statistical analyses were conducted on available time-series data for wells to identify statistically significant trends in water quality concentrations through time. Separate statistical tests were performed on each water quality parameter to determine if a statistically significant relationship between time and concentration exists for each site. This was done to assist in identifying notable patterns and trends in water quality based on data from numerous sites throughout the GDA. Both parametric and non-parametric statistical methods were used to evaluate the data for temporal trends. Non-parametric analysis included the Mann-Kendall, whereas parametric testing consisted of ordinary least squares linear regression.

For the linear regression trend analyses, the correlation coefficients (using date and concentration pairs) were calculated for each site and then evaluated for significance. The significance of a calculated correlation coefficient is dependent on the size of the sample and the magnitude of the correlation coefficient. A t-value was determined from the calculated correlation coefficient and also the number of degrees of freedom (n-2; n representing the number of samples for a site). The t-value was then compared to the t-distribution to determine a corresponding probability (p-value) which will determine if the trend is significant. A p-value of 0.1 was used as a threshold for defining significance. Following the determination of significance for a well’s correlation coefficient for concentration and time, the linear regression slope was calculated for each site using ordinary least squares regression.

The statistical significance of trends can only be determined for wells with three or more samples. The Mann-Kendall and linear regression methods produced very similar results although the linear regression analysis indicated a notably greater number of wells with statistically significant temporal trends. Consequently, only the results from the linear regression method are presented in this report. **Figures 5-59 through 5-63, Figures 5-67 through 5-71, Figures 5-73 through 5-77, and Figures 5-79 through 5-83** present the results of significant trend analyses for concentrations of nitrate, TDS, selenium, and boron based on the linear regression method. The sign and magnitude of any statistically significant trends in concentration are indicated on the figures. In the **Figures 5-59 through 5-63** significant trends in nitrate concentration, trends greater than 0.1 mg/L per year (mg/L/yr) and less than 1 mg/L/yr are indicated as mildly increasing, while trends in nitrate concentrations greater than 1 mg/L/yr are considered increasing. Conversely, nitrate trends between -0.1 and -1 mg/L/yr are considered mildly decreasing and trends less than -1 mg/L/yr are considered decreasing with trends from -0.1 to 0.1 to are considered a very small change. For TDS in **Figures 5-67 through 5-71**, significant temporal trends are considered mildly increasing for values between 10 mg/L/yr and 50 mg/L/yr and increasing for values greater than 50 mg/L/yr. Mildly decreasing TDS trends are rates of change between -10 mg/L/yr and -50 mg/L/yr and decreasing trends are indicated by values less than -50 mg/L/yr. Rates of TDS trends between -10 and 10 mg/L/yr are considered very small change. For selenium trends presented in **Figures 5-73 through 5-77**, trends are displayed as increasing for values above 0.05 mg/L/yr (50 µg/L/yr), mildly increasing for values between 0.01 mg/L/yr and 0.05 mg/L/yr (10 to 50 µg/L/yr), very small change for values ranging from -0.01 mg/L/yr to 0.01 mg/L/yr (-10 to 10 µg/L/yr), mildly decreasing for rates of change between -0.01 and -0.05 mg/L/yr (-10 to -50 µg/L/yr), and decreasing for values less than -0.05 mg/L/yr (-50 µg/L/yr). Similarly, trends in boron concentrations shown in **Figures 5-79 through 5-83** are displayed as increasing (above 0.05 mg/L/yr), mildly increasing (0.01 to 0.05 mg/L/yr), very small change (-0.01 to 0.01 mg/L/yr), mildly decreasing (-0.01 and -0.05 mg/L/yr), and decreasing (less than -0.05 mg/L/yr).

5.4.1 Time-Series Nitrate Concentrations

Data for concentrations of nitrate are not available with sufficient temporal range to warrant evaluation and presentation through time-series graphs. Few sites have a large number of tests for nitrate and most available data are from a relatively short window of time during the late 1980s and early 1990s.

5.4.2 Notable Temporal Trends in Nitrate Concentrations

Figure 5-59 shows the results of all of the statistical temporal trend analysis for nitrate concentrations. A minimum of three sampling events per site are required to identify a trend thereby reducing the number of sites for which trends can be evaluated. For the sites exhibiting statistically significant temporal trends in nitrate concentrations, there is roughly an even number of sites with statistically significant increasing temporal trends in concentrations as there are sites with decreasing trends. About half of the sites show trends with only very slight changes. Increasing trends appear most prominent in the vicinity of the area enclosed by the Merced-Fresno county line, W. Nees Avenue, and N. Russell Avenue. The only site with a decreasing trend is located to the southeast of the intersection between W. Nees Avenue and N. Fairfax Avenue. A mixture of trends in nitrate are also evident at the intersection between W Nees Avenue and N Russell Avenue with data showing both increasing trends and very small changes in this area.

5.4.2.1 Very Shallow Water

Only one datapoint representing the Very Shallow Water has a statistically significant trends in nitrate concentrations. This point is located to the southeast of the W Nees Avenue and N Fairfax Avenue intersection (**Figure 5-60**) and exhibits a trend of mildly decreasing nitrate concentrations. No other sites exhibit any significant trends in concentrations.

5.4.2.2 Shallow Groundwater and Upper Aquifer

As seen in **Figures 5-61 and 5-62**, none of the wells in the Shallow Groundwater zone and Upper Aquifer exhibit statistically significant trends in nitrate concentrations.

5.4.2.3 Lower Aquifer

Two wells in the Lower Aquifer show statistically significant trends in nitrate concentrations (**Figure 5-63**). Although spatial patterns in the trends cannot be evaluated based on the small number of datapoints, one well located near the intersection of W. Nees Avenue and N. Russell Avenue indicates minimal change in nitrate concentration and one well located near N Fairfax Avenue, at the southern border of the GDA shows a mildly increasing trend. All other wells in this depth zone have insufficient data to evaluate a temporal trend or otherwise exhibit no statistically significant temporal trend to observed nitrate concentrations.

5.4.3 Time-Series TDS Concentrations

Figures 5-64 through 5-66 show select graphs of temporal TDS concentrations in various depth zones within the GDA. TDS concentrations through time are plotted on the vertical axis in mg/L with varying value ranges.

5.4.3.1 Very Shallow Water

Figure 5-64 shows select graphs of TDS concentrations over time for the zone of Very Shallow Water. All of the sites depicted on **Figure 5-64** are for tile drain sumps. The data shown on these graphs are all since the 1990s with TDS concentration values generally above 1,500 mg/L and most sites having considerably higher TDS concentrations at times. All of sites displayed exhibit great short-term fluctuations in TDS concentrations suggesting considerable seasonal influences on drainage water within the Very Shallow zone. Longer-term trends show cycles of increasing and decreasing concentrations with notable decreases in TDS concentrations apparent in many wells during a period from the 1990s through the early 2000s. A subsequent short-term increase in TDS is apparent at many locations during the early 2000s with many sites exhibiting notable decreases in TDS concentrations during the time period since 2010, particularly in the northern and eastern parts of the GDA. The overall long-term trends in TDS concentrations exhibited by graphs for the Very Shallow Water zone in **Figure 5-64** appear to be relatively stable since the early 1990.

5.4.3.2 Shallow Groundwater

Graphs of TDS concentrations for six different wells in the Shallow Groundwater zone are depicted in **Figure 5-65**. Most of these wells have very periods of record with most data prior to 1970. Temporal trends are hard to detect from these wells; however, the majority of these wells have trends suggesting stable TDS concentrations during the 1950s and 1960s. The one well with more recent data since 2000 at the intersection at the southern border of the study area and N Fairfax Avenue does exhibit increasing TDS concentrations.

5.4.3.3 Lower Aquifer

No graphs of TDS concentrations within the Upper Aquifer are presented because of limitations in the available data. Somewhat more data are available for wells in the Lower Aquifer. **Figure 5-66** highlights select graphs of TDS concentrations for wells in the Lower Aquifer. As with the Shallow Groundwater zone, the limited range of time represented in the graphs on **Figure 5-66** does not readily enable evaluation of temporal trends in TDS concentrations in the Lower Aquifer. No major trends and patterns are apparent from the graphs, although one well in the central part of the GDA with more recent data exhibits decreasing TDS concentrations during the period from about 2010 to 2015. Wells shown on **Figure 5-66** have concentrations generally in the range between 1,000 and 2,000 mg/L.

5.4.4 Notable Temporal Trends in TDS Concentrations

Significant trends in TDS concentrations are displayed in **Figures 5-67 to 5-71** by depth zone. Considerably more data are available for statistically significant TDS temporal trends than are for nitrate temporal trends discussed above. **Figure 5-67** shows both increasing and decreasing nitrate trends scattered throughout the GDA. However, a more consistent pattern of increasing TDS concentrations is apparent in the northern tip of the GDA along the Outside Canal. A higher density of sites with mildly decreasing TDS concentrations also exists near the Delta-Mendota Canal between the Merced and Fresno County line and N. Russell Avenue.

5.4.4.1 Very Shallow Water

TDS concentration trend data for Very Shallow Water are presented in **Figure 5-68**. Sites in the northern tip of the GDA along the Outside Canal show statistically significant increasing trends in TDS concentrations. A mixture of increasing and decreasing TDS trends are interspersed within the GDA to the east of N Russell Avenue. Along Highway 33 near the boundary of the GDA, a greater number of sites have decreasing concentrations than increasing concentrations. Most sites to the southeast of the W. Nees and N. Fairfax Avenue intersection so not sufficient data to evaluate temporal trends or do not exhibit statistical significance to temporal trends in TDS concentrations.

5.4.4.2 Shallow Groundwater

There are only three wells within the study area in the Shallow Groundwater zone as seen in **Figure 5-69**. All three of the wells show increasing TDS concentrations with all of the wells being located between the Merced-Fresno county line and N Fairfax Avenue.

5.4.4.3 Upper Aquifer

Data for very few wells in the Upper Aquifer zone was available with respect to TDS concentrations. Of the wells that did have data, none displayed any significant trends in the concentrations (**Figure 5-70**).

5.4.4.4 Lower Aquifer

Figure 5-71 presents wells in the Lower Aquifer and related statistically significant temporal trends in TDS concentrations. Only three of the wells within this depth zone displayed significant trends. Two wells within the study area show decreasing trends in TDS concentrations. One of these wells is located near the N. Russell Avenue and W. Nees Avenue intersection while the other is located near the Merced-Fresno county line. Another well near the Merced-Fresno county line shows a significant increasing trend in TDS concentration.

5.4.5 Time-Series Selenium Concentrations

Figure 5-72 shows select graphs of temporal selenium concentrations in Very Shallow Water within the GDA. Selenium concentrations through time are plotted on the vertical axis in mg/L with varying value ranges. Only graphs of selenium concentrations in the Very Shallow zone were presented because of limitations in data for other depth zones. All of the sites depicted on **Figure 5-72** are for tile drain sumps.

The data shown on these graphs are all since the 1990s with widely ranging selenium concentration values depending on location and timing. All of sites displayed exhibit great short-term fluctuations in selenium concentrations similar to trends apparent in TDS concentrations (**Figure 5-64**). As noted above for TDS, the great variability in concentrations is likely a result of seasonal influences on drainage water within the Very Shallow zone. Longer-term trends show cycles of increasing and decreasing concentrations that mimic those noted for TDS. These trends include notable decreases in selenium concentrations in many wells during a period from the 1990s through the early 2000s and a subsequent short-term increase in selenium at many locations during the early 2000s. Many sites exhibit notable decreases in selenium concentrations during the time period since 2010. The overall long-term trends in selenium concentrations exhibited by graphs for the Very Shallow Water zone in **Figure 5-72** appear to be relatively stable to slightly decreasing in most wells since the early 1990.

5.4.6 Notable Temporal Trends in Selenium Concentrations

Figure 5-73 through 5-77 depict statistically significant temporal trends in selenium concentrations in within the GDA. Selenium concentration trend data for all depth zones are displayed in **Figure 5-73**. A general trend of decreasing selenium concentrations is apparent across the GDA in this figure. However, in the area bounded by the Outside Canal, N. Russell Avenue and W. Nees Avenue, mildly increasing to increasing trends are evident in about one half of the sites with decreasing trends dispersed throughout. In contrast, sites within the area directly west bounded by the Merced-Fresno County line, N. Russell Avenue and W. Nees Avenue show mostly very small changes in selenium concentrations over time.

5.4.6.1 Very Shallow Water

Figure 5-74 shows statistically significant temporal trends in Very Shallow Water. The majority of the sites shown on **Figure 5-74** have either decreasing selenium concentrations or very small changes in selenium concentrations. Most of the sites exhibiting increasing concentration trends are located in areas to the north of W. Nees Avenue and east of N. Russell Avenue.

5.4.6.1 Shallow Groundwater and Upper Aquifer

Neither the Shallow Groundwater nor the Upper Aquifer have any wells that exhibit statistically significant trends in selenium concentrations within the GDA (**Figures 5-75 and 5-76**).

5.4.6.2 Lower Aquifer

Very few wells in the Lower Aquifer have data for selenium concentrations and only one well showed a statistically significant temporal trend in selenium concentrations. This well is located near the intersection of W. Nees Avenue and N. Russell Avenue and exhibits a very small temporal change in selenium concentration based on the statistical analysis (**Figure 5-77**).

5.4.7 Time-Series Boron Concentrations

Figure 5-78 shows select graphs of temporal boron concentrations for various depth zones within the GDA. Boron concentrations through time are plotted on the vertical axis in mg/L with varying value ranges. Graphs of boron concentrations for various depths are displayed together on **Figure 5-78** because of the limited number of sites with sufficient data to warrant graphing. Most of the graphs on **Figure 5-78** are for sites with unknown depth information and most of the sites have relatively few tests for boron, all of which occur prior to 1990. Temporal trends in boron illustrated by these graphs suggest generally stable, but relatively high, boron concentrations over longer time periods at most locations, with one Very Shallow Water site indicating considerable short-term fluctuations, likely resulting from season irrigation influences.

5.4.8 Notable Temporal Trends in Boron Concentrations

Data for all sites with boron concentrations are displayed in **Figure 5-79** with statistically significant temporal trends in concentrations displayed at four of the sites. The two sites in the northwestern part of the GDA exhibit increasing trends in boron concentrations whereas the two sites with statistically significant trends located further south show decreasing trends. No other sites within the GDA have statistically significant temporal trends in boron.

No sites representing Very Shallow Water, Shallow Groundwater, or the Upper Aquifer have statistically significant temporal trends in boron concentrations (**Figures 5-80 through 5-82**). Two wells in the Lower Aquifer have significant trends in boron concentrations (**Figure 5-83**); one well has an increasing trend and the other has a mildly decreasing trend in boron concentrations. Both of these Lower Aquifer wells are located in the western part of the GDA (**Figure 5-83**).

5.5 Additional Groundwater Quality Data

The focus of this GAR was on acquiring and summarizing general groundwater quality in the GDA based on chemical constituent data that are widely available and most commonly associated with impacts from irrigated agricultural practices. As a result, the acquisition and summary of groundwater quality data for this GAR focused on nitrate, TDS, and pesticides. Data for selenium and boron were also acquired and evaluated because they occur naturally in high concentrations in groundwater in the area and have implications for agricultural activities within the GDA. Other published reports were reviewed to document other groundwater quality characteristics within the Delta-Mendota Subbasin, where the GDA is located (**Figure 1-3**). As discussed in **Section 2**, groundwater types in the region vary by location and depth and are characterized as transitional (e.g. predominantly chloride, bicarbonate, or sulfate). Concentrations of trace metals and numerous chemical constituents in groundwater were investigated across the Delta-Mendota Subbasin by the USGS in 2013 as part of the SWRCB GAMA Program's Priority Basin Project and the results are summarized by Mathany et al. (2013). Water quality analyses conducted on samples from 45 wells within the Subbasin indicate that most inorganic constituents in groundwater are at concentrations below primary and secondary MCLs. The primary MCL (either set by the USEPA or the California Department of Public Health [CDPH]) is designed to protect public health by limiting the levels of contaminants in public drinking water systems.

Table 5-3 summarizes the notable water quality results for the 45 wells within the Delta-Mendota Subbasin sampled as part of the USGS GAMA study and reported by Mathany et al. (2013). As shown in **Table 5-3**, a few wells sampled as part of this study had concentrations above the Primary MCL for the respective inorganic constituents. However, more commonly, wells sampled had groundwater exceeding SMCL thresholds, which are not health-based standards and are applied to constituents that affect the aesthetic qualities of drinking water, such as taste, odor, and color, or the physical qualities of drinking water, such as scaling and staining. The most common constituents detected above the SMCL included sulfate, manganese, and chloride. Most of the wells sampled are not located within the GDA although these data are helpful because they provide an indication of regional groundwater quality characteristics. Areas that are poorly drained are generally more susceptible to the accumulation of trace elements such as arsenic, boron, and selenium in the shallow subsurface (Randolph, 2003).

5.6 Summary of Groundwater Quality Data

The presence of natural salinity conditions in groundwater throughout the GDA has existed historically as a result of the natural hydrogeologic setting. Natural conditions of groundwater salinity exist throughout all zones of the groundwater system as a result of the contribution of salts from recharge off of the Coast Range mountains. Areas of the GDA are underlain by low-permeability, fine-grained floodplain sediments and clays which impede vertical movement of groundwater, often resulting in poor drainage conditions, shallow groundwater stagnation, and associated accumulation of salts.

To characterize groundwater quality within the GDA, as it relates to impacts from irrigated agriculture, water quality data were gathered from a variety of different sources including GDA districts, USGS, DDW, DWR, SWRCB, and RWQCB. Over 700 nitrate test results were compiled from 260 tile drains and wells and nearly 45,000 TDS test results were compiled from more than 600 tile drains and wells (**Table 5-1a**) distributed throughout the GDA. Pesticide data gathering was limited to that provided by DPR. The locations for the wells provided by DPR are specified to the PLSS section. Additional data for selenium and boron concentrations were also acquired and evaluated.

About one third of the sites for which nitrate data are available represent the Very Shallow Water zone. The maximum nitrate concentrations for most of the Very Shallow sites are above 10 mg/L. Comparison of the maximum and most recent nitrate concentrations suggests that there are minimal differences between these concentrations. The Shallow Groundwater also exhibits elevated nitrate concentrations in areas, although a mixture of sites with low nitrate concentrations is also apparent. Within the Shallow Groundwater zone, recent nitrate concentrations suggest there are slight improvements relative to maximum concentrations. Nitrate data for both the Very Shallow Water zone and the Shallow Groundwater zones have spatial data gaps and are particularly scarce near the town of Mendota. Data representing nitrate concentrations in deeper zones including the Upper Aquifer and Lower Aquifer suggest that concentrations are notably lower than in the Very Shallow Water and Shallow Groundwater. Although few wells with nitrate data are available for the Upper and Lower Aquifers (20 wells combined), they exhibit considerably reduced nitrate concentrations with most below 2.5 mg/L. Statistical analysis conducted on data indicate few sites with statistically significant temporal trends in nitrate concentrations. The few significant trends indicated suggest a mixture of decreasing and increasing nitrate concentrations within different depth zones although few notable patterns in these temporal trends are evident because of the limited number of sites with statistically significant trends.

Approximately half of the wells with TDS data are located in the Very Shallow Water zone. The majority of these sites have maximum historical concentrations exceeding 3,000 mg/L, but some improvement is indicated in the most recent concentrations. Such improvements are indicated in the area bounded by the Delta-Mendota Canal, Merced-Fresno county line, and W. Nees Avenue. In the Shallow Groundwater zone, a pattern of increasing TDS values to the east is evident with a majority of the wells located to the east N Russell Avenue exceeding 3,000 mg/L in contrast with the high number of wells to the west of N Russell Avenue with concentrations below 1,000 mg/L. Few wells in the Upper Aquifer have TDS concentration data and all available data points exceed 1,000 mg/L. The majority of the wells in the Lower Aquifer with TDS concentrations also have values above 1,000 mg/L. Most of the wells with TDS data in the Lower Aquifer are in the central part of the GDA. The most recent TDS concentrations in the Lower Aquifer also indicate values above. 1,000 mg/L.

Statistical analyses of temporal trends in TDS concentrations indicate a mixture of increasing and decreasing TDS concentrations in sites in the Very Shallow Water. Increasing trends exist in the northwestern-most tip of GDA although sites with decreasing trends slightly more common than increasing trends in the rest of the GDA. The Shallow Groundwater and Lower Aquifer zones have wells with generally increasing TDS concentrations along the Merced-Fresno county line; however, one well in the Lower Aquifer zone in this area has a decreasing TDS concentration trend.

Pesticide data from DPR indicate that three PLSS sections overlapping the GDA had a well with a historical pesticide detection. Of these sections, one section had a single well with historical pesticide concentrations that exceeded the water quality objectives.

In addition to nitrate, TDS, and pesticides, data for selenium and boron concentrations were also evaluated. In the zone of Very Shallow Water, the majority of data indicate historical maximum selenium concentrations above 50 µg/L, although many of the sampled sites have recent selenium concentrations that are lower than the maximum values. This trend is most apparent in the area bounded roughly by the Merced-Fresno county line, W. Nees Avenue, and N. Russell Avenue where the majority of Very Shallow Water sites have concentrations below 20 µg/L. Selenium concentrations in the Shallow Groundwater zone exhibit lower maximum concentrations compared to the Very Shallow Water. Although many Shallow Groundwater wells have selenium concentrations above 50 µg/L, concentrations appear to be considerably lower in the western parts of the GDA where about one half of the wells have concentrations below 20 µg/L. The most recent concentrations in selenium suggest a decreasing trend as many of the wells have concentrations below 20 µg/L. Very limited data are available for selenium concentrations in the Upper Aquifer zone; of the available data, most of the wells indicate concentrations below 20 µg/L. Data for selenium concentrations in the Lower Aquifer zone are also very limited although the available selenium data suggest that maximum concentrations are much lower in the Lower Aquifer than in shallower zones with the majority of concentrations below 5 µg/L.

For boron, there are sparse data available for Very Shallow Water and nearly all observed boron concentrations in Very Shallow Water have maximum historical concentrations exceeding 5 mg/L. Most of the Shallow Groundwater data are located in the area between the Merced-Fresno county line and N. Fairfax Avenue. All of the Shallow Groundwater wells have maximum historical boron concentrations above 1 mg/L, with the majority of wells showing concentrations above 2 mg/L. The most recent boron concentrations in Shallow Groundwater include a greater number of wells with values below 1 mg/L. The sparse available boron data in the Upper Aquifer suggest boron concentrations generally in the range of 2 to 5 mg/L. A majority of the wells in the Lower Aquifer with boron data have concentrations between 2 and 5 mg/L although nearly an equal number of wells have concentrations between 1 and 2 mg/L. Notably decreased boron concentrations are apparent in the more eastern parts of the GDA whereas the highest concentrations of boron in the Lower Aquifer are apparent near the Merced-Fresno county line.

Statistical analyses of temporal trends in selenium and boron concentrations. The majority of the Very Shallow Water sites with statistically significant trends exhibit decreasing trends. The only well with a significant trend in the Lower Aquifer zone also has a decreasing trend.

Boron concentrations in the Very Shallow Water, Shallow Groundwater, and Lower Aquifer zones appear to be somewhat lower in the most recent testing than the historical maximum. However, due to the scarce amount of data, few statistically significant temporal trends in boron concentrations were identified. Only two wells in the Lower Aquifer have significant trends but both suggest that boron concentrations have changed very little.

6 GROUNDWATER VULNERABILITY AND PRIORITIZATION

One major component of the GAR is the identification of high vulnerability areas for more focused management and monitoring of agriculture practices and groundwater conditions. Few specifics on methods for determining groundwater vulnerability are provided in the WDR; however, the WDR states that “vulnerability designations will be made by the third-party using a combination of physical properties (soil type, depth to groundwater, known agricultural impacts to beneficial uses, etc.) and management practices (irrigation method, crop type, nitrogen application and removal rates, etc.)”. The definition of high vulnerability areas is provided in Attachment E of the WDR.[5] This section outlines different methods for assessing groundwater vulnerability, including approaches applied to evaluate vulnerability in California, and presents the method developed for determining high vulnerability areas in this GAR. To determine high vulnerability areas, a model for assessing groundwater vulnerability was developed following an index/overlay methodology utilizing a combination of statistical approaches based on observed groundwater quality and hydrogeologic characteristics and incorporation of overlays of other important physical considerations. The results from the groundwater vulnerability assessment were reviewed and evaluated with respect to locations of observed exceedances of groundwater quality standards for nitrate, TDS, and pesticides.

6.1 Overview of Groundwater Vulnerability Assessment

The term groundwater vulnerability has been interpreted and defined in different ways within the scientific and water resource community. Common definitions of groundwater vulnerability couple the roles of intrinsic physical hydrogeologic properties with anthropogenic land use activities to provide a measure of groundwater vulnerability. **The National Research Council (1993) defines groundwater vulnerability as “The tendency or likelihood for contaminants to reach a specified position in the ground water system after introduction at some location above the uppermost aquifer.”** Within this definition, groundwater vulnerability assessments generally fall into two different types: assessments of specific vulnerability and assessments of intrinsic vulnerability. Specific vulnerability is a measure of vulnerability with respect to a specific contaminant or anthropogenic activity, whereas intrinsic vulnerability describes vulnerability without consideration of the characteristics or behavior of a contaminant. In this way, intrinsic vulnerability is a relative measure of the tendency or likelihood for groundwater contamination based on the physical properties and characteristics of an area. Well vulnerability is distinct from groundwater vulnerability and depends on human land use factors and natural physical conditions, but also considers influences related to specific well characteristics and the

[5] Definition of high vulnerability area from Attachment E of WDR: High vulnerability area (groundwater) – Areas identified in the approved Groundwater Quality Assessment Report “…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.” (see section IV.A.3 of the MRP) or areas that meet any of the following requirements for the preparation of a Groundwater Quality Management Plan (see section VIII.H of the Order): (1) there is a confirmed exceedance (considering applicable averaging periods) of a water quality objective or applicable water quality trigger limit (trigger limits are described in section VIII of the MRP) in a groundwater well and irrigated agriculture may cause or contribute to the exceedance; (2) the Basin Plan requires development of a groundwater quality management plan for a constituent or constituents discharged by irrigated agriculture; or (3) the Executive Officer determines that irrigated agriculture may be causing or contributing to a trend of degradation of groundwater that may threaten applicable Basin Plan beneficial uses.

presence of preferential contaminant flow pathways that result in the mixture of water present in a well (Eberts et al., 2013).

Approaches used in groundwater vulnerability assessments can range in complexity from highly subjective evaluations to detailed transport models and can generally be grouped into three different types of methods: index or overlay methods, process-based methods, and statistically-based methods. Each of these types of groundwater vulnerability assessment methods has advantages and limitations.

Index methods typically involve subjective approaches to combining spatial data layers describing the physical characteristics of the hydrogeologic setting (e.g., geology, depth to water, topography) and from these data deriving relative groundwater vulnerability at all locations within a study area. Index methods such as the DRASTIC method developed by USEPA employ a semi-quantitative element to the vulnerability assessment wherein physical attributes are numerically scored and weighted according to the perceived importance of each physical factor (Aller et al., 1987). However, the scoring and weighting system applied to the physical factors is subjectively based and is typically not adjusted for specific local or regional circumstances.

Process-based methods seek to integrate the many physical, chemical, and biological processes and interactions that affect groundwater vulnerability within the framework of a model that attempts to simulate the transport of contaminants. Process-based methods often require a large number of datasets, many of which may not be directly or as readily available, and have other potential limitations related to scaling of processes. However, these methods do not necessarily provide results that are any more reliable than vulnerability assessments resulting from other approaches.

Statistical methods have sought to quantitatively relate multiple physical characteristics to observed groundwater quality in order to develop a statistically-based relationship to describe the relative likelihood for groundwater to be contaminated across a study area. These methods do not seek to identify cause-effect relationships, but rather they are intended to provide a relative measure of likelihood of groundwater contamination occurring under defined circumstances. Statistically-based methods rely on datasets representing the locations and concentrations of water quality observations in addition to spatial data for the independent variables of interest. These data serve as the basis with which to evaluate and quantify relationships between characteristics of the physical setting and the observed water quality.

As mentioned above, one of the most widely used methods to date for assessing intrinsic groundwater vulnerability has been the DRASTIC method developed by the USEPA. The original DRASTIC approach is a semi-quantitative index method that incorporates seven hydrogeologic parameters in calculating a groundwater vulnerability rating: **D**epth to water, Net **R**echarge, **A**quifer media, **S**oil media, **T**opography (slope), **I**mpact of vadose zone media and **C**onductivity (hydraulic) of the aquifer. With DRASTIC, these parameters are scored and weighted across the study area in accordance with specific criteria, which were subjectively determined during the original development of the method (Aller et al.,1987). The scores and weights for all the hydrogeologic parameters are then used to calculate a DRASTIC groundwater vulnerability rating. **Table 6-1** shows the scoring and weighting of parameters for the assessment of intrinsic groundwater vulnerability as outlined by Aller at al. (1987). More recently, various modified DRASTIC approaches have been employed for “calibrating” the scoring and weighting values of parameters in the DRASTIC method using observed groundwater quality data and statistical analyses. In this way, more objective and quantitatively-based relationships among the hydrogeologic parameters and groundwater vulnerability can be established.

The concept of the Nitrate Groundwater Pollution Hazard Index (NHI) similarly utilizes an index method for calculating a risk value based on the combination of crop, irrigation, and soils. In the NHI concept, separate indices for crop type (incorporating nitrogen application and uptake rates), irrigation method, and soil type characteristics are determined with values assigned based on perceived level of risk for nitrate contamination associated with each. The combination of these values, either through summing or multiplying, is then used as a measure for risk to nitrate contamination resulting from the specified crop and soil conditions.

A variety of statistical approaches have been used to assess groundwater vulnerability and relate groundwater quality to natural and anthropogenic variables. One statistical method that has been used in this way is logistic regression, which can be used to predict the presence of a selected water quality parameter exceeding a specified concentration threshold (Antonakos and Lambrakis, 2007; Greene et al., 2004; Nolan et al., 2002; Nolan, 2001; Tesoriero et al., 1998; Tesoriero and Voss, 1997). Logistic regression can be useful in assessing the probability of exceeding a specified water quality concentration threshold; however, the dependent variable must be binary (in two categories). Non-linear regression methods have been used to predict nitrate contamination at a national scale using spatial averaging of observed water quality data to reduce local variability (Nolan and Hitt, 2006). Recently, a method using a random forest classifier was used to predict nitrate and arsenic concentrations in basin-fill aquifers in the southwestern United States (Anning et al., 2012). The random forest classifier is a rule-based method which follows a classification tree (decision tree) that fits a conceptual model. Many of the statistical approaches to assessing groundwater vulnerability have focused on nitrate contamination and have used nitrate groundwater quality observations as the response variable.

6.1.1 Previous Assessments of Groundwater Vulnerability in the Grassland Drainage Area

Although very little specific guidance on determining groundwater vulnerability is provided in the WDR, it does call specific attention to and consideration of previous assessments of Hydrogeologically Vulnerable Areas conducted by the SWRCB and Groundwater Protection Areas identified by DPR. Furthermore, the WDR specifies that should the third party fail to submit a GAR by the required deadline, the Executive Officer will designate default areas of high and low groundwater vulnerability considering these studies (and other approaches), together with areas of exceedances of groundwater quality objectives for which irrigated agricultural waste discharges are a contributing factor. The referenced assessments were performed using different methods with varying factors of consideration and degrees of complexity. The methods used in these approaches are described below.

6.1.1.1 SWRCB Hydrogeologically Vulnerable Areas

A map of *Hydrogeologically Vulnerable Areas* was created in 2000 by the SWRCB in response to Executive Order D-5-99 and in order to identify areas where published literature suggest the presence of soil or rock conditions that may make groundwater more vulnerable to contamination. **Figure 6-1** shows the extent of the areas designated *Hydrogeologically Vulnerable Areas* by the SWRCB in 2011 in the vicinity of the GDA (J. Hartman, personal communication). This map was originally created in 2000 at a scale of 1:250,000 (1 inch = 4 miles) based on DWR and USGS published information and delineates *Hydrogeologically Vulnerable Areas* where geologic conditions include generally more permeable units, enabling higher recharge rates, than in areas where lower permeability or confining layers exist (SWRCB, 2013b). There are no areas designated as Hydrogeologically Vulnerable Areas by SWRCB within the GDA.

6.1.1.2 DPR Groundwater Protection Areas

The DPR developed the California Vulnerability (CALVUL) approach to delineate Groundwater Protection Areas (GWPAs) to fulfill parts of an USEPA mandate for states to develop Pesticide Management Plans, including the development of a statewide vulnerability assessment. The CALVUL method is applied at a PLSS section (one square mile) spatial scale and relies on an empirically developed approach to identifying select soil conditions and characteristics that are common among sections of land where pesticides have been detected. Additionally, sections with depth to groundwater of less than 70 feet were also determined to have a higher probability of having pesticide detections (Troiano et al., 1999a and 1999b). From these associations, GWPAs are identified where soil and depth to water conditions suggest a greater potential for contamination. Ultimately, DPR's CALVUL method identifies GWPAs at the section level where soil characteristics in a section are generally coarse or hardpan and if the depth to groundwater is less than 70 feet. DPR's GWPAs are categorized as leaching, runoff, or leaching or runoff according to likely mechanisms for contamination. Coarse soils with depth to water less than 70 feet are designated vulnerable to leaching, whereas hardpan soils are designated vulnerable to runoff. Sections where pesticide residue has been detected but where soil or depth to groundwater conditions do not suggest a vulnerability to contamination through either leaching or runoff mechanisms are designated as leaching or runoff GWPAs. **Figure 6-1** shows the extent of the areas designated by DPR as GWPAs (DPR, 2013). There are also no areas designated as GWPAs by DPR within the GDA.

6.1.1.3 Other Evaluations of Potential for Groundwater Contamination

Additional studies have characterized the GDA and other nearby areas within the Central Valley based on statistical relationships derived from national studies of groundwater quality (Nolan et al., 2002) and also through standardized techniques such as application of the NHI as performed by Dzurella et al. (2012). In the analysis conducted by Nolan et al. (2002), logistic regression was used to evaluate the statistical relationships between shallow groundwater quality observations and multiple variables representing land use and physical conditions. Nolan et al. (2002) used a threshold nitrate concentration value of 4 mg/L (as N) for conducting the logistic regression analysis. Results from this national study indicated significant positive statistical relationships between locations with observed nitrate concentrations above 4 mg/L and applied nitrogen, population density, presence of well-drained soils, depth to water, and presence of unconsolidated sand and gravel aquifers. These relationships derived at a national scale were then applied to the Central Valley region, including the GDA, to provide a groundwater risk assessment as shown in **Figure 6-2**. Although the application of the logistic regression model was successful in predicting locations with nitrate concentrations below the 4 mg/L (96 percent) across the entire national study area, the success rate of predicting locations with nitrate concentrations above 4 mg/L was relatively low (16 percent). These results suggest a strong need for consideration of variables at a more local scale, particularly as they relate to the physical hydrogeologic setting. Additionally, it is also not known to what degree valuable information relating to the magnitude of nitrate concentrations at levels above 4 mg/L may not have been considered through use of the logistic regression approach.

The application of the NHI presents similar challenges as it utilizes a standard matrix for calculating a risk value based on the combination of crop, irrigation, and soils without regard to many other aspects of the local physical setting. Dzurella et al. (2012) produced a map of risk for nitrate contamination for some parts of the Central Valley based on application of the NHI. In contrast to the SWRCB and DPR studies which determined Hydrogeologically Vulnerable Areas and GWPAs based largely on physical characteristics of the location, the relative "risk" results generated by Nolan et al. (2002) using statistical relationships derived from a national study and the application of the NHI, such as was conducted by Dzurella et al. (2012), are heavily dependent on the specified characteristics associated with the land use. This presents additional challenges for identifying high vulnerability areas as discussed below. It is notable in **Figure 6-2** that the risk assessment by Nolan et al. (2002) indicates higher risk areas primarily in the western and southern parts of the GDA.

Both of these methods derive risk measures for nitrate contamination based on land use factors with relatively lesser consideration of hydrogeologic conditions. The only physical characteristics considered in the NHI are the soils whereas Nolan et al. (2002) incorporates soil drainage characteristics and depth to groundwater, but neither method considers other aspects of the hydrogeologic system. Within the GDA, the existence of subsurface tile drainage systems is a major consideration that is not accounted for in any of the previously discussed approaches to identifying areas of higher groundwater vulnerability. It is also notable that results from the NHI and from Nolan et al. (2002) are specific to the potential for contamination from nitrate only under the mapped land use at the time of the analysis. Consequently, areas associated with land uses having generally high nitrate application rates, are indicated relatively higher risk, although actual land uses and land use practices can and do change. Furthermore, the risk of potential impacts from chemical constituents other than nitrate is largely not considered in these methods for assessing risk.

6.1.2 Groundwater Vulnerability Assessment for Western San Joaquin River Watershed Area

The GAR completed for the Western San Joaquin River Watershed region in March 2015, and approved by the Regional Board in September 2015, involved an assessment of the vulnerability of groundwater for areas surrounding the GDA (LSCE, 2015). The location and extent of the Western San Joaquin River Watershed region in relation to the GDA and the vulnerability areas identified as part of the GAR are illustrated in **Figure 6-3**. In that vulnerability assessment, statistical methods for assessing groundwater vulnerability were utilized to identify and quantitatively describe relationships between physical characteristics of the area and observed groundwater quality. The approach involved using multiple linear regression (hereinafter referred to as multiple regression) statistical analyses to identify relationships between multiple potential independent (explanatory) variables characterizing the physical setting and the dependent (response) variable of observed groundwater quality. Such an approach is a type of index method for assessing groundwater vulnerability, but it minimizes subjective aspects inherent in index methods by determining groundwater vulnerability using statistical relationships with actual observations of groundwater quality within the watershed. A method of determining groundwater vulnerability irrespective of land use was used by accounting for differences in land use in order to decipher differences in groundwater quality that are related to hydrogeologic variables as opposed to differences in groundwater quality that are related to land use. Snapshots of past land use conditions at different points in time were used to consider how land use has influenced water quality.

6.2 Grassland Drainage Area Groundwater Vulnerability Approach

As with Western San Joaquin River Watershed GAR, the approach for determining groundwater vulnerability in the GDA is modeled after the definition of *intrinsic vulnerability* as defined and discussed above and focuses on determining the vulnerability of groundwater to contaminants based on the intrinsic physical properties of the area. Intrinsic physical properties remain relatively static over time and represent conditions that are generally beyond control from management decisions. In contrast, influences from human activities as a result of land use are subject to major changes in trends over short periods of time. Consequently, a measure of groundwater vulnerability that is based on intrinsic physical properties independent of land use conditions is advantageous because physical characteristics of the watershed are less likely to undergo such rapid and major shifts in characteristics. From a practical standpoint, an assessment of groundwater vulnerability that is tied to land use would need to be adjusted in response to changes in land use. Land use considerations were incorporated throughout the process of determining high vulnerability areas as discussed later in the section.

6.2.1 Conceptual Model

The groundwater vulnerability assessment for the GAR is grounded on a conceptual model in which the observed groundwater quality is the result of interactions between land use practices at the surface and the presence of physical hydrogeologic characteristics and processes occurring at a location. Under this conceptual model, the presence of hydrogeologic characteristics that enable potential contaminants to reach the groundwater surface faster make a location more vulnerable to groundwater contamination than a location with hydrogeologic characteristics that impede the ability of contaminants to reach groundwater or attenuate the contamination. Accordingly, hydrogeologic processes and characteristics such as soil properties, the water transmitting properties of subsurface materials, presence of flow barriers (clay layers) to vertical or lateral movement of water, and other physical factors are expected to influence the vulnerability of a location to groundwater contamination.

As discussed in **Section 2**, the hydrogeology of the area consists of distinct depth zones (Very Shallow Water, Shallow Groundwater, Upper Aquifer, Lower Aquifer) in which water occurs and which were used to characterize the hydrogeologic setting for the purpose of this GAR. Each of these zones has distinct groundwater quality characteristics resulting from a combination of natural and anthropogenic influences. The potential for groundwater contamination of each of these zones is different. **Figure 2-8** presents a conceptual illustration of the hydrogeologic system. An unconfined zone of Very Shallow Water exists in some areas with deeper groundwater zones (Shallow Groundwater, Upper Aquifer, and Lower Aquifer) below. The E Clay Member of the Tulare Formation, referred to as the Corcoran Clay Member, is a prominent subsurface feature in the GDA that is believed to provide hydraulic separation between the Upper and Lower Aquifers throughout the GDA. Several shallower clay members of the Tulare Formation, and a white clay layer mapped by Hotchkiss and Balding (1971), are less extensive than the Corcoran Clay, but likely exist in parts of the GDA and represent potential impediments to vertical movement of groundwater below and within the Very Shallow, Shallow Groundwater, and Upper Aquifer zones.

Subsurface tile drains exist in large parts of the GDA and are used to drain percolating water within and directly below the root zone in irrigated areas. As discussed earlier and also noted in the WDRs (Order R5-2015-0095, Section I.3), these drains capture percolating applied water and other shallow water and discharge it through a drainage system that is operated as part of the Grassland Bypass Project. The disposition and fate of drainage water is not covered by the irrigated lands Order and is regulated separately under WDRs for the Grassland Bypass Project. However, the tile drains represent an important consideration in the assessment of vulnerability of groundwater that is not captured by the drainage system. The tile drains are believed to greatly limit the vertical movement of applied water into the groundwater system.

The potential for vertical hydraulic communication between the land surface and groundwater is the primary consideration in understanding the vulnerability of groundwater to impacts from irrigated agriculture. Consequently, characterization of the nature of vertical hydraulic relationships and relating physical conditions that affect (increase or decrease) vertical hydraulic communication between the land surface and the subsurface and within the subsurface was the focus of the groundwater vulnerability evaluation conducted for the GDA.

6.2.1.1 Hydrogeologic Variables of Interest

6.2.1.1.1 *Soil Characteristics*

Conceptually, the soil properties are expected to influence the observed groundwater quality in areas of irrigated agriculture because higher conductivity soils or soils with better drainage characteristics may enable more rapid infiltration of applied nitrogen into the groundwater. However, salt and nitrate may also tend to accumulate in soils with characteristics that cause stagnating water conditions and prevent flushing. Such conditions have been previously documented throughout areas of the GDA which can lead to natural evapoconcentration of salt and nitrate in the shallow subsurface. NRCSSSURGO of soil mapping includes a characterization of soils for evaluating relationships with groundwater quality and vulnerability. The spatial distribution of soil characteristics within the GDA are presented in **Figures 2-26 through 2-29**. Soil drainage class was identified by Nolan et al. (2002) as having a statistically significant correlation with nitrate concentrations at a national scale. In other analyses in the Eastern San Joaquin River Watershed, a statistically significant positive relationship was observed between soil hydraulic conductivity and nitrate concentrations (LSCE, 2014). The weighted (based on thickness of soil layers) harmonic mean of the saturated hydraulic conductivity for the soil profile, as derived from the SSURGO dataset, was calculated for the GDA. The harmonic mean is a method of averaging in which low values are more heavily weighted and is commonly used for averaging soil conductivities where flow is perpendicular to layering. Use of the harmonic mean as a representative averaging method for hydraulic conductivities of stratified geologic materials has been widely used and is consistent with methods used in the derivation of hydraulic conductivity data for groundwater flow models in the area (Faunt et al., 2009; Phillips et al., 2007, Belitz et al., 1993). **Figures 2-26 and 2-27** show the spatial distribution of physical soil characteristics of vertical saturated hydraulic conductivity and drainage class throughout the GDA.

6.2.1.1.2 *Deeper Subsurface Properties*

The conceptual model for groundwater vulnerability holds that the hydraulic conductivity of deeper subsurface materials is likely to influence the observed groundwater quality and the ability of chemicals to move vertically into and through the groundwater zones or between groundwater zones; the vertical movement of chemicals is expected to occur more readily in subsurface sediments that are hydraulically conductive. Both sediment texture and vertical hydraulic conductivity data are available at a cell size of one-square mile for CVHM cells within the GDA as shown on **Figures 2-30 through Figure 2-36**. The CVHM sediment texture data were originally derived from approximately 8,500 well drillers' logs throughout the Central Valley and represent the percentage of coarse geologic materials in 50 foot intervals across the Central Valley Floor. Vertical hydraulic conductivity values for layers in CVHM were derived from the sediment texture data and aggregated by model layer (Faunt et al., 2009). Consequently, the CVHM sediment texture dataset is advantageous because it retains a higher level of vertical resolution (50 feet intervals) as compared to the CVHM vertical hydraulic conductivity data, which have been aggregated within each of the model layers. In accordance with the conceptual model the percent coarse of subsurface sediments might be positively correlated with nitrate concentrations and groundwater vulnerability.

6.2.1.1.3 *Corcoran Clay*

The Corcoran Clay member of the Tulare Formation geologic unit represents a prominent hydrostratigraphic feature in the GDA with varying depth and thickness. The Corcoran Clay is a low-permeability stratigraphic unit present in a large area of the Central Valley. However, the depth and thickness of the unit in the area are spatially variable (**Figures 2-9 and 2-10**). Several properties of the Corcoran Clay, as derived from CVHM datasets, are available for consideration with respect to influence on groundwater vulnerability; however, from a conceptual standpoint, these characteristics of the Corcoran Clay are only expected to relate with vulnerability of the Lower Aquifer. The spatial datasets from CVHM representing properties of the Corcoran Clay are shown in **Figure 2-9 and Figure 2-10**.

6.2.1.1.4 *Depth to Groundwater*

From a conceptual standpoint, depth to the groundwater surface might be expected to be correlated with observed nitrate concentration. A relationship might exist because in the conceptual model for groundwater vulnerability, the depth to groundwater represents the distance that infiltrating water must travel before it reaches the groundwater surface. As a result, because of factors relating to the attenuation of the chemical in time and concentration, the observed nitrate concentration could be expected to be less with greater depth to groundwater. In the neighboring Eastern San Joaquin River Watershed, a negative relationship existed between depth to water and observed nitrate concentrations (LSCE, 2014). However, in some studies a positive relationship between depth to groundwater and nitrate concentration has been noted in evaluating relationships in shallow groundwater (Nolan et al., 2002; Burkart et al., 1999). It has been suggested that this might be because of denitrification processes occurring in very shallow groundwater.

There are considerations specific to the GDA concerning the potential relationships between depth to groundwater and groundwater quality that are important to recognize. These include the presence of very shallow depth to water and poor drainage of some areas that in part have led to reduced crop productivity and other problems for irrigated agriculture. Additionally, the presence of multiple groundwater depth zones, with varying degrees of confinement (causing differences in groundwater levels), is an important recognition when evaluating relationships between groundwater quality and depth to water. Furthermore, the presence of subsurface tile drains that discharge water from the Very Shallow zone is believed to play a very important role in reducing vertical migration of water from the surface into the groundwater system. Spatial datasets representing the depth of recent spring groundwater levels within each of the depth zones throughout the GDA were developed from the best available water level data as part of this GAR. These depth-to-water datasets were generated in an effort to represent typical recent groundwater level conditions although the availability of recent groundwater level data in some areas of the GDA was limited. The minimum depth to water in 2012 as mapped by DWR was used to characterize the Very Shallow Water zone. **Figures 3-4 through 3-9** show the most recent depth to groundwater datasets for spring that were generated as part of this GAR. However, in part because of the variability in confinement of different zones and in the nature and degree of the hydraulic communication between different depth zones across the GDA, consideration of depth to groundwater in the groundwater vulnerability assessment is challenging.

6.2.1.1.5 *Topographic Slope*

The topographic slope might influence groundwater vulnerability in areas with high topographic variability because of its potential relationship with groundwater recharge. Precipitation runoff is relatively higher in areas of higher slope which results in less groundwater recharge; conversely, infiltration of precipitation, hence natural groundwater recharge, is expected to be higher in low topographic slope areas. Topographic slope throughout the GDA was calculated from the USGS national elevation dataset (NED) 10-meter resolution digital elevation model (DEM) as shown in **Figure 2-2**. Because slopes are relatively low and reasonably uniform across most of the GDA, this is not anticipated to be a major factor in groundwater vulnerability in the area.

6.2.2 Groundwater Quality in the Context of the Physical Conceptual Model

Nitrate is a widespread contaminant in groundwater in the United States which has been primarily associated with anthropogenic influences, including agricultural fertilization activities, leaching from septic tanks and sewer facilities, confined animal feeding operations, discharge to land of wastewater, food processor waste, unprotected wellheads, improperly abandoned wells, and lack of backflow prevention on wells. Nitrate contamination is also one of the primary groundwater quality concerns in areas of irrigated agriculture in the GDA. As an essential nutrient for plant growth, nitrogen is a component in many fertilizers that has been applied in agricultural areas for many decades. Nitrate is the dominant form of nitrogen in groundwater, and nitrate concentrations are regulated throughout the State of California. Naturally-occurring concentrations of nitrate in groundwater are typically relatively low in most environments; although, research indicates that localized sources of organic nitrogen and nitrate in geologic materials within Coast Ranges rocks can result in high nitrate concentrations in sediments of the Tulare Formation along the western San Joaquin Valley (Strathouse and Sposito, 1980; Sullivan et al., 1979). Despite this potential for naturally-sourced nitrate to affect groundwater quality in areas, for the purposes of this groundwater vulnerability analysis, observations of nitrate in the groundwater are considered to be primarily a function of the application of nitrogen through fertilization practices (where applicable) at the surface and subsequent processes of transporting the contaminant through the subsurface into the groundwater. Nitrate concentrations are a useful indicator of influence from irrigated agriculture, when compared with other commonly available groundwater quality measures such as TDS or EC, which indicate general water salinity and are known to occur naturally in high concentrations in most areas within the GDA. Similarly, concentrations of selenium and boron are also naturally high in drainage water and groundwater in the area and therefore are also not necessarily a useful indicator of influences from irrigated agriculture.

6.2.2.1 Comparison of Water Quality Trends by Depth Zone

Spatial and temporal trends and patterns in groundwater quality characteristics within each of the three depth zones are presented and discussed in detail in **Section 5**. **Figures 6-4 through 6-23** are select geologic cross-sections presented in **Section 2** with water quality observations within one mile of the cross-section shown by depth zone. Only those sample locations for which a depth zone could be interpreted based on available data are shown on these cross-sections. These figures more directly illustrate differences in groundwater quality between the depth zones and relative to subsurface characteristics and configuration. Data presented in these figures suggest that each of the depth zones has unique water quality characteristics that vary by location and depth within the GDA. Nitrate concentrations provide an indication of potential groundwater vulnerability and influences from irrigated agricultural practices whereas TDS, selenium, and boron concentrations are naturally high in the area and are therefore not good indicators of influences from agricultural practices.

6.2.2.1.1 *Very Shallow Water*

Generally, the concentrations of nitrate in Very Shallow Water, as measured in drainage water from tile drain sumps and from very shallow wells (less than 15 feet deep), are relatively high across the GDA.

This pattern is illustrated in cross-sections **Figures 6-4 through 6-8** and is also apparent from maps presented in **Section 5.** The concentrations of TDS in Very Shallow Water sampled from drains and very shallow wells are also displayed on cross-sections in **Figures 6-9 through 6-13** and in maps in **Section 5**. Very Shallow Water is notably high in TDS concentrations with maximum historical concentrations above 3,000 mg/L in many areas of the GDA, although there are some areas, particularly in the southern part of the GDA, where concentrations are relatively lower. As discussed above, the poor drainage conditions in soils and shallow sediments have resulted in a zone of Very Shallow Water across much of the GDA, and these areas have experienced concentration of salts within the soil column and Very Shallow Water zone. For these same reasons, there are high selenium concentrations present in Very Shallow Water within the GDA as highlighted in **Figures 6-14 through 6-18**. Selenium concentrations in the Very Shallow Water in the GDA are highest in the interior and central parts of the GDA with generally lower concentrations along the edges. This pattern is particularly apparent in cross-sections C and H (**Figures 6-14 and 6-17**). Considerably less data are available for boron concentrations in the Very Shallow Water, but those available data indicate high concentrations (**Figures 6-19 through 6-23**).

6.2.2.1.2 *Shallow Groundwater*

In contrast with the widespread and consistently high concentrations of nitrate sampled historically in Very Shallow Water within the GDA, the Shallow Groundwater exhibits notably lower concentrations in many areas of the GDA and considerable variability in concentrations. The relationship between historical nitrate concentrations in Shallow Groundwater and the physical characteristics of the GDA are highlighted in cross-sections shown on **Figures 6-4 through 6-8**. Much of the available data on nitrate concentrations in Shallow Groundwater are from the late 1980s and early 1990s. Research conducted in the late 1980s by the USGS (Deverel and Fio, 1991; Fio and Deverel, 1991) on subsurface flow of water to tile drains in drained agricultural fields showed that groundwater below 50 feet in drained areas had all been recharged prior to 1953. This suggests that much of the Shallow Groundwater sampled prior to the early 1990s was likely recharged at a time before the installation of the tile drain systems, which occurred mainly in the 1960s and 1970s. The role of the tile drains as a mechanism for reducing vertical migration of irrigation recharge is believed to be an important factor affecting in the vulnerability of groundwater in the GDA and the concentrations of nitrate at greater depth within the groundwater system.

In comparison with Very Shallow Water, TDS concentrations in Shallow Groundwater are also generally lower, although the cross-sections (**Figures 6-9 through 6-13**) also indicate some areas where Shallow Groundwater is relatively higher in TDS than the Very Shallow Water. This pattern is most evident in the southern and more eastern parts of the GDA and particularly apparent in cross-sections D and H shown on **Figure 6-10 and Figure 6-12.** Although the Shallow Groundwater zone is defined as depths between 15 and 100 feet in this GAR, this depth zone can still experience evapoconcentration of salts, especially in areas where the hydrogeologic characteristics enable more direct hydraulic communication between the Very Shallow and Shallow Groundwater zones. In such areas where soil drainage conditions are poor and where the water table rises close to the ground surface, salts have historically accumulated within the Shallow Groundwater zone. Additionally, the Shallow Groundwater zone is also naturally high in salinity derived from the sediments underlying the GDA, which are largely sourced from the Coast Range marine sediments.

Selenium concentrations in Shallow Groundwater exhibit similar spatial patterns as the Very Shallow Water with relatively higher concentrations across much of the central portion of the GDA and lower concentrations along the edges (**Figures 6-13 through 6-18**). Elevated selenium concentrations in the

Shallow Groundwater may be largely a result of evapoconcentration processes similar to what occurs in Very Shallow Water. However, selenium concentrations in the Shallow Groundwater are notably lower than in Very Shallow Water in many areas of the GDA. Boron concentrations in the Shallow Groundwater are similar to those observed in the Very Shallow Water with generally high concentrations present throughout much of the GDA (**Figures 6-19 through 6-23**).

6.2.2.1.3 *Semi-Confined Upper Aquifer (above Corcoran Clay)*

As was evident in water quality maps discussed in **Section 5**, the number of wells in the Upper Aquifer plotted on the cross-sections is relatively small and considerably less than for either the Very Shallow Water or the Shallow Groundwater zones. The available data on nitrate and TDS concentrations in the Upper Aquifer displayed on these figures suggest that concentrations of nitrate in the Upper Aquifer are lower than in the Shallow Groundwater as illustrated by data presented in cross-sections on **Figures 6-4 through 6-8**; however, the limited amount of nitrate concentration data that can be attributed to the Upper Aquifer makes it difficult to draw comparisons of groundwater quality between the Upper Aquifer and the Shallow Groundwater and Very Shallow Water zones. TDS concentrations displayed on cross-sections (**Figure 6-9 through 6-13**) also indicate areas where TDS concentrations in the Upper Aquifer are relatively lower than the Shallow Groundwater and Very Shallow Water, although TDS concentrations in the Upper Aquifer still exceed 1,500 mg/L. Groundwater in the Upper Aquifer likely has slightly lower TDS than the shallower zones because it is less influenced from evapoconcentration processes, although water in the Upper Aquifer is still highly saline as a result of natural geologic materials and processes.

Although there are relatively few datapoints representing selenium and boron concentrations in the Upper Aquifer on the cross-sections (**Figures 6-14 through 6-23**), these data show similar patterns as the Shallow Groundwater although selenium concentrations in the Upper Aquifer are lower than the Shallow Groundwater.

6.2.2.1.4 *Confined Lower Aquifer (below Corcoran Clay)*

The greater density of groundwater quality data for wells in the confined Lower Aquifer show some notable patterns in nitrate and TDS concentrations. Like the Upper Aquifer, nitrate concentrations in the Lower Aquifer appear to be relatively low as illustrated in cross-sections C, G, H, and J (**Figures 6-4 through 6-9**). Although the available data on nitrate concentrations are limited, the data displayed on the cross-sections suggest that nitrate concentrations in the Lower Aquifer are likely very low and less than 5 mg/L across the GDA. The low nitrate concentrations in the Lower Aquifer are consistent with the conceptualization of the Corcoran Clay as a considerable impediment to deep percolation of groundwater recharge from irrigated agriculture. More data are available for TDS concentrations in the Lower Aquifer. These data suggest that although TDS concentrations are naturally high throughout the Lower Aquifer they are generally lower than in any of the overlying groundwater zones with higher concentrations more common in the southern part of the GDA. Groundwater quality data shown in cross-sections (**Figures 6-9 through 6-13**) illustrate the notably lower TDS concentrations within the Lower Aquifer with most concentrations below 1,500 mg/L. However, there is considerable variability in TDS concentrations even within the Lower Aquifer with numerous locations where TDS concentrations are greater than 1,500 or 3,000 mg/L because of naturally occurring salinity conditions.

Selenium concentrations in the Lower Aquifer shown on cross-sections C, G, H, and J (**Figures 6-14 through 6-18**) are all relatively low, although these data are limited. Boron concentrations in the Lower Aquifer shown on cross-sections (**Figure 6-19 through 6-23**) are somewhat lower than in any of the other depth zones, with a greater number of wells with boron concentrations below 2 mg/L although most wells in the Lower Aquifer still exhibit boron concentrations in excess of 2 mg/L with some above 5 mg/L.

6.2.3 Approach to Assessing Groundwater Vulnerability

Numerous challenges exist for evaluating groundwater vulnerability in this hydrogeologic setting. The intent of the groundwater vulnerability assessment in this GAR is to detect signals in the groundwater system that can be used to objectively evaluate the vulnerability. The naturally high salinity present throughout the groundwater system makes the detection and identification of influences from irrigated agriculture difficult. Furthermore, the existence of several distinct zones of subsurface water, ranging from a zone of Very Shallow Water within 15 feet of the ground surface to a deep confined zone (Lower Aquifer) below a considerable aquitard, complicates the assessment of vulnerability in the region. Importantly, subsurface tile drains installed since the 1960s and 1970s in large areas of the GDA represent an additional consideration in assessing the vulnerability of groundwater below the Very Shallow Water zone. Nitrate concentrations in groundwater are a more conservative indicator of influences from irrigated agriculture than TDS and the availability of these data are much more limited than for TDS, which limited interpretations made based on statistical comparisons of nitrate data very difficult. Statistical methods and comparisons were used as a tool for identifying important relationships between the characteristics and mechanisms of the hydrogeologic system and the observed groundwater quality at a location. However, because of the some of the complexities in the hydrogeologic system and data limitations, some physical mechanisms or characteristics that could not be directly analyzed in relation to nitrate concentrations were also considered in the vulnerability analysis.

The Western San Joaquin River Watershed area surrounds the GDA (**Figure 6-3**), and the relationships between hydrogeologic characteristics and groundwater quality that were derived for that area were extremely important considerations in the assessment of vulnerability in the GDA. In part because of the relatively smaller size of the GDA, the availability of groundwater quality data with which to quantitatively evaluate relationships between groundwater vulnerability and hydrogeologic characteristics was somewhat limited. These limitations make some statistically-based approaches for evaluating groundwater vulnerability less suited for the GDA. However, the Western San Joaquin Watershed area encompasses a much larger area surrounding the GDA and the greater availability of groundwater quality data enabled more robust statistical evaluations of intrinsic physical factors relating to vulnerability as part of that GAR. Additionally, because subsurface tile drainage systems are not as extensive in the Western San Joaquin River Watershed area, the vulnerability analysis there is based on natural physical characteristics, which can also be applied with the GDA. Consequently, the approach used to assess groundwater vulnerability in the GDA relied heavily on relationships identified in the Western San Joaquin River Watershed analysis and other physical factors, including presence of subsurface drainage systems, which are believed to influence the intrinsic vulnerability of groundwater within the GDA. Informed by statistical analyses from the Western San Joaquin River Watershed GAR and from the GDA, select datasets for physical properties and conditions interpreted to be important factors in the potential for contaminants to migrate from the ground surface into the groundwater were used to assess the vulnerability of areas throughout the GDA.

6.2.4 Statistical Analyses of Associations Between Observed Water Quality and Physical Hydrogeologic Conditions

6.2.4.1 Western San Joaquin River Watershed Vulnerability Analysis

The approach to determining groundwater vulnerability developed for the Western San Joaquin River Watershed GAR was based on adaptations to index- and overlay- based methods and incorporated identification of important input physical variables based on the results from statistical analyses. In that vulnerability assessment, bivariate comparisons were used to evaluate potential relationships between physical characteristics and groundwater quality and multiple regression analyses were used to detect significant relationships between hydrogeologic characteristics and observed groundwater quality conditions across the Western San Joaquin River Watershed region, while controlling for different land use types. In determining groundwater vulnerability for the Western San Joaquin River Watershed GAR (LSCE, 2015), the statistical relationship between observed groundwater quality and different aspects of the physical hydrogeologic characteristics of the area were used to model the relative likelihood of groundwater impacts from irrigated agriculture in all areas of the watershed based on the hydrogeologic conditions present. As discussed above, nitrate concentrations in groundwater are a better indicator of anthropogenic influences than are TDS concentrations, especially in the Western San Joaquin Watershed area and GDA where there is documented natural and historical occurrence of high salinity water in all groundwater zones. Furthermore, nitrate data are more broadly available than most other contaminants associated with irrigated agricultural practices such as pesticides. For these reasons, nitrate was used as measure for groundwater quality impacts from irrigated agriculture for the purposes of assessing the intrinsic groundwater vulnerability of areas within the Western San Joaquin River Watershed area.

The hydrogeologic variables investigated in the Western San Joaquin River Watershed region focused on independent (indicator) variables that could be evaluated in a manner consistent with the conceptual model including soil drainage class, soil hydraulic conductivity, deeper subsurface sediment texture, depth to water, and Corcoran Clay characteristics. Multiple regression analyses were conducted using observed nitrate concentrations as the dependent (response) variable to evaluate correlations with physical hydrogeologic independent variables. Land use categories as mapped for three time periods (circa-1990s, circa-2000s, and 2013) were evaluated as controlling independent variables during the assessment.

Using multiple regression, statistically significant independent variables were identified and selected for further comparison and evaluation from quantitative and qualitative standpoints as vulnerability models. The vulnerability areas indicated by each of the models were compared and evaluated and thresholds indicating high vulnerability for significant variables were determined through qualitative assessments based on professional judgment and using comparisons of areas relative to observed nitrate concentrations, especially exceedances. A hydrogeologic high vulnerability area (HHVA) defined on hydrogeologic characteristics and represented largely by soils with relatively well draining characteristics, was identified. Because of the limited available data relating to groundwater and hydrogeologic conditions in the southwestern part of the Western San Joaquin River Watershed region, assessment of groundwater vulnerability in that area was conducted through review of additional information relating to more local groundwater and subsurface conditions in this area. The HHVA encompassed most wells with elevated nitrate concentrations; however, additional locations of outlier wells with maximum historical nitrate concentrations of 10 mg/L (as N) or greater and also wells with maximum concentrations greater than or equal to 5 mg/L that exhibit statistically significant increasing trends in concentrations were incorporated through delineation of HWVAs through inclusion of a 0.5-

mile radius around outlier wells when they are located away from the HHVA. The high vulnerability area defined for the Western San Joaquin River Watershed region includes the combined HHVA and HWVA areas and totals 292,171 acres as displayed on **Figure 6-3**. Detailed discussion of the statistical analyses conducted for determining groundwater vulnerability in the Western San Joaquin River Watershed are included in that GAR (LSCE, 2015), although key aspects of the analysis and outcome are also summarized below. Physical characteristics identified to be associated with groundwater vulnerability in the Western San Joaquin River Watershed were used to inform the assessment of groundwater vulnerability in the GDA, including through comparison with observed nitrate concentrations, as discussed later in this section.

6.2.4.2 Investigation of GDA Vulnerability Relationships and Statistical Analyses

The somewhat limited availability of nitrate concentration data in the GDA and confounding factors related to the timing of water quality measurements in relationship to the timing of tile drain installation, make the GDA less suited for application of a statistical evaluation of relationships between observed nitrate concentrations and physical characteristics for determining groundwater vulnerability. However, bivariate comparisons were conducted using data from within the GDA to subjectively evaluate potential relationships between physical characteristics and observed nitrate concentrations. To address some of the spatial clustering (laterally and vertically) of data points for these comparisons, nitrate concentrations were averaged for all sample sites within each PLSS section and by depth zone. This was done for both the maximum and average concentration for each sample site. The physical characteristics of each PLSS section were extracted using a spatially weighted average for the area within each section.

6.2.4.2.1 *Soil Characteristics*

The conceptual model for groundwater vulnerability suggests that a positive relationship between the ability of soils to transmit water and the observed nitrate concentration in groundwater might be expected. Soil drainage class consistently identified as being statistically significantly positively correlated with observed nitrate concentrations in the groundwater vulnerability model for the Western San Joaquin River Watershed. This means that the more well-drained soils correlate with higher observed nitrate concentrations across the entire Western San Joaquin River Watershed region. Although soil hydraulic conductivity was negatively correlated with observed nitrate concentrations in the Western San Joaquin River Watershed region, this may have been due to the presence of very shallow groundwater in some areas where soils are also of lower hydraulic conductivity. Similar areas might also exhibit conditions of higher nitrate conditions, although potentially not because of the soil properties. Such confounding issues present considerable challenges in understanding the associations between physical characteristics and groundwater quality. Under the conceptual model for groundwater vulnerability, the soils with better drainage characteristics are expected to be more vulnerable to vertical movement of water from the surface, although locations with soils of lower hydraulic conductivity might tend to exhibit higher nitrate concentrations because these soils do not drain as readily and therefore salts and nutrients tend to accumulate in these soils through evapoconcentration and limited flushing.

Bivariate plots of soil characteristics versus observed nitrate concentrations for the GDA are displayed in **Figure 6-24** by depth zone (not including Very Shallow Water). **Figure 6-24a** shows the average of the maximum nitrate concentration observed within each section compared with the average soil vertical hydraulic conductivity for sections. A tendency for higher nitrate concentrations in sections with higher soil hydraulic conductivity is apparent in this graph, although there are exceptions to this pattern. This general trend is most evident for wells classified as Shallow Groundwater wells and to a lesser degree for data with unknown depth. Similarly, in **Figure 6-24b,** which displays the average maximum nitrate concentration by section with soil drainage characteristics, a pattern of higher nitrate concentrations in sections with better drainage characteristics is also evident in the GDA. Similar patterns in the relationships between soil characteristics and TDS concentrations are also apparent in **Figure 6-25**, although TDS concentrations are not a reliable indicator of influences from agricultural or other land use practices.

Spatial relationships between soil characteristics and observed nitrate concentrations are displayed in **Figures 6-26 and 6-27**. The tendency for higher nitrate concentrations in areas of higher soil hydraulic conductivity and better soil drainage characteristics is consistent with the conceptual model for vulnerability.

6.2.4.2.2 *Deeper Subsurface Sediment Texture*

A positive relationship between the percentage of coarse materials in the deeper subsurface as represented by the CVHM sediment texture model (Faunt et al., 2009 and 2010) and the observed nitrate concentrations in groundwater would also be expected with coarser materials correlating with higher nitrate observations. High percent coarseness typically translates to higher hydraulic conductivity, which would be expected to enable greater vertical movement of nitrate in the subsurface; in contrast, low percentages of coarse materials could indicate the presence of barriers to vertical hydraulic movement that could potentially prevent flushing of the hydrogeologic system resulting in build-up of salt and nutrient concentrations in the groundwater system. In the groundwater vulnerability analyses for the Western San Joaquin River Watershed, the average percentage of coarse materials in the upper 200 feet provided a particularly meaningful and useful measure of subsurface sediment texture that captures deeper subsurface sediment composition in a manner that is consistent with the hydrostratigraphy in the area and the vulnerability conceptual model. The Corcoran Clay is greater than 200 feet deep throughout the majority of the GDA (**Figure 2-9**); therefore, this measure of deeper subsurface texture represents a characterization of a thick section of the subsurface that overlies the Corcoran Clay.

For the groundwater vulnerability analysis in the Western San Joaquin River Watershed regions, the average percent coarse of subsurface materials in the upper 200 feet was a statistically significant variable, although the sign of the correlation with nitrate concentrations was negative. This indicates a correlation between increasing percent coarse sediments and decreasing observed nitrate concentrations, which is counterintuitive to mechanisms and processes relating overlying land use activities with observed groundwater quality based on the groundwater vulnerability conceptual model. Based on the conceptual model for groundwater vulnerability, it is unlikely that these results indicate real conditions and processes associated with finer-textured subsurface materials leading to higher concentrations of nitrate in groundwater as a result of influences from land use practices. Although there are conceivable processes and conditions through which this correlation may exist, it was not utilized as an indicator of groundwater vulnerability in the Western San Joaquin River Watershed assessment.

Bivariate comparisons between observed nitrate concentrations and subsurface sediment textures for depth intervals of zero to 100 feet and also zero to 200 feet are presented in **Figure 6-28**. The average sediment texture is similar for both the upper 100 feet and the upper 200 feet intervals. These plots indicate the presence of high nitrate concentrations in sections with ranging textures in the upper 100 feet (**Figure 6-28a**) and upper 200 feet intervals (**Figure 6-28b**). Interestingly though, in sections with relatively higher percentages of coarse materials in excess of 60 percent, the average maximum nitrate concentrations are more commonly above 10 mg/L nitrate as N, especially in Shallow Groundwater. As the percentage of coarse materials decreases, nitrate concentrations exhibit a wider range of values and are more evenly distributed across the range of concentrations. This may be in part because historical land use practices are variable across the GDA and observed concentrations are a result of interactions between both land use practices and the hydrogeologic characteristics. Although the multiple regression analyses utilized for the Western San Joaquin River Watershed region attempt to control for some of the variability in land use history, limitations in available data for the GDA in combination with other confounding factors, make such an approach less suitable for assessing vulnerability in the GDA.

Comparisons between subsurface sediment texture and TDS concentrations illustrated in **Figure 6-29** exhibit similarly variable relationships as those observed with nitrate, although sections with higher percentages of coarse materials have generally lower TDS concentrations. This could be a result of natural dissolution processes associated with high salinity geologic materials, particularly in finer-grained sediments, and also may be related to deeper flushing of groundwater that occurs in coarser-textured sediments. However, TDS concentrations in groundwater are not a reliable indicator of influences from agricultural or other land use practices.

The areas of highest percentages of coarse deeper subsurface materials tend to overlap with areas where soils have higher hydraulic conductivity and better drainage characteristics, particularly in the western and southern parts of the GDA where alluvial fan deposits are more common (**Figure 6-30**). The spatial relationship between subsurface sediment texture and observed nitrate concentrations are also displayed on **Figure 6-30**. Consistent spatial relationships between nitrate concentrations and subsurface sediment texture are not readily apparent in **Figure 6-30,** although there is considerable spatial agreement between the areas of highest percentages of coarse materials and areas of higher conductivity and better drained soils displayed in **Figures 6-26 and 6-27**, especially in the southwest part of the GDA.

6.2.4.2.3 *Depth to Water and Vertical Hydraulic Gradient*

The conceptual model for groundwater vulnerability holds that any relationship between depth to water and observed nitrate concentration in groundwater is expected to be negative; the likelihood of encountering higher nitrate concentrations in groundwater is expected to decrease as depth to groundwater increases. However, Nolan et al. (2002) found a positive relationship between depth to water and nitrate concentrations at a national scale, meaning that as depth to water increases the predicted nitrate concentration increases, and attributed this to potential biodegradational processes that occur in groundwater at shallow depths. Although this relationship is generally counterintuitive for other reasons, depth to water was not significantly correlated with nitrate concentrations in the Western San Joaquin River Watershed region. Groundwater occurs at relatively shallow depths across much of the GDA and the Western San Joaquin River Watershed region which may make any potential relationship between observed groundwater quality and depth to water insignificant or difficult to detect.

In the GDA, generalized depth to groundwater contours were interpreted for recent spring time periods within each depth zone based on available data (**Figure 3-4, 3-6, 3-7, and 3-8**). These interpretations are subject to considerable limitations resulting from the sparcity of data in many parts of the GDA. **Figures 3-14 and 3-15** illustrate calculated vertical hydraulic gradient values (differences in water surface elevations) between the Very Shallow Water, Shallow Groundwater, and Upper Aquifer zones based on the interpreted depth to water data. These maps highlight areas where differential water surface heads across depth zones could enable vertical movement of water between depth zones. More positive vertical gradient values between zones suggest potential for downward water movement, whereas areas with more negative values have greater potential for upward movement of water. Although there is considerable uncertainty associated with the contours of depth to water and the resultant calculated vertical hydraulic gradients, it is notable that many of the areas exhibiting the greatest potential for downward migration of water based on head differences are located along the western margins of the GDA where soil hydraulic conductivity and drainage are relatively higher and where subsurface sediment textures are coarser.

Hydrographs of water levels for well pairs representing different depths shown in **Figure 3-17** also highlight locations where greater potential for downward movement of groundwater exists. Several locations exhibit water levels that suggest there are differences in hydraulic head within the Shallow Groundwater zone, with some indicating upward hydraulic gradients and lower potential for deep percolation of water from the surface. A notably higher potentiometric surface elevation exists in wells completed at depths of between 90 and 100 feet when compared with shallower wells of less than 60 feet, especially in some western and central parts of the GDA (**Figure 3-17**). The water level hydrographs on **Figure 3-17** show trends that are not entirely consistent with the hydraulic gradient indicated between Very Shallow Water and Shallow Groundwater in **Figures 3-14 and 3-15**. This further highlights uncertainty associated with any potential relationship between depth to water and groundwater vulnerability within the GDA.

6.2.4.3 Subsurface Tile-Drained Areas

As discussed above, considerable areas within the GDA are drained by subsurface tile drain systems designed to capture applied irrigation water percolating below the root zone and also to drain areas of higher water table or perched water. The mapped locations of known tile drain lines within GDA are presented as **Figure 3-5**. The presence of subsurface tile drainage systems is difficult to evaluate as a factor affecting groundwater vulnerability from a quantitative and statistical standpoint. Limitations in the spatial and temporal availability of nitrate concentration data prevent accurate characterization of the role of tile drain systems in affecting influences from irrigated agriculture on groundwater. However, functionally the tile drains are designed to intercept water percolating below the root zone and also remove water that has percolated to a shallow water table. Research conducted by the USGS in the late 1980s discovered an upward vertical hydraulic gradient within approximately 50 feet of the ground surface in fields with tile drain systems (Deverel and Fio, 1991; Fio and Deverel, 1991). In these studies, a considerable fraction of the water captured by tile drains originated from below 20 feet, which is consistent with the upward hydraulic gradients within the Very Shallow Water and Shallow Groundwater zones that are also evident in some well pairs in the GDA (**Figure 3-17**). This suggests that tile drains function to limit percolation of water below the zone of Very Shallow Water and also remove some water that is within the Shallow Groundwater zone. In areas within the GDA where tile drains have been installed, their existence and operation is essential to enabling use of the land for irrigated agriculture. Discharge of water captured from tile drains is covered by separate WDRs for the Grassland Bypass Project.

Guidelines for the installation of tile drains prepared for the SWRCB by the Westside Resource Conservation District and the Center for Irrigation Technology at the California State University, Fresno (Westside Resource Conservation District, 2005) suggest a range of values from about 300 to 550 feet may be appropriate for the typical spacing of tile drain lines, depending on soil characteristics and irrigation method. Spacing can be increased in fields where high efficiency irrigation methods are used.

Also, depending on the design (depth, diameter, orientation) of the tile drainage system, appropriate spacing between drain lines may be greater (DWR, 1971). Mapped tile drain lines within the GDA indicate considerable variability in spacing ranging from less than 200 feet to greater than 800 feet. The tile drain network configurations depend on site-specific conditions and drain design parameters including soil properties, irrigation method, crop type, drain depth and capacity, and other factors, all of which are considered during installation of tile drains. Importantly though, the intent of these subsurface drainage systems is to capture water percolating below the root zone and to keep the root zone unsaturated across the entire field. Accordingly, drainage water within the Very Shallow Water zone across the entirety of a tile-drained field is expected to be captured by a tile drain system. A buffer of 400 feet on tile lines was applied to represent the extent of areas within the GDA that are drained by the mapped tile drains shown in **Figure 3-5**. This drainage capture zone for tile-drain lines is conceptually consistent with general guidelines and practices relating to the design of tile drains in the west side of the San Joaquin Valley and represents complete spatial coverage of fields in which tile-drains have been installed. Groundwater flow model simulations by Fio and Deverel (1991) indicated lengthy flowpaths to tile drains under irrigated and non-irrigated conditions. The resulting area considered to be drained by subsurface tile drains for the purpose of assessing groundwater vulnerability in this GAR is presented on **Figure 6-31**.

From a conceptual standpoint, tile-drained areas represent areas with lower potential for deep percolation of irrigation recharge and where agricultural practices are less likely to impact groundwater zones below the zone of Very Shallow Water.

6.2.5 Determination of High Vulnerability Area for the GDA

Through consideration of physical factors identified to be associated with groundwater vulnerability in the Western San Joaquin River Watershed region, comparisons of nitrate concentrations within the GDA in relation to soil and subsurface sediment characteristics, and incorporation of additional factors that limit groundwater vulnerability based on understanding of conceptual mechanisms and processes, an area of high vulnerability was defined for the GDA.

Soil vertical hydraulic conductivity and drainage characteristics were determined to be the most meaningful variables with which to assess vulnerability, based on several factors:

- Statistical results from the Western San Joaquin River Watershed groundwater vulnerability assessment indicating significance and reasonable conceptual relationships with vulnerability,
- Assessment of bivariate plots of nitrate concentrations and soil characteristics within the GDA, and
- Visual spatial comparison with observed nitrate concentrations in groundwater.

Through qualitative and quantitative evaluation of potential physical factors related to groundwater vulnerability based on observed nitrate concentrations coupled with consideration of the conceptual aspects of each, soil characteristics were identified as a key factor in groundwater vulnerability in the GDA. Soils with vertical hydraulic conductivity values of greater than 1 feet per year (ft/day) are believed to represent areas of relatively higher groundwater vulnerability. These soils also have better drainage characteristics, a physical characteristic which was a key factor in the determination of the Western San Joaquin River Watershed high vulnerability area. **Figure 6-32** presents the frequency of wells exceeding the nitrate MCL by soil characteristics at the well location. This does not include Very Shallow Water sites. A considerable fraction of the exceedance wells are located within areas with soils of higher hydraulic conductivity and well-drained conditions as shown on **Figure 6-32**. Additionally, a great number of exceedance wells are within close proximity to the mapped soils with hydraulic conductivity greater than 1 ft/day and moderately well-drained to well-drained soil classes, which is evident in **Figures 6-24 and 6-25** although it is not illustrated in **Figure 6-32**. Although the greatest number of exceedance wells occurs in soils with vertical hydraulic conductivity between 0.5 and 1 ft/day and somewhat poorly drained conditions, these classes of soils also represent dominant areas of the GDA. Also, of the frequency of exceedance wells at locations with these conditions is skewed by a high density of wells (15 wells) occurring at a single site. **Figure 6-32** shows the notable absence of exceedance wells areas of the lowest hydraulic conductivity soils and poor drainage characteristics. Together, soils of higher hydraulic conductivity (> 1 ft/day) and better drainage characteristics (moderately to well drained) were identified as the HHVA within the GDA.

As was noted during the evaluation of groundwater vulnerability for the Western San Joaquin River Watershed region, review of available data relating to the hydrogeologic conditions and groundwater quality conditions in the western portion of the GDA suggested a need for some unique treatment of this area. There are notably fewer wells with data and no identified nitrate exceedances in groundwater within this part of the GDA, which is located close to the base of the Coast Range. Additional review of hydrogeologic information was conducted in this area in order to evaluate whether the soil characteristics provide a reasonable measure for assessing vulnerability in this area. This evaluation consisted of a focused review of additional available data sources, including mapped geology, lithologic logs from wells and testholes, and groundwater level and quality data within this area. The area to the west of the California Aqueduct is characterized by relatively lower-permeability alluvial fan deposits (Croft, 1972) shown in **Figure 2-6**, and lithologic logs indicate the presence of considerable clay deposits throughout the vertical profile at many sites on the western side of the aqueduct. Additionally, available data representing groundwater levels in the area indicate that depth to groundwater is great over much of this area, with some shallower groundwater levels occurring only in the vicinity of the California Aqueduct, likely resulting from leakage by the canal. These factors, in conjunction with the generally higher slopes, which also constrain the locations of irrigated agriculture and irrigation practices to high efficiency methods, suggest the area to the west of the California Aqueduct within the GDA is largely lower vulnerability.

Areas where historical nitrate exceedances exist in groundwater (all depth classes except for Very Shallow Water) represent areas of documented impacts on groundwater quality. To account for some of the ambiguity associated with the HHVA cutoff based on mapped soil characteristics, and because of the gradational nature (transition from coarse to fine deposits) and potential intrinsic heterogeneity and discontinuity of soils and other subsurface materials, some minor adjustments were made to the extent of the HHVA to encompass exceedance wells in close proximity to the HHVA. These exceedance locations represent areas where groundwater has already been impacted and the extension of the HHVA in these areas takes into consideration the presence of exceedances in proximity to soils believed to have higher vulnerability characteristics.

Areas where exceedances have occurred but which fall outside the HHVA, without any indication of hydrogeologic factors or greater areal extent to the exceedances, were designated as HWVAs because they have been added to capture wells with nitrate exceedances, although there are no other indicators of hydrogeologic vulnerability at these locations. A 0.5-mile buffer was defined around outlier exceedance wells to define each HWVA; this buffer was used because it is consistent with the proximity to the more vulnerable soils where most exceedances occurred, suggesting a potential for source areas to influence water quality at a distance. This buffer distance was also applied in the designation of the high vulnerability area for the Western San Joaquin River Watershed region. The HWVAs are also identified on **Figure 6-33** illustrating the locations of exceedances resulting in the HWVAs.

Following the conceptual model for groundwater vulnerability used in this assessment and discussed above, subsurface tile drains are believed to effectively reduce the vulnerability of groundwater to impacts from irrigated agriculture by intercepting percolating irrigation water at very shallow depths thereby preventing the migration of water and water quality constituents to greater depths and into the underlying groundwater. Accordingly, areas with subsurface drainage systems within the GDA are considered areas of relatively lower vulnerability for impacts to groundwater from irrigated agriculture, including those areas that are within the defined HHVA. The tile-drained areas were subtracted from the HHVA to reduce the extent of the HHVA, except for in areas within 0.5 miles of a nitrate exceedance.

The HWVAs are included as part of the high vulnerability area designated in this GAR, but are distinct from the HHVA because they are not in areas of predicted high vulnerability based on hydrogeologic conditions. In the future, additional information may be obtained to evaluate whether these HWVAs are appropriately designated as high vulnerability. There may be unique characteristics of the vulnerability outlier wells within the HWVAs with regard to potential contaminant sources or well construction that have contributed to the elevated nitrate concentration. Additionally, closer evaluation of water quality trends in all wells in these areas may help evaluate the general groundwater quality in the immediate area of any exceedances and identify whether the exceedances are a result of a spurious and anomalously high results or possibly because of some other localized impact. The combined areas of the HHVAs and HWVAs represent the GDA HVA as defined for this GAR. The individual components comprising the GDA HVA are presented in **Figure 6-33**. The extent of the entire GDA HVA is presented in **Figure 6-34**. **Table 6-2** summarizes the locations of wells with historical nitrate exceedances in relation to the GDA HVA and its components.

Table 6-3 summarizes and compares the vulnerability areas as developed in this GAR. The total number of acres in the HHVA is approximately 23,449 acres. Approximately 21,196 acres of the HHVA occur within the irrigated lands portion of the GDA representing about 25 percent of the irrigated acres. The addition of the HWVAs increases the high vulnerability area by 4,345 acres to a total of 27,794 acres within the GDA. Of these 27,794 acres of the GDA HVA, 24,659 acres are identified as irrigated lands.

6.2.6 Comparison of the Grassland Drainage Area High Vulnerability Area and Groundwater Quality Conditions

A visual comparison of the GDA HVA developed in this GAR with results from Nolan et al. (2002), as presented in **Figure 6-2**, illustrates general agreement across most of the GDA. Soil drainage class is a statistically significant variable included in the analysis by Nolan et al. (2002), although that analysis also included an inverse relationship with depth to water in addition to a basic mapped geology and land use considerations. Areas identified by Nolan et al. (2002) as having higher probability of having nitrate concentrations above 4 mg/L are also generally identified as part of the GDA HVA (**Figure 6-34**). Among the many differences between methods employed by Nolan et al. (2002) and those used in determining the GDA HVA in this GAR, one of the main aspects that differentiates the method used in this assessment is its focus on the physical hydrogeologic characteristics and conditions as they relate to vulnerability. Variability in land use was considered and controlled for in statistical analyses conducted to identify significant relationships between physical conditions and groundwater quality in the Western San Joaquin River Watershed GAR, which was a major consideration in the assessment of vulnerability of the GDA. However, unlike with the assessment by Nolan et al. (2002) and the NHI methods, land use was not used as an input to define the vulnerability in this assessment. As discussed above, this is important because the GDA HVA represents an area with intrinsically higher groundwater vulnerability, regardless of the land use, which is a variable that can, and is likely to, change in time.

A comparison of the GDA HVA and sections within the GDA in which a historical pesticide detection occurred is presented in **Figure 6-35**. As is illustrated by **Figure 6-35**, all three of the sections with pesticide detections or exceedances overlap at least part of the GDA HVA. As discussed in **Section 5**, pesticide data available from DPR are only provided by the section in which the well is located. A comparison of TDS concentrations relative to the GDA HVA is shown in **Figure 6-36**. Many potential confounding factors unrelated to irrigated agriculture exist with observed TDS concentrations in groundwater. Accordingly, while the GDA HVA also captures many wells exhibiting high salinity, the presence of naturally occurring high salinity in areas makes this comparison less meaningful as an indicator of groundwater vulnerability to impacts from irrigated agriculture within the GDA. Approximately 36 percent of the wells with TDS concentrations between 1,500 and 3,000 mg/L are located within the GDA HVA (**Table 6-2**). Of the wells with TDS concentrations of at least 3,000 mg/L, 66 percent of these wells are inside the GDA HVA.

Selenium concentrations in groundwater in the area are also confounded by factors unrelated to irrigated agriculture and are not a reliable indicator of groundwater vulnerability to irrigated agriculture influences. Nevertheless, **Figure 6-37** displays the observed selenium concentrations in groundwater in relation to the GDA HVA. Most of the locations at which high selenium concentrations have been observed fall within the GDA HVA.

6.2.7 Summary of Grassland Drainage Area High Vulnerability Area

The approach to determining groundwater vulnerability developed in this GAR is based on adaptations to index- and overlay-based methods and incorporates identification of important physical variables based on the results from statistical analyses and comparisons conducted for the GDA and also for the Western San Joaquin River Watershed GAR. Bivariate comparisons were used to evaluate potential relationships between physical characteristics and groundwater quality. Results from multiple regression analyses for the Western San Joaquin River Watershed GAR were used to identify significant relationships between hydrogeologic characteristics and observed groundwater quality conditions across the greater GDA region, while controlling for different land use types. Analyses were conducted to identify relationships between physical characteristics and vulnerability within the context of the hydrogeologic system present within the GDA consisting of four depth zones (a zone of Very Shallow Water, a Shallow Groundwater zone, a semi-confined Upper Aquifer, and a confined Lower Aquifer below the Corcoran Clay). Hydrogeologic variables investigated focused on soil drainage class, soil hydraulic conductivity, and deeper subsurface sediment texture. Only hydrogeologic variables that could be evaluated in a manner consistent with the conceptual model were considered in the vulnerability assessment. Evaluating vulnerability within the GDA was challenging due to the complex hydrogeologic setting and data limitations. Considerable area within the GDA has subsurface tile drain systems which effectively intercept percolating water and other water in the zone of Very Shallow Water. These drains were installed mainly in the 1960s and 1970s, and their existence and timing of installation made quantitative approaches to assessing groundwater vulnerability within the GDA very difficult.

Considering mechanisms and processes relating to vulnerability based on quantitative and qualitative comparisons, thresholds indicating high vulnerability for physical factors believed to be important for groundwater vulnerability were determined and adjusted using qualitative assessments based on professional judgment and using comparisons of areas relative to observed nitrate concentrations, especially exceedances. Following this process, a high vulnerability area defined on hydrogeologic characteristics (HHVA) and represented largely by soils with high hydraulic conductivity and relatively well draining characteristics, was identified. Minor adjustments to the HHVA were made in the vicinity of nitrate exceedances and in select areas along the western edge of the GDA where available data relating to groundwater and hydrogeologic conditions are limited. In the southwestern part of the GDA, additional information relating to more local groundwater and subsurface conditions were reviewed and an area west of the California Aqueduct was excluded from the HHVA based on this review. The HHVA encompasses most wells with elevated nitrate concentrations. The locations of wells with maximum historical nitrate concentrations of 10 mg/L (as N) or greater were incorporated through delineation of HWVAs through inclusion of a 0.5-mile radius around outlier wells when they are located away from the HHVA.

Areas with subsurface tile drains exist to intercept percolating water from applied irrigation and other Very Shallow Water and act to effectively limit downward vertical movement of water quality constituents from irrigated agriculture. These areas are considered lower vulnerability areas, including where they are in soils of higher hydraulic conductivity and drainage characteristics, except where they are within 0.5 miles of an observed nitrate exceedance.

The high vulnerability area defined for the GDA HVA includes the combined HHVA and HWVA areas and totals 27,794 acres, of which 24,659 acres are irrigated land (**Figure 6-34**).

6.3 Prioritization of High Vulnerability Area

For planning of future monitoring and management efforts focused on the GDA HVA and to fulfill requirements of the WDR, all areas within the HVA were prioritized. In Attachment B the WDR identifies a number of factors to be considered in prioritizing high vulnerability areas. These factors include the following:

- Identified exceedances of water quality objectives for which irrigated agriculture waste discharges are the cause, or a contributing source;
- Proximity to areas contributing recharge to urban and rural communities that rely on groundwater as a source of supply;
- Existing field and operational practices identified to be associated with irrigated agricultural waste discharges that are the cause or source of groundwater quality degradation;
- The largest acreage commodity types comprising up to at least 80 percent of irrigated agriculture in the high vulnerability areas;
- Legacy or ambient groundwater conditions;
- Groundwater basins currently proposed to be under review by CV-SALTS; and
- Identified constituents of concern.

In an effort to objectively incorporate the many factors identified for consideration as part of the prioritization, a system was developed with which to calculate priority values across the high vulnerability area. From these priority calculations, priority areas ranging from priority 1 (high priority) to priority 4 (low priority) were identified to inform groundwater monitoring and management efforts.

6.3.1 Prioritization Calculation Approach

In order to capture the prioritization factors identified in the WDR, a prioritization matrix was developed in which various components of the prioritization scheme are ranked and weighted in order to calculate continuous priority values across the GDA HVA. **Table 6-4** describes the prioritization matrix used in detail, including all of the factors identified in the WDR and how they are accounted for in the matrix. Many of the prioritization components identified in the WDR overlap with and relate to common conditions. For example, there is overlap in consideration of legacy conditions of the groundwater, locations of MCL exceedances, and identified constituents of concern since they all represent measures of groundwater quality conditions. In order to understand the overall weighting of the general conditions measured by these components, **Table 6-4** shows how components were grouped into categories and how weighting of individual components was treated in the priority calculation. Some additional components not identified in the WDR were included in the prioritization matrix, including measures of groundwater vulnerability and temporal trends in groundwater quality.

Using the parameters identified in the prioritization matrix, a priority value was calculated for all locations (on a 30-meter cell scale, or 900 square meter cell size) within the HVA. For each component considered in the priority calculation, all locations within the HVA received a ranking value of zero to ten (from low to high) based on the measures of each specific component at the location. This was performed for all components included in the prioritization matrix (**Table 6-4**). After all components were ranked for each location, a weighting of the components was applied based on the relative importance of each component in the prioritization calculation. Factors of greater importance in the priority calculation were weighted higher. In this way, a priority value was calculated for all locations within the HVA from which high priority areas could be identified. The components and groupings included in the prioritization matrix are detailed in **Table 6-4** and further discussed below. In rankings of all components, if no data were available with which to perform the ranking for a location, then a neutral ranking value of five was assigned to the location. This was done to minimize potential biasing of the prioritization as a result of limitations in data availability.

The prioritization matrix components were grouped into four main categories for understanding and context of the overall weighting of factors. These four categories include: hydrogeologic groundwater vulnerability, existing groundwater quality conditions, land use, and other factors, including proximity to communities reliant on groundwater. The hydrogeologic groundwater vulnerability component was used as a way of incorporating a measure of intrinsic vulnerability at locations based on factors believed to represent vulnerable conditions, including those used in the determination of groundwater vulnerability described above. The hydrogeologic groundwater vulnerability component was ranked according to several different physical factors that are identified or believed to influence the vulnerability of groundwater. These include soil hydraulic conductivity which represents higher vulnerability conditions and tile-drained areas which effectively reduce vulnerability. Subsurface sediment texture was also included as a way of incorporating information about potential for transport of groundwater at greater depths. These measures were assigned a combined weight of 15 percent as shown in **Table 6-4**.

Legacy or ambient conditions of groundwater quality were incorporated through measures of the observed groundwater quality and from temporal trends in groundwater quality. Groundwater nitrate concentrations in the Very Shallow Water, most of which are from measurements of water quality in tile drain sumps, were not considered as part of this factor because they are not representative of groundwater conditions and are not covered by the GDA WDR. The factors associated with legacy and ambient groundwater conditions and its weighting is provided in **Table 6-4**. These measures were ranked from zero to ten based on average nitrate concentration and average temporal trend in nitrate in any zone within one-half mile. The nitrate data used in ranking these measures are shown in **Figures 5-14 through 5-21** in **Section 5**. Factors related to MCL exceedances were incorporated through a ranking based on distance from the nearest nitrate exceedance. Ranking value for distance from an MCL exceedance decreased with distance from the exceedance location following guidelines outlined in **Table 6-4**. The data shown in **Figures 5-14 through 5-21** were used in this ranking and a relatively low weighting of 2.5 percent was applied because a measure of extreme nitrate concentrations was also included through incorporation of average nitrate concentration. The last component identified in the WDR relating to existing groundwater quality conditions is identified constituents of concern. Pesticide detection data from DPR were used to represent this measure for ranking in the prioritization calculation. The ranking for this factor was conducted based on detections or exceedances occurring in a section. This component was also weighted relatively low at 2.5 percent because data from DPR are only provided to a section spatial resolution. Data used for ranking of this component are shown in **Figure 5-58.**

The components identified in the WDR, including existing field or operational practices and the largest acreage commodities comprising up to at least 80 percent of irrigated agriculture within the HVA, were considered as general measures related to land use. To incorporate these factors, the prioritization matrix used typical applied nitrogen rates, typical irrigation method, and top 80 percent commodities within the HVA as ranking measures. Typical applied nitrogen rate by land use category was ranked at locations following applied nitrogen value ranges for 2005 shown in **Table 4-2**. Land use was determined from USDA 2014 land use data as shown in **Figure 4-5**. Accordingly, ranking values for applied nitrogen were assigned to land use categories and it was weighted at 7.5 percent. Typical irrigation method by land use category was based on data from DWR circa-2000s land use surveys and as shown in **Table 4-5** and was ranked by location using the 2014 USDA land use data. Land use categories were ranked zero to ten based on percentage of different types of irrigation methods used in the circa-2000s land use time period. Irrigation method was weighted at 12.5 percent in the priority calculation. Whether a commodity represents one of the commodities that comprise the top 80 percent of the HVA was also incorporated as a yes/no factor based on land use category and was weighted at 2.5 percent. The top land use categories are shown in **Table 4-4**.

Other prioritization factors identified in the WDR such as proximity to contributing areas to communities reliant on groundwater and groundwater basins currently under review by CV-SALTS were also incorporated. Proximity to contributing areas for communities reliant on groundwater was included based on the calculated contributing groundwater to locations of the communities identified, as described in **Section 3** and shown on **Figure 3-20** and listed in **Table 3-2**. The ranking system was based on distance from the community boundary with a greater weighting on locations within a contributing area to a community reliant on groundwater. This factor was weighted high at 30 percent because these communities rely on groundwater as a significant source of supply. Initial Analysis Zones (IAZ) from CV-SALTS and the preliminary prioritization determined by CV-SALTS for each IAZ with respect to nitrate in groundwater were used as a prioritization factor (LWA, LSCE et al., 2013). Priority IAZs were identified as those with a priority value of 3 or 4 assigned by CV-SALTS. The weighting of this factor was relatively low at 2.5 percent.

From applying this prioritization matrix, priority values ranging from zero to ten (low to high priority) were calculated for the entire GDA HVA. The calculated priority levels within the GDA HVA are shown on **Figure 6-38**.

6.3.2 Identified Priority Areas

Figure 6-38 presents the prioritization of areas within the GDA HVA. Four priority levels are assigned in order of highest (Priority 1) to lowest (Priority 4). Because the proximity to communities reliant on groundwater has a high weighting in the prioritization matrix, some high priority areas are focused around mapped communities, including in the vicinity of Firebaugh, Mendota, and several small DUCs and public water systems within the GDA, although many of these communities are outside the GDA HVA. Areas where groundwater vulnerability factors more heavily influence the prioritization rank (i.e., soil drainage class and sediment texture) are also apparent in parts of the GDA, especially along the western edge, although this influence is not as notable as some other prioritization factors. Higher priority ranking values relating to groundwater quality (e.g., nitrate concentrations and exceedances) are one of the most evident features in **Figure 6-38** displayed as generally higher priority areas with a notably large area of high priority in the vicinity of the W. Nees Avenue and N. Russell Avenue intersection.

Table 6-5 summarizes the acreages designated as part of the GDA HVA by priority level. The total prioritized acreage reported in **Table 6-5** is less than the GDA HVA area reported in **Table 6-3** because of the gridding process used during prioritization. Approximately 6,229 acres of the GDA HVA are located within the highest priority area (Priority 1) and of those acres about 95 percent (5,898) are irrigated lands (based on 2014 USDA data). About 6,628 acres of the GDA HVA are Priority 2 of which 6,042 acres are irrigated lands (based on 2014 USDA data). The remaining 14,656 acres of the GDA HVA are in the relatively lower priority areas (Priority 3 and 4) and include approximately 12,471 acres of irrigated lands (based on 2014 USDA data). Although all of the GDA HVA has been prioritized and summarized in **Table 6-5** and shown in **Figure 6-38**, prioritization intended for implementation of management and monitoring of agricultural practices as part of the ILRP, will only be implemented on irrigated lands within the GDA. The prioritization of irrigated lands within the GDA HVA is presented in **Figure 6-39**.

As shown in **Table 6-6**, based on 2014 USDA land use data, nut trees and vegetables currently represent the largest agricultural land use categories by area across each of the top three priority area types. According to 2014 USDA land use data, agricultural land use categories make up 5,847 acres of the total Priority 1 area. Vegetables cover 1,818 acres within the Priority 1 area, which is about 31 percent of the agricultural lands within the Priority 1 area. Nut trees represent the next largest agricultural land use category within the Priority 1 area with a total of 988 acres with 779 acres of idle agricultural land within the Priority 1 area in 2014. Only 378 acres within the Priority 1 area are categorized as non-agricultural lands based on 2014 USDA land use data. Within the Priority 2 area, vegetables represent the largest agricultural land use category encompassing 2,372 acres with a little more than half as many acres of nut trees (1,220 acres). Grain and idle agricultural lands are the next most frequent agricultural land use category within the Priority 2 area with about 895 and 707 acres, respectively. A total of about 227 acres (based on 2014 USDA data) of the Priority 2 area are non-agricultural lands. The dominant land use category in the Priority 3 area is nut trees (2,251 acres), which makes up about 31 percent of the Priority 3 area with also a large number of acres of vegetables (1,314 acres) and idle agricultural land (1,308 acres) within the Priority 3 area. A greater amount of non-agricultural and unirrigated lands within the GDA HVA are within Priority 4 areas with non-agricultural lands representing about 569 acres of the Priority 4 area although unirrigated areas (including dry-farmed areas) total over 1,250 acres of the Priority 4 area. The Priority 4 area includes 7,437 acres and about 83 percent (about 6,170 acres) of this area is irrigated land, according to 2014 USDA and GDA districts data, with about 4,105 acres of idle agricultural land. The identified communities reliant on groundwater within the GDA are shown in relation to the prioritization of the GDA HVA in **Figure 6-40**. Although some communities reliant on groundwater are located outside the GDA HVA, those communities within the GDA HVA are located in areas designated primarily as Priority 1.

6.3.3 Summary of Prioritization

All areas within the HVA were prioritized for planning of future monitoring and management efforts. In accordance with factors identified in the WDR, prioritization incorporated many considerations including, but not limited to, the following:

- Identified exceedances of water quality objectives,
- Proximity to communities reliant on groundwater,
- Existing land uses, and
- Legacy or ambient groundwater conditions.

Additional factors were included to incorporate the vulnerability of areas. To objectively incorporate the many factors to be considered, a prioritization system was developed with which to calculate priority values across the high vulnerability area. From these priority calculations, priority areas ranging from priority 1 (high priority) to priority 4 (low priority) were identified to inform groundwater monitoring and management efforts. The priority areas for the GDA HVA are presented in **Figures 6-38 through 6-40** and are summarized in **Table 6-6**.

7 GROUNDWATER MONITORING PROGRAMS

This GAR highlights various entities that have historically conducted monitoring and sampling within the GDA. The WDR specifies that within one year from the approval of the GAR, the Steering Committee for the GDA shall develop a workplan for conducting trend monitoring that meets the objectives and minimum requirements of the Monitoring and Reporting Program (MRP). The objectives for the trend monitoring program include:

- Determine current water quality conditions of groundwater relevant to irrigated agriculture.
- Develop long-term water quality information that can be used to evaluate the regional effect (i.e., no site-specific effects) of irrigated agriculture and its practices.

The design and implementation of the trend monitoring program will include (among other considerations) a groundwater monitoring network that will address:

- High and low groundwater vulnerability areas in the Coalition region.
- Use of shallow wells "but not necessarily wells completed in the uppermost zone of first encountered groundwater" (WDR R5-2019-0095, Attachment B, III, C).
- The potential suitability of existing monitoring networks such as those developed for purposes of groundwater management plans.
- The rationale for the distribution of the trend monitoring wells.

This section summarizes the groundwater monitoring networks that have been developed by federal, state, and local entities to preliminarily assess the distribution of existing monitoring wells that may potentially be used for purposes of the Coalition's trend monitoring program. As indicated in previous sections, well construction data are lacking for many monitored wells. Therefore, as part of the trend monitoring workplan, additional examination of available records for existing monitoring wells, which are potential candidates for inclusion in the trend network, will be needed in many cases to determine the construction of the candidate wells. **Table 7-1** and **Figures 7-1 through 7-10** summarize the availability of historical monitoring within the GDA and indicate potential wells for consideration as part of a monitoring program. Wells monitored recently (since 2005) are summarized in **Table 7-2** and **Figures 7-11 through Figure 7-17** by the entity and depth zone for which data were available.

7.1 Sources of Information on Existing Groundwater Monitoring Programs

7.1.1 California Department of Water Resources

Data from DWR is readily available from the DWR California Statewide Groundwater Elevation Monitoring (CASGEM) web portal. DWR is involved in monitoring groundwater levels and groundwater quality throughout California. The DWR groundwater level data retrieved was comprised of 836 different wells with a total of 14,928 measurements. These data made up a majority of the data used to examine groundwater levels, contributing roughly 92 percent of all data. The majority of water level measurements were taken prior to 1970. Measurements for the remaining decades were steady, ranging between 1,000 and 2,000 per decade. Notably, in the 1990s, the number of water level measurements was lower. The 836 wells with water level data were distributed between all depth zones with the largest number of wells in the Lower Aquifer. A substantial number of wells were lacking information with which to classify them into a depth zone.

A total of 85 wells had nitrate data with a total of 141 samples collected over the last 100 years. The majority of these samples were taken prior to 1970. DWR water quality data also included TDS, boron, and selenium concentrations. Historical DWR data include a total of 127 wells sampled for TDS yielding 466 samples, 112 wells for boron yielding 225 samples, and four wells for selenium yielding 6 samples.

7.1.2 State Water Resources Control Board (Geotracker and DDW)

Several sampling programs whose data are made available by the SWRCB programs exist within the GDA. Data available from the SWRCB and DDW (labeled DDW in relevant tables) included data for nitrate, TDS, and selenium. A total of 3 wells were sampled 14 times for nitrate, 2 wells were sampled 96 times for TDS, and 2 wells were sampled 13 times for selenium. All of these samples were collected after 2000.

7.1.3 United States Geological Survey

USGS provided data for groundwater levels and groundwater quality within the GDA. All USGS data provided well depths and all of those wells were located in the Shallow Groundwater zone. In all, water levels were measured in 80 wells a total of 1,218 times by the USGS prior to 2000. The majority of these measurements were made in the 1990s.

For groundwater quality data, USGS data included 166 wells sampled 563 times for nitrate, 291 wells sampled 1,541 times for TDS, 216 wells sampled 441 times for boron, and 187 wells sampled 426 times for selenium. All nitrate and selenium samples were collected during the 1980s or later.

7.1.4 California Department of Pesticide Regulation

As a requirement of the Pesticide Contamination Prevention Act (PCPA), DPR maintains a database of results from sampling of wells for pesticides that are submitted to DPR from local, county, and state agencies. Multiple agencies report groundwater testing data to DPR, including CDPH and SWRCB. In the past, the SWRCB has also collected groundwater quality data through the GAMA program, and these results are reported to DPR. Some sampling of wells for pesticides is also conducted by DPR as part of groundwater monitoring programs aimed at delineating GWPAs and also to determine if pesticides classified as potential contaminants have reached groundwater as a result of their legal use.

When DPR receives a result indicating a pesticide detection, the detection is investigated to determine if it was the result of legal agricultural practices, and whether additional sampling is necessary. However, DPR does not conduct additional sampling if any of the following circumstances exist: 1) the pesticide is no longer sold in California, 2) follow-up samples do not detect the pesticide, 3) the pesticide is regulated as a groundwater contaminant and located within a GWPA, or 4) the pesticide is naturally occurring, although DPR will consider additional sampling if there is evidence that the detection is the result of pesticidal use of the compound. When pesticide detections are located outside of the GWPAs, DPR will determine if the GWPAs need to be expanded to include new areas.

Data provided by DPR for use in this GAR were only available at a spatial resolution accurate to the section (approximately one square mile) in which the well is located. DPR provided well pesticide test data for 23 unique wells in 18 sections.

7.1.5 RWQCB – Dairy Monitoring Programs

Within the Coalition region, the RWQCB provided data for one well from the dairy monitoring program, with one test result for nitrate. No depth information was provided for this well and the location coordinate accuracy for the well is unknown, but likely of poor, quality. RWQCB data was not available for groundwater levels or for TDS, boron, and selenium.

7.1.6 GDA Districts

No groundwater level data were available from the GDA districts; however, considerable water quality data were available from the GDA districts and Steering Committee. Most of the water quality data available from the GDA districts was for tile drain sumps. A total of 5 sites had nitrate data, 208 sites had TDS, and 136 sites had selenium data. All selenium samples were collected after 1989 and all nitrate samples were collected prior to 1970.

7.2 Summary of Existing Groundwater Monitoring Programs

A variety of different agencies have historically monitored groundwater conditions in the GDA. DWR, DDW, USGS, and the GDA districts maintain data which are updated somewhat regularly with new information. DWR and USGS have the largest data sets available for the study area for both groundwater levels and groundwater quality parameters, although the GDA districts and the Steering Committee have been monitoring Very Shallow Water with regularity. **Table 7-2** summarizes recent groundwater monitoring in the GDA.

7.2.1 Overview of Data Gaps

An extensive data collection effort was conducted for this GAR. However, despite all the data collected, supporting information regarding samples was often times incomplete or non-existent. Many wells are lacking well depths and perforation data and recent data for some groundwater quality parameters are scarce. In particular, data are lacking for nitrate concentrations, especially in the Upper Aquifer (**Table 7-2**).

Many of the wells for which data are available were assigned to a depth zone based on their use type, when well depth information is not known. Identification of well construction information will be important for any wells chosen as part of a future monitoring program to ensure the program is properly designed to meet its objectives. If depth or other construction information is not readily known, it may be advantageous to obtain this information through construction logs or other well records, in order to consider a well for inclusion as part of a monitoring program.

Recent water quality samples consist of TDS and selenium data more than other constituents. Only 33 samples were collected for nitrate since 2010s. Additional monitoring for nitrate will be needed for future monitoring programs in the GDA. In addition, the majority of the wells with nitrate samples are located in the Very Shallow Water and Shallow Groundwater zones with much less data in the Upper Aquifer and Lower Aquifer.

As seen in **Figure 7-14**, spatial data gaps exist in recent monitoring along the California Aqueduct and southeast of the N Fairfax Avenue and W Nees Avenue for water quality in the Very Shallow Water zone. The area along the California aqueduct is included in the GDA HVA.

Figure 7-15 illustrates the large data gaps present in recent monitoring of the Shallow Groundwater zone. Only a small area southeast of the N. Fairfax Avenue and W. Nees Avenue intersection has monitoring in the Shallow Groundwater since 2010. Similarly, the majority of the recent groundwater monitoring in the Upper Aquifer is limited to areas along the canals in the northern portion of the GDA. Recent monitoring of the Shallow Groundwater and Upper Aquifer are limited in the GDA HVA.

Figure 7-16 illustrates the relatively few wells in the Lower Aquifer that have been monitored recently. The scarce amount of data available does not provide coverage of the HVAs. Recently monitored wells of unknown depth shown in **Figure 7-17** provide addition future monitoring opportunities for consideration if depth information can be obtained.

7.2.2 Potential Monitoring Wells

The best candidates for monitoring wells will be wells for which the depths and lengths of perforated intervals and casings are available and that are accurately located with GPS or other coordinate information. Well completion reports and drillers' logs should be acquired for all monitoring wells. For the purposes of future trend monitoring, monitoring wells should not be assigned to an aquifer based on well-use only. Ideally, these wells should also have an existing record of groundwater quality and level data.

The overall construction of potential monitoring wells should also be considered. Poorly constructed wells with pathways for water to travel between aquifers can produce inaccurate monitoring results. Driller's logs and well completion reports can be used to identify wells that are suitable for sampling one aquifer without mixing water from aquifers above or below the target aquifer.

Wells in the Shallow Groundwater and Upper Aquifer zones within the GDA HVA (**Figure 7-14**) will be important for monitoring networks as these wells will be best suited for characterizing the impact of changing irrigation practices; however, as described above, there is a lack of recently monitored wells, particularly for the Upper Aquifer in the GDA. Further investigation of historically, but not recently, monitored wells may increase the coverage of wells for monitoring the Upper Aquifer zone.

8 REFERENCES

References Cited

AECOM. 2011. Groundwater management plan for the northern agencies in the Delta-Mendota Canal Service Area. Prepared for the San Luis & Delta-Mendota Water Authority.

Aller, L., T. Bennett, J. H. Lehr, R.J. Petty, and G. Hackett. 1987. DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings: NWWA/EPA Series, EPA-600/2-87-035. U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, 455 p.

Anning, D.W., A.P. Paul, T.S. McKinney, J.M. Huntington, L.M. Bexfield, and S.A. Thiros. 2012. Predicted nitrate and arsenic concentrations in basin-fill aquifers of the southwestern United States. U.S. Geological Survey Scientific Investigations Report 2012-5065.

Belitz, K., S.P. Phillips, and J.M. Gronberg. 1993. Numerical simulation of ground-water flow in the Central Part of the western San Joaquin Valley, California. U.S. Geological Survey Water-Supply Paper 2396, 69 p.

Bertoldi, G.L., R.H. Johnston, and K. D. Evenson. 1991. Ground water in the Central Valley, California – A Summary Report. U.S. Geological Survey Professional Paper 1401-A.

Burkart, M.R., D.W. Kolpin, R.J. Jaquis, and K.J. Cole. 1999. Agrichemicals in ground water of the midwestern USA: relations to soil characteristics. Journal of Environmental Quality, Vol. 28, No. 6, 1908.

California Department of Pesticide Regulation (DPR). 2013. Ground Water Protection Area shapefiles, http://www.cdpr.ca.gov/docs/emon/grndwtr/gwpa_shapefiles.htm.

California Department of Water Resources (DWR). 2003. California's groundwater. DWR Bulletin 118, http://www.water.ca.gov/groundwater/bulletin118/san_joaquin_river.cfm.

California Department of Public Health (CDPH). 2015. California Environmental Health Tracking Program, Public Water Systems Boundary Tool, http://www.ehib.org/page.jsp?page_key=762.

California Department of Water Resources (DWR). 2010. Lines of Equal Elevation of Water in Wells, Unconfined Aquifer, San Joaquin Valley, Spring 2010, http://www.water.ca.gov/pubs/groundwater/lines_of_equal_elevation_of_water_in_wells_unconfined_aquifer_san_joaquin_valley_spring_2010/sjv2010spr_unc_elev.pdf.

California Department of Water Resources (DWR). 1971. Bio-engineering aspects of agricultural drainage, San Joaquin Valley, California: Nutrients from tile drainage systems. Water Pollution Control Research Series DWR No. 174-6.

California State Water Resources Control Board (SWRCB). 2013. Water quality goals online database, http://www.waterboards.ca.gov/water_issues/programs/water_quality_goals/search.shtml.

California State Water Resources Control Board (SWRCB). 2016. Division of Drinking Water, DRINC Web Portal, http://www.drinc.ca.gov.

Croft, M. G. 1972. Subsurface geology of the Late Tertiary and Quarternary water-bearing deposits of the southern part of the San Joaquin Valley, California. U.S. Geological Survey Water-Supply Paper 1999-H.

Davis, G.H. and J. F. Poland. 1957. Ground-water conditions in the Mendota- Huron Area Fresno and Kings Counties, California. U.S. Geological Survey Water Supply Paper No. 1360-G.

Davis, G. H., J.H. Green, S.H. Olmstead, and D.W. Brown. 1959. Ground water conditions and storage capacity in the San Joaquin Valley, California. U.S. Geological Survey Water Supply Paper No. 1469, 287 p.

Davis, G.H., B.E. Lofgren, S. Mack. 1964. Use of ground-water reservoirs for storage of surface water in the San Joaquin Valley California. U.S. Geological Survey Water-Supply Paper 1618.

Deverel, S.J. and J.L. Fio. 1991. Groundwater flow and solute movement to drain laterals, western San Joaquin Valley, California: 1. Geochemical Assessment. Water Resources Research, Vol. 27, No. 9, 2233.

Doll, D. and C. DeBuse (eds). 1996. Almond Production Manual. UC Division of Agriculture and Natural Resources.

Dzurella, K.N., J. Medellín-Azuara, V.B. Jensen, A.M. King, N. De La Mora, A. Fryjoff-Hung, T.S. Rosenstock, T. Harter, R. Howitt, A.D. Hollander, J. Darby, K. Jessoe, J. Lund, G. S. Pettygrove. 2012. Nitrogen source reduction to protect groundwater quality Technical Report 3, Addressing nitrate in California's drinking water with a focus on Tulare Lake Basin and Salinas Valley groundwater, Report for the State Water Resources Control Board Report to the Legislature. Center for Watershed Sciences, University of California, Davis. 174 p.

Eberts, S.M., M.A. Thomas, and M.L. Jagucki. 2013. The quality of our Nation's water – Factors affecting public-supply-well vulnerability to contamination - understanding observed water quality and anticipating future water quality. U.S. Geological Survey Circular 1385, 120p.

ESRI. 2016. ArcGIS 10.4, ESRI, Redlands, California.

Faunt, C., R.T. Hanson, K. Belitz, W. Schmid, S. Predmore, D. L. Rewis, and K. McPherson. 2009. Groundwater availability of the Central Valley Aquifer, California. U.S. Geological Survey Professional Paper 1766, http://pubs.usgs.gov/pp/1766/.

Faunt, C.C., Belitz, K., and Hanson, R.T. 2010. Development of a three-dimensional model of sedimentary texture in valley-fill deposits of Central Valley, California, USA. Hydrogeology Journal, Vol. 18, 625.

Fio, J.L. and S.J. Deverel. 1991. Groundwater flow and solute movement to drain laterals, western San Joaquin Valley, California: 2. Quantitative hydrologic assessment. Water Resources Research, Vol. 27, No. 9, 2247.

Geissler, D. and W.R. Horwath. 2013. Cotton Production in California. California Department of Food and Agriculture Fertilizer Research and Education Program, February 2013, http://apps.cdfa.ca.gov/frep/docs/Cotton_Production_CA.pdf.

Greene, E.A., A.E. LaMotte, and K.A. Cullinan, 2004. Ground-water vulnerability to nitrate contamination at multiple thresholds in the Mid-Atlantic Region using spatial probability models. U.S. Geological Survey Scientific Investigations Report 2004-5118.

Gronberg, J.M. and Spahr, N.E. 2012. County-Level Estimates of Nitrogen and Phosphorus from Commercial Fertilizer for the Conterminous United States, 1987–2006. National Water-Quality Assessment Program. U.S. Geological Survey Scientific Investigations Report 2012-5207, 30 p.

Hotchkiss, W.R. and G.O. Balding. 1971. Geology, hydrology, and water quality of the Tracy-Dos Palo area, San Joaquin Valley, California. U.S. Geological Survey Open-File Report 72-169, 107 p.

Larry Walker Associates (LWA), Luhdorff & Scalmanini Consulting Engineers (LSCE), Systech, PlanTierra, Kennedy Jenks, Carollo Engineers. 2013. CV-SALTS Initial conceptual model (ICM) technical services, Tasks 7 and 8 – Salt and nitrate analysis for the Central Valley Floor and a focused analysis of Modesto and Kings subregions, final report.

Le Strange, M., W.L. Schrader, and T.K. Hartz. 2000. Fresh-Market Tomato Production in California. ANR Publication 8017.

Ludington, S., B.C. Moring, R.J. Miller, K.S. Flynn, P.A. Stone, and D.R. Bedford. 2005. Preliminary integrated databases for the United States – Western States: California, Nevada, Arizona, and Washington. U.S. Geological Survey Open-File Report 2005-1305, http://pubs.usgs.gov/of/2005/1305.

Luhdorff and Scalmanini, Consulting Engineers (LSCE). 2014. East San Joaquin Water Quality Coalition Groundwater Quality Assessment Report. January 2014.

Luhdorff and Scalmanini, Consulting Engineers (LSCE). 2015. Western San Joaquin River Watershed Groundwater Quality Assessment Report. Prepared in conjunction with Davids Engineering and Larry Walker Associates. Prepared for San Joaquin Valley Drainage Authority on behalf of Westside San Joaquin River Watershed Coalition. March 2015.

Mathany, T.M., M.K. Landon, J.L. Shelton, and K. Belitz. 2013. Groundwater-quality data in the Western San Joaquin Valley study unit, 2010: Results from the California GAMA program. U.S. Geological Survey Data Series 706.

Mendenhall, W.C., R.B. Dole, and H. Stabler. 1916. Ground water in the San Joaquin Valley, California. U.S. Geological Survey Water-Supply Paper 398, 310 p.

Meyer, T.D., D.B. Marcum, S.B. Orloff, and J.L. Schmierer. 2007. Alfalfa Fertilization Strategies. In C. G. Summers and D. H. Putnam, eds., Irrigated Alfalfa Management for Mediterranean and Desert Zones. Chapter 6. Oakland: University of California Agriculture and Natural Resources Publication 8292, http://alfalfa.ucdavis.edu/IrrigatedAlfalfa.

Miller, R. E., J. H. Green, and G. H. Davis. 1971. Geology of the compacting deposits in the Los Banos-Kettleman City Subsidence Area, California. U.S. Geological Survey Professional Paper: 497-E.

Munier, D., T. Kearney, G.S. Pettygrove, K. Brittan, M. Mathews, and L. Jackson. 2006. Fertilization of small grains. In UC ANR (Ed.). Small Grain Production Manual, ANR Publication 8208.

National Research Council (NRC). 1993. Groundwater vulnerability assessment, contamination potential under conditions of uncertainty. National Academy Press, Washington, D.C., 210 p., http://books.nap.edu/books/0309047994/html.

Nolan, B.T. 2001. Relating nitrogen sources and aquifer susceptibility to nitrate in shallow ground waters of the United States. Ground Water, Vol. 39, No. 2, 290.

Nolan, B.T., K.J. Hitt, and B.C. Ruddy. 2002. Probability of nitrate contamination of recently recharged groundwaters in the conterminous United States. Environmental Science & Technology, Vol. 36, No. 10, 2138.

Nolan, B.T. and K.J. Hitt. 2006. Vulnerability of shallow groundwater and drinking-water wells to nitrate in the United States. Environmental Science & Technology, Vol. 40, No. 24, 7834.

Phillips, S.P., C.T. Green, K.R. Burow, J.L.Shelton, and D.L. Rewis, 2007. Simulation of multiscale groundwater flow in part of the northeastern San Joaquin Valley, California: U.S. Geological Survey Scientific Investigations Report 2007-5009, 43 p.

PolicyLink. 2013. California unincorporated: mapping disadvantaged communities in the San Joaquin Valley, 48 p., http://www.policylink.org/sites/default/files/CA_UNINCORPORATED_2.PDF.

PRISM Climate Group. 2014. Annual mean precipitation 1980-2010 data, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu.

Quinn, N.W.T., J.C. McGahan, and M.L. Delamore. 1998. Innovative drainage management techniques to meet monthly and annual selenium load targets. California Agriculture, Vol. 52, No. 5, 12.

Randolph, B.F. 2003. Managing groundwater quality and quantity in the San Joaquin Valley, California: integrated strategies for protecting groundwater in arid regions. University of California, Berkeley M.S. Environmental Science, Policy and Management Thesis Paper Professor T.N. Narasimhan, Chair.

Rosenstock, T.S., Liptzin, J.S., and Tomich, T.P. 2013. Nitrogen fertilizer use in California: Assessing the data, trends and a way forward. California Agriculture. Vol. 67, No. 1, 68.

San Luis and Delta-Mendota Water Authority (SLDMWA). 2015. Waste Discharge Requirement Order No. 5-01-234, Update of long-term Drainage Management Plan and submittal of monitoring results. Letter to Central Valley Regional Water Quality Control Board for Grassland Area Farmers, December 17, 2015, http://www.waterboards.ca.gov/centralvalley/water_issues/grassland_bypass/2015_longterm_drainage_plan.pdf.

Strathouse, S. M. and Sposito, G., 1980, Geologic nitrogen may pose hazard. California Agriculture, Vol. 34, No. 8, 20, August-September 1980.

Sullivan, P.J., G. Sposito, S.M. Strathouse, and C.L. Hansen. 1979. Geologic nitrogen and the occurrence of high nitrate soils in western San Joaquin Valley, California. Hilgardia, Vol. 47, No. 2, 15.

Tesoriero A.J. and F.D. Voss, 1997. Predicting the probability of elevated nitrate concentrations in the Puget Sound Basin: implications for aquifer susceptibility and vulnerability. Groundwater, Vol. 35, No. 6, 1029.

Tesoriero, A.J., E.L. Inkpen, and F.D. Voss,.1998. Assessing groundwater vulnerability using logistic regression, Source Water Assessment and Protection 98: A Technical Conference April 28-30, 1998, Double Tree Hotel Campbell Centre Dallas, Texas. U.S. Geological Survey Water Resources Division, 157 p.

Troiano, J., J. Marade, and F. Spurlock. 1999a. Empirical modeling of spatial vulnerability applied to a norflurazon retrospective well study in California. Journal of Environmental Quality, Vol. 28, 397.

Troiano, J., F. Spurlock, and J. Marade. 1999b. Update of the California vulnerability soil analysis for movement of pesticides to groundwater: October 14, 1999. State of California Environmental Protection Agency, Department of Pesticide Regulation.

United States Census Bureau (Census). 2014. American Communities Survey, 2012 5-year estimates, https://www.census.gov/programs-surveys/acs/. Accessed June 10, 2014.

University of California at Davis (UCD). 2015. Cost and Return Studies, http://coststudies.ucdavis.edu/, Accessed February 5, 2015.

Viers, J.H., Liptzin, D., Rosenstock, T.S., Jensen, V.B., Hollander, A.D., McNally, A., King, A.M., Kourakos, G., Lopez, E.M., De La Mora, N., Fryjoff-Hung, A., Dzurella, K.N., Canada, H.E., Laybourne, S., McKenney, C., Darby, J., Quinn, J.F. & Harter, T. 2012. Nitrogen Sources and Loading to Groundwater. Technical Report 2 in: Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater. Report for the State Water Resources Control Board Report to the Legislature. Center for Watershed Sciences, University of California, Davis.

Westside Resource Conservation District. 2005. A technical advisor's manual: Managing agricultural irrigation drainage water, A guide for developing Integrated On-Farm Drainage Management Systems. Developed for the State Water Resources Control Board in conjunction with the Center for Irrigation Technology, California State University, Fresno.

Wright, L. 2014. 2013 Fresno County Annual Crop & Livestock Report. Department of Agriculture. Fresno County, California. 41 p.

General References

Belitz, K. and J. H. Frederick. 1990. Character and evolution of ground-water flow system in the central part of the western San Joaquin Valley, California. U.S. Geological Survey Water-Supply Paper 2348.

Belitz, K. and S.P. Phillips. 1994. Simulation of water-table response to management alternatives, Central part of the western San Joaquin Valley, California. U.S. Geological Survey Water-Resources Investigations Report 91-4193, 41p.

Belitz, K. and S.P. Phillips. 1995. Alternative to agricultural drains in California's San Joaquin Valley: results of a regional-scale hydrogeologic approach. Water Resources Research, Vol. 37, No. 8, 1845.

Bennett, G.L., K. Belitz, and B.J. Milby Dawson. 2006. California GAMA Program - Groundwater quality data in the northern San Joaquin basin study unit, 2005. U.S. Geological Survey Data Series 196, 122 p.

Bertoldi, G. L. 1971. Chemical quality of ground water in the Dos Palos-Kettleman City Area San Joaquin Valley California. U.S. Geological Survey Open-File Report 6413-20, 45 p.

Bertoldi, G.L., R.H. Johnston, and K. D. Evenson. 1991. Ground water in the Central Valley, California – A Summary Report. U.S. Geological Survey Professional Paper 1401-A.

Boyle. 2007. Groundwater management plan for the northern agencies in the Delta-Mendota Canal Service Area and a portion of San Joaquin County.

Burow, K.R., J.L. Shelton, and N.M. Dubrovsky. 1998. Occurrence of nitrate and pesticides in ground water beneath three agricultural land-use settings in the eastern San Joaquin Valley, California: U.S. Geological Survey Water-Resources Investigations Report 97-4284, 51 p.

California Department of Pesticide Regulation (DPR). 2000. Depth to groundwater database. http://www.cdpr.ca.gov/docs/emon/pubs/ehapreps/eh0002.pdf.

California Department of Public Health (CDPH). 2013. Water quality analyses database files. http://www.cdph.ca.gov/certlic/drinkingwater/Pages/EDTlibrary.aspx.

California Department of Water Resources (DWR). 2006. San Joaquin Valley Groundwater Basin Delta-Mendota Subbasin. DWR Bulletin 118, http://www.water.ca.gov/pubs/groundwater/bulletin_118/basindescriptions/5-22.07.pdf.

California Department of Water Resources (DWR), San Joaquin District. 1981. Depth to the Top of Corcoran Clay. 1:253,440 scale map.

California Department of Water Resources (DWR). Land and water use data. Unpublished.

California Department of Water Resources (DWR). no date shown. A preliminary assessment of salt-affected soils in the San Joaquin Valley. Map. Data Sources: USDA NRCS, SSURGO.

California State Water Resources Control Board. 1999/2011. Hydrogeologically vulnerable areas map (references appear to be 1999 or earlier; map noted as updated March 10, 2011).

Central Valley Regional Valley Water Quality Control Board. 2012. Irrigated Lands Regulatory Program, http://www.swrcb.ca.gov/rwqcb5/water_issues/irrigated_lands/index.shtml.

Central Valley Regional Water Quality Control Board. 2015. Order R5-2015-0095. Waste discharge requirements General Order for growers in the Grassland Drainage Area.

CH2M Hill. 1988. San Joaquin Valley hydrologic and salt load budgets. A report prepared for the San Joaquin Valley Drainage Program, Sacramento, California.

Davis, G.H., and T.B. Coplen. 1989. Late Cenozoic palehydrology of the western San Joaquin Valley, California, as related to structural movements in the Central Coast Ranges. Geological Society of America Special Paper 234, 40 p.

Deverel, S.J., R.J. Gilliom, R. Fuji, J.A. Izbicki, and J.C. Fields. 1984. Distribution of selenium and other inorganic constituents in shallow ground water of the San Luis Drain service area, San Joaquin Valley, California: A preliminary study. U.S. Geological Survey Open-File Report 84-4319.

Deverel, S.J. and R. Fuji. 1988. Processes affecting the distribution of selenium in shallow groundwater of agricultural areas, western San Joaquin Valley, California. Water Resources Research, Vol. 24, No. 4, 516.

Deverel, S.J. and S.K. Gallanthine. 1988. Relation of salinity and selenium in shallow groundwater to hydrologic and geochemical processes, western San Joaquin Valley, California. U.S. Geological Survey Open-File Report 88-336, 23 p.

Deverel, S.J. and S.P. Millard. 1988. Distribution and mobility of selenium and other trace elements in shallow ground water of the western San Joaquin Valley, California. Environmental Science and Technology, Vol. 22, No. 6, 697.

Deverel, S.J. and S.K. Gallanthine. 1989. Relation of salinity and selenium in shallow groundwater to hydrologic and geochemical processes, western San Joaquin Valley, California. Journal of Hydrology, Vol. 109, 125.

Dubrovsky, N.M., J.D. Steven, and J.G. Robert 1993. Reprinted from: Regional ground-water quality. Edited by William M. Alley. New York: Van Nostrand Reinhold.

Dubrovsky, N.M., J.M. Neil, R. Fuji, R.S. Oremland, and J.T. Hollibaugh. 1990. Influence of redox potential on selenium distribution in ground water, Mendota, western San Joaquin Valley, California. U.S. Geological Survey Open-File Report 90-138.

Entrix. 2009. Grassland Bypass Project, 2010-2019 Final Environmental Impact Statement and Environmental Impact Report, August 2009.

Gronberg, J.M. and K. Belitz. 1992. Estimation of a water budget for the Central part of the western San Joaquin Valley, California. U.S. Geological Survey Water-Resources Investigations Report 91-4192, 22 p.

Harradine, F.F. 1950. Soils of Western Fresno County, California: University of California, Berkeley.

Izbicki, J. A. 1984. Chemical quality of water at 14 sites near Kesterson National Wildlife Refuge, Fresno and Merced Counties, California. U.S. Geological Survey Open-File Report 84-582.

Izbicki, J. A. 1989. Chemical quality of agricultural drainage water tributary to Kesterson Reservoir, Fresno and Merced counties, California, January and August 1984. U.S. Geological Survey Open-File Report 87-380.

Izbicki, J.A., C.L. Stamos, L.F. Metzger, K.F. Halford, T.R. Kulp, and G.L. Bennett. 2008. Source, distribution, and management of arsenic in water from wells, eastern San Joaquin ground-water subbasin, California. U.S. Geological Survey Open-File Report 2008-1272, http://pubs.usgs.gov/of/2008/1272/.

Kratzer, C.R. and R.N. Biagtan. 1997. Determination of travel times in the Lower San Joaquin River Basin, California, from dye-tracer studies during 1994-1995. U.S. Geological Survey Water Resources Investigations Report 97-4018, 20 p.

Larry Walker Associates, Luhdorff & Scalmanini Consulting Engineers, Systech, Newfields, Kennedy Jenks, Carollo Engineers. 2010. CV-SALTS Salt and nitrate sources pilot implementation study report.

Laudon, J. and K. Belitz. 1989. Texture and depositional history of near-surface alluvial deposits in the Central Part of the western San Joaquin Valley, California. U.S. Geological Survey Open-File Report 89-235, 19 p.

Ludington, S., B.C. Moring, R.J. Miller, K.S. Flynn, P.A. Stone, D.R. Bedford. 2005. Preliminary integrated databases for the United States – Western States: California, Nevada, Arizona, and Washington. U.S. Geological Survey Open-File Report 2005-1305, http://pubs.usgs.gov/of/2005/1305.

Mendenhall, W.C., R.B. Dole, and H. Stabler. 1916. Ground water in the San Joaquin Valley, California. U.S. Geological Survey Water-Supply Paper 398, 310 p.

Mitten, H.T., R.A. LeBlanc, and G.L. Bertoldi. 1970. Geology, hydrology, and quality of water in the Madera Area, San Joaquin Valley, California. U.S. Geological Survey Open-File Report 6410-03, 49 p.

Page, R.W. 1973. Base of fresh ground water (approximately 3,000 micromhos) in the San Joaquin Valley, California: U.S. Geological Survey Hydrologic Investigations Atlas HA-489, 1 sheet, scale 1:500,000.

Page, R.W. 1986. Geology of the fresh groundwater basin of the Central Valley, California, with texture maps and sections. U.S. Geological Survey Professional Paper 1401-C, 54 p.

Phillips, S.P. and K. Belitz. 1991. Calibration of a texture-based model of a ground-water flow system, western San Joaquin Valley, California. Ground Water, Vol. 39, No. 5, 702.

Presser, T. S. and S. E. Schwarzbach. 2008. Technical analysis of in-valley drainage management strategies for the western San Joaquin Valley, California. U.S. Geological Survey Open-File Report 2008-1210, 37 p., http://pubs.usgs.gov/of/2008/1210/.

Rauschkolb RS. Mikkelsen DS. 1978. Survey of fertilizer use in California — 1973. UC Division of Agricultural Sciences Bulletin 1887, 25 p.

San Joaquin Valley Drainage Program. 1990. A management plan for agricultural subsurface drainage and related problems on the Westside San Joaquin Valley, Final Report.

Troiano, J., B. Johnson, S. Powell, and S. Schoenig. 1992. Profiling areas vulnerable to groundwater contamination by pesticides in California. Final Report to the State of California Environmental Protection Agency, Department of Pesticide Regulation, EH 92-09.

Troiano, J., F. Spurlock, and J. Marade. 2000. Update of the California soil analysis for movement of pesticides to groundwater: October 14, 1999. State of California Environmental Protection Agency, Department of Pesticide Regulation, EH 00-05.

USDA National Agricultural Statistics Service (NASS). 2014. National agricultural statistics service surveys: agricultural chemical use program, www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/index.asp. Accessed May 28, 2014.

Williamson, A.K., D. E. Prudic, and L. A. Swain. 1989. Ground-water flow in the Central Valley, California. U.S. Geological Survey Professional Paper 1401-D, 127 p.

TABLES

Table 1-1
Cross-Reference Table between GAR Outline and WDR General Order R5-2015-0095

GAR Items Identified in Monitoring and Reporting Program (Attachment B) of the WDR General Order for Growers in the Grassland Drainage Area		Addressed in GAR Outline
1. Objectives		
A.	Provide an assessment of available, applicable and relevant data and information to determine the high and low vulnerability areas where discharges from irrigated lands may result in groundwater quality degradation.	Throughout
B.	Establish priorities for implementation of monitoring and studies within high vulnerability areas.	Sections 5 & 6
C.	Provide a basis for establishing workplans to assess groundwater quality trends.	Throughout
D.	Provide a basis for establishing workplans and priorities to evaluate the effectiveness of agricultural management practices to protect groundwater quality.	Throughout
E.	Provide a basis for establishing groundwater quality management plans in high vulnerability areas and priorities for implementation of those plans.	Throughout
2. Components		
A.	Detailed land use information with emphasis on land uses associated with irrigated agricultural operations. The information shall identify the largest acreage commodity types in the third-party area, including the most prevalent commodities comprising up to at least 80% of the irrigated agricultural acreage in the third-party area.	Section 4
B.	Information regarding depth to groundwater, provided as a contour map(s).	Section 3
C.	Groundwater recharge information, including identification of areas contributing recharge to urban and rural communities where groundwater serves as a significant source of supply. Disadvantaged communities must be identified.	Section 3
D.	Soil survey information, including significant areas of high salinity, alkalinity and acidity.	Section 3
E.	Shallow groundwater constituent concentrations (potential constituents of concern include any material applied as part of the agricultural operation, including constituents in irrigation supply water [e.g., pesticides, fertilizers, soil amendments, etc.] that could impact beneficial uses or cause degradation).	Section 5
F.	Information on existing groundwater data collection and analysis efforts relevant to this Order (e.g., Department of Pesticide Regulation [DPR] United States Geological Survey [USGS] State Water Board Groundwater Ambient Monitoring and Assessment [GAMA], California Department of Public Health, local groundwater management plans, etc.). This groundwater data compilation and review shall include readily accessible information relative to the Order on existing monitoring well networks, individual well details, and monitored parameters. For existing monitoring networks (or portions thereof) and/or relevant data sets, the third-party should assess the possibility of data sharing between the data-collecting entity, the third- party, and the Central Valley Water Board.	Sections 5 & 7
3. Data Review and Analysis		
A.	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.	Section 5
B.	Determine the merit and feasibility of incorporating existing groundwater data collection efforts, and their corresponding monitoring well systems for obtaining appropriate groundwater quality information to achieve the objectives of and support groundwater monitoring activities under this Order. This shall include specific findings and conclusions and provide the rationale for conclusions.	Section 7
C.	Prepare a ranking of high vulnerability areas to provide a basis for prioritization of workplan activities.	Section 6
D.	The GAR shall discuss pertinent geologic and hydrogeologic information for the third-party area(s) and utilize GIS mapping applications, graphics, and tables, as appropriate, in order to clearly convey pertinent data, support data analysis, and show results.	Sections 3, 5 & 6
4. Groundwater Vulnerability Designations		
A.	Designate high/low vulnerability areas for groundwater in consideration of high and low vulnerability definitions provided in Attachment E of the Order.	Section 6
B.	The vulnerability designations will be made by the third-party using a combination of physical properties (soil type, depth to groundwater, known agricultural impacts to beneficial uses, etc.) and management practices (irrigation method, crop type, nitrogen application and removal rates, etc.).	Section 6
C.	The third-party shall provide the rationale for proposed vulnerability determinations.	Section 6
5. Considerations for Prioritization of High Vulnerability Groundwater Areas		
A.	Identified exceedances of water quality objectives for which irrigated agriculture waste discharges are the cause, or a contributing source.	Section 6
B.	The proximity of the high vulnerability area to areas contributing recharge to urban and rural communities where groundwater serves as a significant source of supply.	Section 6
C.	Existing field or operational practices identified to be associated with irrigated agriculture waste discharges that are the cause, or a contributing source (i.e., practices as currently known and available).	Section 6
D.	The largest acreage commodity types comprising up to at least 80% of the irrigated agricultural acreage in the high vulnerability areas and the irrigation and fertilization practices employed by these commodities.	Section 6
E.	Legacy or ambient conditions of the groundwater.	Sections 5 & 6
F.	Identified constituents of concern, e.g., relative toxicity, mobility.	Sections 5 & 6

Table 3-1
Summary of Assembled Groundwater Level Data

Historical Groundwater Level Measurements																				
Monitoring Entity	Number of Wells	Number of Measurements	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Domestic Wells	Unknown Well Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Measurements Pre-1970s	Measurements in 1970s	Measurements in 1980s	Measurements in 1990s	Measurements in 2000s	Measurements in 2010s
DWR	836	14,928	512	0	114	85	3	634	49	151	147	253	236	6,588	2,759	1,052	655	2,361	1,513
USGS	80	1,218	60	0	0	0	0	80	0	80	0	0	0	36	0	17	1,165	0	0
Total	916	16,146	572	0	114	85	3	714	49	231	147	253	236	6,624	2,759	1,069	1,820	2,361	1,513

Groundwater Level Measurements Since 2005													
Monitoring Entity	Number of Wells	Number of Measurements	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Domestic Wells	Unknown Well Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone
DWR	439	3,420	157	0	114	84	3	8	5	78	57	79	220
USGS	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	439	3,420	157	0	114	84	3	8	5	78	57	79	220

Table 3-2
Boundaries for Designation of Communities Reliant on Groundwater

Name of Boundary	Source of Original Boundary	DAC if CDP	Final Boundary Status as Community Reliant on Groundwater	Information Sources Reviewed/Contacted
Firebaugh City	Census Designated Place	Yes	**Included**	DRINC - 1010005
Mendota City	Census Designated Place	Yes	**Included**	DRINC - 1010021
Hamburg Farms	Disadvantaged Unincorporated Community	N/A	**Included**	Comparison in ArcGIS
Oro Loma	Disadvantaged Unincorporated Community	N/A	**Included**	Comparison in ArcGIS
Olam Spices and Vegetables	DDW Public Water Supply Well Locations	N/A	**Included** - defined extent to developed area	DRINC - 1009091, aerial imagery

Table 4-1
Summary of Irrigated and Non-Irrigated Lands Within the GDA

Land Area Description	Acres	Percent
Total Grassland Drainage Area	103,857	100.0%
Cultivated Agricultural Land [1]	*69,282*	*66.7%*
Idle Agricultural Land [1]	*29,036*	*28.0%*
Non-Agricultural Land [1]	*5,538*	*5.3%*
Total Irrigated Land [2]	86,477	83.3%

Notes:
[1] Based on 2014 USDA land use data
[2] Based on 2014 USDA and GDA districts data
Differences in total irrigated land area and agricultural land area occur because of existence of dry-farmed agricultural areas.

Table 4-2
Land Use Classification System

GAR Group	DWR (Circa-1990 and Circa-2000)[a]		USDA (2008 and 2014)		Applied Nitrogen[b]	
Land Use Category	Land Use Codes	Land Use Description	Land Use Codes	Land Use Description	(lbs nitrogen/ac/year) 1973	2005
Citrus/ Subtropical	All "C" codes	Eucalyptus	-	-	-	-
Dairy/ Farmsteads	All "S" codes	Livestock Feedlots, Farmsteads, Dairies	-	-	-	-
Field Crops	F1, F6	Field crops, Corn, Cotton	1, 2, 42, 43, 45, 46	Cotton, Dbl Crop WinWht/Corn, Corn, Dbl Crop Oats/Corn, Dbl Crop WinWht/Sorghum, Dbl Crop Barley/Sorghum	Cotton[c]: 109 Corn[c]: 145	Cotton[c]: 174 Corn[c]: 213
Fruit Trees	D10	Miscellaneous deciduous	39, 40, 41	Pomegranates, Plums, Apricots	95-133	102-130
Grain	All "G" codes	Grain and hay crops	5, 6, 7, 8, 33	Winter Wheat, Barley, Oats, Triticale, Durum Wheat	88	177
Grapes	All "V" codes	Grapes	69	Grapes	53-57	27-44
Grasses	All "P" codes	Alfalfa and Alfalfa Mixtures, Mixed Pasture, Native Pasture	36, 37, 131, 176	Alfalfa, Other Hay/Non Alfalfa, Barren, Grass/Pasture	22[c]	12[c]
Idle	All "I" codes	Idle	61	Fallow/Idle Cropland	-	-
Non Agricultural	All "NV", "NW", "U", "UC", "UI", "UL", "UR", "UV"	Dwellings with density of 1-8+ units/ac, dwellings with lots sizes of 1-5 acres, Urban Landscape, Schools, Manufacturing, Assembling, & General Processing, Fruit & Vegetable Canneries & Processing, Residential, Extractive Industries, Commercial, Lawn Area, Vacant, Storage & Distribution, Industrial, Unpaved Areas, Native Vegetation, Urban, Water Surface	111, 121, 122, 123, 124, 152, 190,195	Developed/Open Space, Developed/Low Intensity, Developed/Med Intensity, Open Water, Herbaceous Wetlands, Developed/High Intensity, Woody Wetlands, Shrubland	-	-
Nut Trees	D12, D13, D14	Pistachios, Walnuts, Almonds	75, 76, 204	Almonds, Pistachios, Walnuts	120-148	138-179
Rice	All "R" codes	Rice	3	Rice	86	130
Seeds/ Beans	All "F" codes except F1 and F6	Safflower, Beans (dry), Sudan, Sugar Beets	6, 33, 42	Safflower, Dry Beans, Sunflower	51	91
Vegetables	All "T" codes, F6	Truck, Nursery and Berry Crops, Peppers, Onions and Garlic, Flowers, Nursery and Christmas Tree Farms, Artichokes, Carrots, Melons, Squash, Cucumbers, Asparagus	44, 48, 49, 53, 54, 206, 207, 208, 209,213,227	Tomatoes, Onions, Honeydew Melons, Watermelons, Asparagus, Garlic, Cantaloupes, Lettuce, Peas, Carrots	Tomatoes: 142 Others: 95 - 287	Tomatoes: 180 Others: 151 - 346

a. Circa-1990 DWR land use combines data for Fresno County (1986), Madera County (1995), Merced County (1995), San Joaquin County (1988), and Stanislaus County (1996); Circa-2000 DWR land use combines data for Fresno County (2000), Madera County (2001), Merced County (2002), San Joaquin County (1996), and Stanislaus County (2004).

b. Source of applied nitrogen rates, unless otherwise noted, is Rosenstock, T.S. et al., 2013, Nitrogen fertilizer use in California: assessing the data, trends and a way forward, California Agriculture, Vol. 67(1), pp. 68-79.

c. Source of applied nitrogen rates for alfalfa, 1975 and 2005: Viers, J.H. et al., 2012, Nitrogen Sources and Loading to Groundwater, Technical Report 2, Assessing Nitrate in California's Drinking Water with a focus on Tulare Lake Basin and Salinas Valley Groundwater, Center for Watershed Sciences, University of California, Cavis, prepared for the California State Water Resources Control Board.

Table 4-3
Changes in Land Use

Land Use Category	Acres Within GDA By Land Use Year			
	Circa-1990 (DWR)	Circa-2000 (DWR)	2008 (USDA)	2014 (USDA)
Citrus/Subtropics	*0.05*	*7.6*	*0.8*	
Dairy/Farmstead	*120*	*350*		
Field Crops	*54,164*	*44,348*	*17,186*	*9,291*
Fruit Trees	*177*	*74*	*11*	*845*
Grain	*5,749*	*3,799*	*16,420*	*12,237*
Vineyards	*555*	*686*	*230*	*4,289*
Pasture & Alfalfa	*9,077*	*11,456*	*22,418*	*14,321*
Nut Trees	*462*	*668*	*8,437*	*10,488*
Rice	*3,085*	*3,629*	*605*	*699*
Seeds/Beans	*1,903*	*756*	*3,695*	*22*
Vegetables	*21,659*	*28,804*	*21,585*	*17,091*
Total Cultivated Cropland	**96,951**	**94,577**	**90,588**	**69,282**
Idle Cropland	*708*	*1,523*	*4,295*	*29,036*
TOTAL AGRICULTURAL AREA	**97,659**	**96,100**	**94,883**	**98,319**
Non-Agricultural	*6,200*	*7,775*	*8,993*	*5,538*
GRAND TOTAL	**103,860**	**103,875**	**103,876**	**103,857**

Note: Land use data from DWR and USDA are developed using different methods with different degrees of precision and accuracy; differences in methodology may affect acreage values reported for land uses for different time periods.

Table 4-4
Top Agricultural Crop Categories by Acreage

Crop Category	2014 USDA Acres	Cumulative Percent	Top 80 Percent Crop Category
Vegetables	17,091	25%	Yes
Pasture & Alfalfa	12,690	44%	Yes
Grain	12,237	62%	Yes
Nut Trees	10,488	78%	Yes
Field Crops	9,291	91%	Yes
Vineyards	4,289	98%	No
Fruit Trees	845	99%	No
Rice	699	100%	No
Seeds/Beans	22	100%	No
Citrus/Subtropics	0	100%	No
TOTAL	**67,652**		

Table 4-5
Summary of Irrigation Practices

From Circa-2000 Land Use Survey (DWR)						
Agricultural Land Use Category	Acres	Irrigation Method Percent of Agricultural Area				
		Microirrigation	Sprinkler	Gravity	Unknown	Not Irrigated
Field Crops	40,178	0.4%	4.8%	90.6%	4.1%	0.0%
Vegetables	28,804	8.0%	10.1%	80.8%	1.1%	0.0%
Pasture and Alfalfa	11,456	0.0%	2.7%	96.6%	0.1%	0.7%
Seeds/Beans	4,926	0.0%	8.7%	89.4%	1.9%	0.0%
Grain	3,799	0.0%	1.6%	84.0%	7.7%	6.7%
Rice	3,629	0.0%	0.0%	100.0%	0.0%	0.0%
Idle Agricultural Land	1,523	0.0%	0.0%	0.0%	100.0%	0.0%
Vineyards	686	100.0%	0.0%	0.0%	0.0%	0.0%
Nut Trees	668	84.4%	0.0%	15.6%	0.0%	0.0%
Dairy/Farmsteads	350	0.0%	0.0%	0.0%	0.0%	100.0%
Fruit Trees	74	0.0%	0.0%	100.0%	0.0%	0.0%
Citrus/Subtropical	8	0.0%	0.0%	0.0%	100.0%	0.0%
Overall Circa-2000 From DWR	**96,100**	**3.9%**	**5.9%**	**85.5%**	**4.1%**	**0.7%**

From 2015 GDA District Data						
Area Description	Acres	Irrigation Method Percent of Agricultural Area				
		Microirrigation	Sprinkler	Gravity	Unknown	Not Irrigated
Panoche Drainage District	37,964	96.3%	0.0%	0.7%	0.0%	3.0%
Firebaugh Canal Water District	22,000	59.1%	0.0%	31.8%	0.0%	9.1%
Charleston Drainage District	4,313	76.8%	0.0%	23.2%	0.0%	0.0%
Pacheco Water District	4,242	96.2%	0.0%	3.8%	0.0%	0.0%
Total Cropped Area	**66,519**	**83.3%**	**0.0%**	**12.1%**	**0.0%**	**4.6%**

Table 5-1a
Summary of Water Quality Data

Historical Nitrate Concentration Data																						
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results Over 5 mg/L (as N)	Drains/Wells with Results Over 10 mg/L (as N)	Drains/Wells with Results Over 20 mg/L (as N)	Samples Tested Pre-1970s	Samples Tested in 1970s	Samples Tested in 1980s	Samples Tested in 1990s	Samples Tested in 2000s	Samples Tested in 2010s
DDW	3	14	0	0	1	0	1	1	0	0	0	3	0	0	0	0	0	0	0	0	2	12
DWR	85	141	0	0	0	3	0	82	0	3	0	0	82	4	9	3	131	2	5	2	1	0
GDA Districts	5	7	5	0	5	0	0	0	0	0	0	5	0	1	0	0	7	0	0	0	0	0
RWQCB	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
USGS	166	563	163	17	0	0	3	146	89	66	6	5	0	9	32	105	0	0	474	68	0	21
Total	260	726	168	17	7	3	4	229	89	69	6	14	82	14	41	108	138	2	479	70	4	33

Historical TDS Concentration Data																						
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results Over 500 mg/L	Drains/Wells with Results Over 1,000 mg/L	Drains/Wells with Results Over 1,500 mg/L	Samples Tested Pre-1970s	Samples Tested in 1970s	Samples Tested in 1980s	Samples Tested in 1990s	Samples Tested in 2000s	Samples Tested in 2010s
DDW	2	96	1	0	0	0	1	1	0	0	0	2	0	0	0	2	0	0	0	0	6	90
DWR	127	466	0	0	0	0	0	127	0	5	0	0	122	8	49	70	442	8	10	4	2	0
GDA Districts	208	42896	67	136	15	55	1	1	172	20	0	16	0	5	9	193	22	0	0	8,777	26,594	7,503
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	291	1541	185	44	0	0	6	241	143	76	8	64	0	28	49	210	212	3	1,119	165	0	42
Totals	628	44999	253	180	15	55	8	370	315	101	8	82	122	41	107	475	676	11	1,129	8,946	26,602	7,635

Historical Selenium Concentration Data																						
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results <0.005 mg/L	Drains/Wells with Results 0.005-0.02 mg/L	Drains/Wells with Results >0.02 mg/L	Samples Tested Pre-1970s	Samples Tested in 1970s	Samples Tested in 1980s	Samples Tested in 1990s	Samples Tested in 2000s	Samples Tested in 2010s
DDW	2	13	0	0	0	0	1	1	0	0	0	2	0	0	1	1	0	0	0	0	1	12
DWR	4	6	0	0	0	0	0	4	0	0	0	0	4	0	1	3	0	0	3	2	1	0
GDA Districts	136	7,353	0	136	0	0	0	0	136	0	0	0	0	0	2	134	0	0	0	1,933	4,273	1,147
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	187	426	185	17	0	0	2	168	106	72	5	4	0	19	32	136	0	0	353	63	0	10
Total	329	7,798	185	153	0	0	3	173	242	72	5	6	4	19	36	274	0	0	356	1,998	4,275	1,169

Historical Boron Concentration Data																						
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results <0.7 mg/L	Drains/Wells with Results 0.7-1.0 mg/L	Drains/Wells with Results <1.0 mg/L	Samples Tested Pre-1970s	Samples Tested in 1970s	Samples Tested in 1980s	Samples Tested in 1990s	Samples Tested in 2000s	Samples Tested in 2010s
DDW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DWR	112	225	0	0	0	0	0	112	0	5	0	0	107	3	4	105	213	4	5	2	1	0
GDA Districts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	216	441	216	17	0	0	0	199	89	61	8	58	0	1	2	213	86	1	317	28	0	9
Total	328	666	216	17	0	0	0	311	89	66	8	58	107	4	6	318	299	5	322	30	1	9

Table 5-1b
Summary of Recent Water Quality Data

Nitrate Data Since 2005																
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown Type	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results Over 5 mg/L (as N)	Drains/Wells with Results Over 10 mg/L (as N)	Drains/Wells with Results Over 20 mg/L (as N)
DDW	3	14	0	0	1	0	1	1	0	0	0	3	0	0	0	0
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GDA Districts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RWQCB	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
USGS	9	21	6	0	0	0	3	6	0	0	5	4	0	0	4	0

Total Dissolved Solids (TDS) Data Since 2005																
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown Type	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results Over 500 mg/L	Drains/Wells with Results Over 1000 mg/L	Drains/Wells with Results Over 1500 mg/L
DDW	2	96	0	0	0	0	1	1	0	0	0	2	0	2	74	20
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GDA Districts	178	19,835	42	136	0	41	0	1	159	19	0	0	0	102	435	19,267
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	12	42	6	0	0	0	6	6	0	0	5	7	0	13	10	19

Selenium Data Since 2005																
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown Type	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results <0.005 mg/L	Drains/Wells with Results 0.005-0.02 mg/L	Drains/Wells with Results >0.02 mg/L
DDW	3	13	0	0	0	0	1	1	0	0	0	2	0	2	1	0
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GDA Districts	136	3,050	0	136	0	0	0	0	136	0	0	0	0	109	610	2,331
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	7	10	5	0	0	0	2	5	0	0	4	3	0	6	3	1

Boron Data Since 2005																
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown	Very Shallow Water	Shallow Groudwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results <0.7 mg/L	Drains/Wells with Results 0.7-1.0 mg/L	Drains/Wells with Results <1.0 mg/L
DDW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GDA Districts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	6	9	6	0	0	0	0	6	0	0	5	1	0	0	0	0

Table 5-2
Summary of Pesticide Detections and Exceedances

Pesticide	Wells Sampled	Wells with Detection	Number of Sample Detections	Wells with Exceedance	Sections Sampled	Sections with Detection	Sections with Exceedance	Concentration in Samples with Detections (µg/L)			Exceedance Threshold[1] (µg/L)	Basis for Exceedance Threshold[1]
								Average	Minimum	Maximum		
DBCP (Dibromochloropropane)	12	1	209	1	8	1	1	0.23	0.01	10.10	0.2	CA Primary MCL
Atrazine	20	1	2	0	17	1	0	0.06	0.01	0.20	1	CA Primary MCL
Molinate	11	1	1	0	7	1	0	0.01	0.01	0.01	20	CA Primary MCL
EPTC	8	1	1	0	6	1	0	0.03	0.01	0.07	40	MN HBV (Chronic)
Alachlor ESA	4	1	1	0	4	1	0	0.53	0.05	1.38	4	WI DNR PAL
Total[2]	**23**	**3**	**214**	**1**	**18**	**3**	**1**					

[1] Source of threshold: California Environmental Protection Agency, State Water Resources Control Board, Compilation of Water Quality Goals (http://www.waterboards.ca.gov/water_issues/programs/water_quality_goals/#data_downloads)

[2] Total does represent the sum of individual pesticide detections and exceedances because multiple pesticides may be detected in a single well.

TABLE 5-3
Summary of General Groundwater Quality Results from Other Studies

Delta-Mendota Subbasin USGS GAMA Study from Mathany et al. (2013) (Total wells sampled in 2010 = 45)				
Water Quality Constituent	**Detections**	**Exceedances**	**Exceedance Threshold** (µg/L)	**Threshold Type**
Arsenic	--	5	10	Primary MCL
Molybdenum	--	3	40	Primary MCL
Nitrite plus Nitrate (as Nitrogen)	--	9	10*	Primary MCL
Perchlorate	19	0	6	Primary MCL
Selenium	--	1	50	Primary MCL
Uranium	43	2	30	Primary MCL
Pesticides	19	0	Various	Various
Volatile Organic Compounds	16	0	Various	Various
Chloride	--	19	250*	Secondary MCL
Iron	--	5	300	Secondary MCL
Manganese	--	19	50	Secondary MCL
Sulfate	--	26	250*	Secondary MCL
Strontium	--	3	4,000	USEPA lifetime health advisory level
1,2,3-Trichloropropane	1	19	40	USEPA lifetime health advisory level
Boron	--	22	1,000	CDPH Notification level

* Units are expressed in mg/L.

1. CDPH Notification (Action) Level; Health-based notification level established by CDPH for some constituents in drinking water that lack MCLs. If the constituent is detected in drinking water at concentrations greater than the action level local governing bodies must be notified.

TABLE 6-1
Summary of DRASTIC Parameter Weighting and Ranking System
(after Aller et al, 1987)

Parameter		Range of Values/Description	Units	Rating	Weight
D	**D**epth to Water	0-5 5-15 15-30 30-50 50-75 75-100 >100	feet	10 9 7 5 3 2 1	5
R	Net **R**echarge	0-2 2-4 4-7 7-10 >10	inches per year	1 3 6 8 9	4
A	**A**quifer Media	Massive Shale Metamorphic/Igneous Weathered Metamorphic/Igneous Glacial Till Bedded Sandstone, Limestone, and Shale Massive Sandstone Massive Limestone Sand and Gravel Basalt Karst Limestone		1-3 2-5 3-5 4-6 5-9 4-9 4-9 4-9 2-10 9-10	3
S	**S**oil Media	Thin or Absent Gravel Sand Peat Shrinking and/or Aggregated Clay Sandy Loam Loam Silty Loam Clay Loam Muck Nonshrinking and Nonaggregated Clay		10 10 9 8 7 6 5 4 3 2 1	2
T	**T**opography (Slope)	0-2 2-6 6-12 12-18 >18	% slope	10 9 5 3 1	1
I	**I**mpact of the Vadose Zone Media	Confining Layer Silt/Clay Shale Limestone Sandstone Bedded Limestone, Sandstone, Shale Sand and Gravel with significant Silt and Clay Metamorphic/Igneous Sand and Gravel Basalt Karst Limestone		1 2-6 2-5 2-7 4-8 4-8 4-8 2-8 6-9 2-10 8-10	5
C	**C**onductivity (Hydraulic) of the Aquifer	1-100 100-300 300-700 700-1,000 1,000-2,000 >2,000	Gallons per day/ feet squared	1 2 4 6 8 10	3

Table 6-2
Summary of Nitrate and TDS Concentrations Relative to High Vulnerability Areas

Well Depth Category	Wells by Nitrate Concentration Relative to High Vulnerability Areas				Wells by TDS Concentration Relative to High Vulnerability Areas			
	Wells Inside Area		Wells Remaining Outside Area(s)		Wells Inside Area		Wells Remaining Outside Area(s)	
	5-10 mg/L (as N)	>=10 mg/L (as N)	5-10 mg/L (as N)	>=10 mg/L (as N)	1,500-3,000 mg/L	>=3,000 mg/L	1,500-3,000 mg/L	>=3,000 mg/L
Well Locations Relative to Hydrogeologic High Vulnerability Area								
Total Number of Wells[1]	**3**	**42**	**7**	**24**	**38**	**31**	**88**	**49**
Percent of Wells[1]	**30%**	**64%**	**70%**	**36%**	**30%**	**39%**	**70%**	**61%**
Shallow Groundwater	2	34	2	21	9	27	15	35
Upper Aquifer				1	1		3	1
Lower Aquifer			2		10		30	7
Unknown depth zone	1	8	3	2	18	4	40	6
Very Shallow Water (tile drains and wells < 15 feet)	5	41		40	8	65	22	199
Well Locations Relative to Combined Hydrogeologic High Vulnerability Area and High Well Vulnerability Area								
Total Number of Wells[1]	**5**	**66**	**5**	**0**	**45**	**53**	**81**	**27**
Percent of Wells[1]	**50%**	**100%**	**50%**	**0%**	**36%**	**66%**	**64%**	**34%**
Shallow Groundwater	3	55	1		10	48	14	14
Upper Aquifer		1			2		2	1
Lower Aquifer	1		1		11		29	7
Unknown depth zone	1	10	3		22	5	36	5
Very Shallow Water (tile drains and wells < 15 feet)	5	71		10	11	110	19	154

1. Values for total number and percentages of wells do not include Very Shallow Water sample sites represented by tile drain sumps and wells < 15 feet deep.

Of the 21 wells outside of the Hydrogeologic High Vulnerability Area, 15 are located at a single site.

Sites in the Very Shallow Water zone are not included as high vulnerability outliers because they represent water that is drained by tile drainage systems and are covered by separate WDRs associated with the Grassland Bypass Project.

Five remaining wells outside the high vulnerability areas with a nitrate concentration between 5-10 mg/L (as N) did not have statistically significant increasing trends and therefore were not included in the High Well Vulnerability Area.

Table 6-3
Summary of Acreages for GDA High Vulnerability Areas

Vulnerability Area Description	Total Within GDA (Acres)	Within Irrigated Area[1] (Acres)
Lower Vulnerability Tile-Drained Areas[2]	*53,195*	*43,022*
Hydrogeologic High Vulnerability Area (HHVA)	**23,449**	**21,196**
High Well Vulnerability Area (HWVA)	**4,345**	**3,463**
Total High Vulnerability Area (GDA HVA)	**27,794**	**24,659**

[1] Includes irrigated land as identified from 2014 USDA and GDA districts data.

[2] Tile-drained areas are lower vulnerability areas and reduce the size of the HHVA.

Table 6-4
Matrix for Prioritization of Grassland Drainage Area High Vulnerability Area

Prioritization Component Category	Prioritization Component Identified in the Order (Att. B)	Description of Component Used in Prioritization Method	Ranking Factors		Component Weighting	
			Ranking Metric	Range of Ranking	Percent	Comments
Hydrogeologic Groundwater Vulnerability	Additional component not directly specified in order for prioritization purposes	**Soil Vulnerability** Includes ranking of the vulnerability based on soil hydraulic conductivity and soil drainate class.	Soil hydraulic conductivity	0 to 10 (low to high) based on soil hydraulic conductivity; (Ksat in ft/day: 0-0.5=2, 0.5-1=4, 1-2=6, 2-4=8, 4-6=9, >6=10)	7.5%	High - Collectively represents weighting of importance of hydrogeologic characteristics
		Subsurface Tile Drainage Systems Includes reduction in the the ranking of soil vulnerability based on existence of subsurface tile drainage system.	Location within or not within tile-drained area	Tile present=soil vulnerability multiplied by 0.5, tile absent=soil vulnerability multiplied by 1	Reduces soil vulner-ability, where present	
		Subsurface Sediment Vulnerability Includes ranking of the vulnerability based on subsurface sediment texture.	Average percentage of coarse sediments indicated for the upper 200 feet, based on CVHM sediment texture model	0 to 10 (low to high) based on average percent coarse for 0 to 200 feet (AVG PC 0-200: <30 = 0, 30-35=1, 35-40=2, 40-45=3, 45-50=4, 50-55=5, 55-60=6, 60-65=7, 65-70=8, 70-75=9, >75=10)	7.5%	
Existing Groundwater Quality Conditions	Legacy or ambient conditions of the groundwater.	**Observed Groundwater Quality Concentrations** Includes an evaluation and ranking of areas based on observed groundwater nitrate concentrations (does not include Very Shallow Water).	Average nitrate concentration for location based on wells within 1/2 mile	0 to 10 (low to high) based on average concentration; 5 (neutral) for locations without any concentration data within 1/2 mile; (nitrate [mg/L as N]: <1=0, 1-2=1, 2-3=2, 3-4=3, 4-5=4, 5-6=5, 6-7=6, 7-8=7, 8-9=8, 9-10=9, >10=10)	15%	High
		Temporal Trend in Groundwater Quality Includes evaluation and ranking of areas based on recent trend (degrading, improving, etc.) in groundwater nitrate concentration (does not include Very Shallow Water).	Average trend for location based on wells within 1/2 mile	0 to 10 (low to high) based on average water quality trend; 5 (neutral) for locations without any trend data within 1/2 mile (mg/L/yr: <-1=0, -1--0.5=1, -0.5--0.1=2, -0.1-0.1=5, 0.1-0.5=8, 0.5-1=9, >1=10)	10%	Moderate
	Identified exceedances of water quality objectives for which agricultural waste discharges are the cause, or a contributing source.	**MCL Exceedances** Includes evaluation and ranking of areas according to presence/absence of nitrate concentrations observations that are above the drinking water MCL.	Distance from nearest nitrate MCL exceedance	0 to 10 (low to high) inversely related to distance from nearest nitrate exceedance; 5 (neutral) for locations without any WQ observations within specified distance; (miles: >2=0, 1.5-2=2, 1-1.5=4, 0.5-1=6, 0.25-0.5=8, <0.25=10)	2.5%	Low - weighted low to avoid double-counting; measured concentration is also considered in ambient water quality component
	Identified constituents of concern.	**Pesticide Detections** Includes evaluation and ranking of areas based on presence/absence of detectable concentrations of pesticides in groundwater samples.	Wells with a pesticide detection within a section	0 to 10 (low to high) based on sections with wells tested for pesticides; 5 (neutral) for sections without any pesticide observations; (tested but no detection=0, with detection, but no exceedance=8, exceedance=10)	2.5%	Low - Pesticide detection data from DPR are at coarse spatial accuracy
Land Use	Existing field or operational practices identified to be associated with irrigated agriculture water discharges that are the cause, or a contributing source.	**Typical Nitrogen Application Rate** Includes evaluation and ranking of areas based on typical nitrogen application rates for land uses (Rosenstock and others, 2013; Viers and others, 2012) using 2014 USDA land use designation.	Typical nitrogen application rate for land use	0 to 10 based on typical nitrogen application rate; (lbs/ac/yr: <50=0, 50-100=3, 100-150=7, >150=10)	7.5%	Low-Moderate
		Typical Irrigation Method Includes ranking of areas based on typical irrigation method for land uses (using 2014 USDA land use designation) in accordance with irrigation method statistics derived from circa-2000s DWR land use survey irrigation method data.	Typical irrigation method for land use	0 to 10 based on typical irrigation method; (micro=3, sprinkler=6, gravity=10)	12.5%	Moderate-High
	The largest acreage commodity types comprising up to at least 80% of the irrigated agricultural acreage in the GDA and the irrigation and fertilization practices employed by these commodities.	**Top Commodities** Includes evaluation and ranking of areas based on percent of land area that is of a land use category comprising 80% of the irrigated acreage within the GDA (based on 2014 USDA land use designation).	Presence/absence of top 80% land use category	0 = Absent 10 = Present; (Top 80% land use category=10, Other land use category=0)	2.5%	Low
Other Factors	Proximity of high vulnerability areas to areas contributing recharge to urban and rural communities where groundwater serves as a significant source of supply.	**Proximity to Public Groundwater Supply** Includes evaluation and ranking of areas by proximity to public water systems and communities reliant on groundwater.	Distance, within 2 miles, from public water system or community reliant on groundwater Within contributing area/Not within contributing area	0 to 10 (low to high) inversely related to distance from public supply system reliant on groundwater; multiplier of 1 for locations within contributing area and multiplier of 0.5 for locations outside of contributing area; (miles: >2=0, 1.5-2=2, 1-1.5=4, 0.5-1=6, 0.25-0.5=8, <0.25=10)	30%	High
	Groundwater basins currently or proposed to be under review by CV-SALTS.	**CV-SALTS Priority Areas** Includes Initial Analysis Zones (IAZ) that were identified by CV-SALTS as being high priority with respect to nitrate in groundwater.	Location within or not within IAZ identified as high priority by CV-SALTS	0 = Not within priority IAZ 10 = Within priority IAZ	2.5%	Low

Table 6-5
Summary of Acreages for Priority Areas Within the GDA High Vulnerability Area

Area Description	Total Within GDA (Acres)	Within Irrigated Area* (Acres)
High Vulnerability Area (GDA HVA)[1]	27,794	24,659
Prioritization of High Vulnerability Area (GDA HVA)[2,3]	**27,512**	**24,412**
Priority 1	6,229	5,898
Priority 2	6,628	6,042
Priority 3	7,219	6,301
Priority 4	7,437	6,170

* Includes irrigated land as identified from 2014 USDA and GDA districts data.

[1] Acreage values for GDA HVA as reported on Table 6-3.

[2] Acreage values reported for prioritized areas differ from those on Table 6-3 because of gridding used during the prioritization process.

[3] Priority areas are in order from highest (1) to lowest (4).

Table 6-6
Summary of Land Uses within Priority Areas

Description	Priority 1 (Acres)	Priority 2 (Acres)	Priority 3 (Acres)	Priority 4 (Acres)	Total (Acres)
High Vulnerability Area (GDA HVA)	6,229	6,628	7,219	7,437	27,512
Irrigated Lands Within GDA HVA* (from 2014 USDA and GDA Districts data)	5,898	6,042	6,301	6,170	24,412
Land Use Category Within GDA HVA* (2014 USDA land use data)					
Agricultural Land Use Categories	*5,847*	*6,398*	*6,834*	*6,859*	*25,938*
Vegetables	*1,818*	*2,372*	*1,314*	*361*	*5,865*
Nut Trees	*988*	*1,220*	*2,251*	*512*	*4,971*
Idle	*779*	*707*	*1,308*	*4,105*	*6,899*
Field Crops	*766*	*405*	*480*	*43*	*1,694*
Grain	*546*	*895*	*686*	*401*	*2,527*
Pasture and Alfalfa	*554*	*329*	*192*	*235*	*1,311*
Vineyard	*347*	*437*	*561*	*1,187*	*2,532*
Fruit Trees	*46*	*33*	*41*	*14*	*134*
Seeds/Beans	*2*	*0*	*1*	*1*	*4*
Non Agricultural	*378*	*227*	*376*	*569*	*1,550*
Total Categorized [1]	*6,225*	*6,624*	*7,210*	*7,428*	*27,488*

* Irrigated lands area calculations are based on USDA 2014 data together with data from GDA districts; land use category calculations are based on USDA 2014 cropscape data. Total crop acres differ from irrigated acres because some agricultural areas are dry-farmed.

[1] Total prioritized acreages by land use category are slightly less than the total GDA HVA because of minor gaps in USDA 2014 land use data.

Table 7-1
Summary of Historical Groundwater Monitoring

Wells With Historical Groundwater Level Measurements

Monitoring Entity	Number of Wells	Number of Measurements	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Domestic Wells	Unknown Well Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Measurements Pre-1970s	Measurements in 1970s	Measurements in 1980s	Measurements in 1990s	Measurements in 2000s	Measurements in 2010s
DWR	836	14,928	512	0	114	85	3	634	49	151	147	253	236	6,588	2,759	1,052	655	2,361	1,513
USGS	80	1,218	60	0	0	0	0	80	0	80	0	0	0	36	0	17	1,165	0	0
Total	916	16,146	572	0	114	85	3	714	49	231	147	253	236	6,624	2,759	1,069	1,820	2,361	1,513

Historical Nitrate Concentration Data

Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown Well Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Samples Tested in Pre-1970s	Samples Tested in 1970s	Samples Tested in 1980s	Samples Tested in 1990s	Samples Tested in 2000s	Samples Tested in 2010s
DDW	3	14	0	0	1	0	1	1	0	0	0	3	0	0	0	0	0	2	12
DWR	85	141	0	0	0	3	0	82	0	3	0	0	82	131	2	5	2	1	0
GDA Districts	5	7	5	0	5	0	0	0	0	0	0	5	0	7	0	0	0	0	0
RWQCB	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0
USGS	166	563	163	17	0	0	3	146	89	66	6	5	0	0	0	474	68	0	21
Total	260	726	168	17	7	3	4	229	89	69	6	14	82	138	2	479	70	4	33

Historical TDS Concentration Data

Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown Well Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Samples Tested Pre-1970s	Samples Tested in 1970s	Samples Tested in 1980s	Samples Tested in 1990s	Samples Tested in 2000s	Samples Tested in 2010s
DDW	2	96	1	0	0	0	1	1	0	0	0	2	0	0	0	0	0	6	90
DWR	127	466	0	0	0	0	0	127	0	5	0	0	122	442	8	10	4	2	0
GDA Districts	208	42896	67	136	15	55	1	1	172	20	0	16	0	22	0	0	8,777	26,594	7,503
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	291	1541	185	44	0	0	6	241	143	76	8	64	0	212	3	1,119	165	0	42
Totals	628	44999	253	180	15	55	8	370	315	101	8	82	122	676	11	1,129	8,946	26,602	7,635

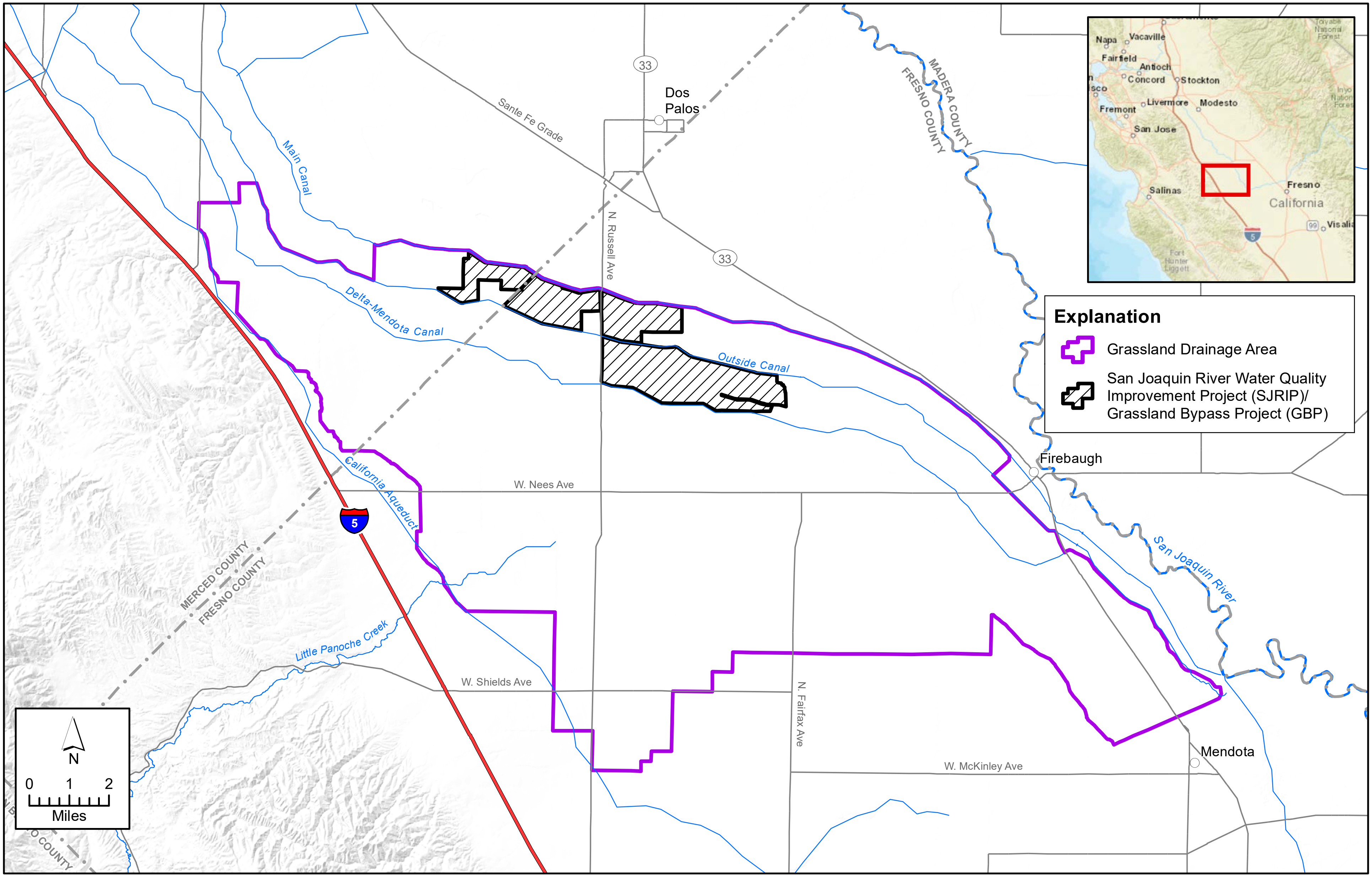
Table 7-2
Summary of Recent Groundwater Monitoring

Groundwater Level Measurements Since 2005													
Monitoring Entity	Number of Wells	Number of Measurements	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Domestic Wells	Unknown Well Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone
DWR	439	3,420	157	0	114	84	3	8	5	78	57	79	220
USGS	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	439	3,420	157	0	114	84	3	8	5	78	57	79	220

Nitrate Data Since 2005																
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results Over 5 mg/L (as N)	Drains/Wells with Results Over 10 mg/L (as N)	Drains/Wells with Results Over 20 mg/L (as N)
DDW	2	14	0	0	1	0	1	1	0	0	0	3	0	0	0	0
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GDA Districts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RWQCB	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
USGS	9	21	6	0	0	0	3	6	0	0	5	4	0	0	2	0
Total	12	36	6	0	2	0	4	7	0	0	5	8	0	0	2	0

Total Dissolved Solids (TDS) Data Since 2005																
Monitoring Entity	Number of Drains/ Wells	Number of Samples	Wells with Known Depth	Tile Drains	Irrigation Wells	Monitoring Wells	Public Supply Wells	Unknown Type	Very Shallow Water	Shallow Groundwater	Upper Aquifer	Lower Aquifer	Unknown Depth Zone	Drains/Wells with Results Over 500 mg/L	Drains/Wells with Results Over 1000 mg/L	Drains/Wells with Results Over 1500 mg/L
DDW	2	96	0	0	0	0	1	1	0	0	0	2	0	0	0	2
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GDA Districts	178	19,835	42	136	0	41	0	1	159	19	0	0	0	7	2	169
RWQCB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USGS	12	42	6	0	0	0	6	6	0	0	5	7	0	2	4	6
Total	192	19,973	48	136	0	41	7	8	159	19	5	9	0	9	6	177

FIGURES



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 1-1 Location Map.mxd

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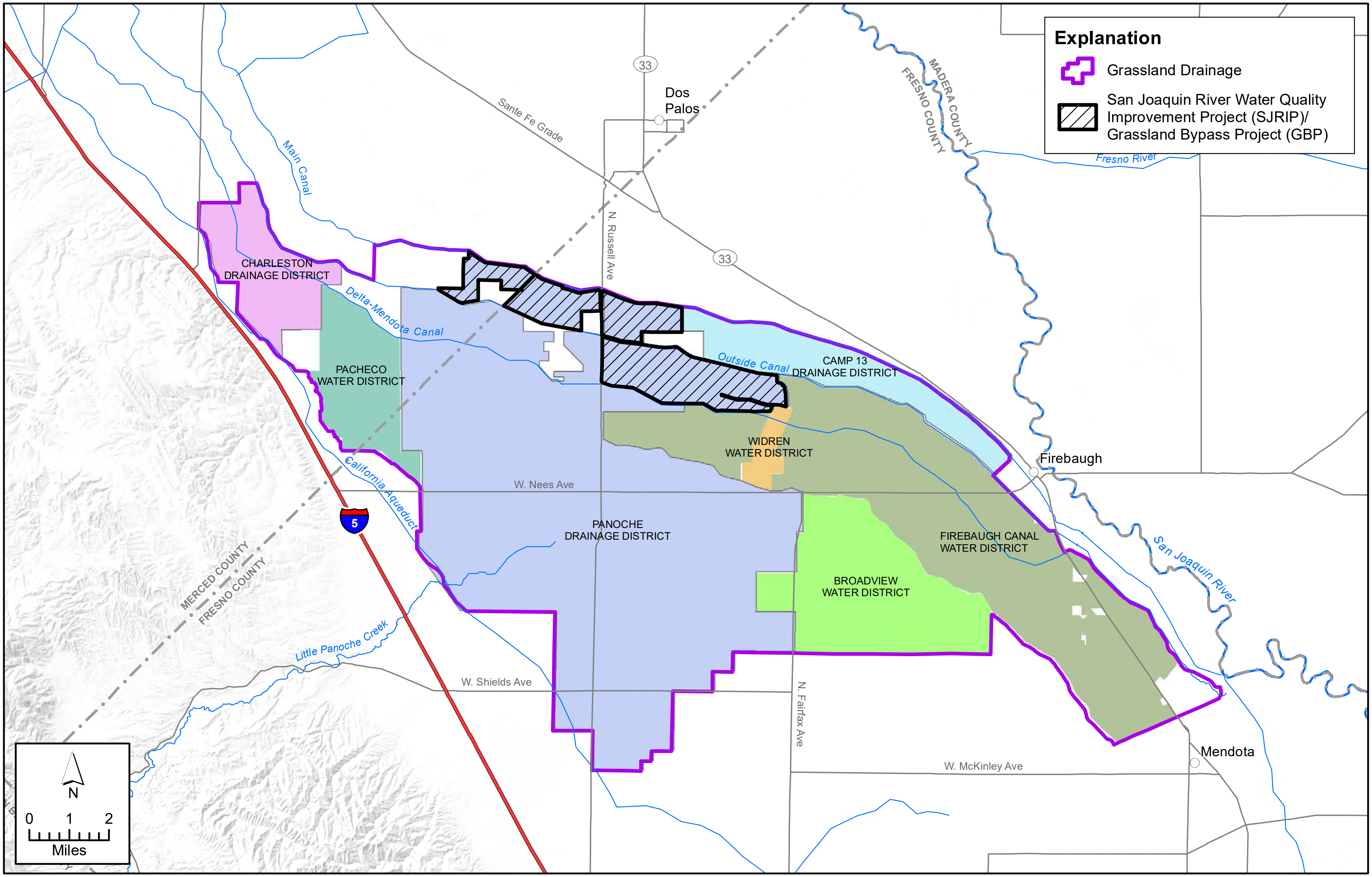
FIGURE 1-1
Grassland Drainage Area Coalition Location Map

Grassland Drainage Area Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 1-2 Grassland Drainage Area Coalition Member Districts.mxd

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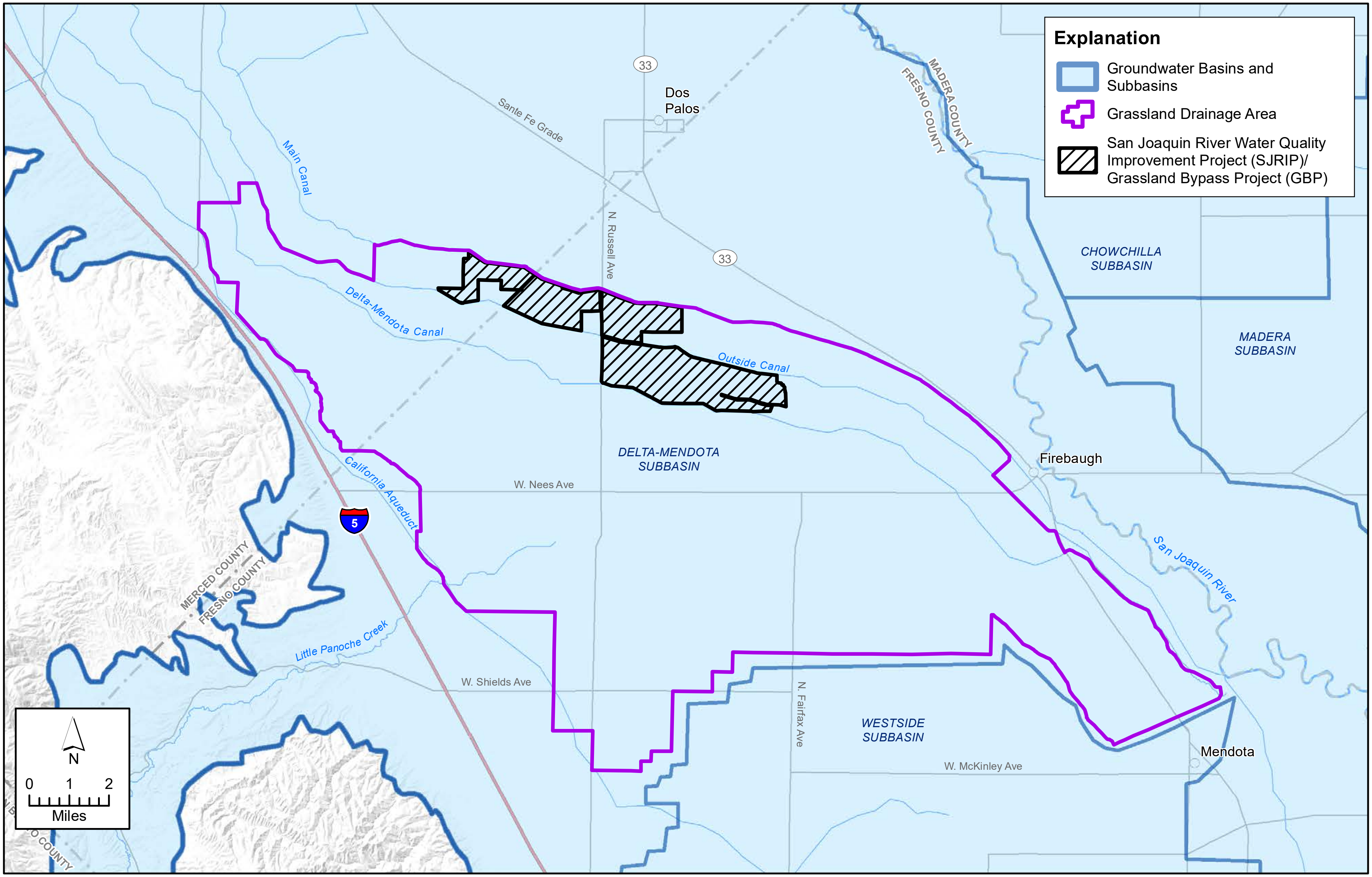
FIGURE 1-2
Map of Grassland Drainage Area Coalition Member Districts

Grassland Drainage Area Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 1-3 Groundwater Basins and Subbasins.mxd

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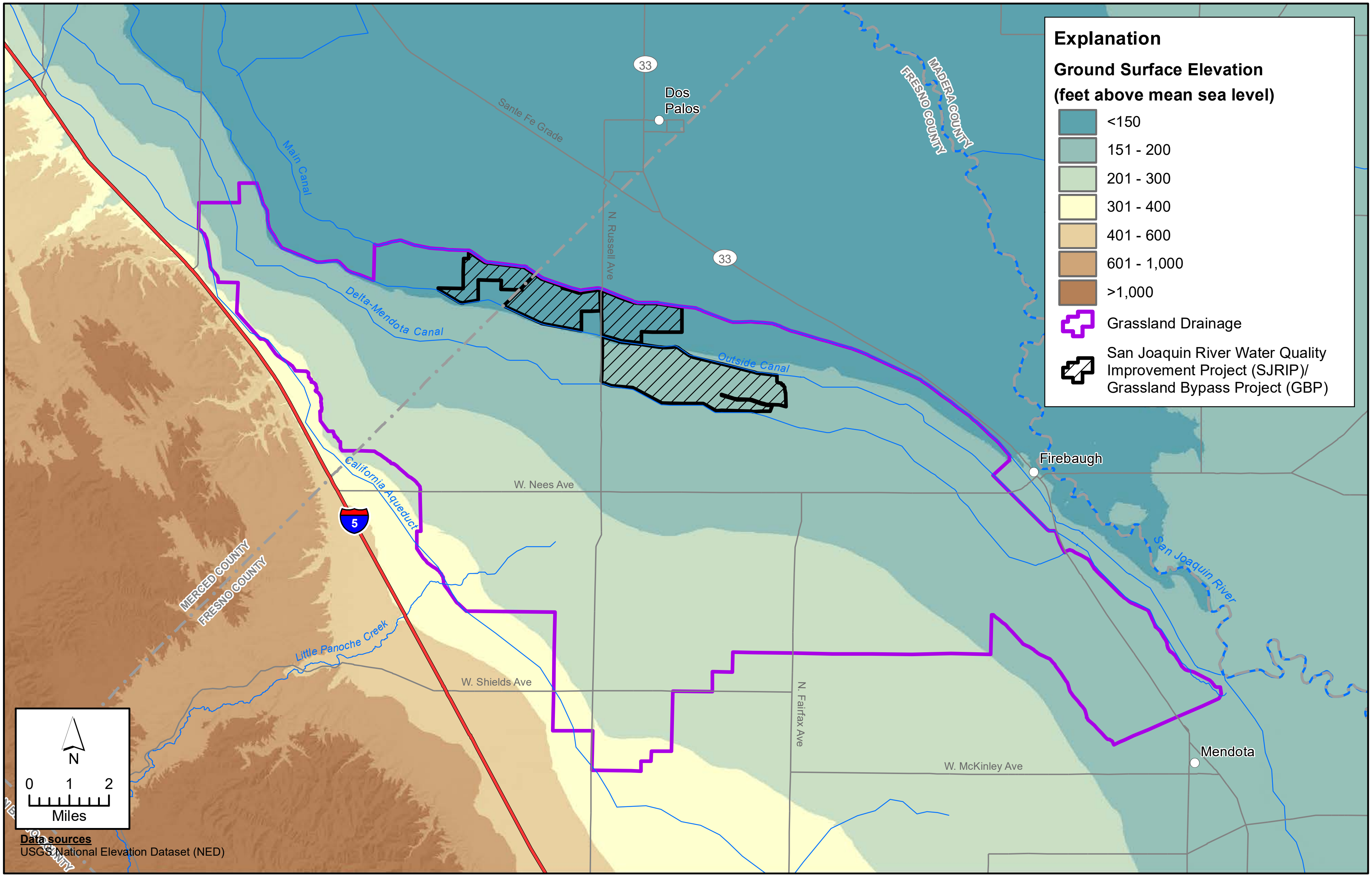
FIGURE 1-3
Map of DWR-Designated Groundwater Basins and Subbasins
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-1 Elevation.mxd

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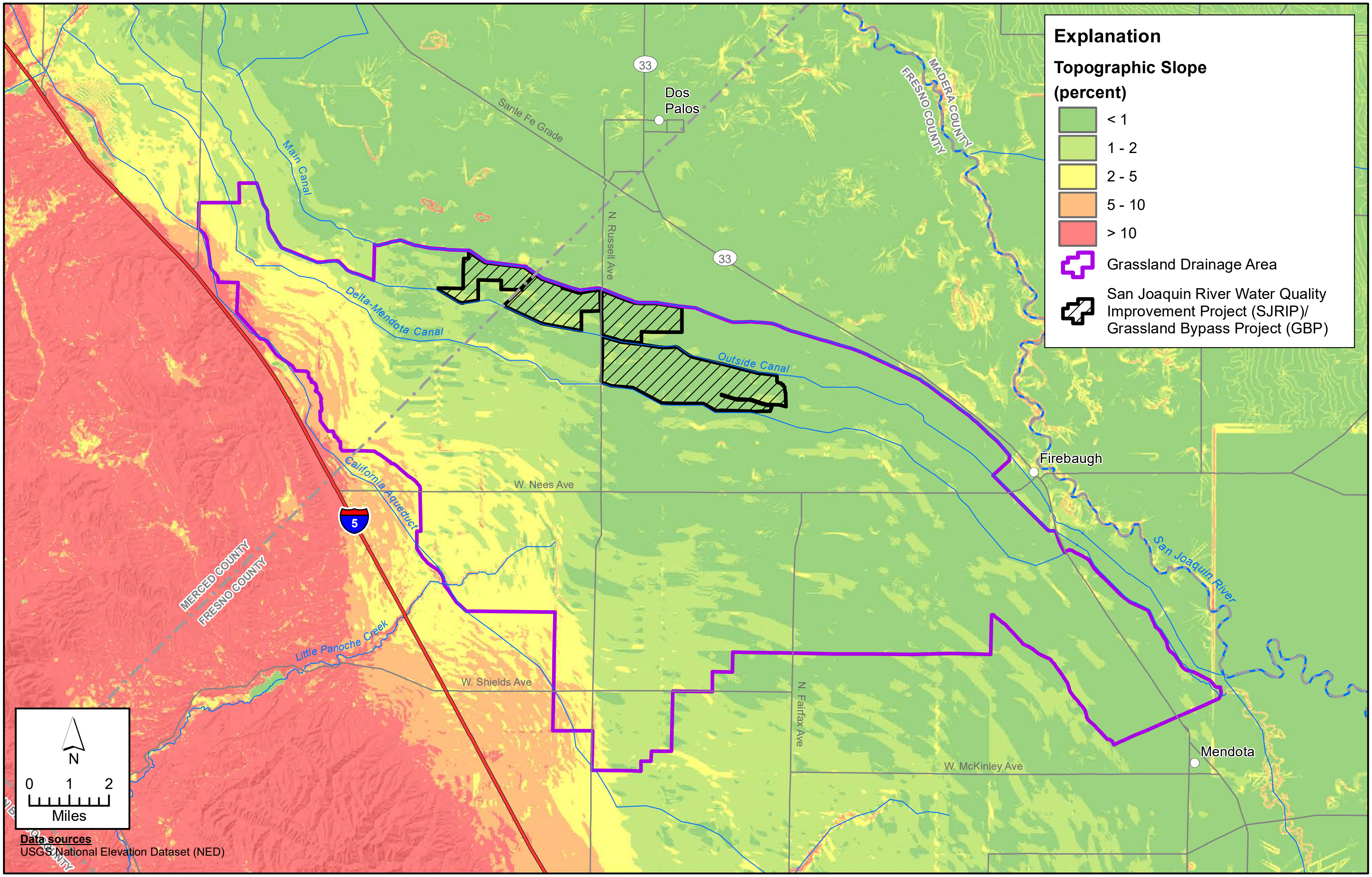
FIGURE 2-1

Map of Ground Surface Elevation

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-2 Slope.mxd

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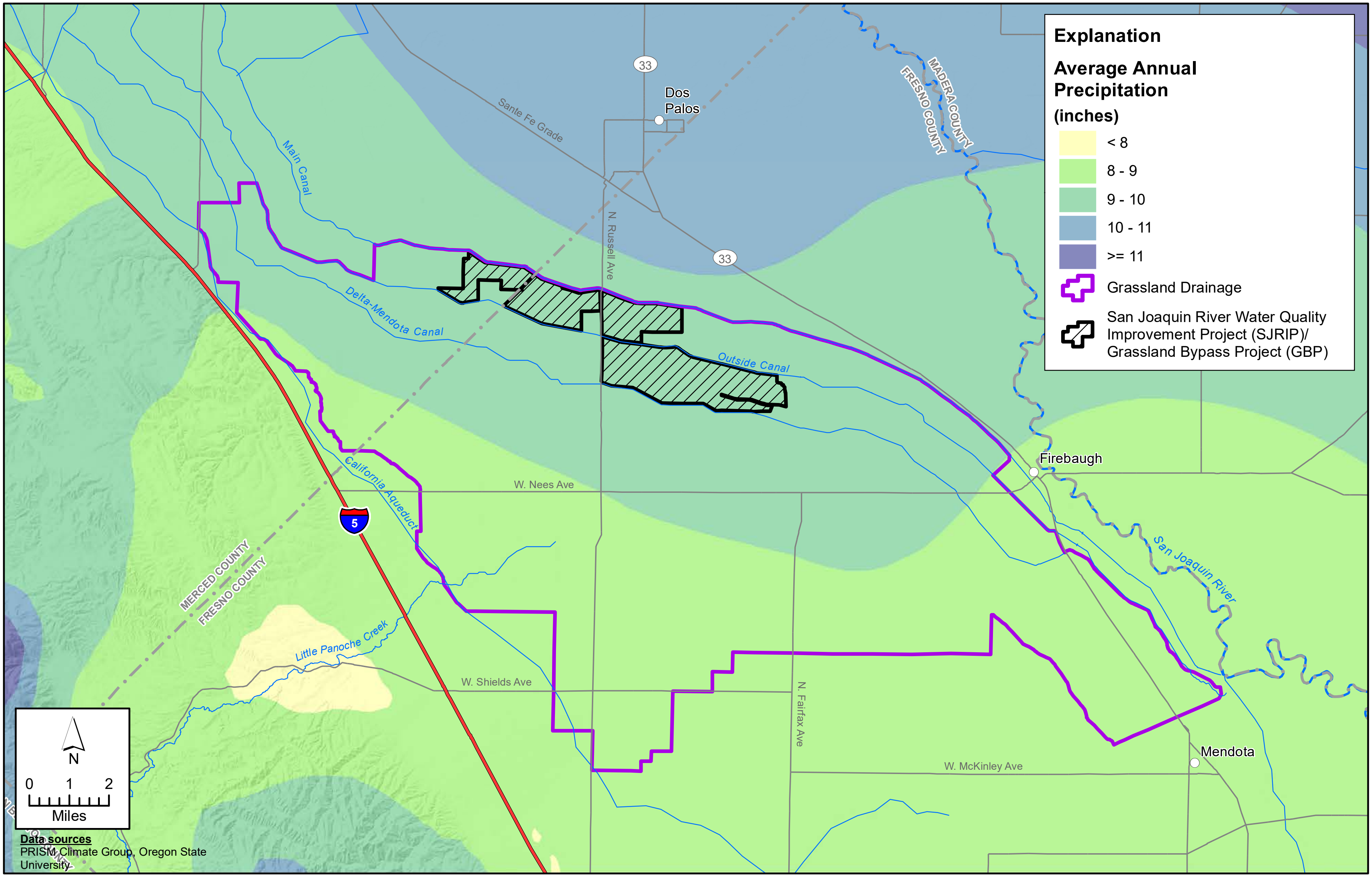
FIGURE 2-2

Map of Topographic Slope

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-3 Precipitation.mxd

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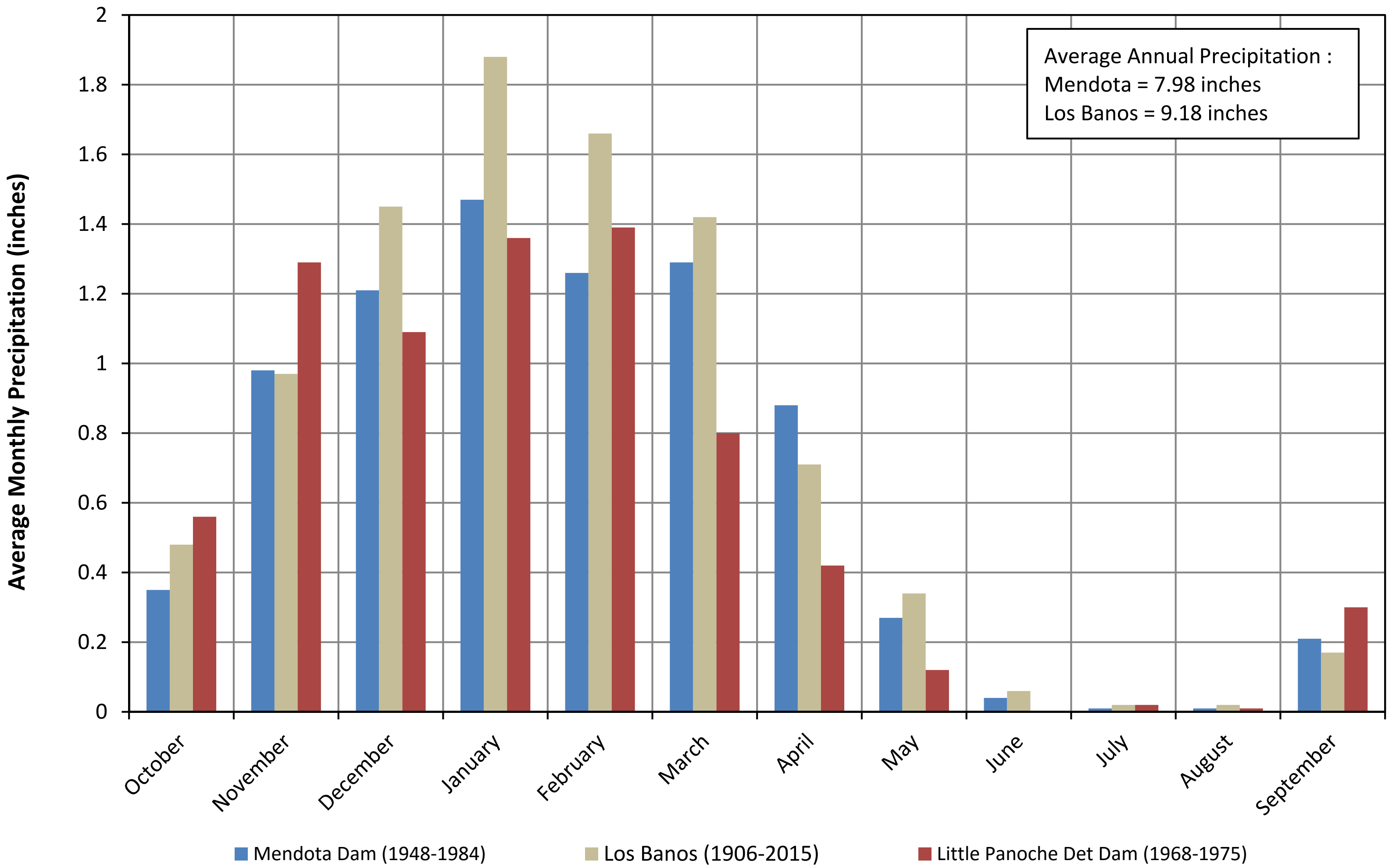
FIGURE 2-3

Map of Average Annual Precipitation

Grassland Drainage Area
Groundwater Quality Assessment Report



Data from Western Regional Climate Center

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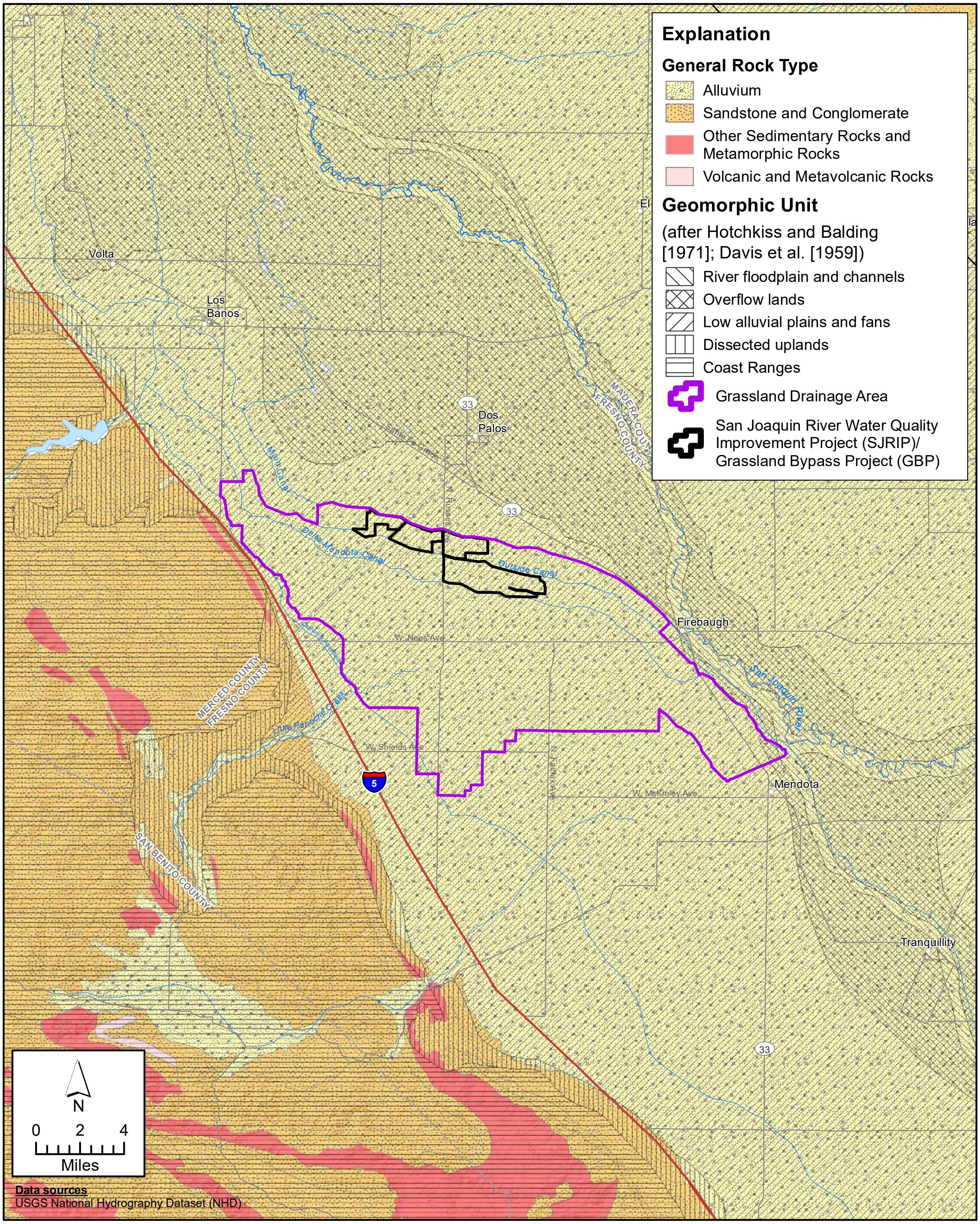
FIGURE 2-4

Average Monthly Precipitation

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-5 General Geologic Map.mxd

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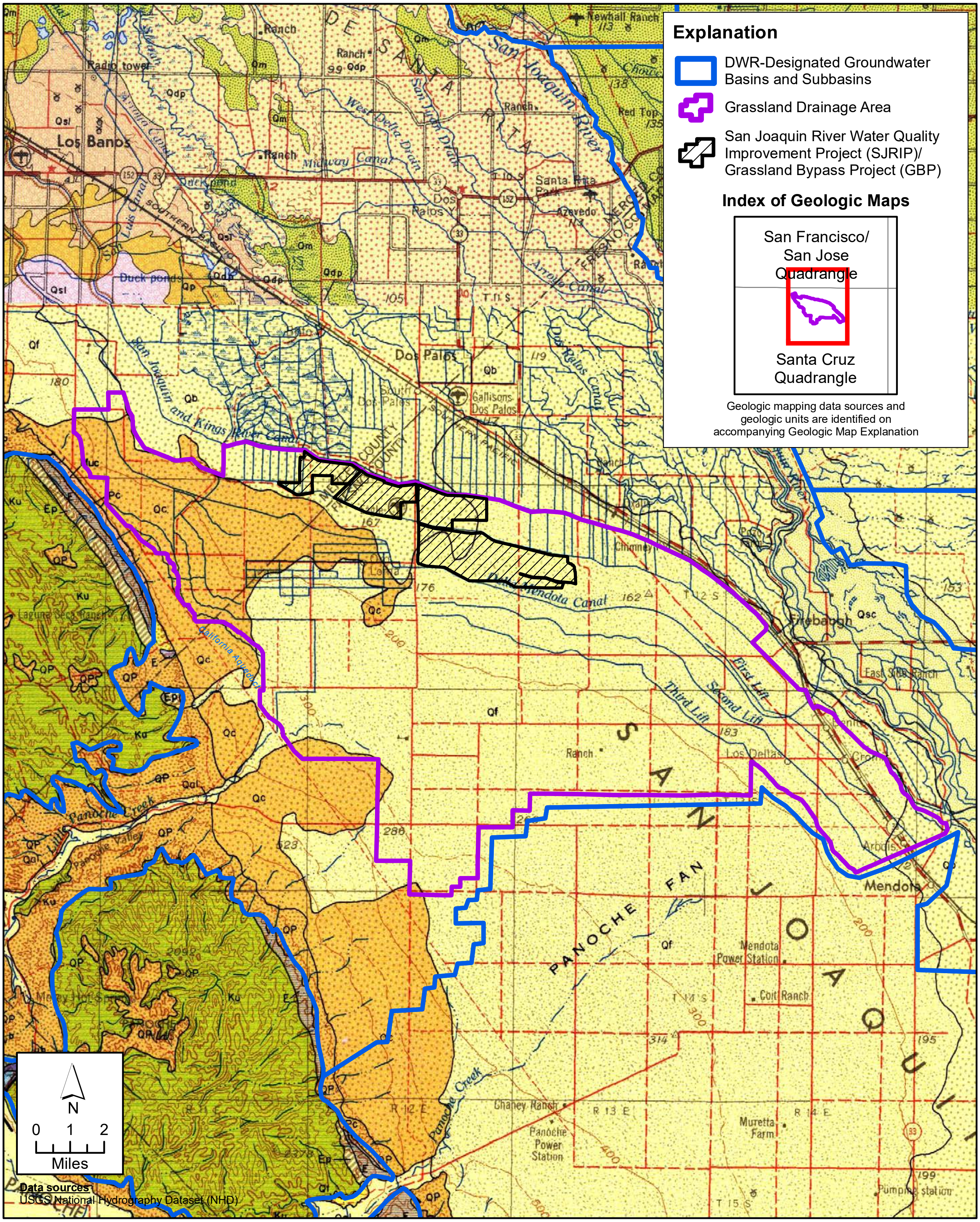
FIGURE 2-5

Generalized Geologic Map

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-6 Grasslands Geologic Map.mxd

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FIGURE 2-6
Geologic Map of the Grassland Drainage Area Vicinity
Grassland Drainage Area
Groundwater Quality Assessment Report

Compiled Geologic Map Explanation

San Francisco-San Jose Quadrangle

Qdp	Dos Palos Alluvium
Qp	Patterson Alluvium
Qf	Alluvial fan deposits
Qsl	San Luis Ranch Alluvium
Qm	Modesto Formation

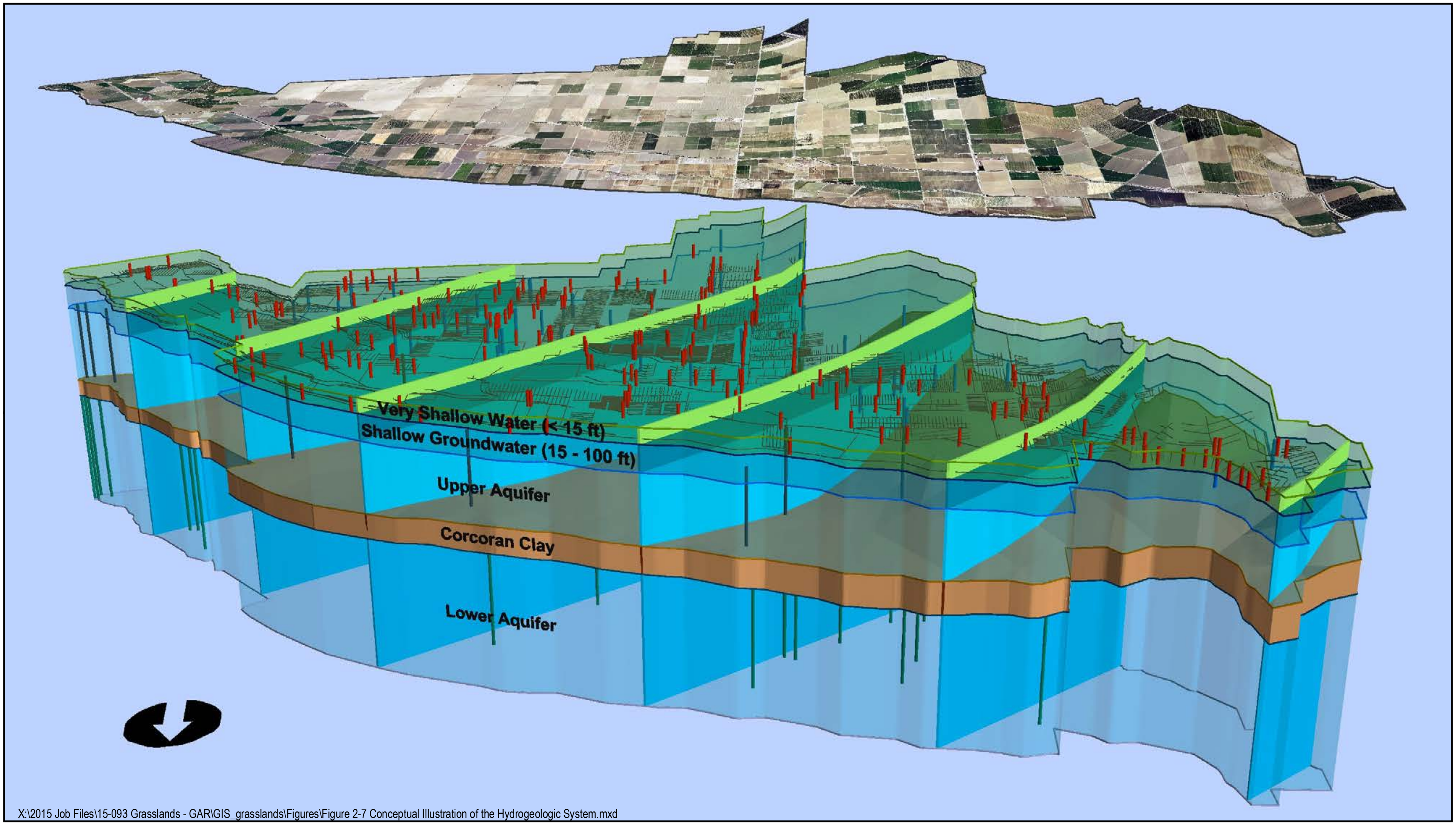
Santa Cruz Quadrangle

Qal	Alluvium
Qsc	Stream channel deposits
Qf	Fan deposits
Qb	Basin deposits
Qc	Pleistocene nonmarine
QP	Plio-Pleistocene nonmarine
E	Eocene marine
Ep	Paleocene marine
Ku	Upper Cretaceous marine

Geologic Map compiled from:

1. Wagner, D.L., Bortugno, E.J., and Mc Junkin, R.D., 1991
   Geologic Map of the San Francisco - San Jose Quadrangle
   California Geological Survey, Regional Geologic Map No. 5A, 1:250,000 scale.
2. Jennings, C.W. and Strand, R.G., 1958
   Geologic Atlas of California - Santa Cruz Quadrangle
   California Geological Survey, Geologic Atlas of California Map No. 020, 1:250,000 scale.

FIGURE 2-6 (EXPLANATION)
Geologic Map of the Grassland Drainage Area Vicinity



- **Very Shallow Water:** Zone of tile drains dominated by very shallow drainage water within 15 feet of ground surface
- **Shallow Groundwater:** Below Very Shallow Water between 15 and 100 feet deep; up to 85 feet thick
- **Upper Aquifer:** From 100 feet to top of Corcoran Clay; from 50 to 400 feet thick
- **Corcoran Clay:** E Clay member of the Tulare Formation from 150 to 500 feet deep; 40 to 140 feet thick
- **Lower Aquifer:** Below Corcoran Clay from 200 to 550 feet deep

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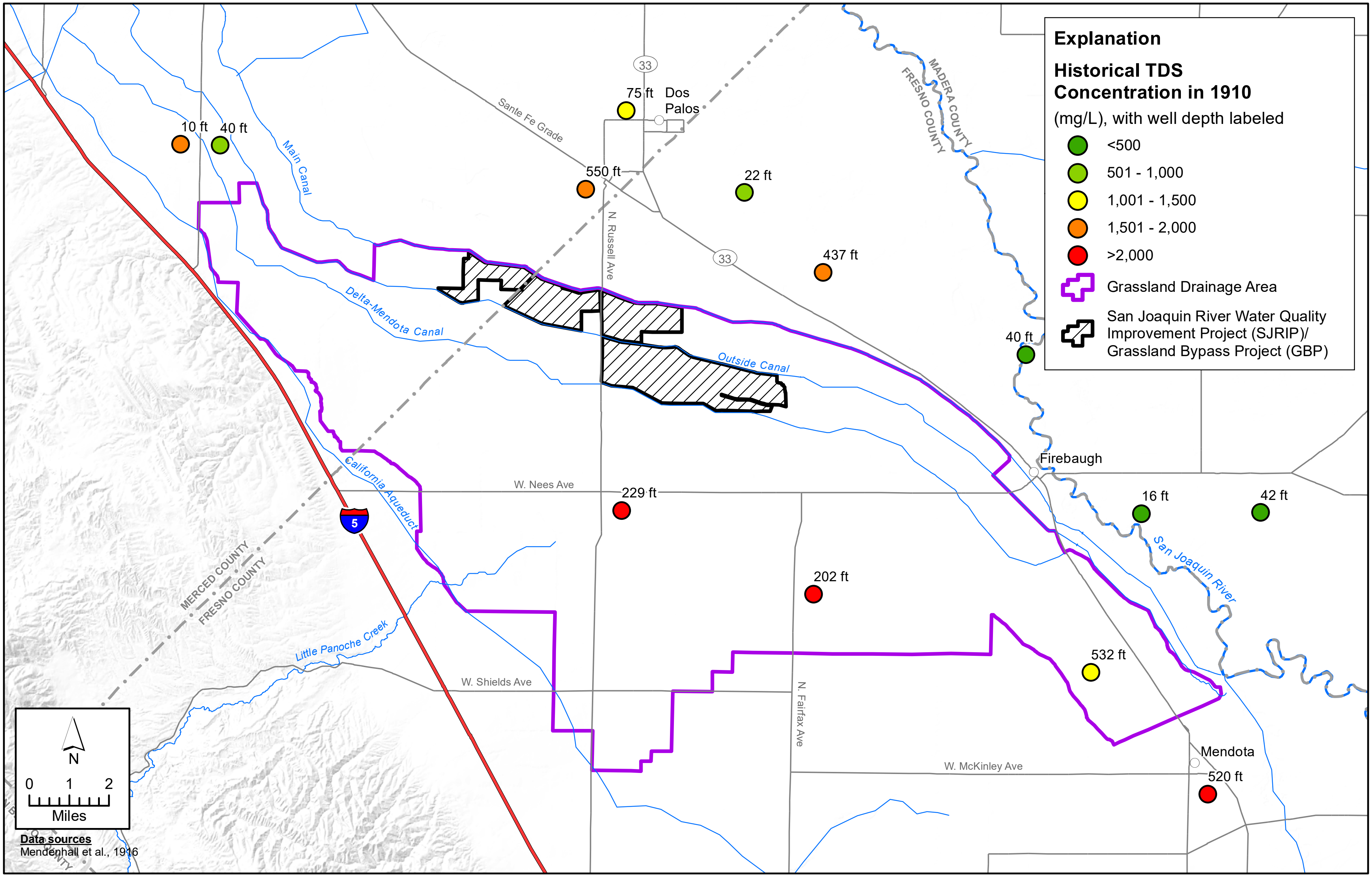
FIGURE 2-7
Conceptual Illustration of the Hydrogeologic System in the Grassland Drainage Area



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-8 Historical TDS Concentrations.mxd

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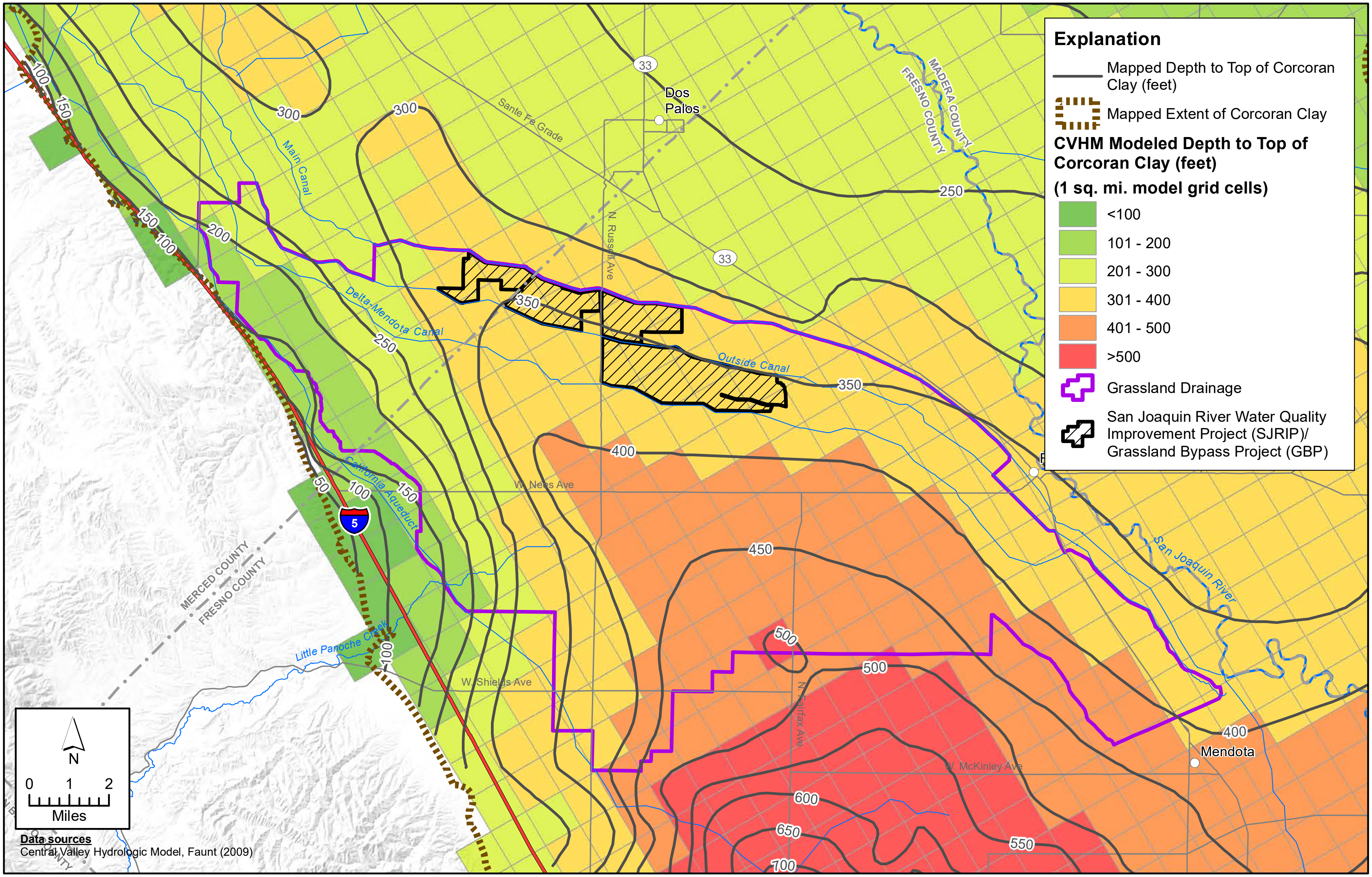
FIGURE 2-8
Map of Historical (1910) TDS Concentrations in the Grassland Drainage Area Vicinity
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-9 Corcoran Clay Depth.mxd

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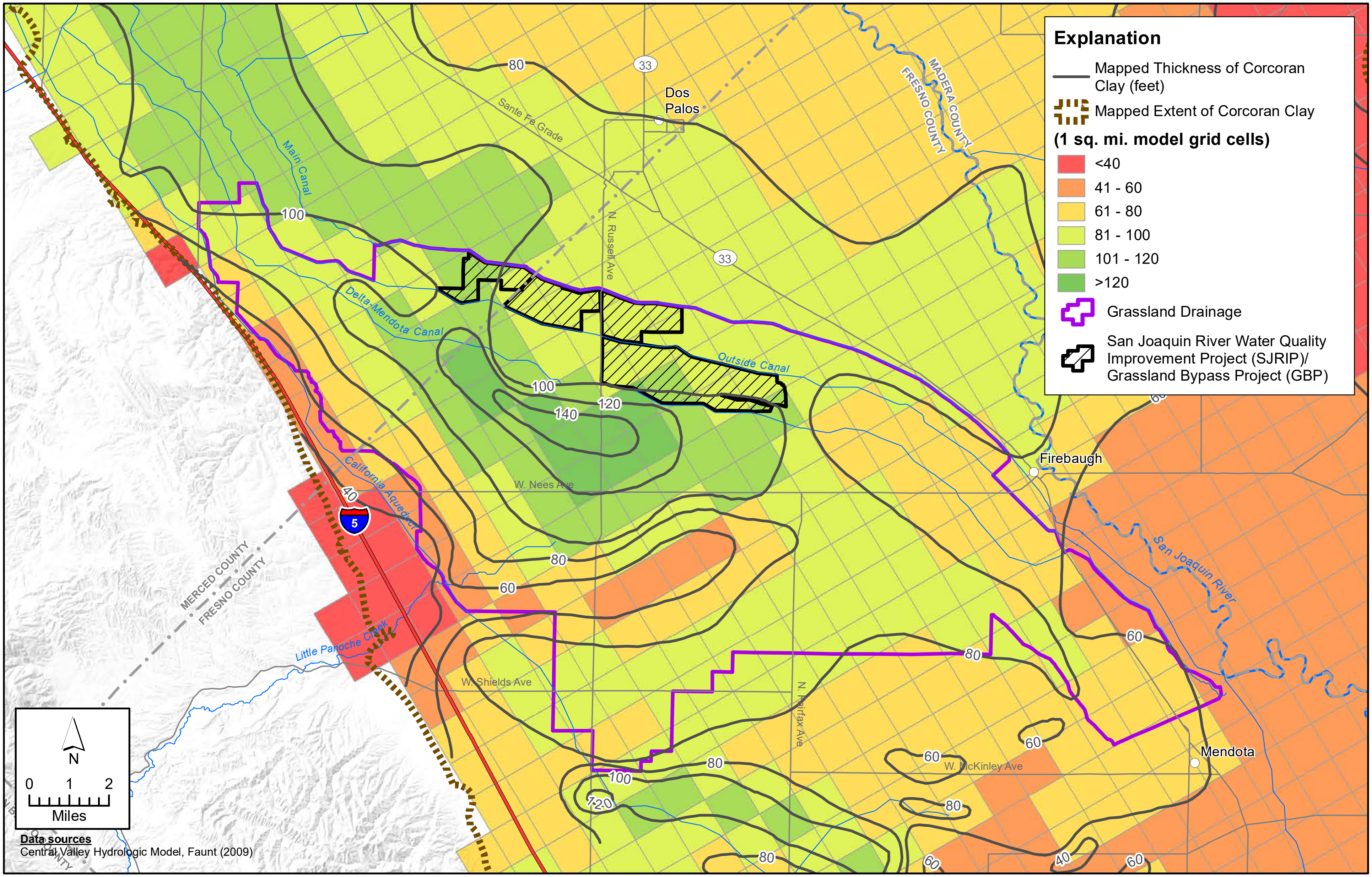
FIGURE 2-9
Map of Corcoran Clay Characteristics: Extent and Depth
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-10 Corcoran Clay Thickness.mxd

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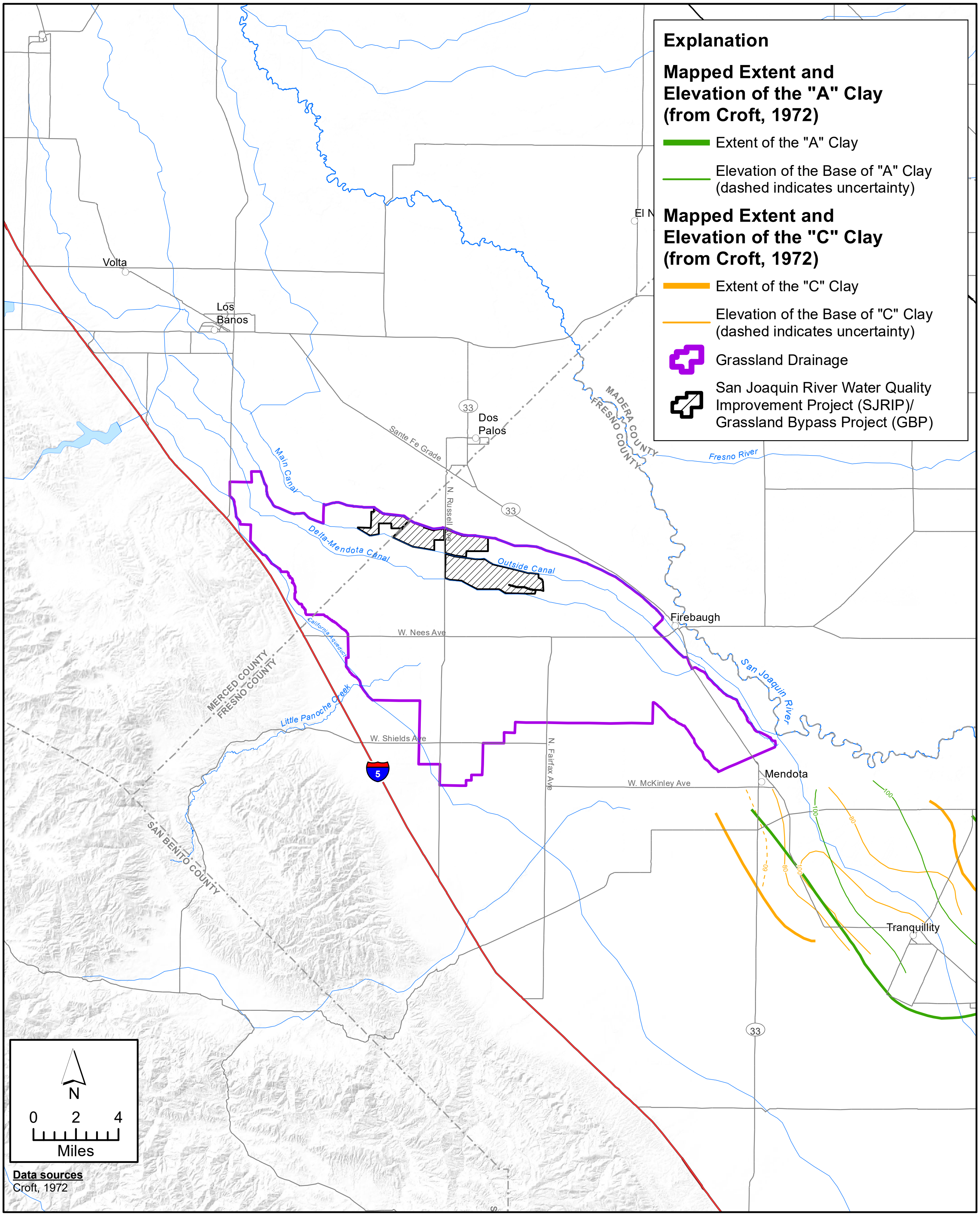
FIGURE 2-10
Map of Corcoran Clay Characteristics: Thickness
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-11 Other Clay Layers.mxd

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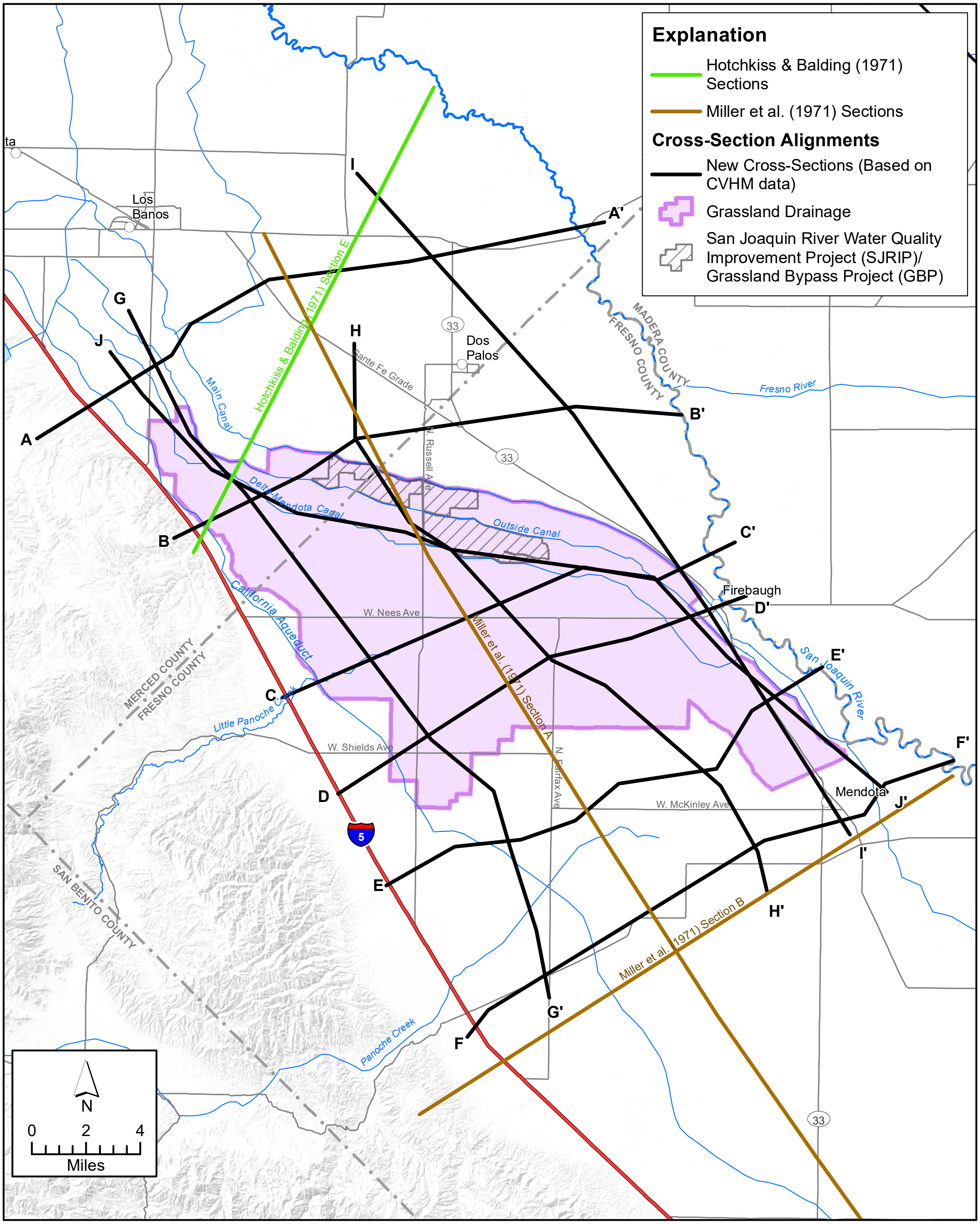
FIGURE 2-11
Map of Other Clay Layers (non-Corcoran Clay) Within the Upper Tulare Formation
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-12 Cross-Section Location Map.mxd

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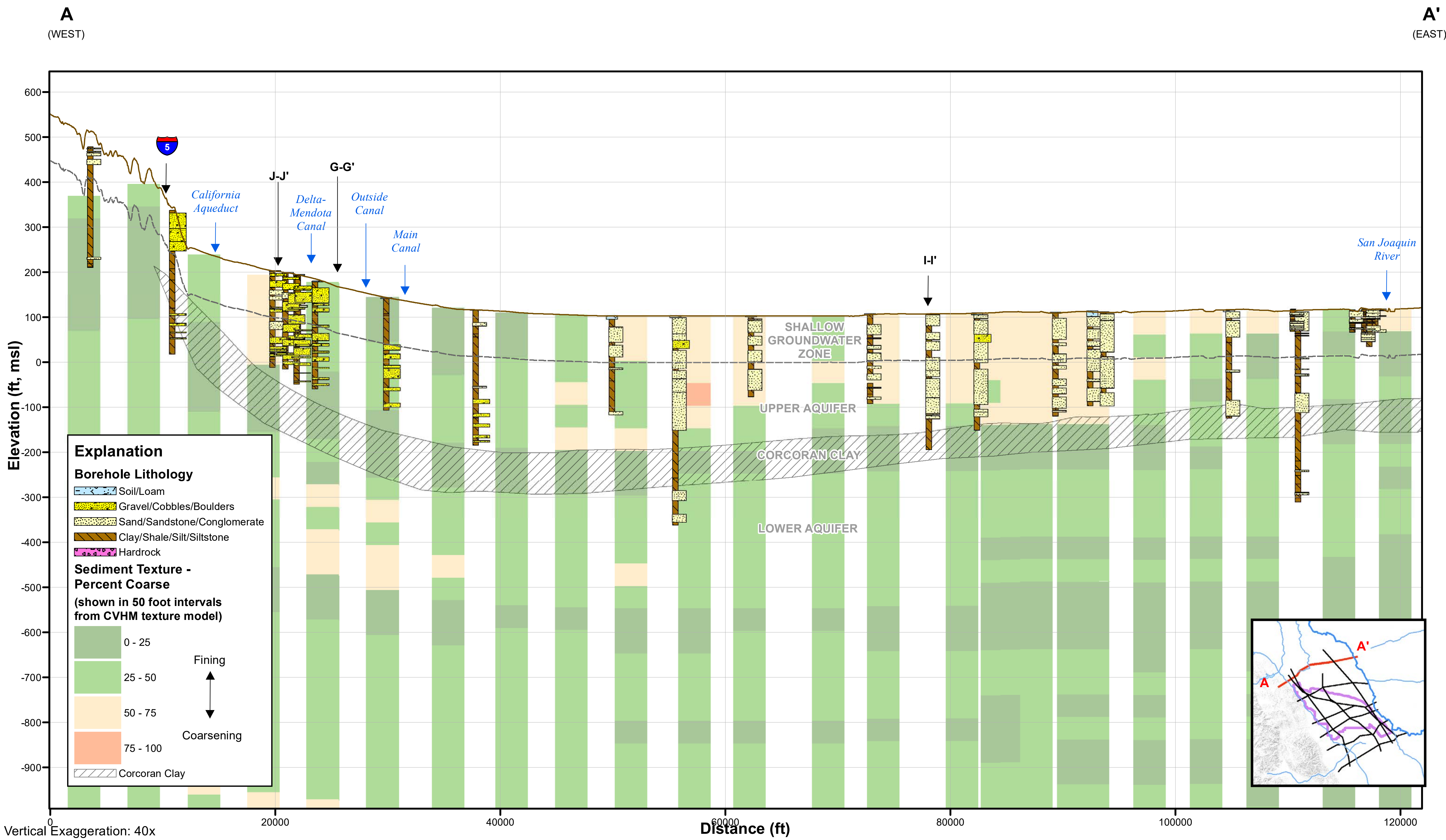
FIGURE 2-12

Cross-Section Location Map

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-13 Geologic Cross-Section A.mxd

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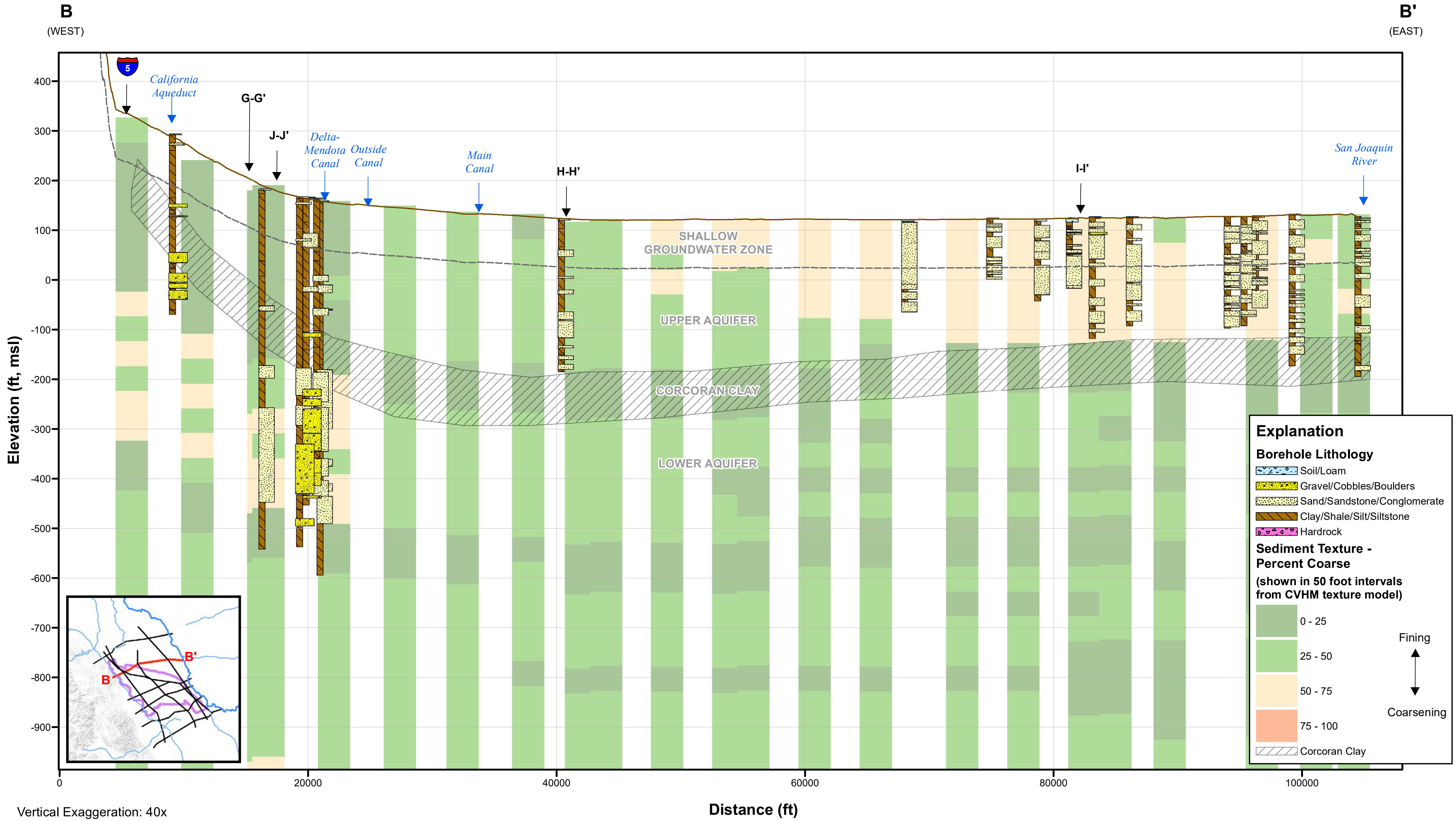
FIGURE 2-13

Geologic Cross-Section A-A'

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-15 Geologic Cross-Section B.mxd

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FIGURE 2-14

Geologic Cross-Section B-B'

Grassland Drainage Area
Groundwater Quality Assessment Report

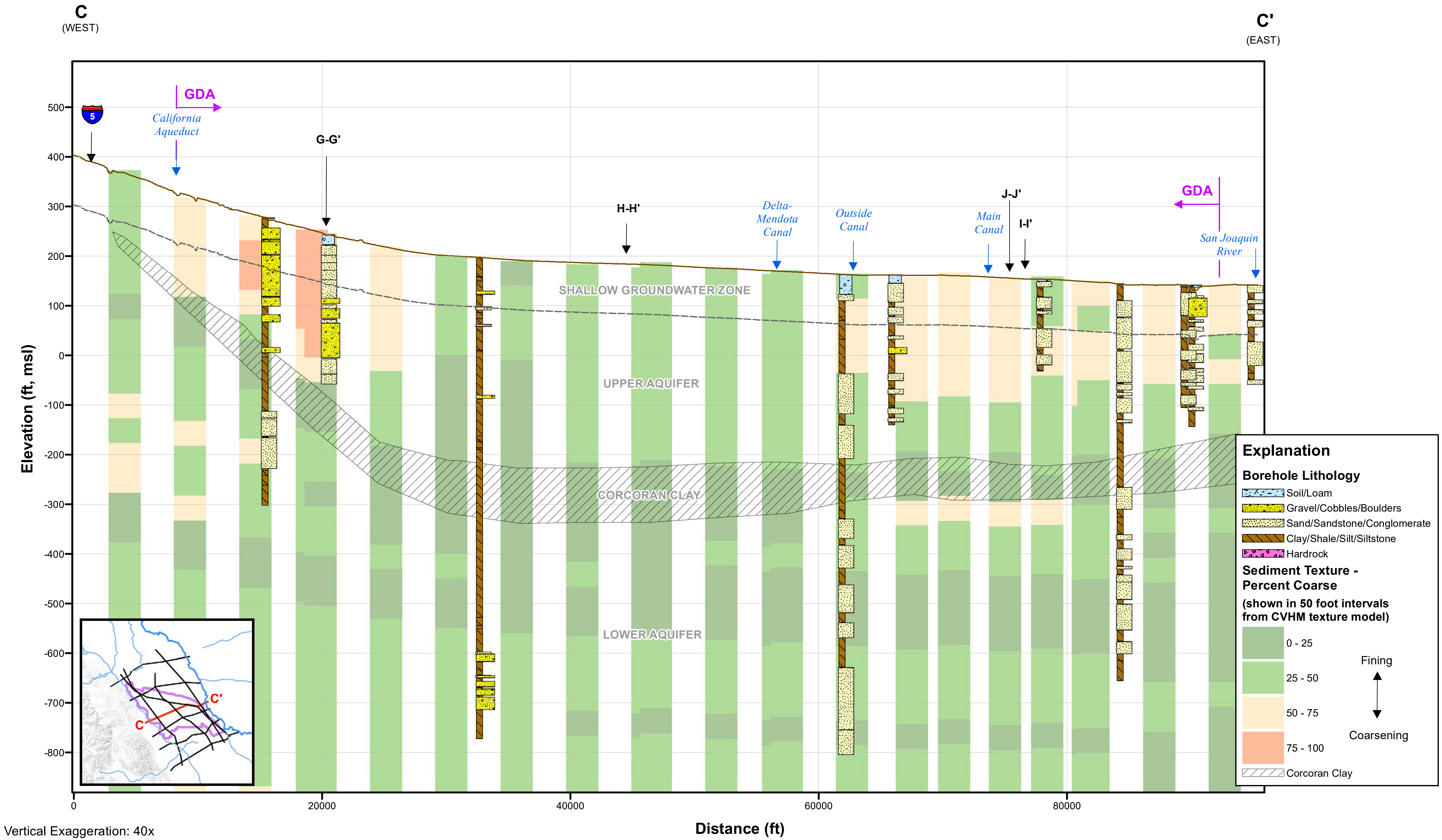

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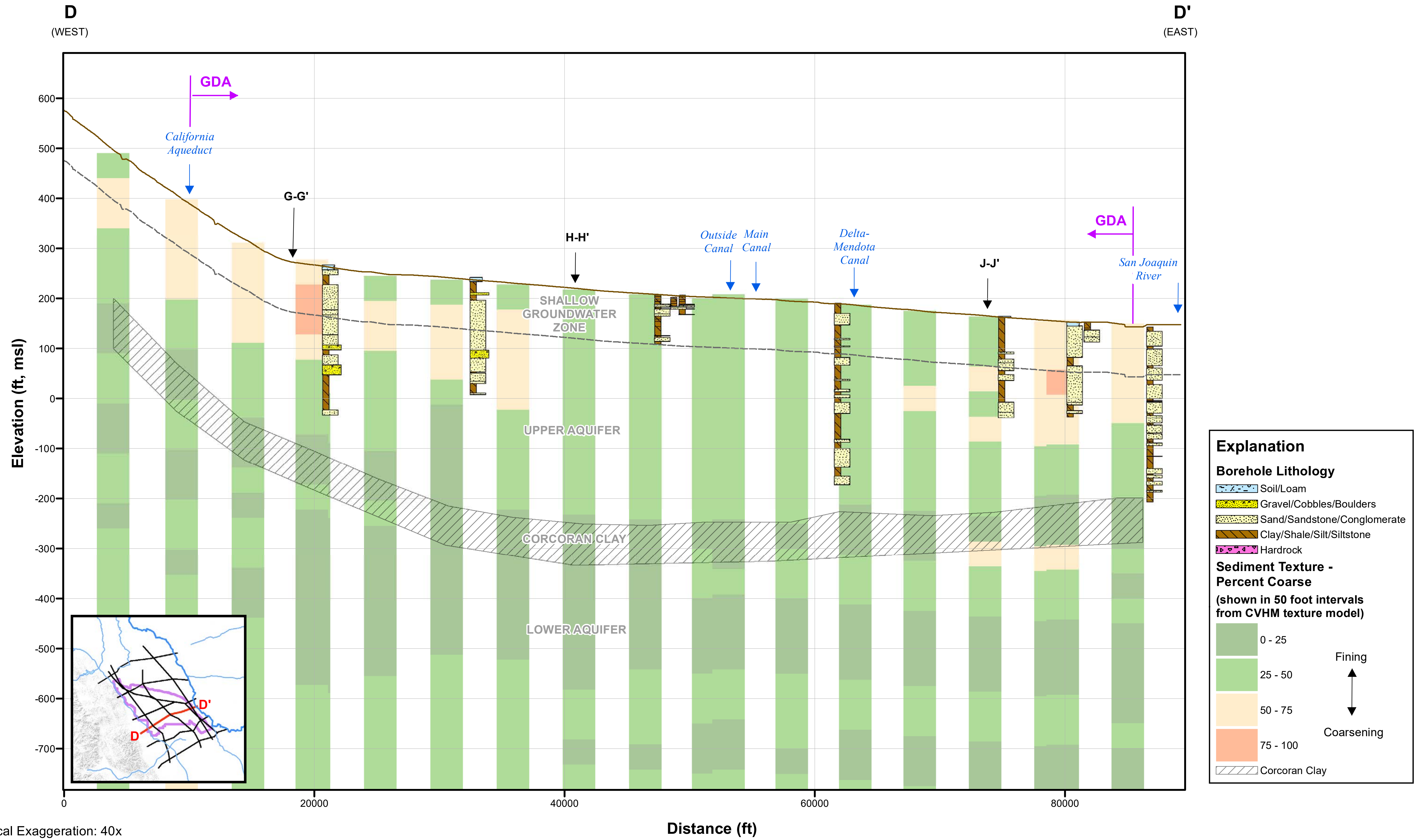
FIGURE 2-15

Geologic Cross-Section C-C'

Grassland Drainage Area
Groundwater Quality Assessment Report



Vertical Exaggeration: 40x

X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-16 Geologic Cross-Section D.mxd

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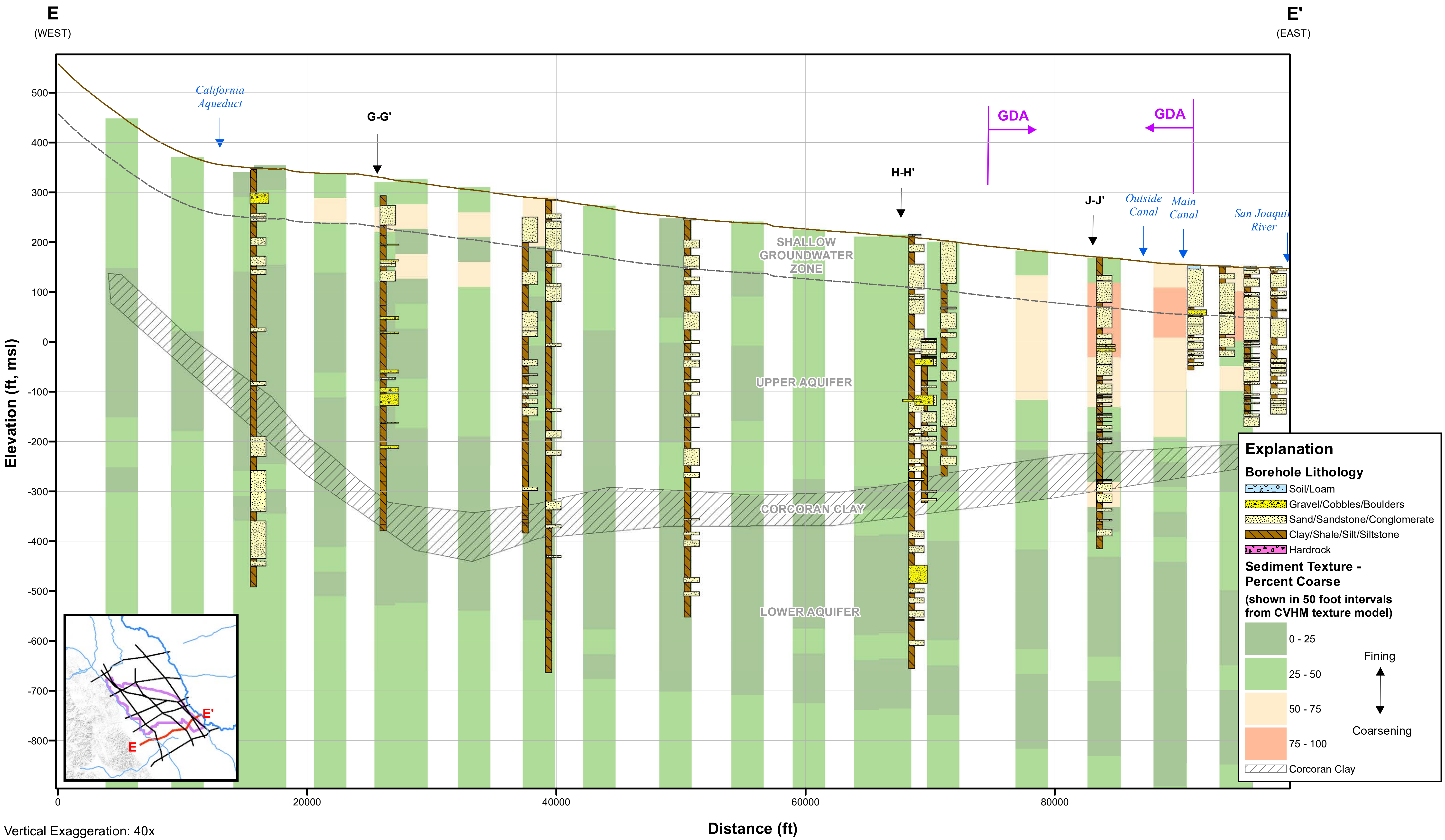
FIGURE 2-16

Geologic Cross-Section D-D'

Grassland Drainage Area
Groundwater Quality Assessment Report



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X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-17 Geologic Cross-Section E.mxd

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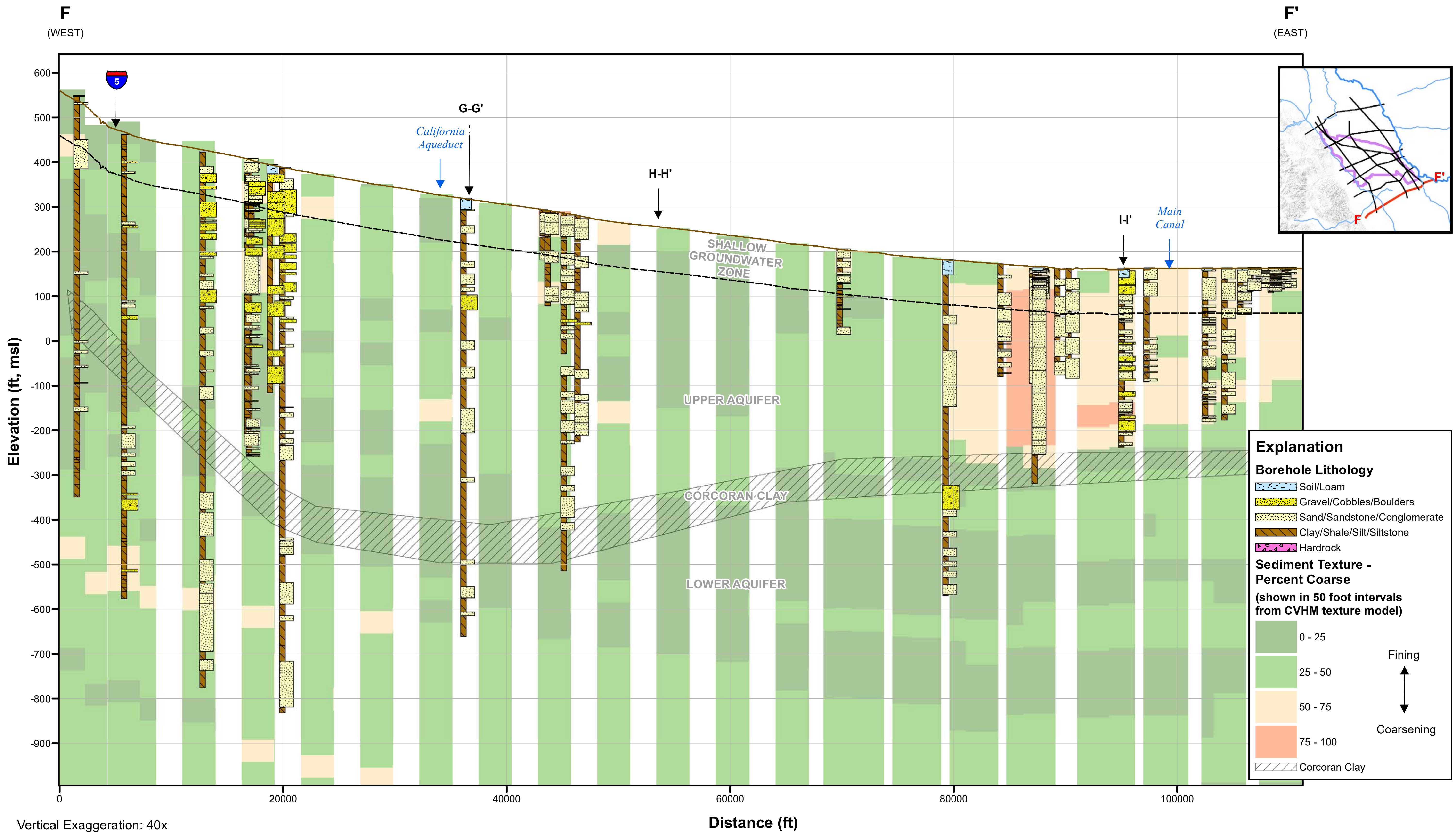
FIGURE 2-17

Geologic Cross-Section E-E'

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-18 Geologic Cross-Section F.mxd

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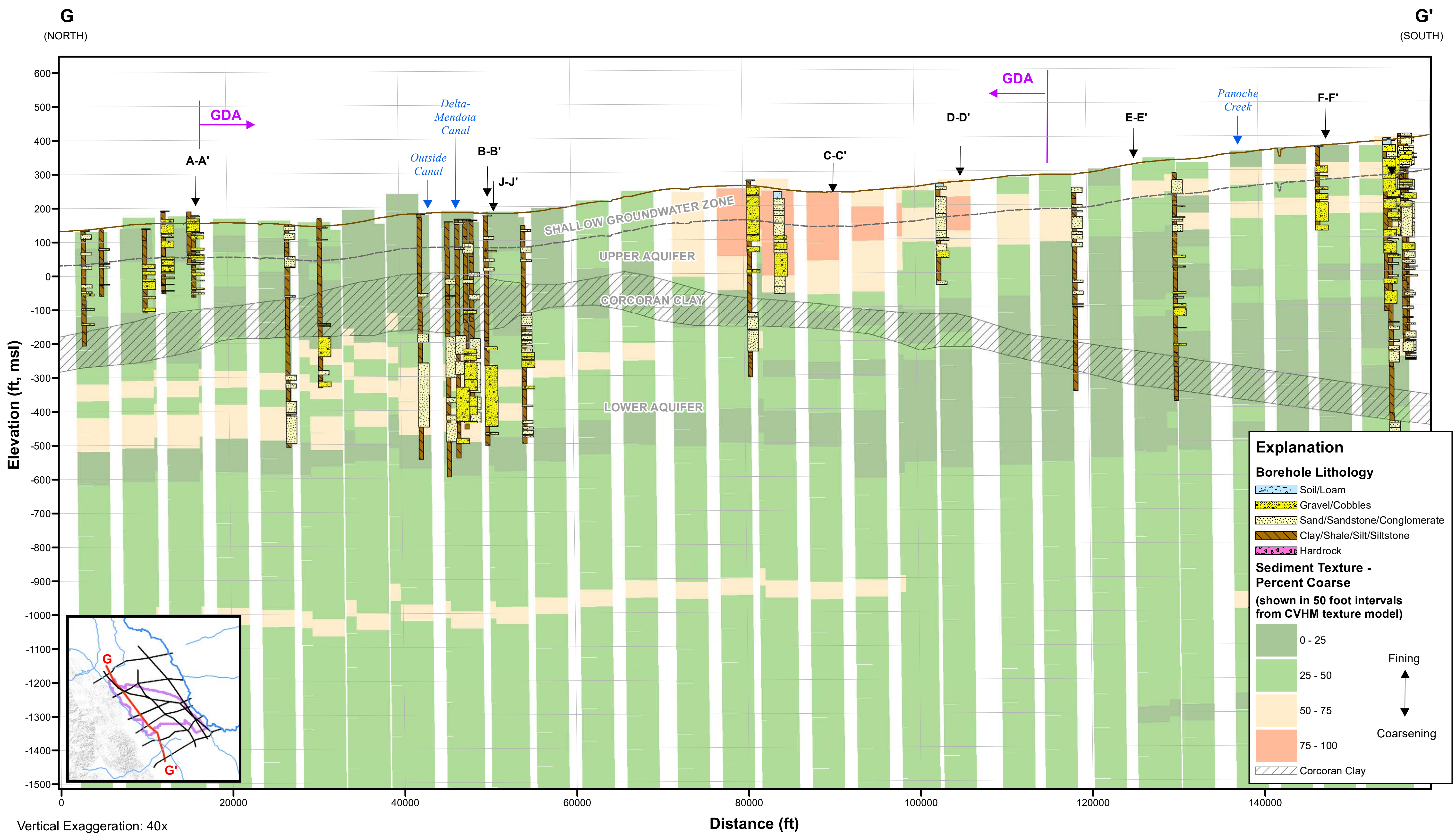
FIGURE 2-18

Geologic Cross-Section F-F'

Grassland Drainage Area
Groundwater Quality Assessment Report



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X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-19 Geologic Cross-Section G.mxd

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FIGURE 2-19

Geologic Cross-Section G-G'

Grassland Drainage Area
Groundwater Quality Assessment Report

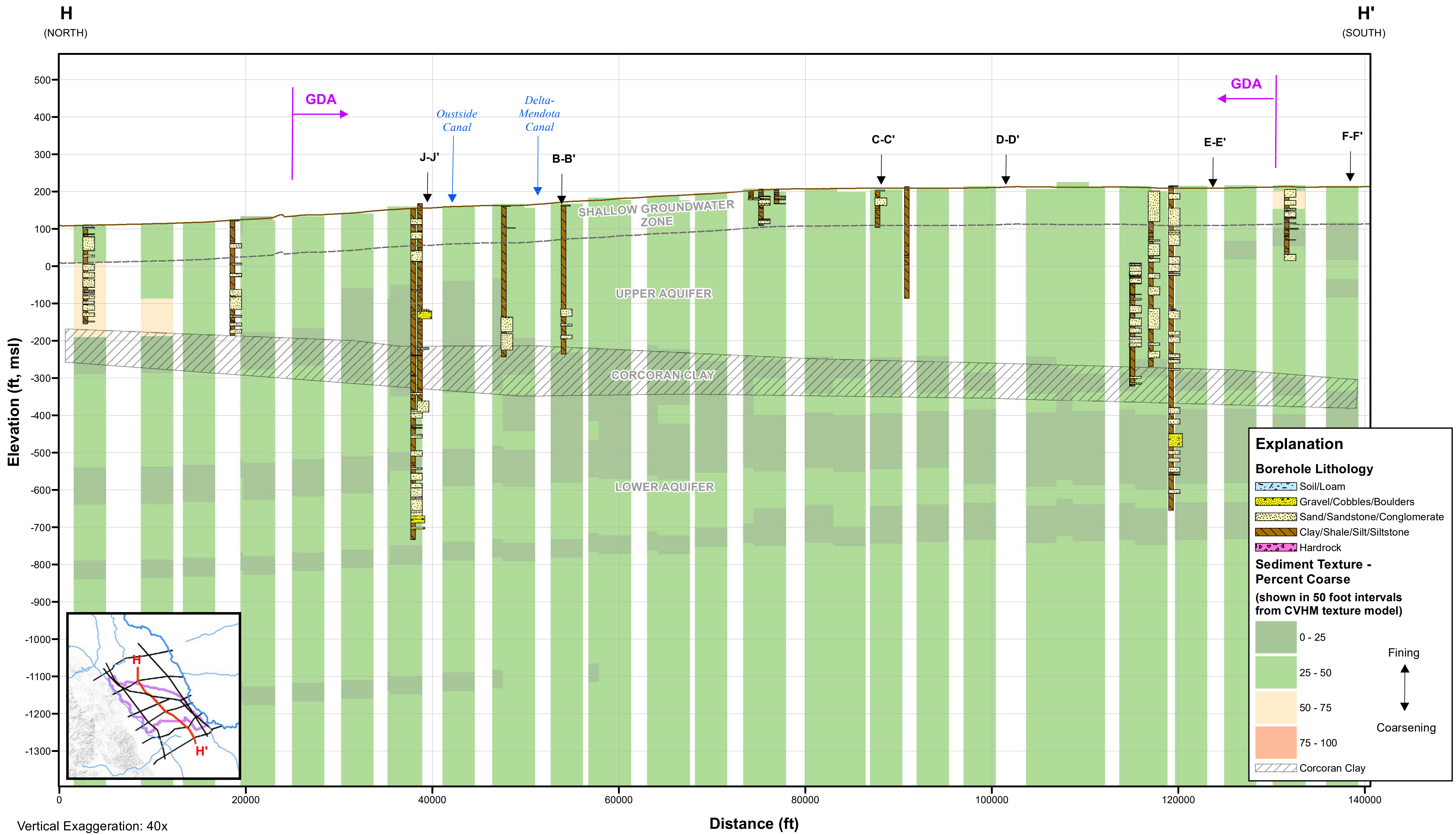

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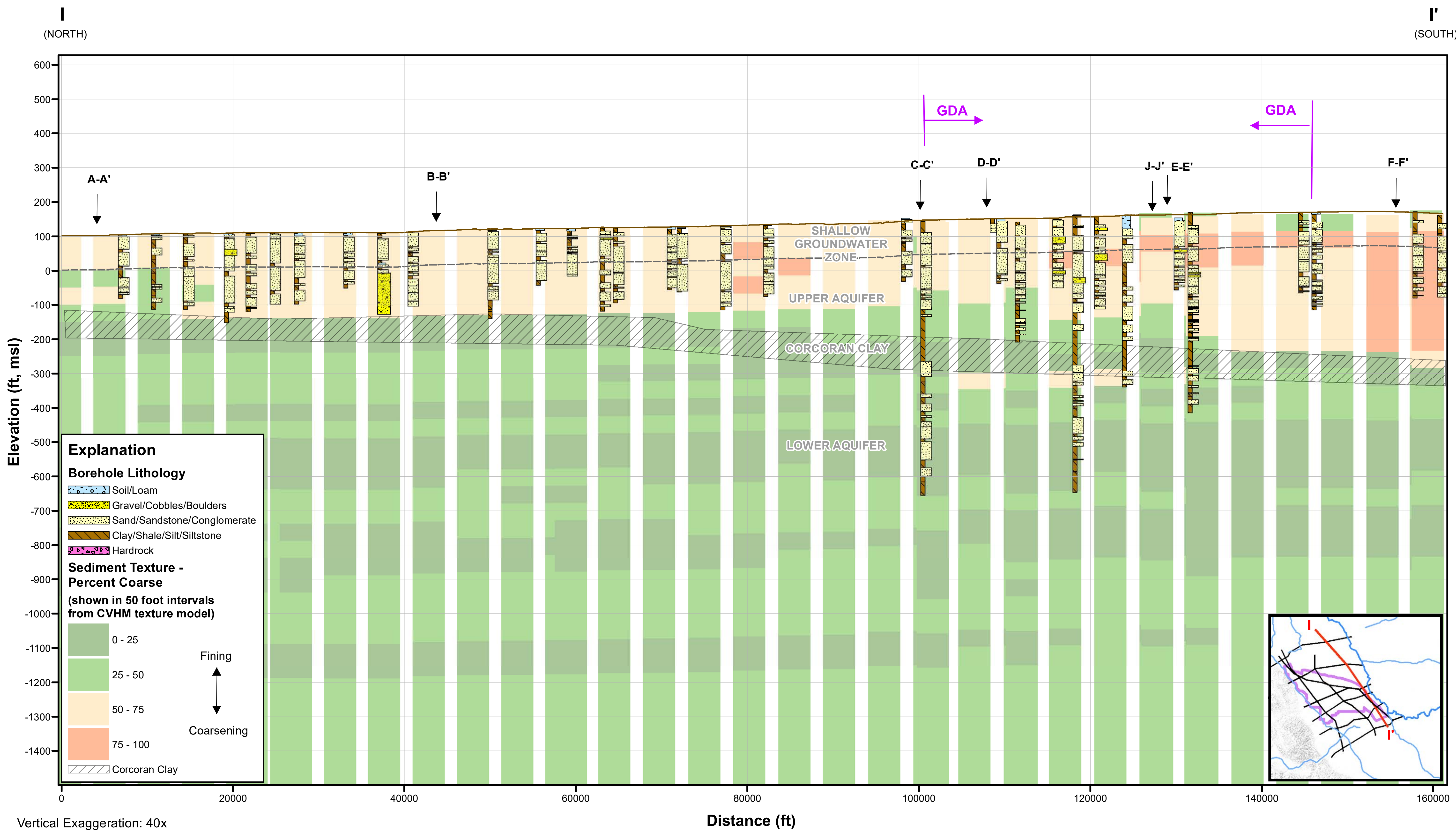
FIGURE 2-20

Geologic Cross-Section H-H'

Grassland Drainage Area
Groundwater Quality Assessment Report



Vertical Exaggeration: 40x

X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-21 Geologic Cross-Section I.mxd

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FIGURE 2-21

Geologic Cross-Section I-I'

Grassland Drainage Area
Groundwater Quality Assessment Report

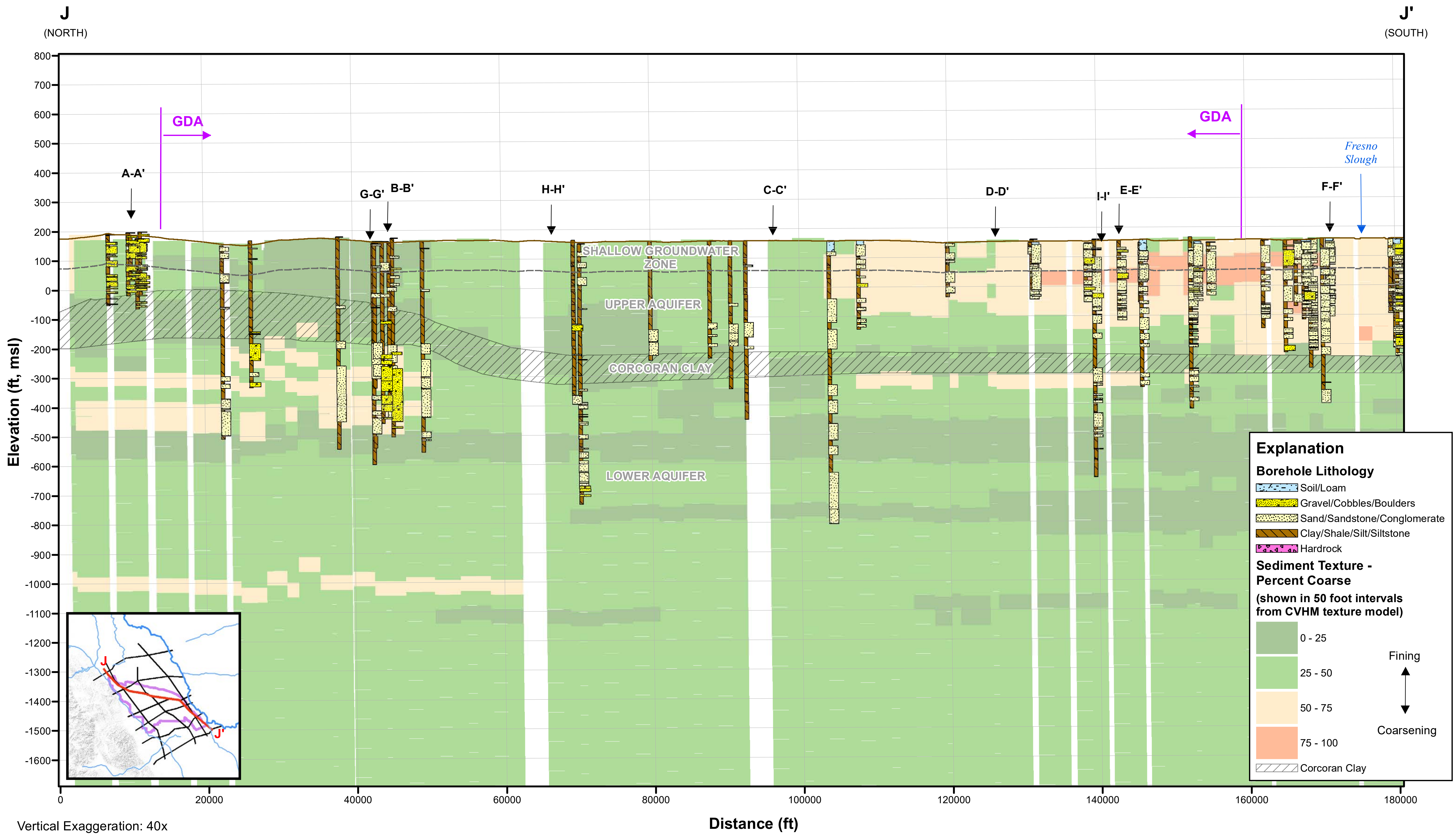

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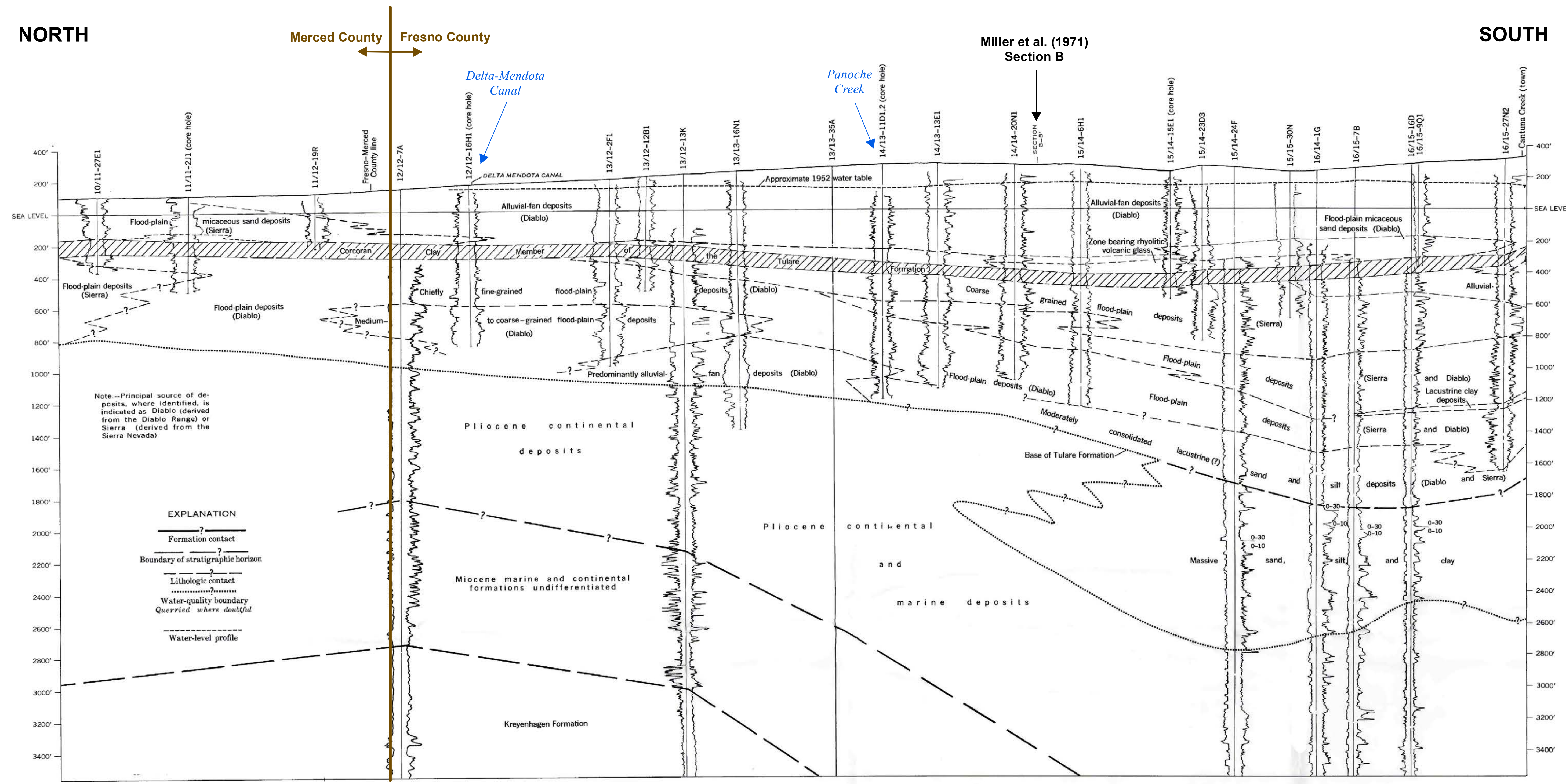
FIGURE 2-22

Geologic Cross-Section J-J'

Grassland Drainage Area
Groundwater Quality Assessment Report



Vertical Exaggeration: 26x

X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-23 Miller 1971 Geologic Cross-Section A.mxd

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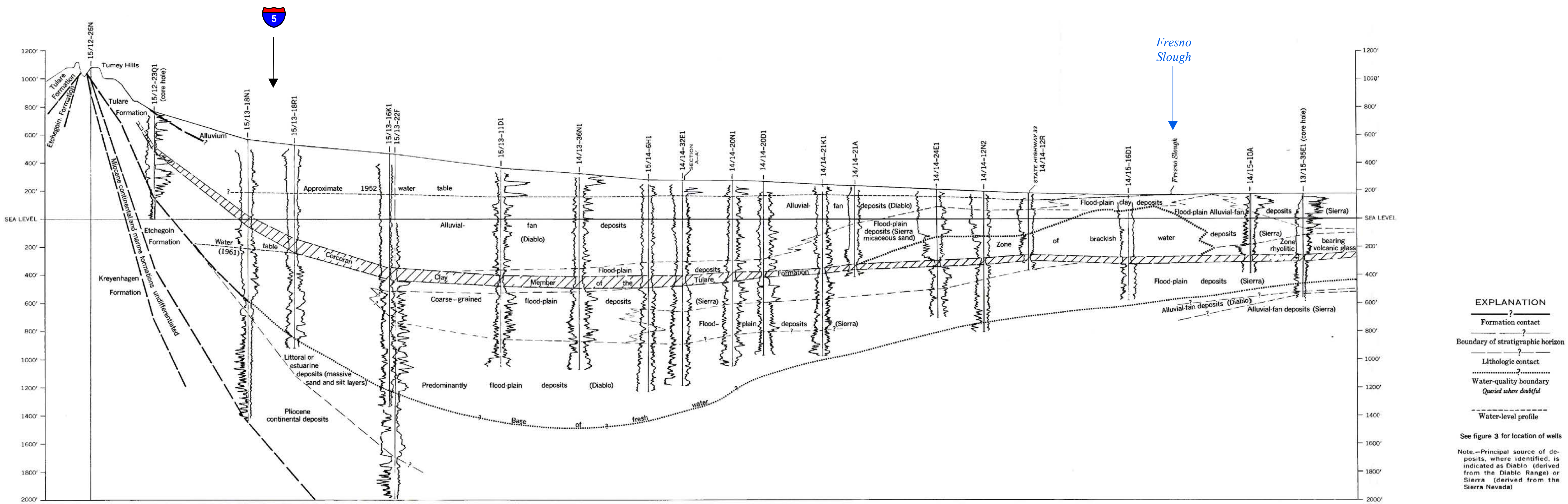
FIGURE 2-23

Miller (1971) Geologic Cross-Section A

Grassland Drainage Area
Groundwater Quality Assessment Report

WEST

EAST



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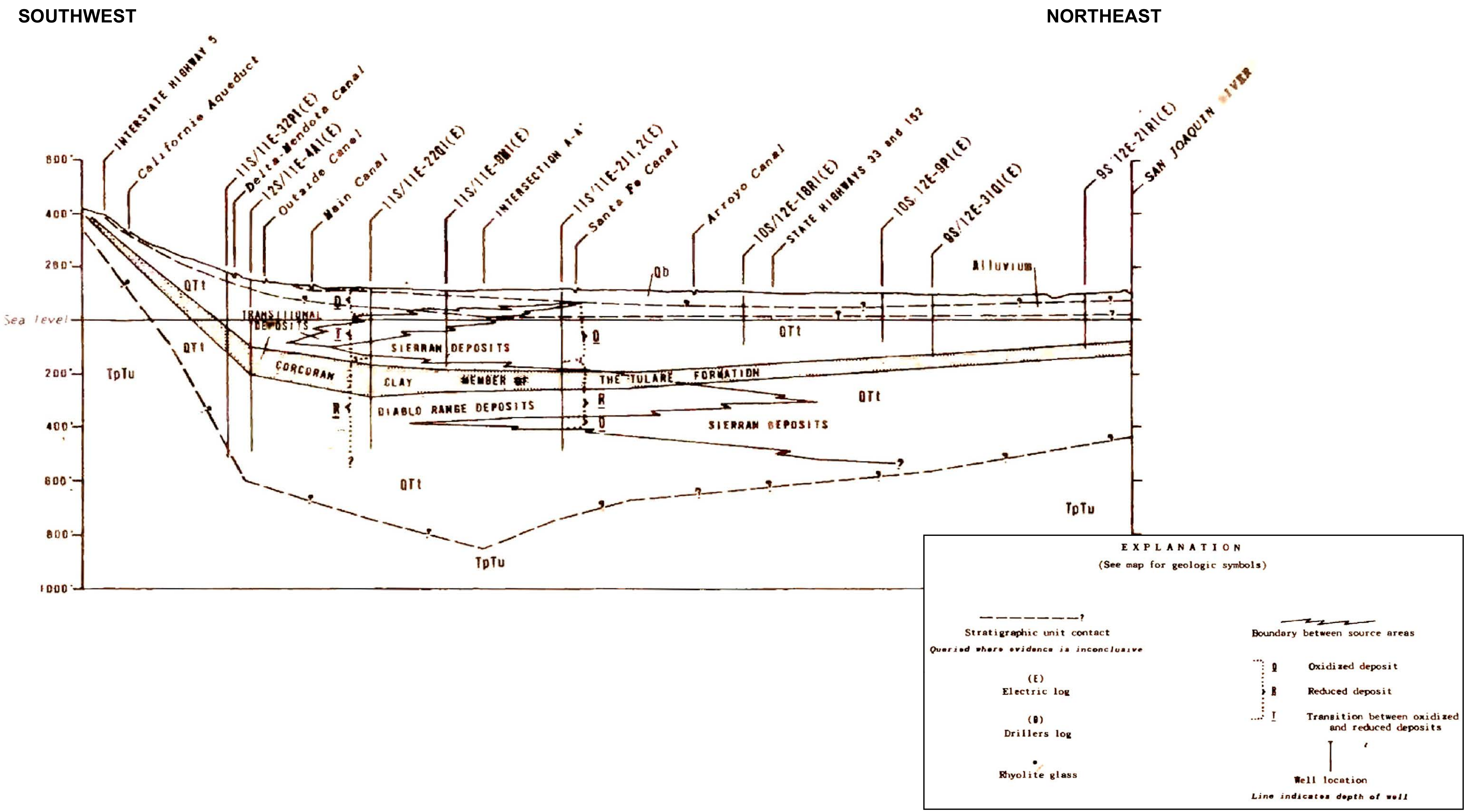
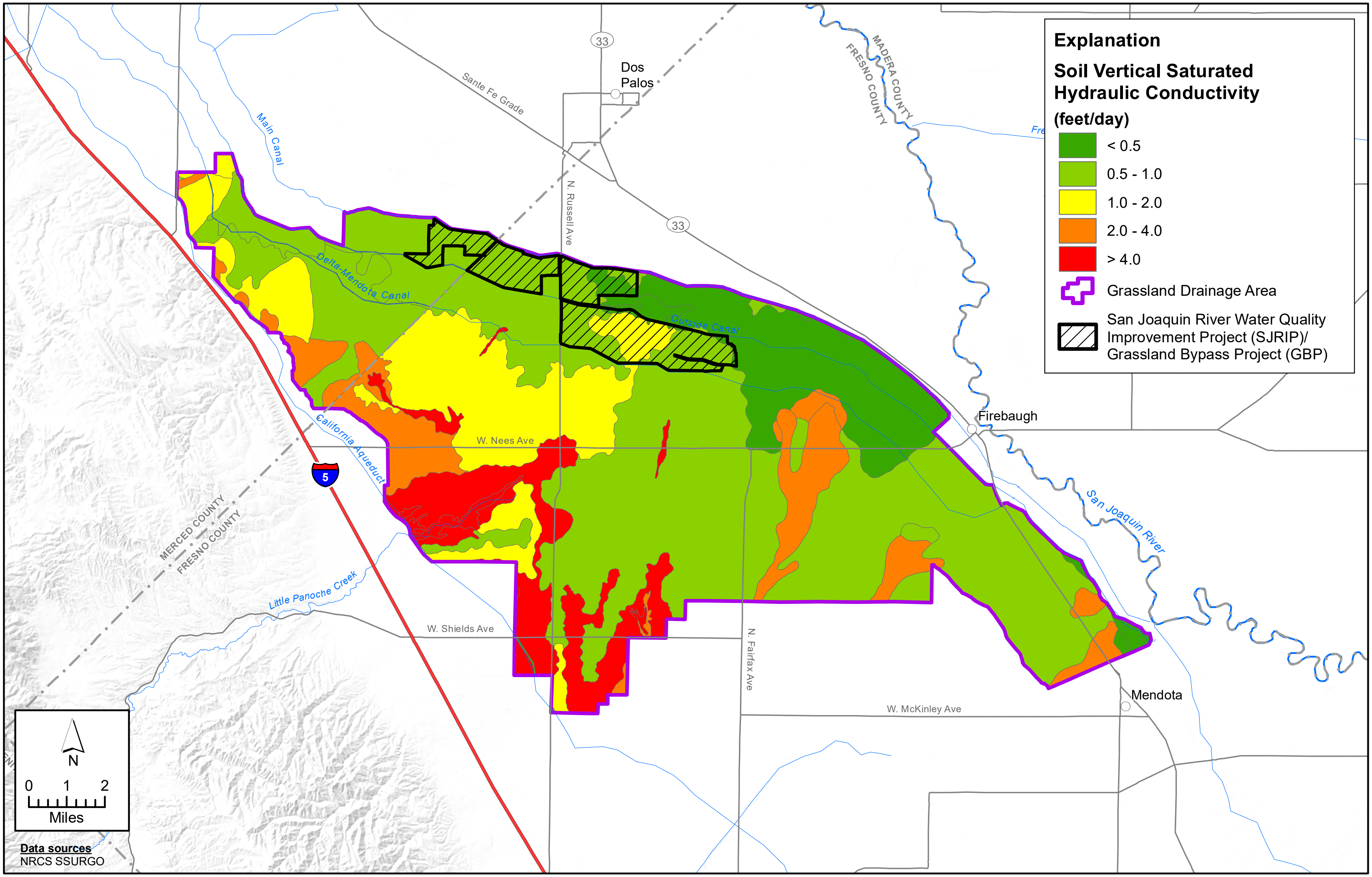


FIGURE 2-25

Hotchkiss and Balding (1971) Geologic Cross-Section E



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-26 Soil Hydraulic Conductivity.mxd

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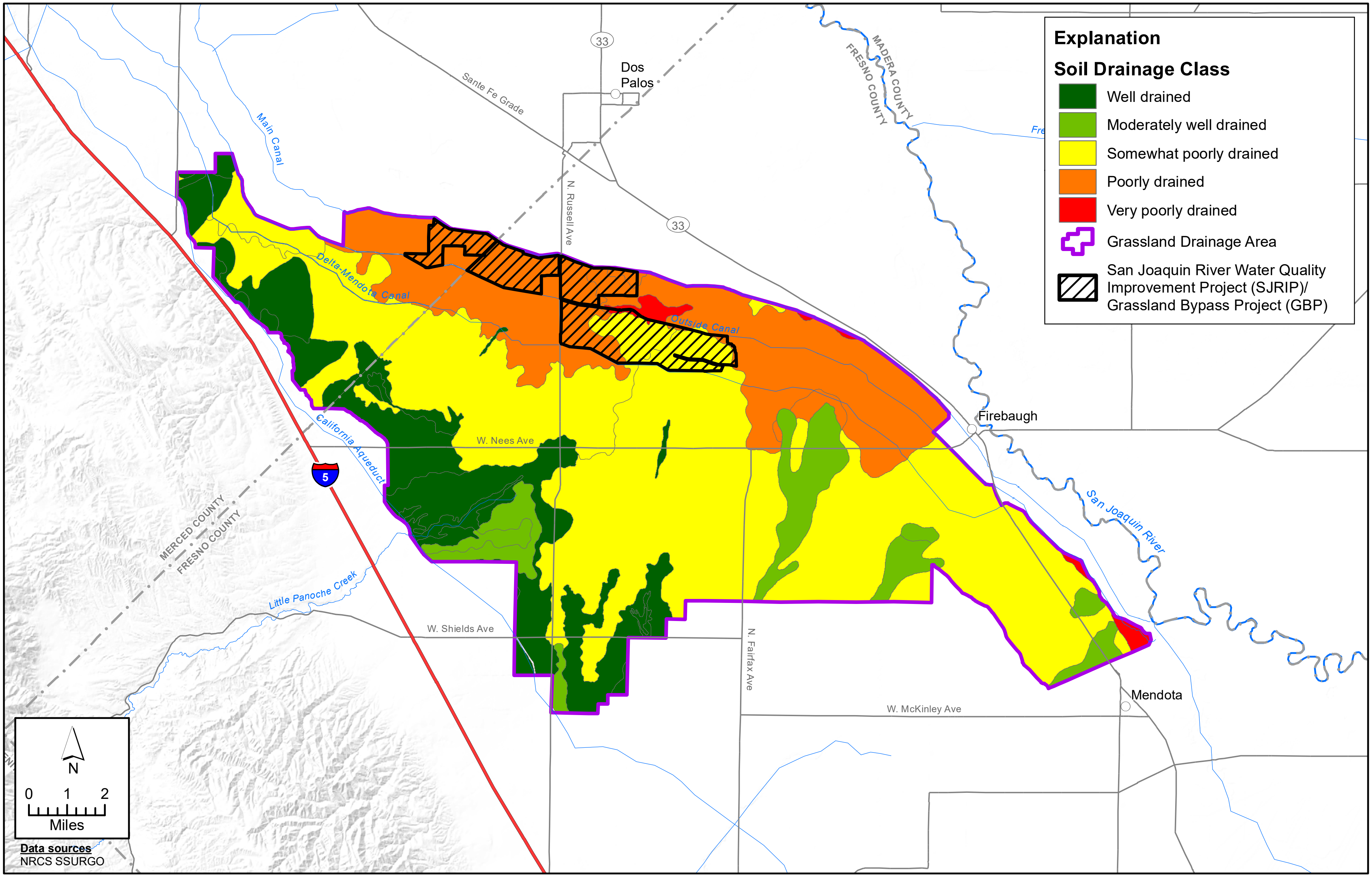
FIGURE 2-26

Map of Soil Hydraulic Conductivity

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-27 Soil Drainage Characteristics.mxd

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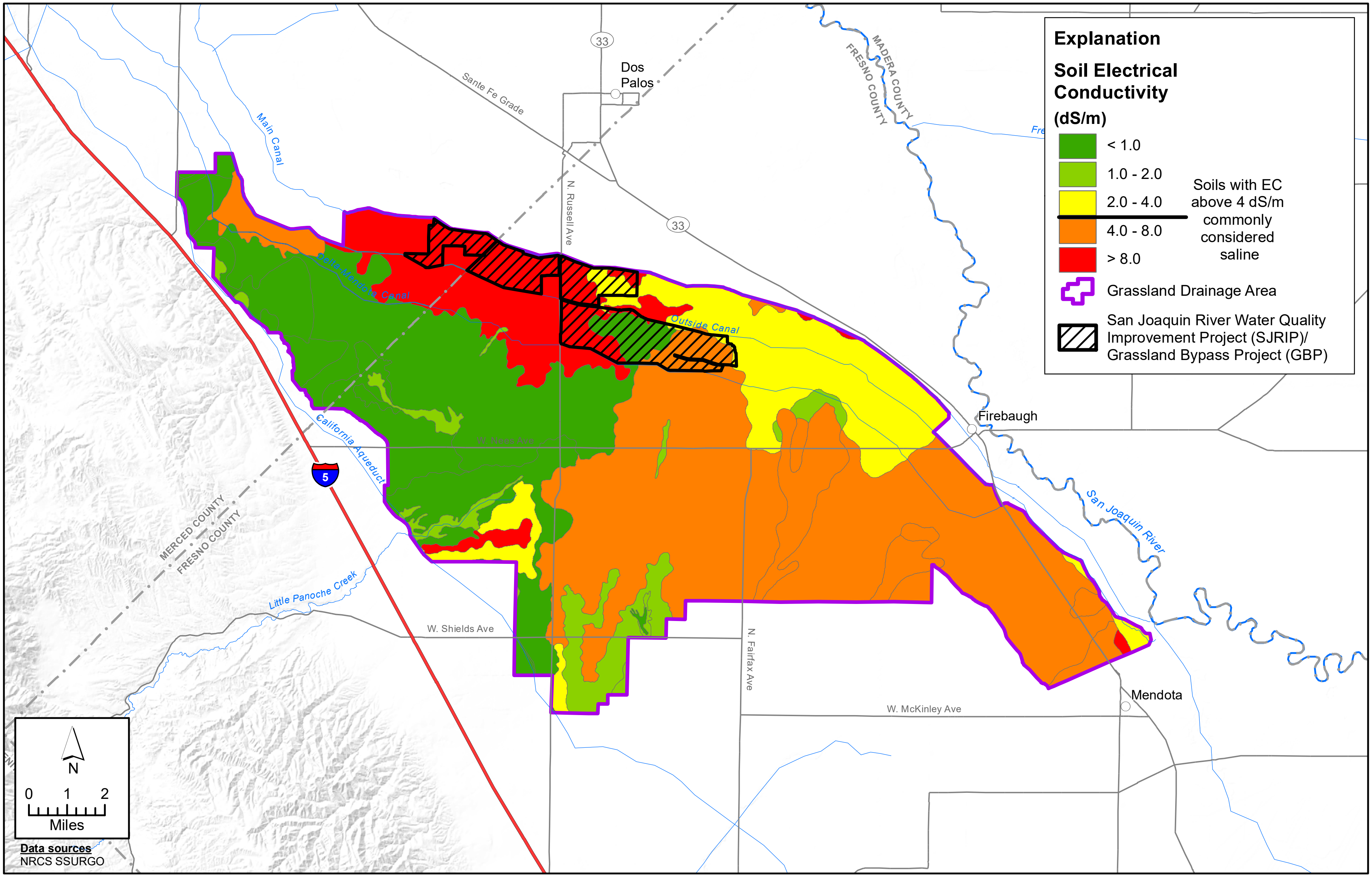
FIGURE 2-27

Map of Soil Drainage Characteristics

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-28 Soil Salinity.mxd

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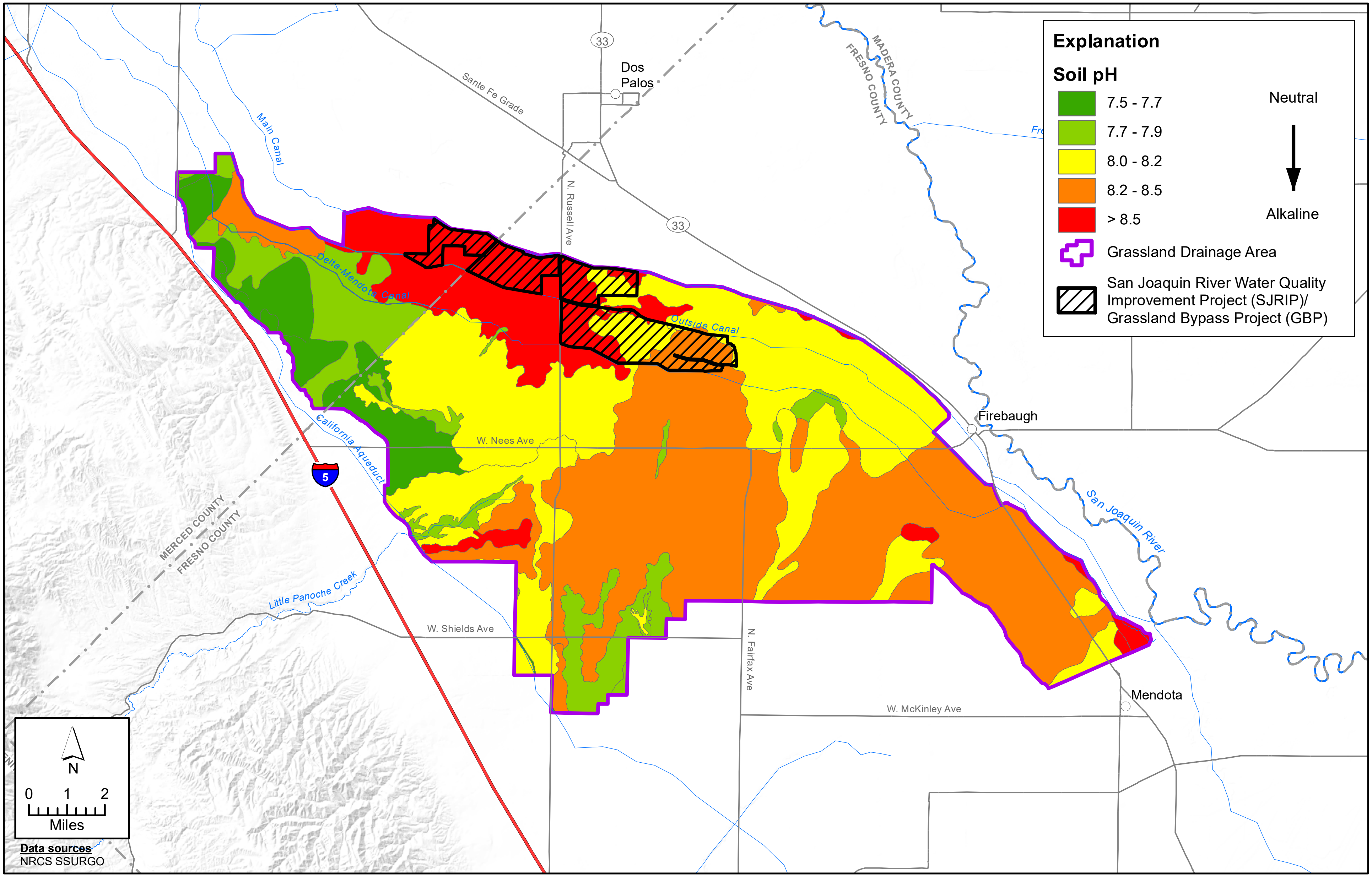
FIGURE 2-28

Map of Soil Salinity

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-29 Soil pH.mxd

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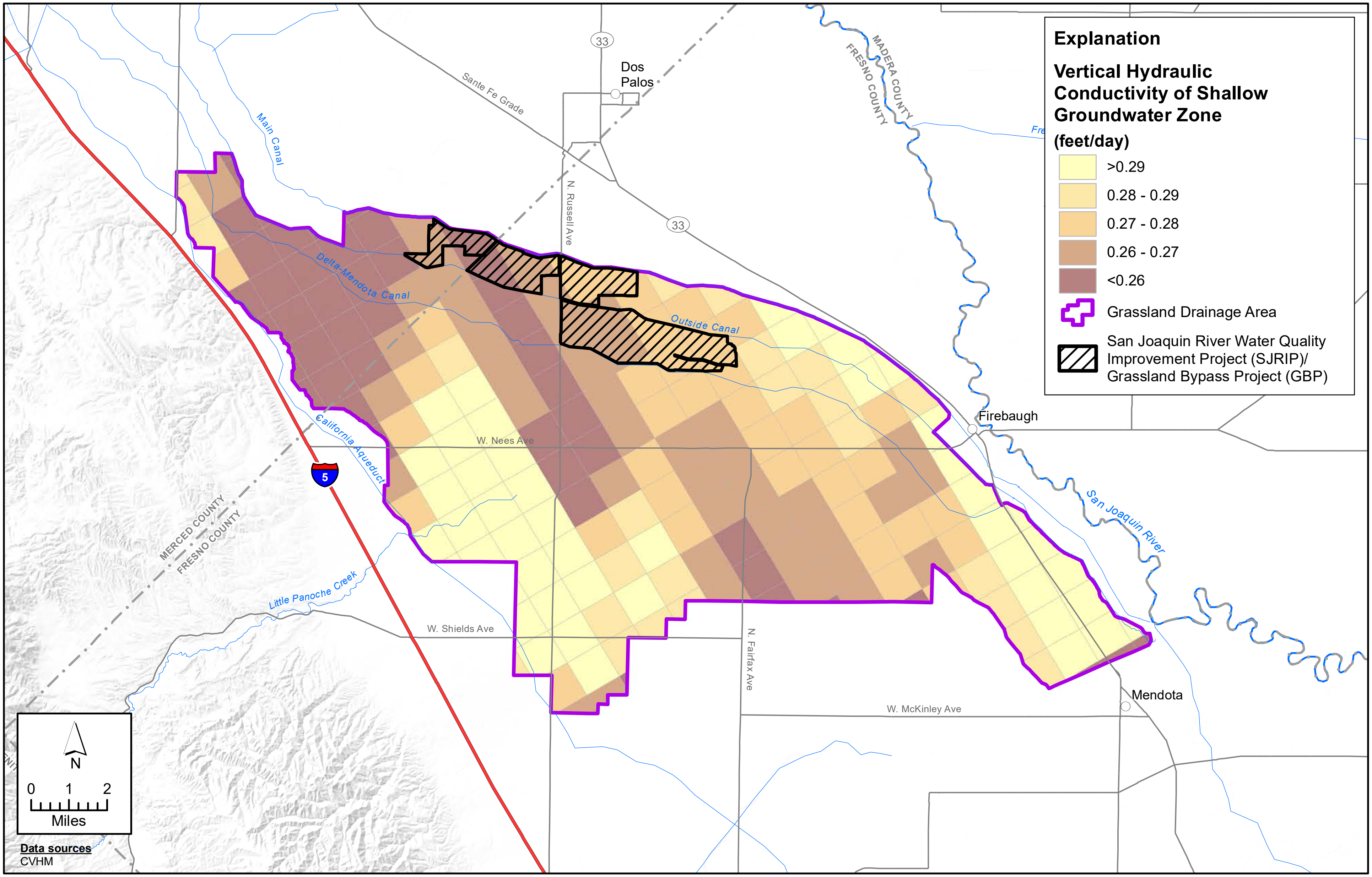
FIGURE 2-29

Map of Soil pH

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-30 Vertical Hydraulic Conductivity Shallow Groundwater.mxd

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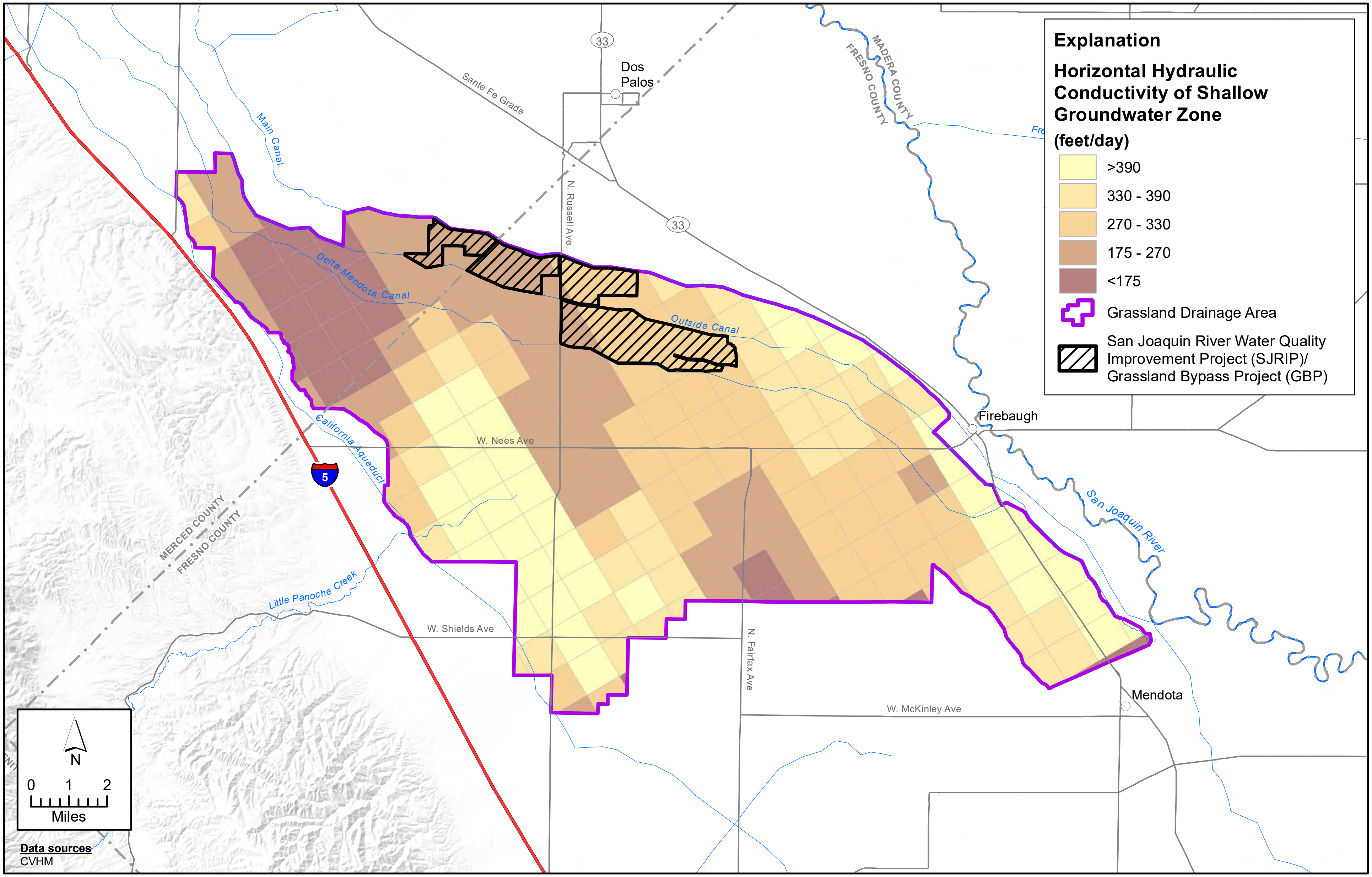
FIGURE 2-30
Map of Vertical Hydraulic Conductivity: Shallow Groundwater Zone
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-31 Horizontal Hydraulic Conductivity Shallow Groundwater.mxd

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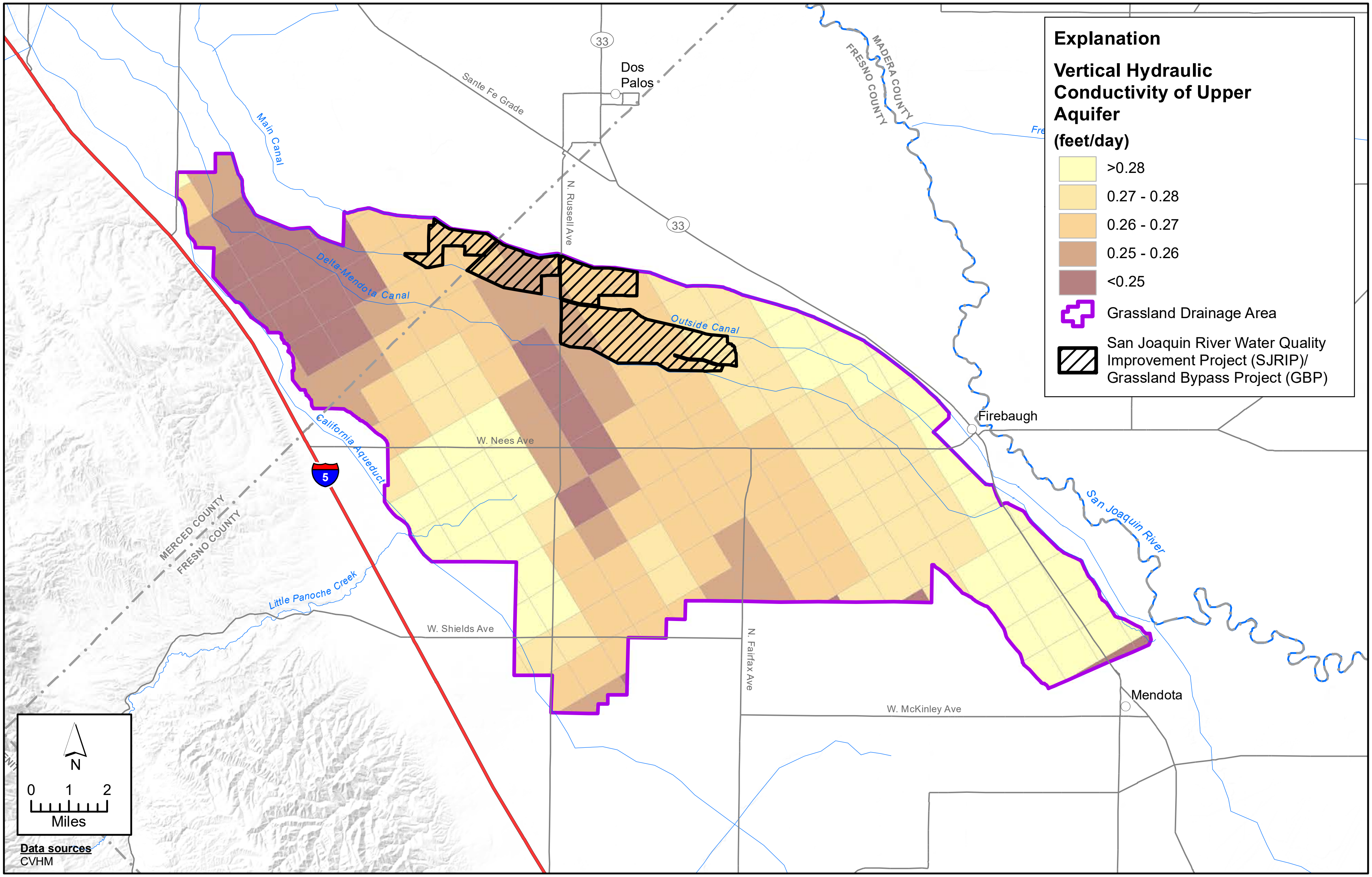
FIGURE 2-31
Map of Horizontal Hydraulic Conductivity: Shallow Groundwater Zone
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-32 Vertical Hydraulic Conductivity Upper Aquifer.mxd

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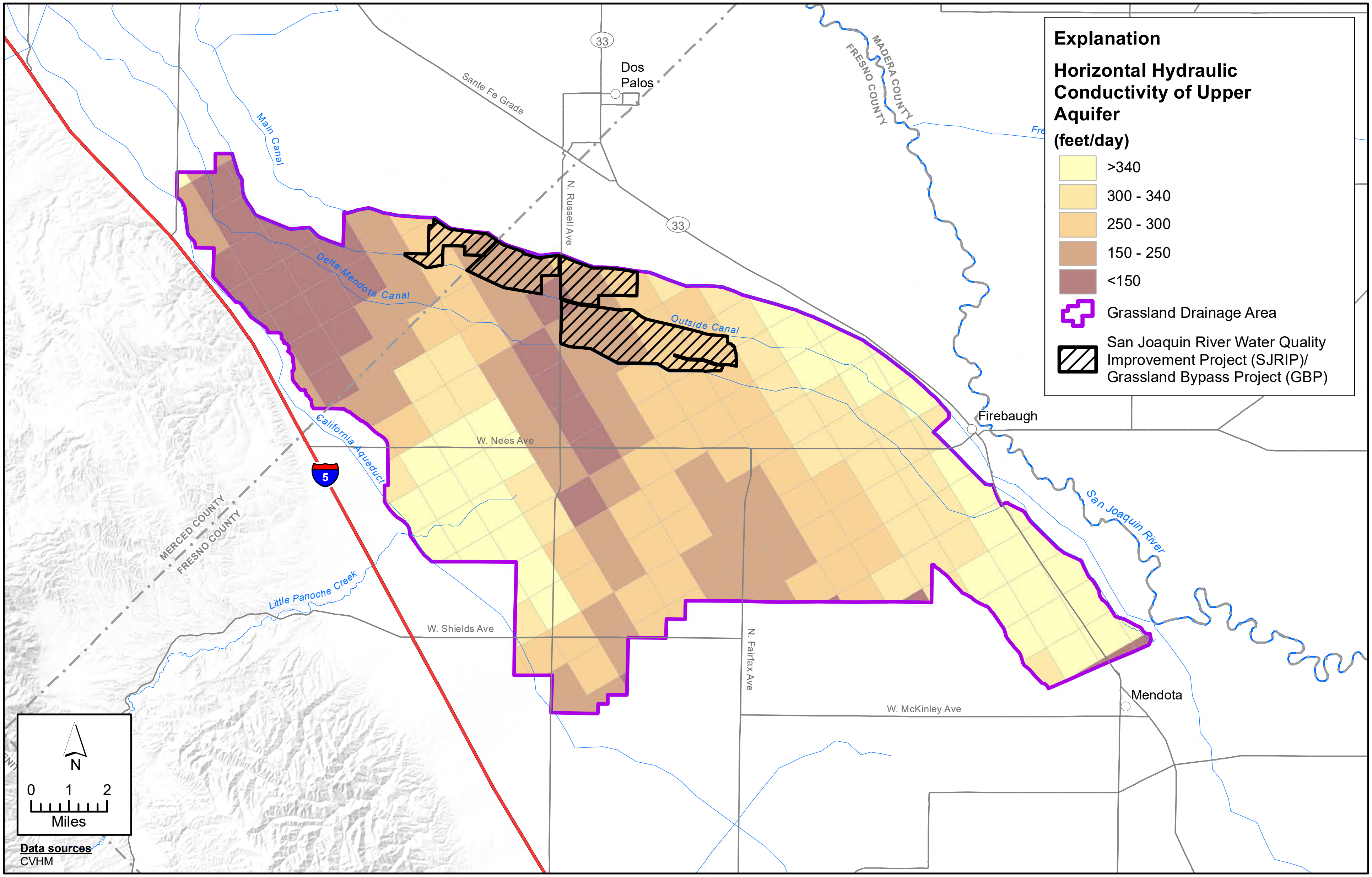
FIGURE 2-32
Map of Vertical Hydraulic Conductivity: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-33 Horizontal Hydraulic Conductivity Upper Aquifer.mxd

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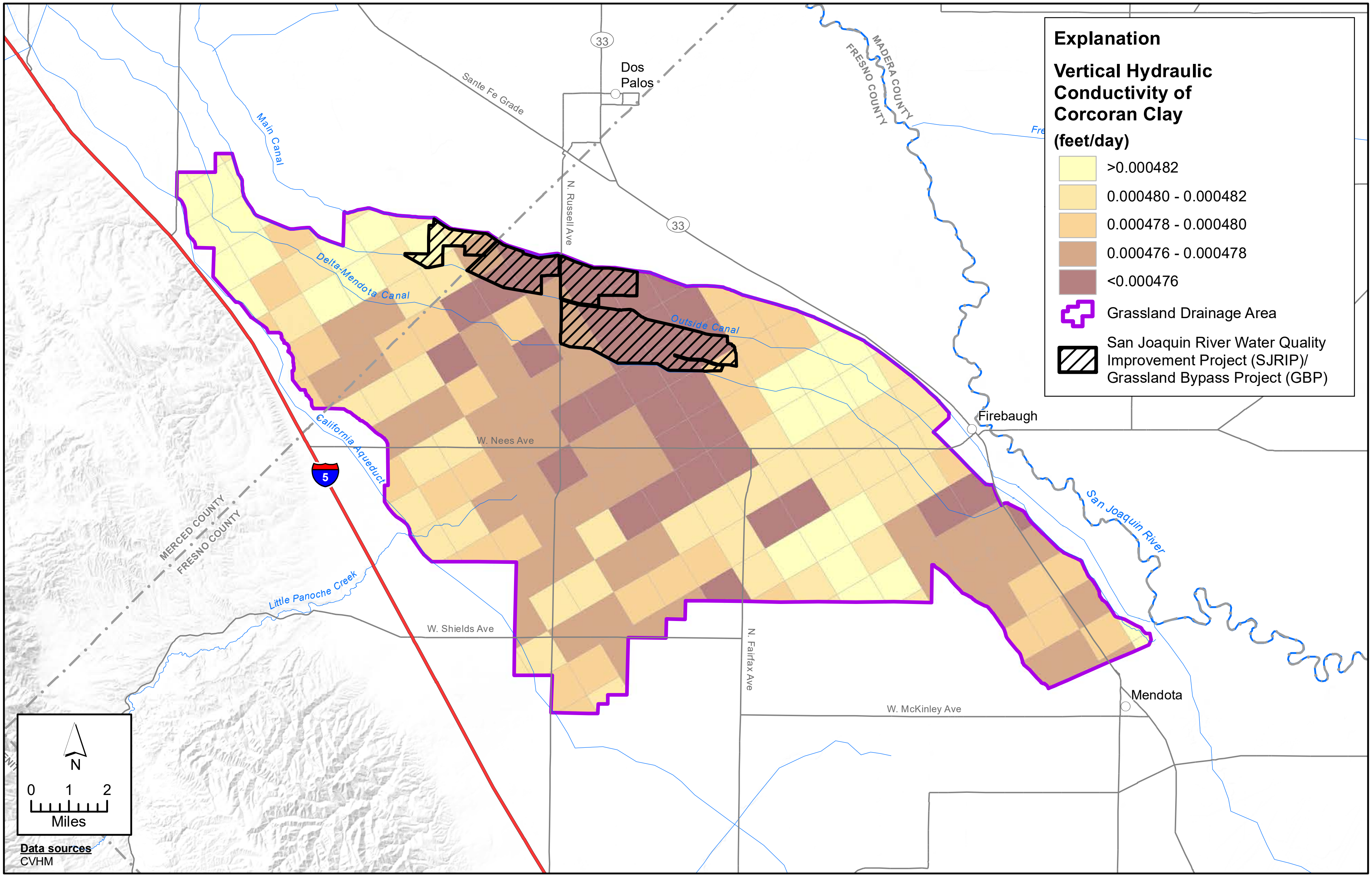
FIGURE 2-33
Map of Horizontal Hydraulic Conductivity: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 2-34 Vertical Hydraulic Conductivity Corcoran Clay.mxd

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FIGURE 2-34
Map of Vertical Hydraulic Conductivity: Corcoran Clay
Grassland Drainage Area
Groundwater Quality Assessment Report

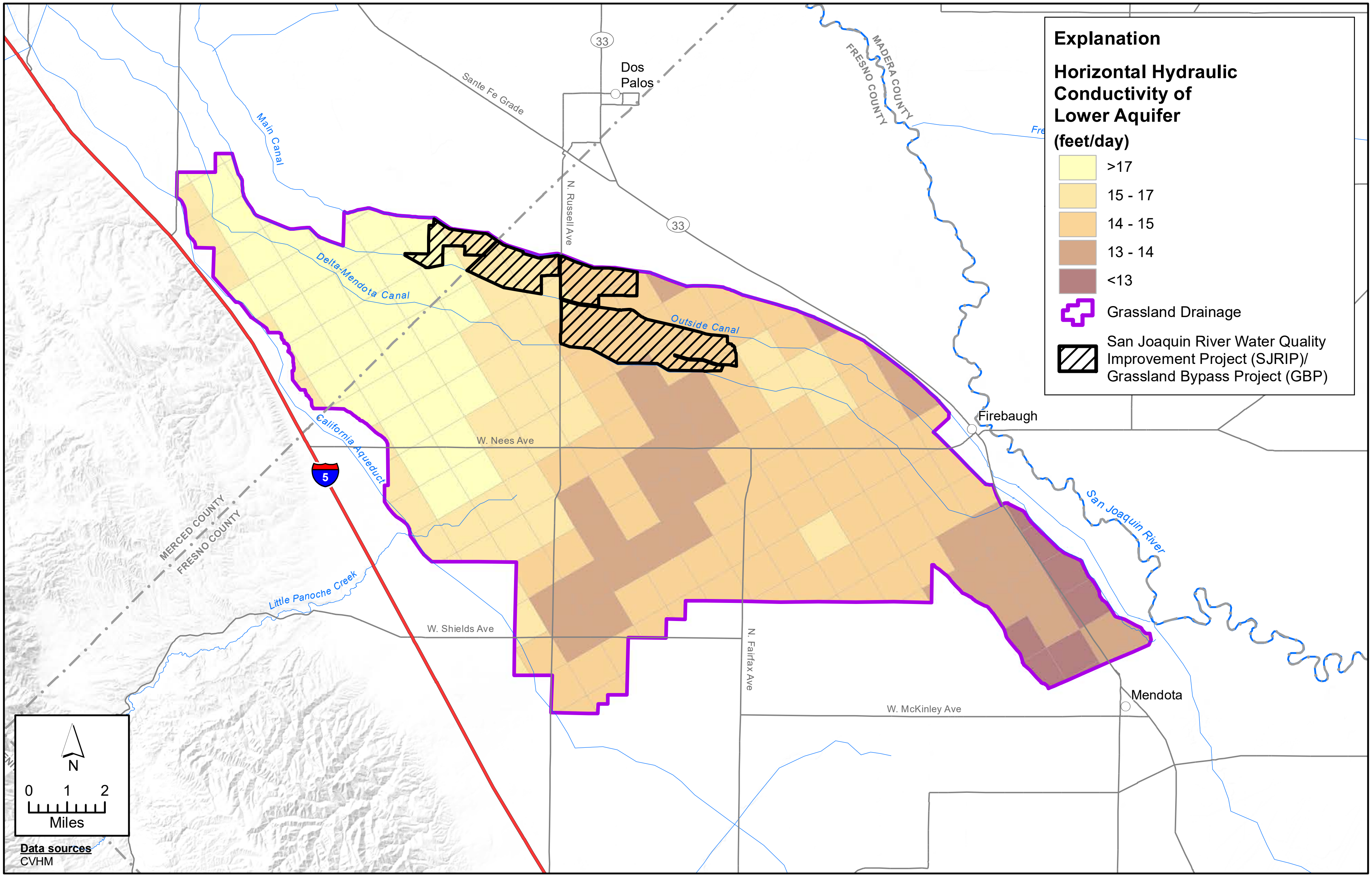

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FIGURE 2-35
Map of Horizontal Hydraulic Conductivity: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

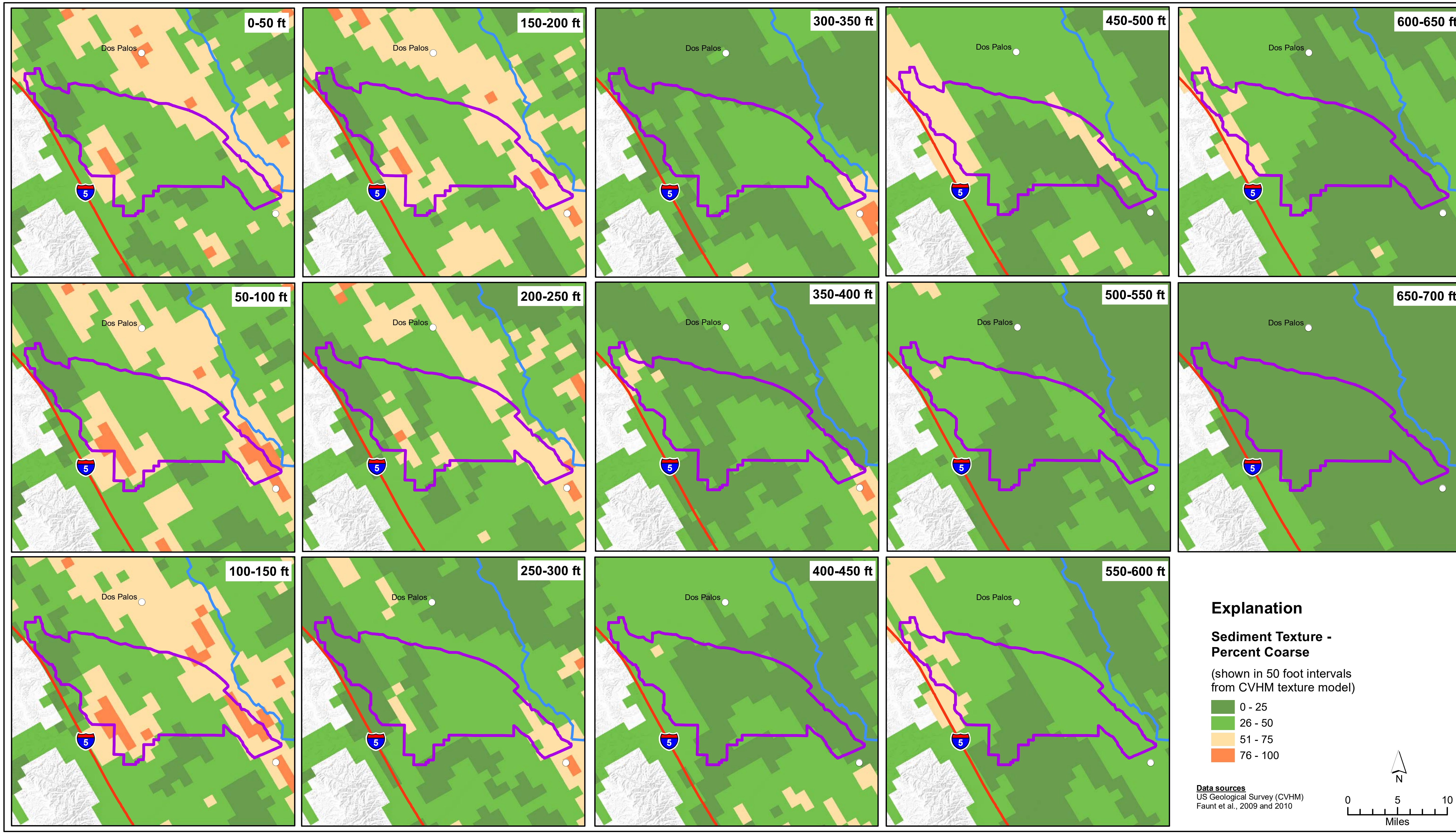

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FIGURE 2-36A
CVHM Sediment Texture Model
0 to 700 Feet

Grassland Drainage Area
Groundwater Quality Assessment Report

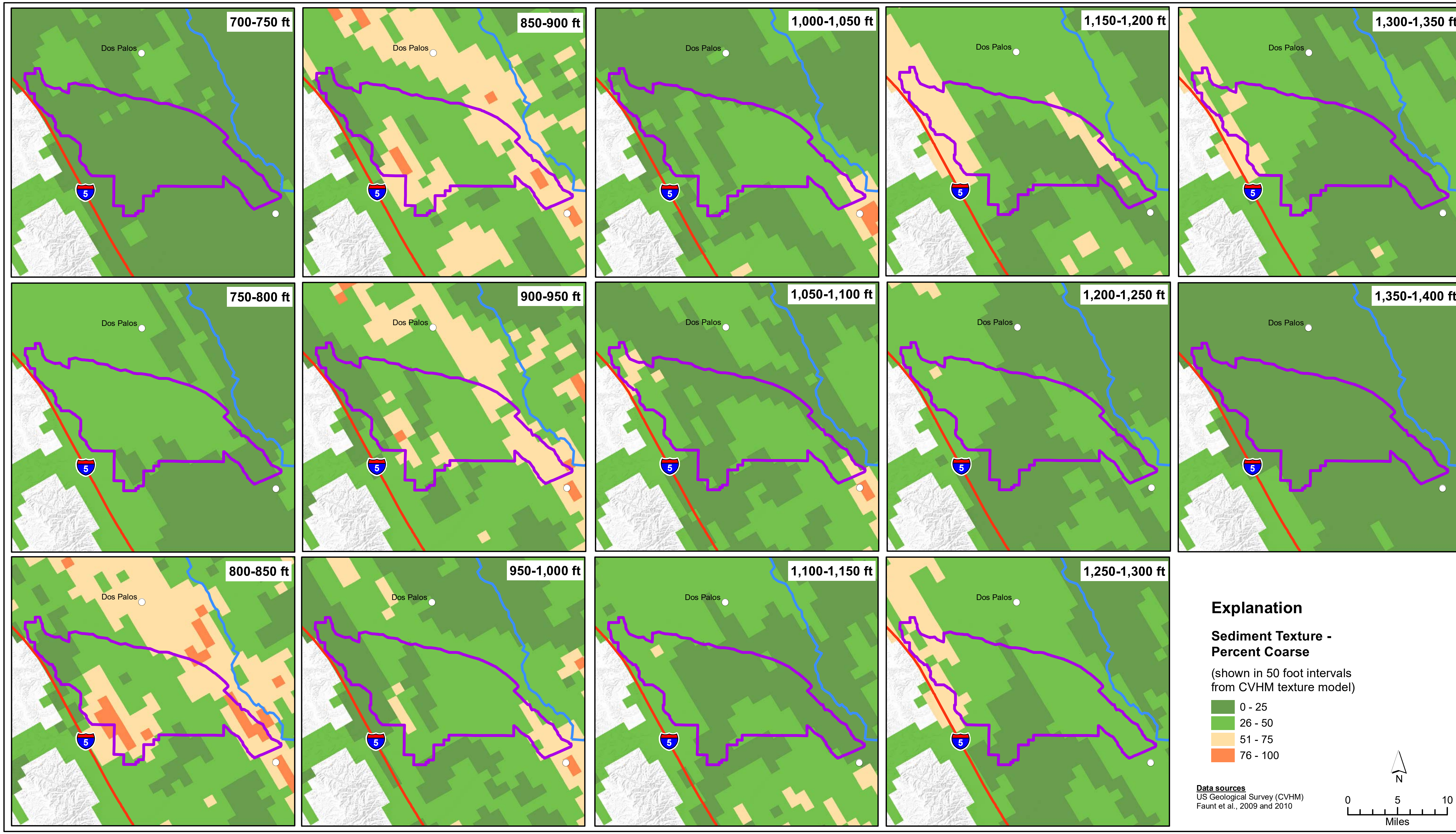

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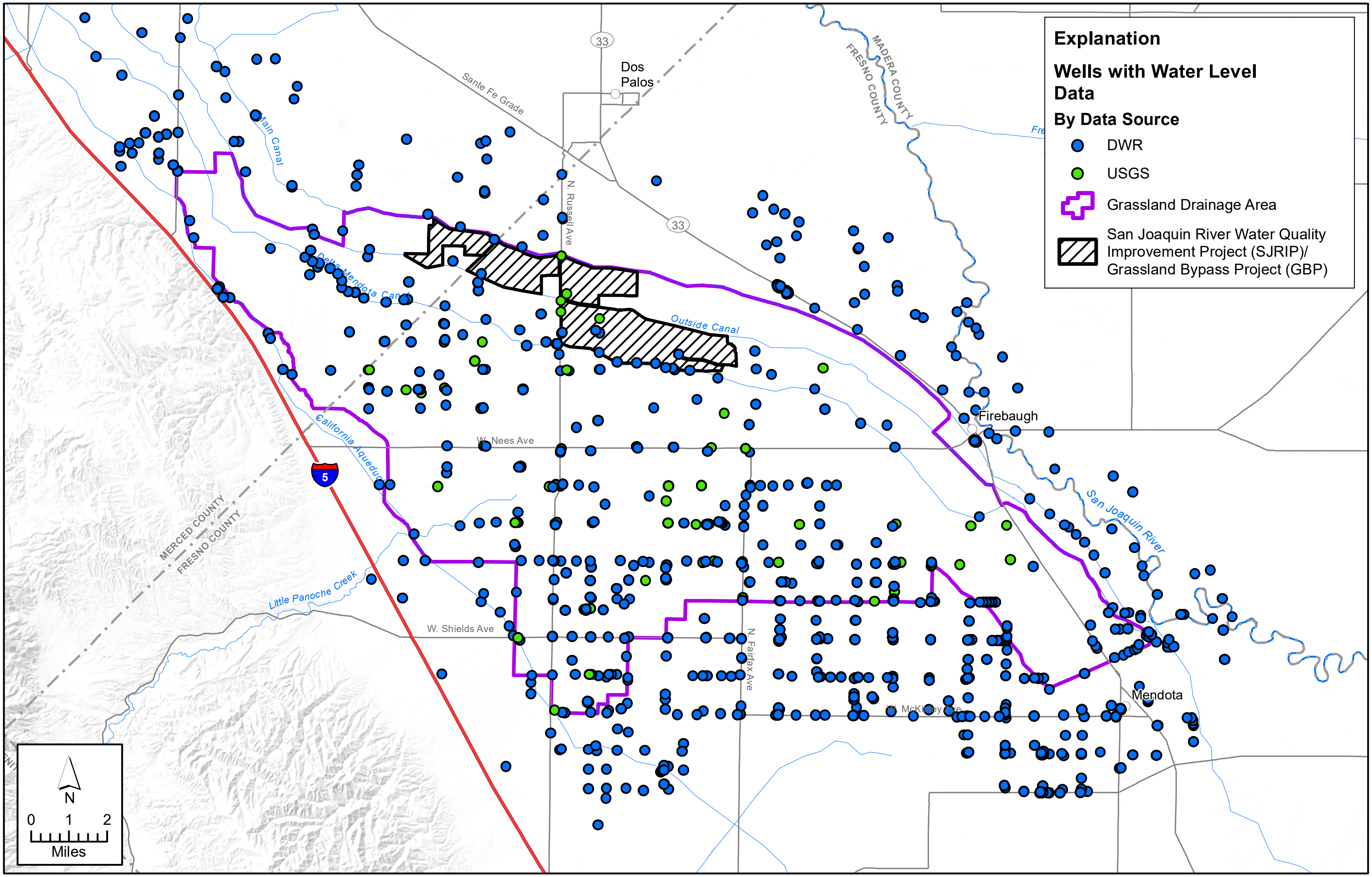
FIGURE 2-36B
CVHM Sediment Texture Model
700 to 1,400 Feet

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-1 Groundwater Level Data by Source.mxd

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FIGURE 3-1

Map of Groundwater Level Data by Source

Grassland Drainage Area
Groundwater Quality Assessment Report

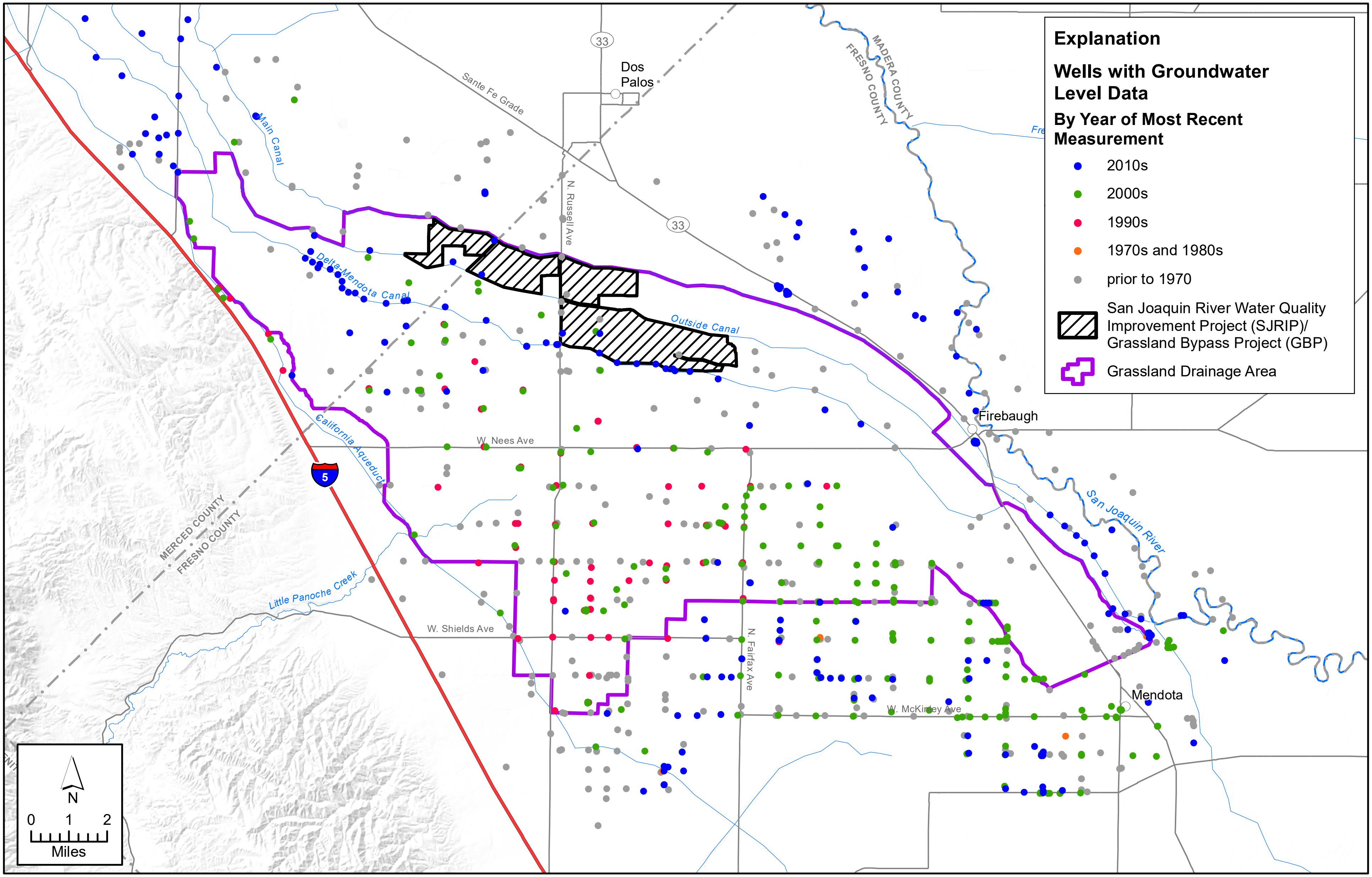

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FIGURE 3-2

Map of Groundwater Level Data by Year

Grassland Drainage Area
Groundwater Quality Assessment Report

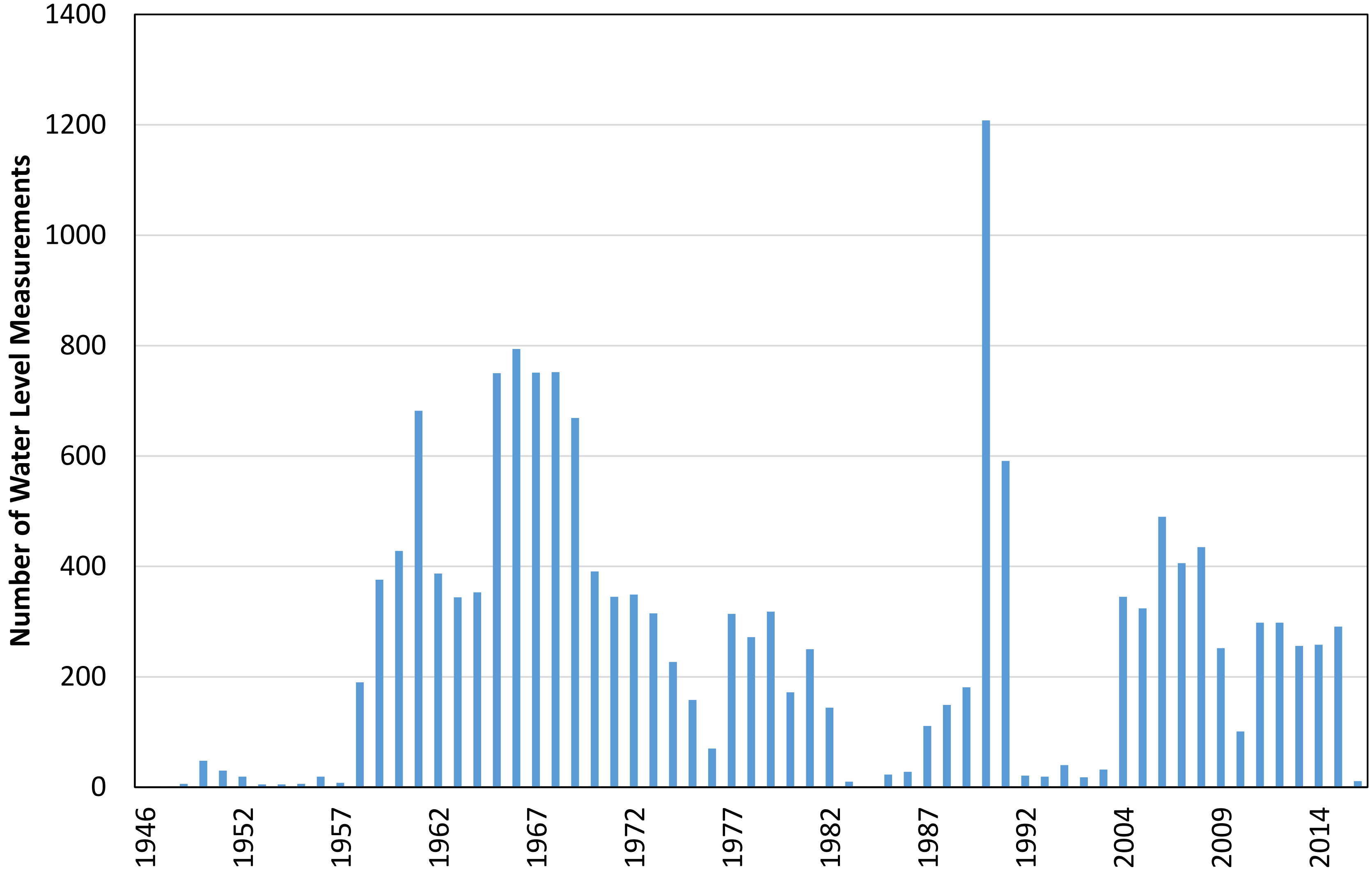

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FIGURE 3-3

Summary of Groundwater Level Data by Year

Grassland Drainage Area
Groundwater Quality Assessment Report

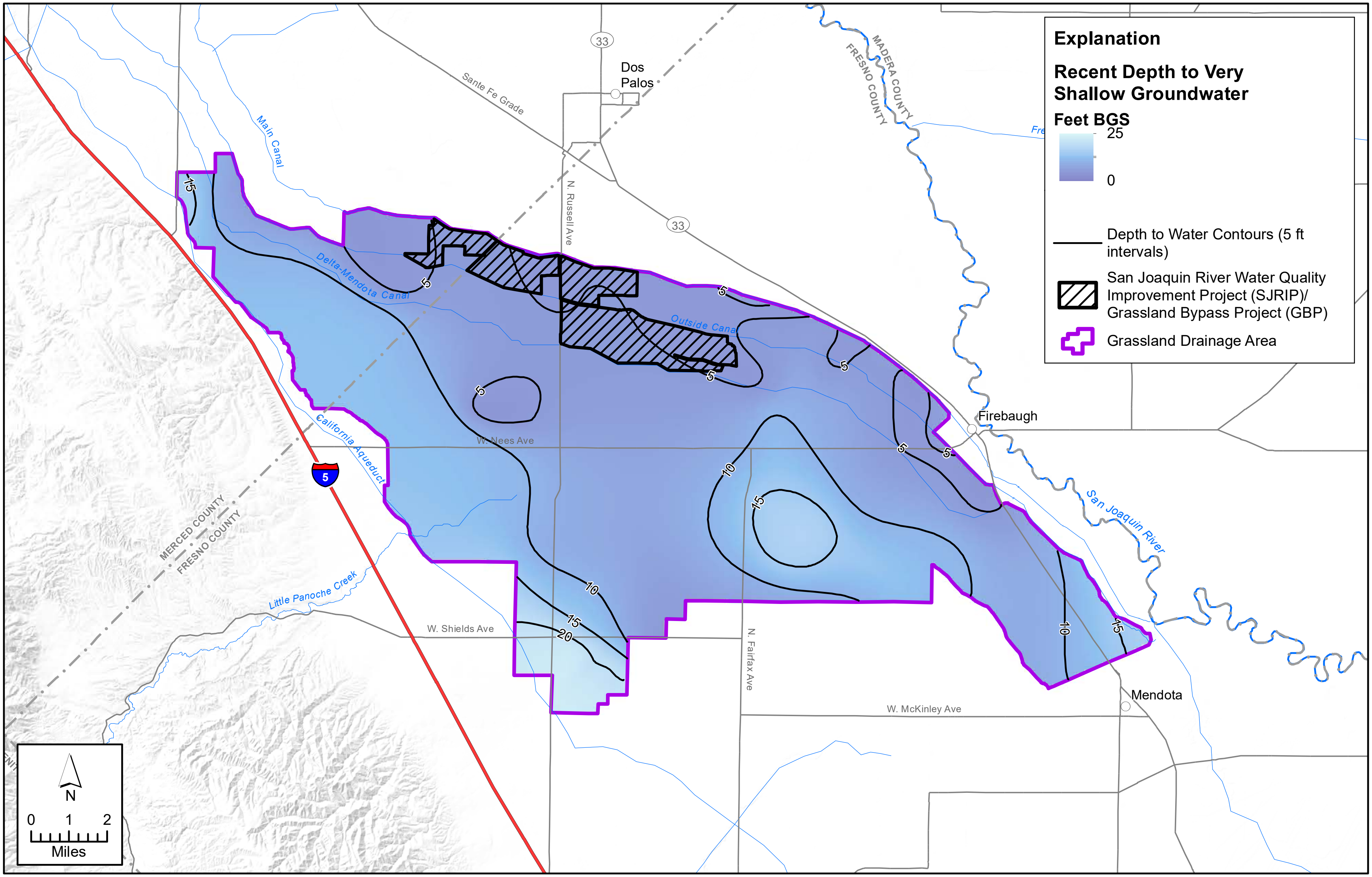

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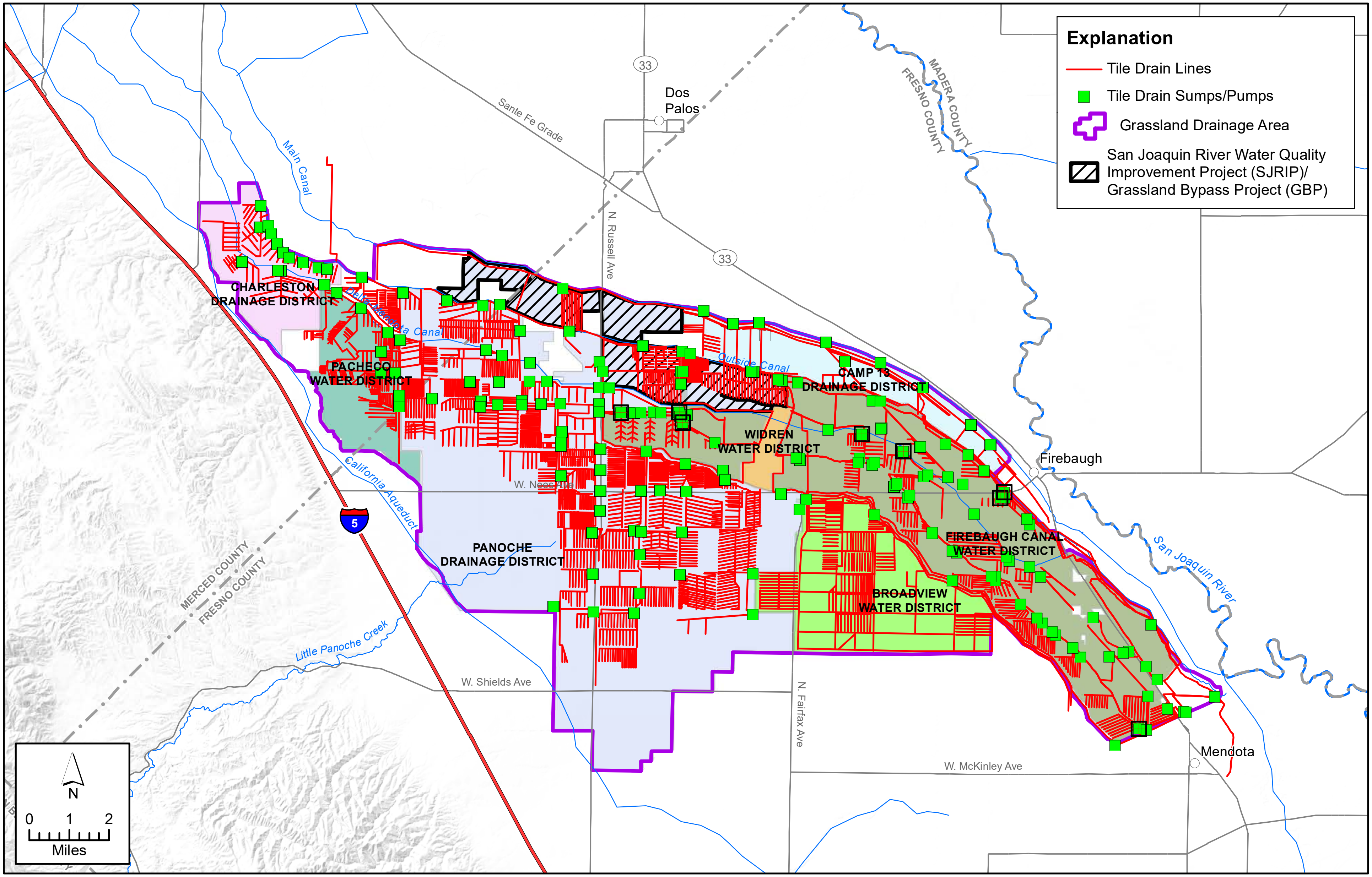
FIGURE 3-4
Map of DWR 2012 Depth to Water: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-5 Map of Tile Drains.mxd

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FIGURE 3-5

Map of Subsurface Tile Drain Locations

Grassland Drainage Area
Groundwater Quality Assessment Report

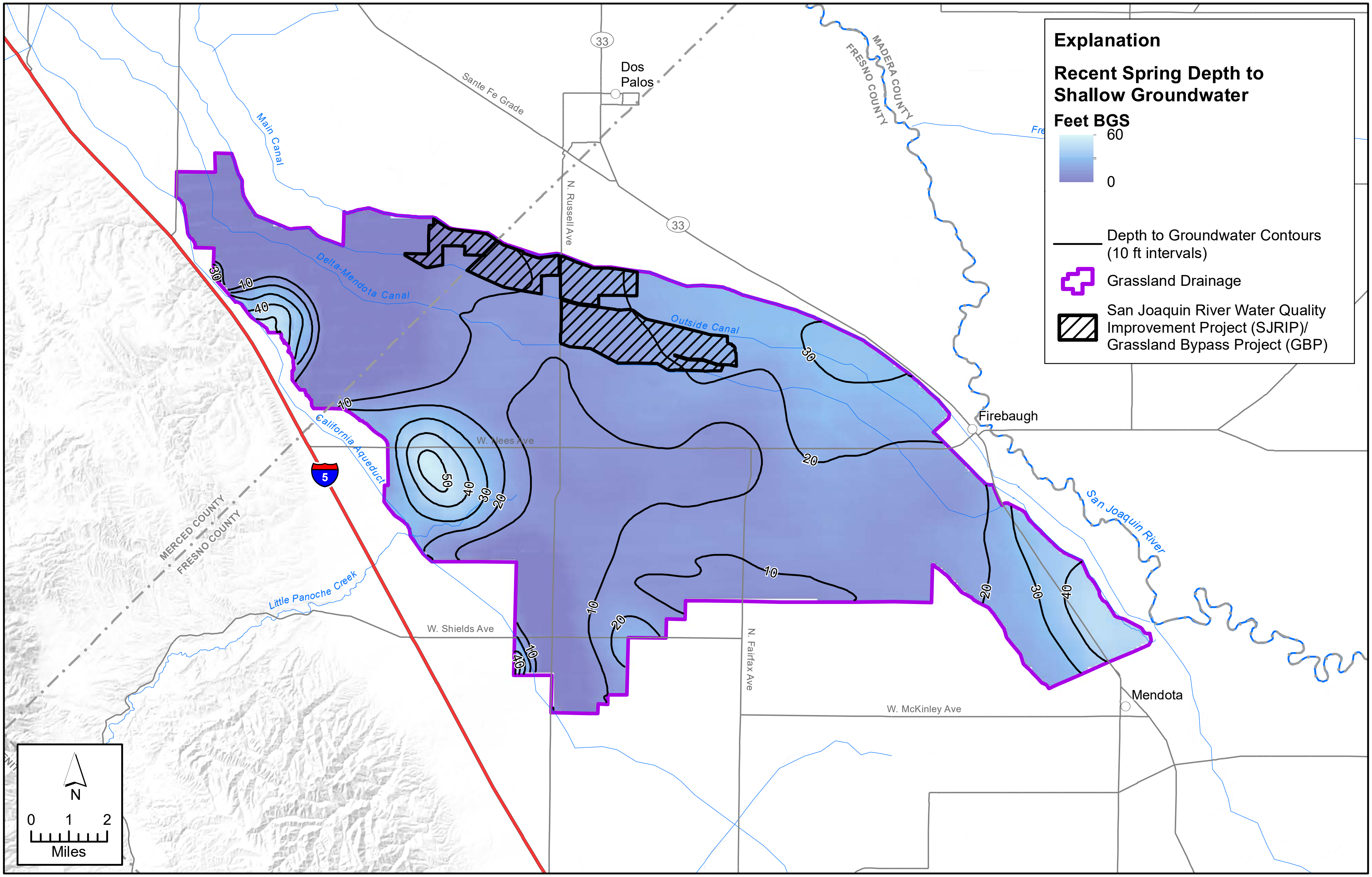

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FIGURE 3-6
Map of Recent Spring Depth to Groundwater: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

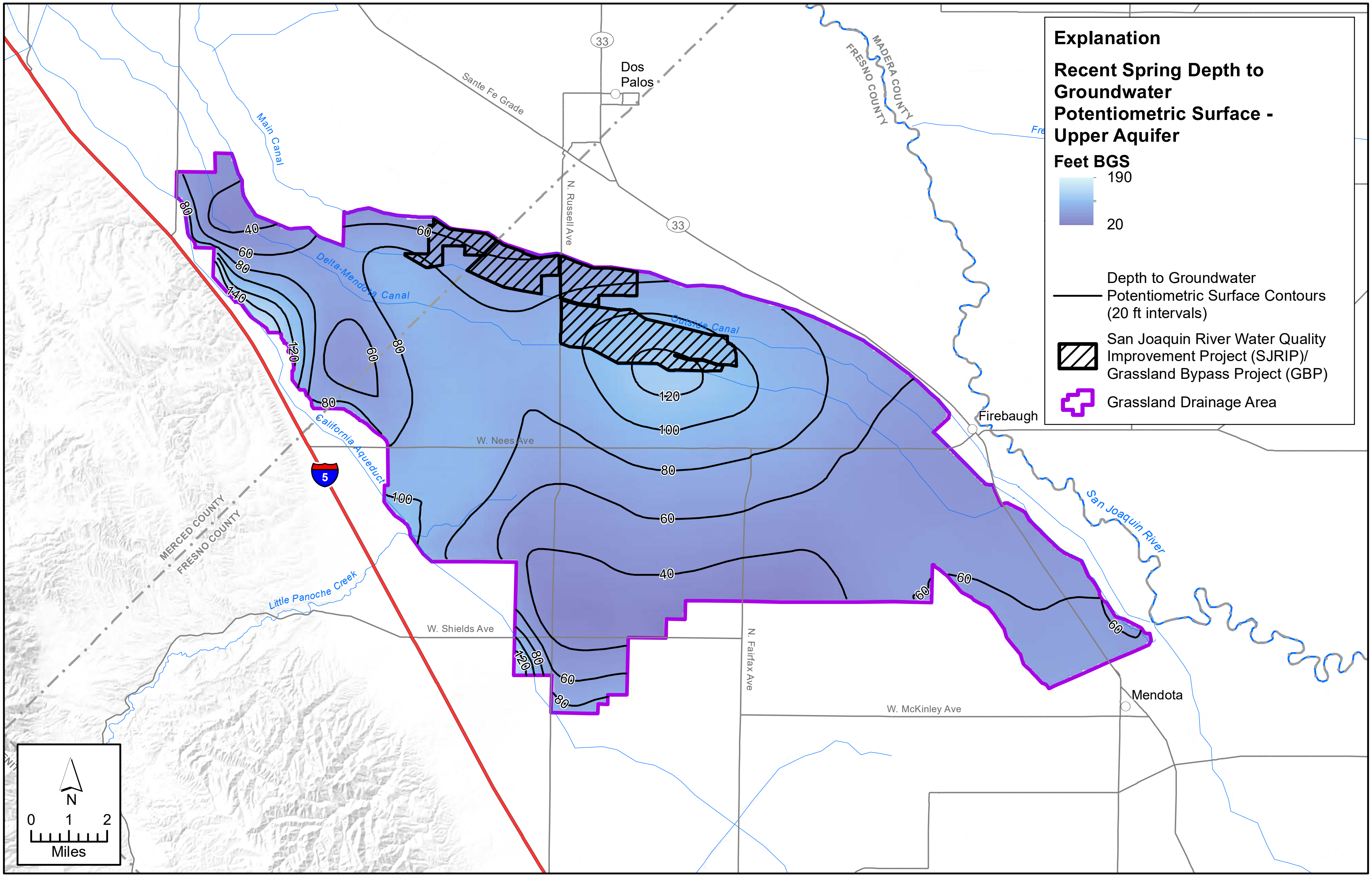

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FIGURE 3-7
Map of Recent Spring Depth to Groundwater Potentiometric Surface: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

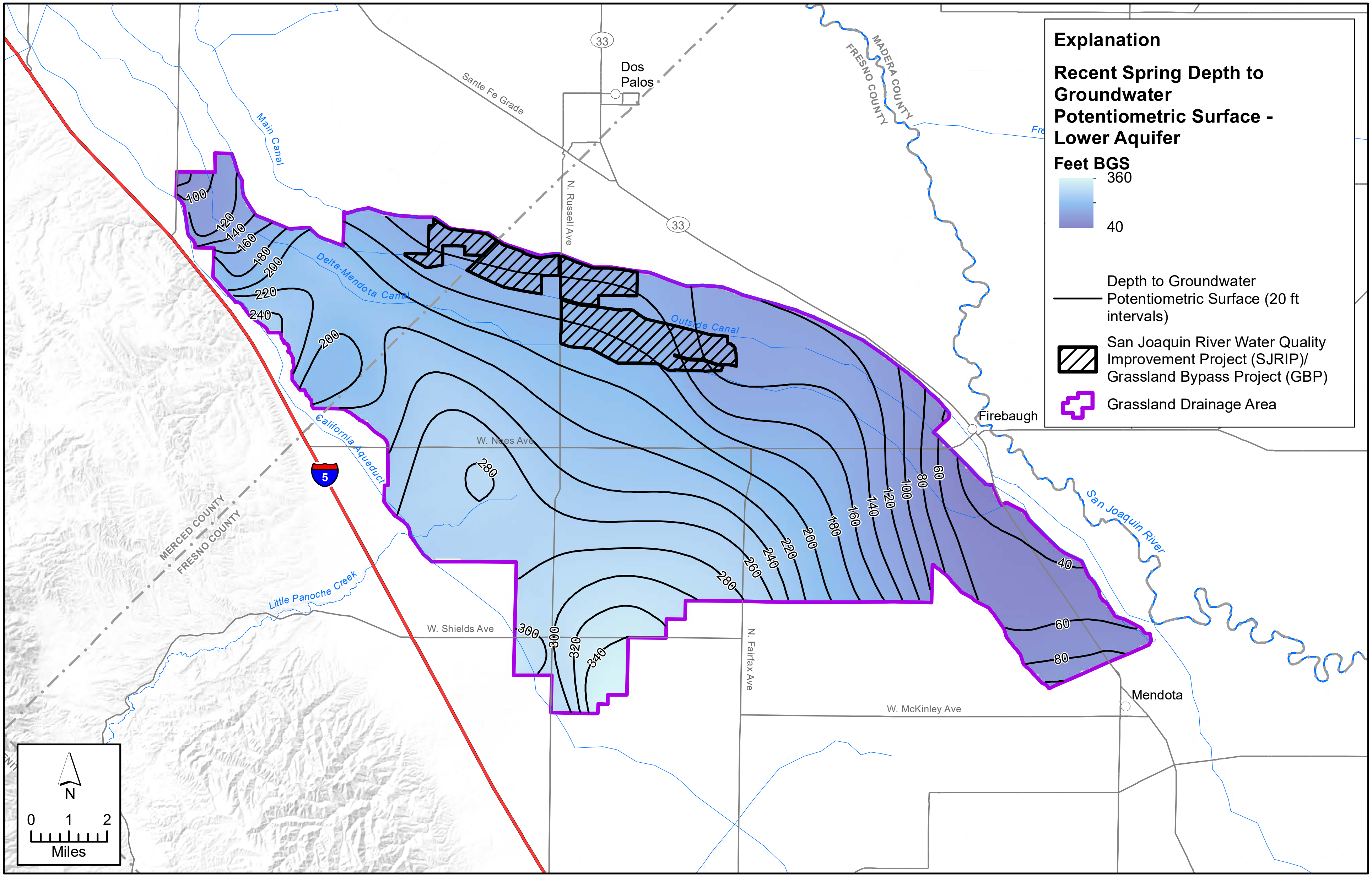

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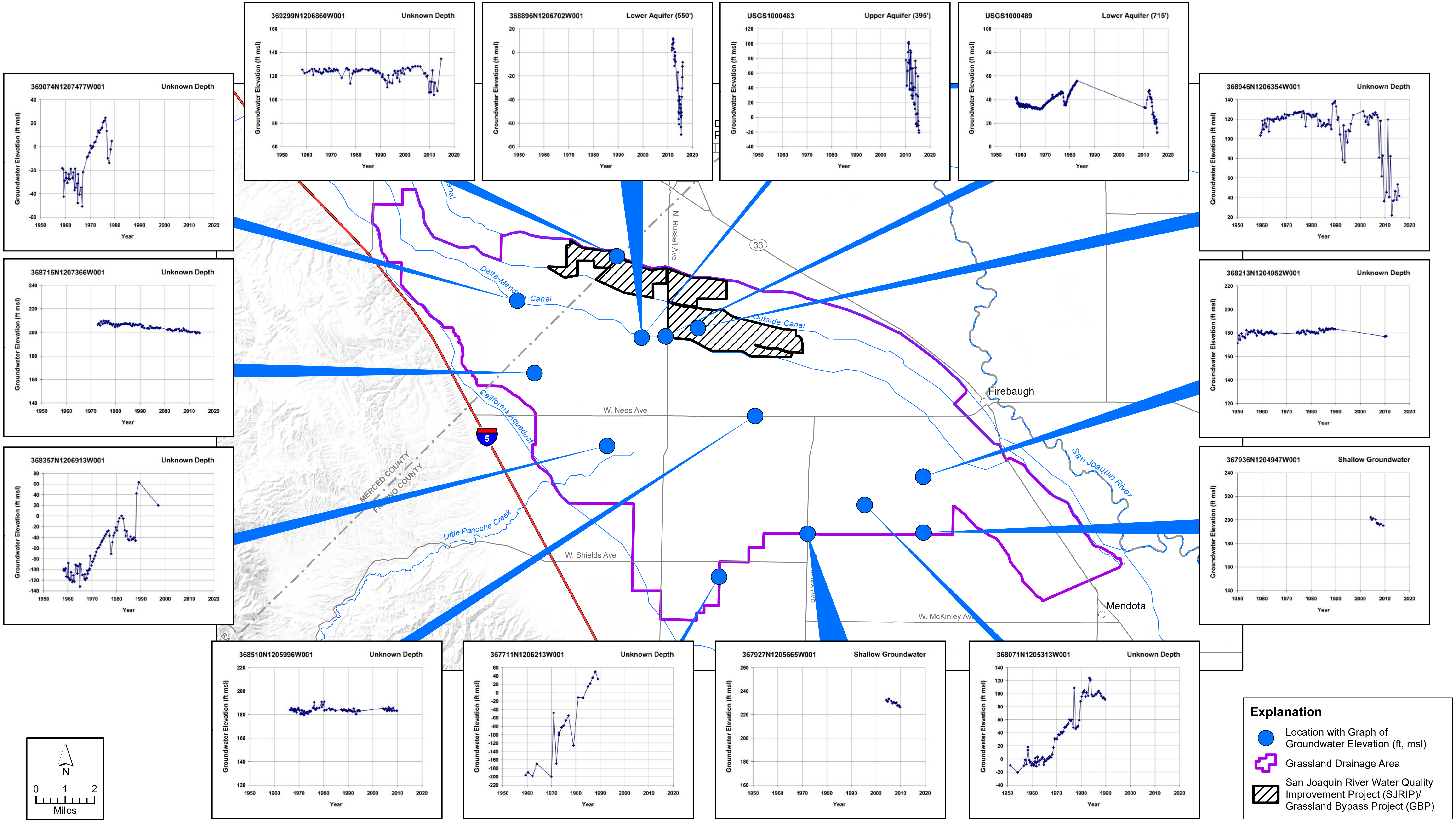
FIGURE 3-8
Map of Recent Spring Depth to Groundwater Potentiometric Surface: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-9 Select Graphs of Water Levels Various Depths.mxd

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FIGURE 3-9
Select Graphs of Groundwater Elevations: Various Depths
Grassland Drainage Area
Groundwater Quality Assessment Report

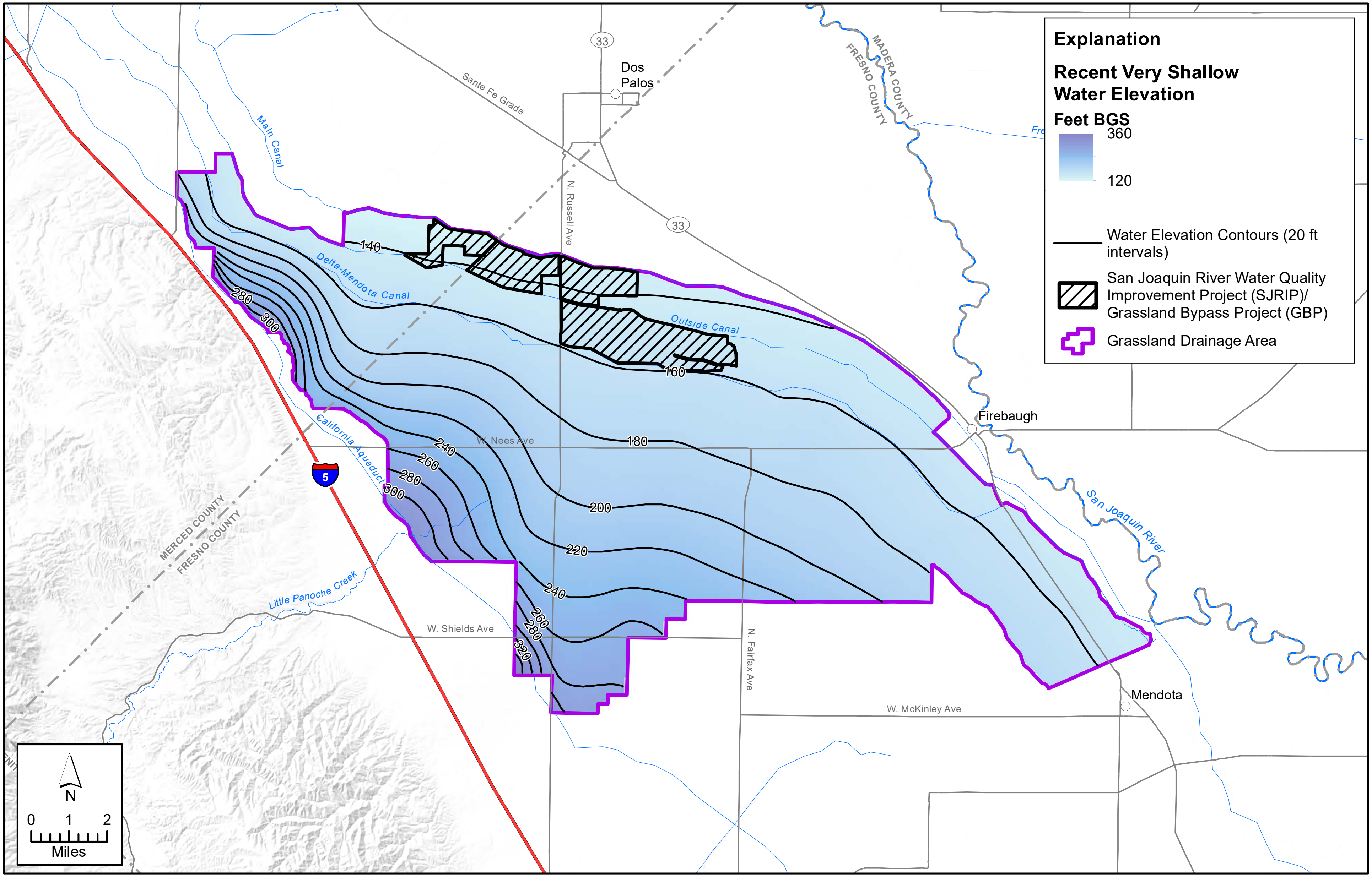

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FIGURE 3-10
Map of DWR 2012 Water Elevation: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

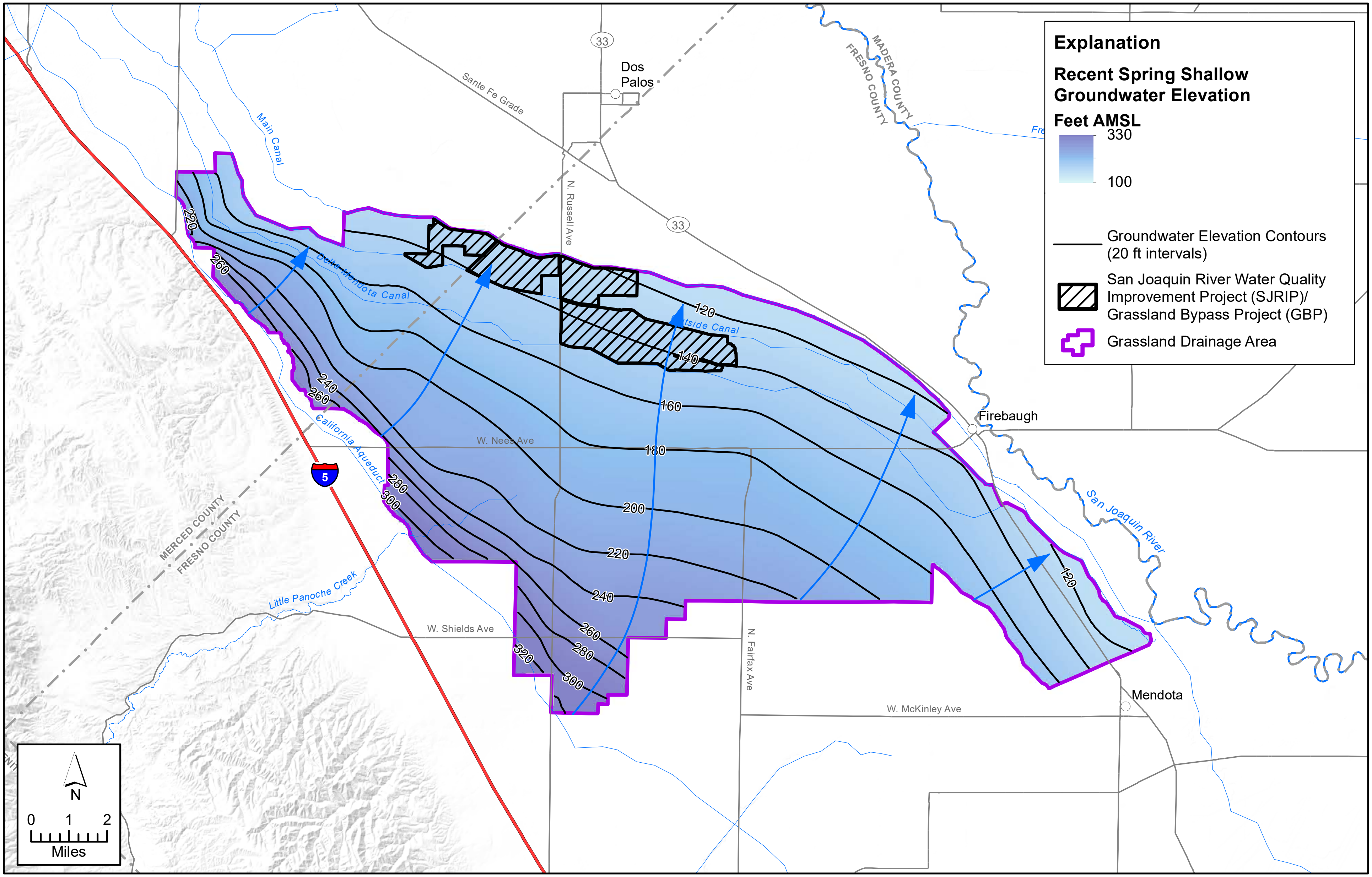

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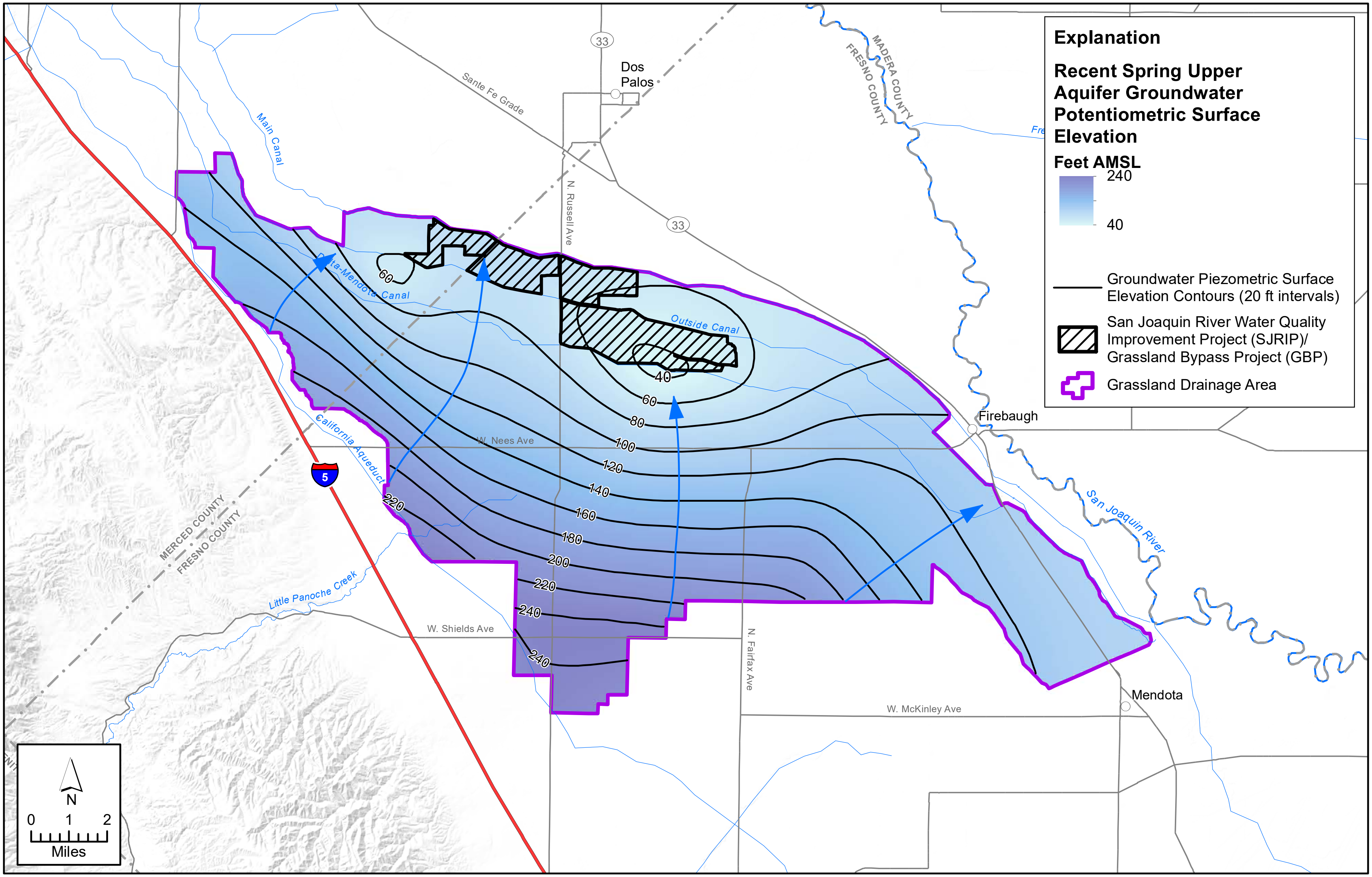
FIGURE 3-11
Map of Recent Spring Groundwater Elevation: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-12 Recent Spring Groundwater Potentiometric Surface Elevation Upper Aquifer.mxd

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FIGURE 3-12
Map of Recent Spring Groundwater Potentiometric Surface Elevation: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

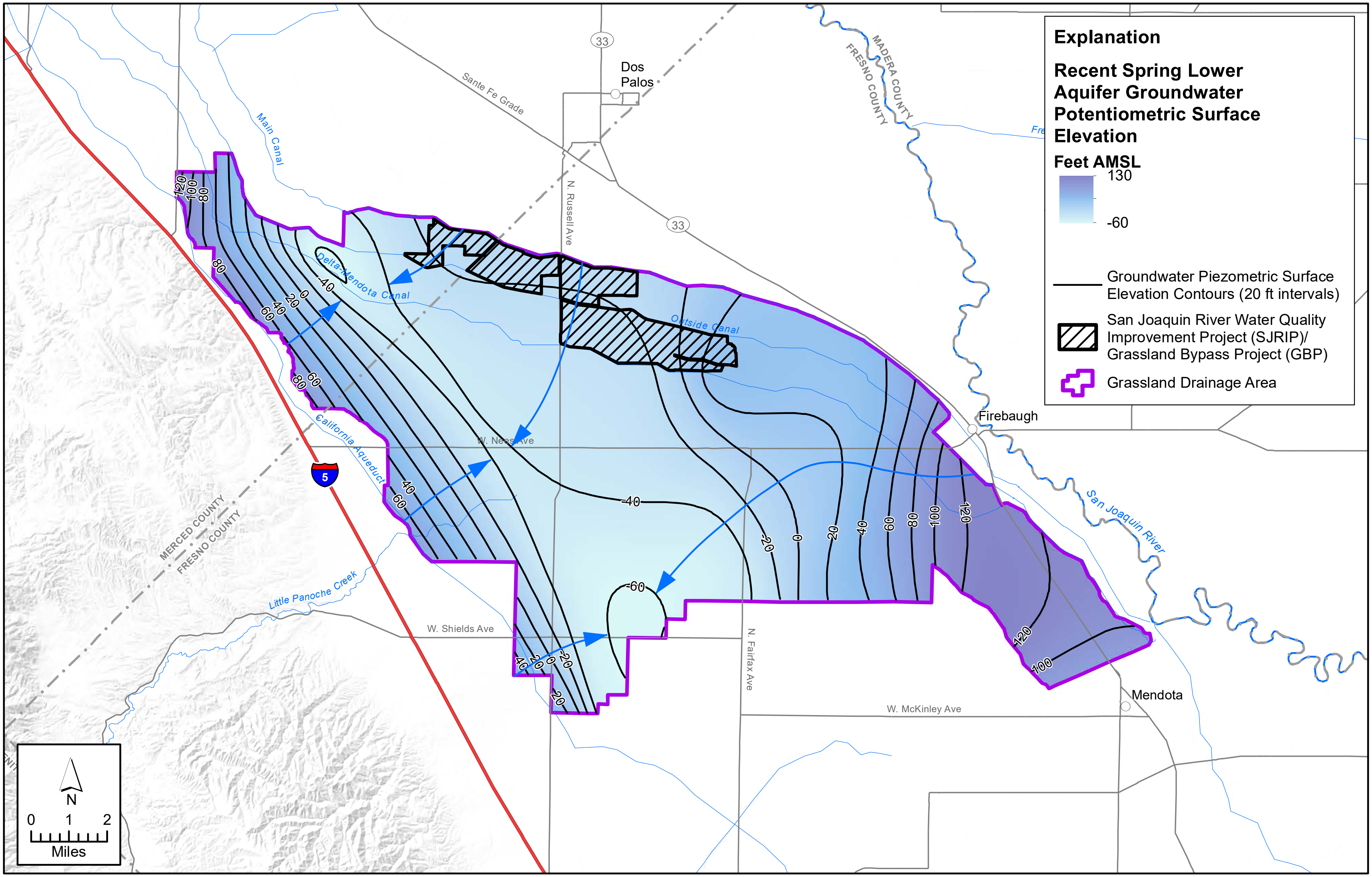

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FIGURE 3-13
Map of Recent Spring Groundwater Potentiometric Surface Elevation: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

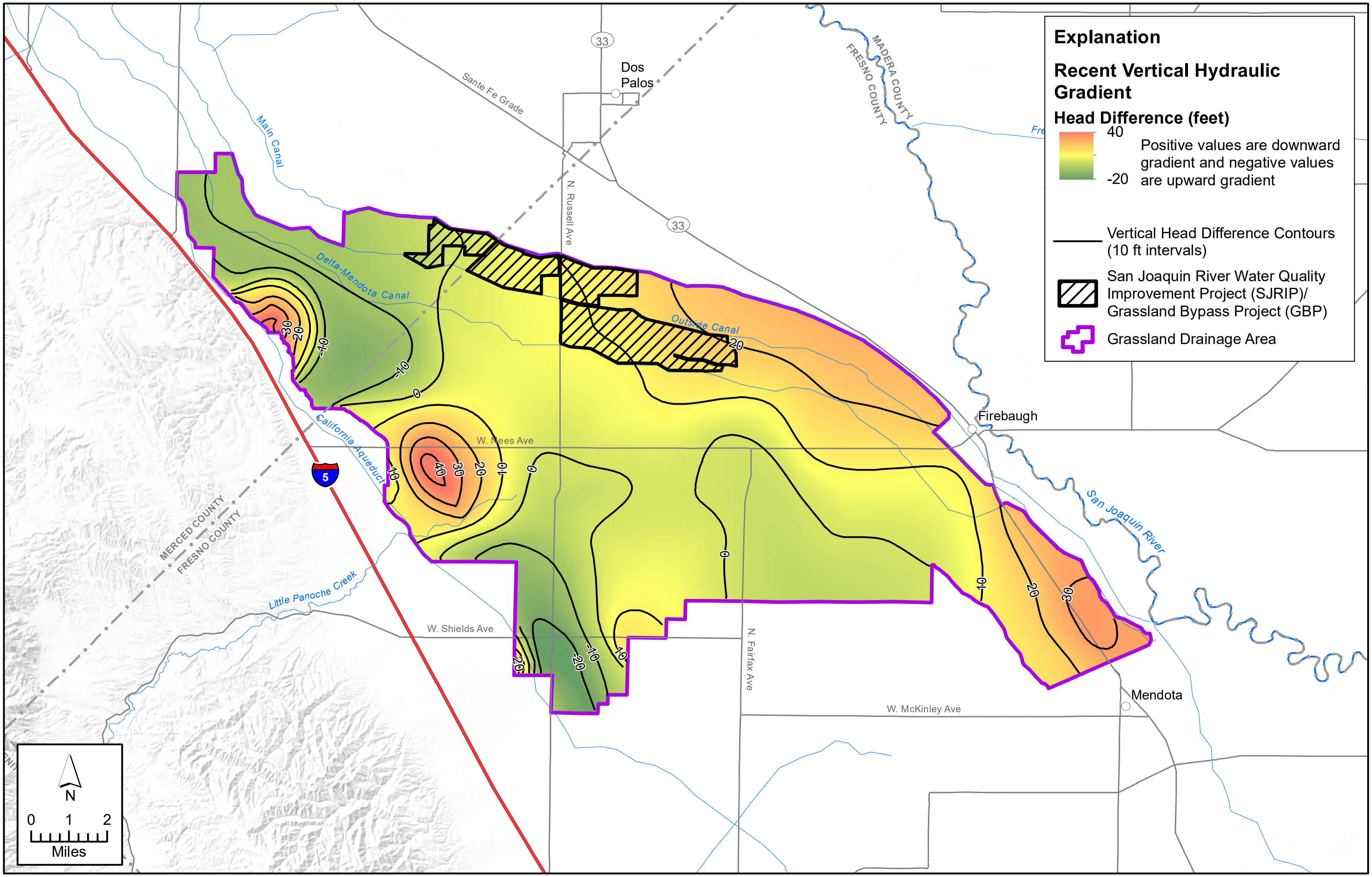

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FIGURE 3-14
Map of Recent Vertical Hydraulic Gradient: Very Shallow Water to Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

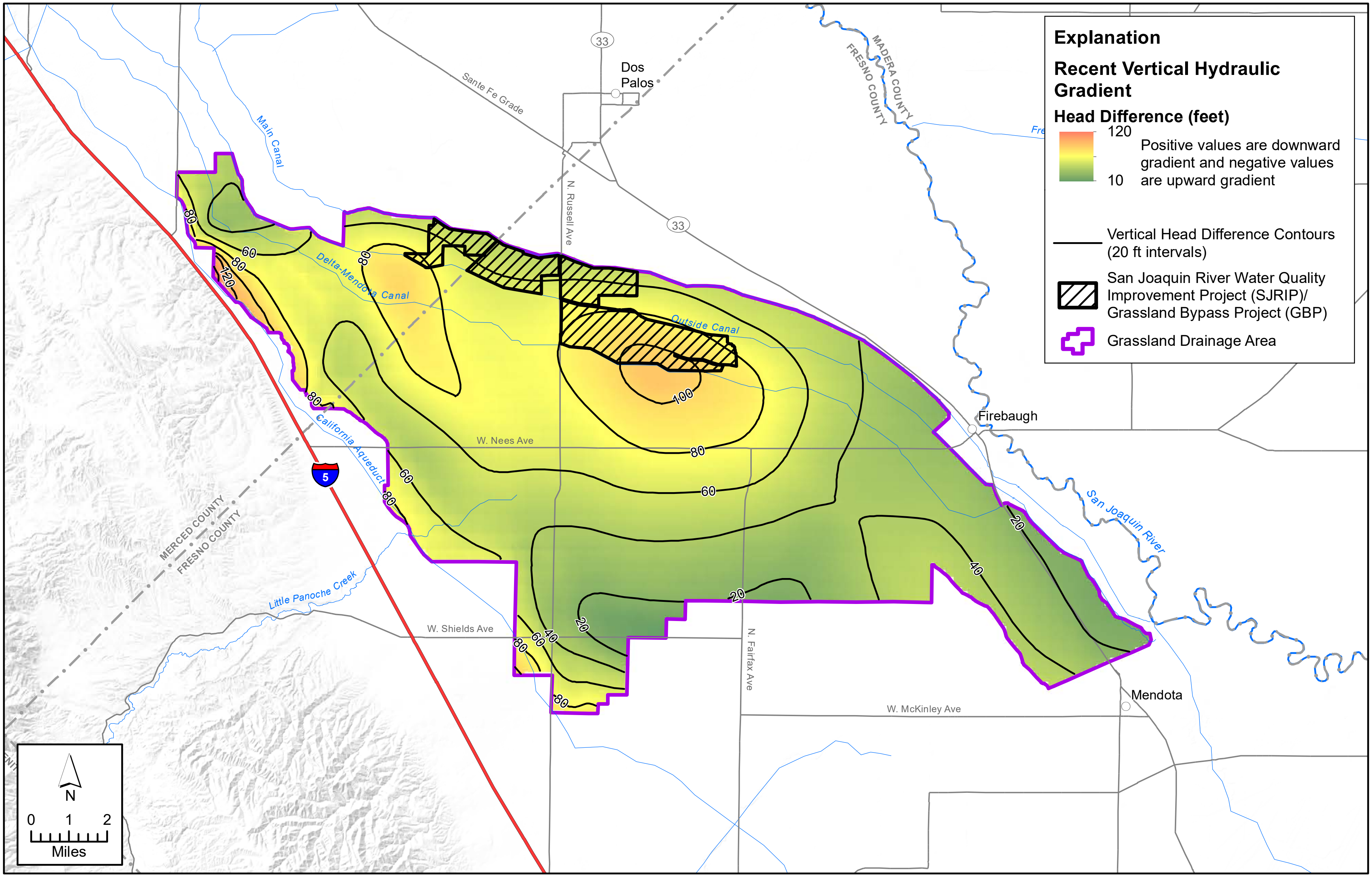

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FIGURE 3-15
Map of Recent Vertical Hydraulic Gradient: Shallow Groundwater to Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

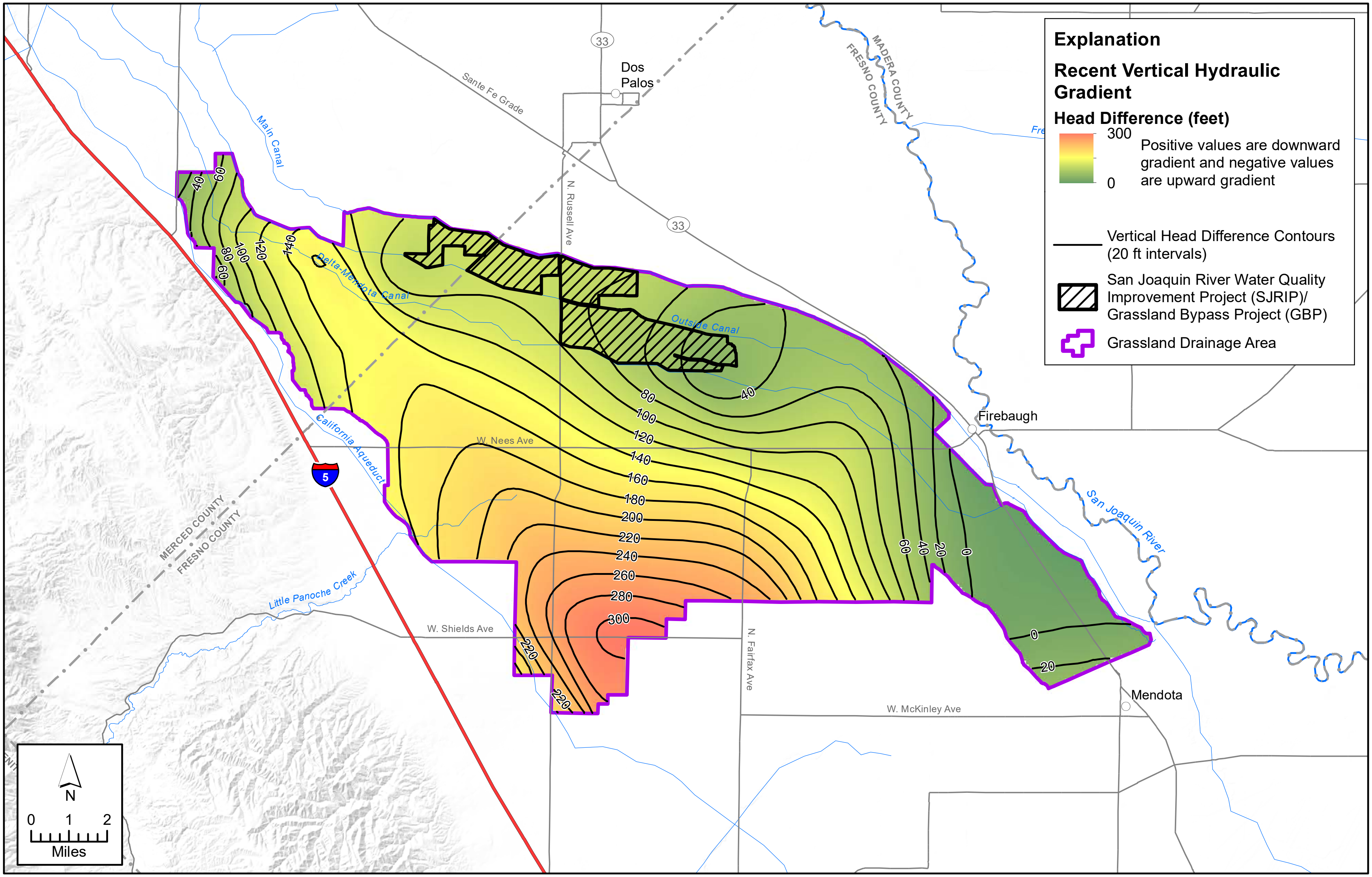

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FIGURE 3-16
Map of Recent Vertical Hydraulic Gradient: Upper to Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

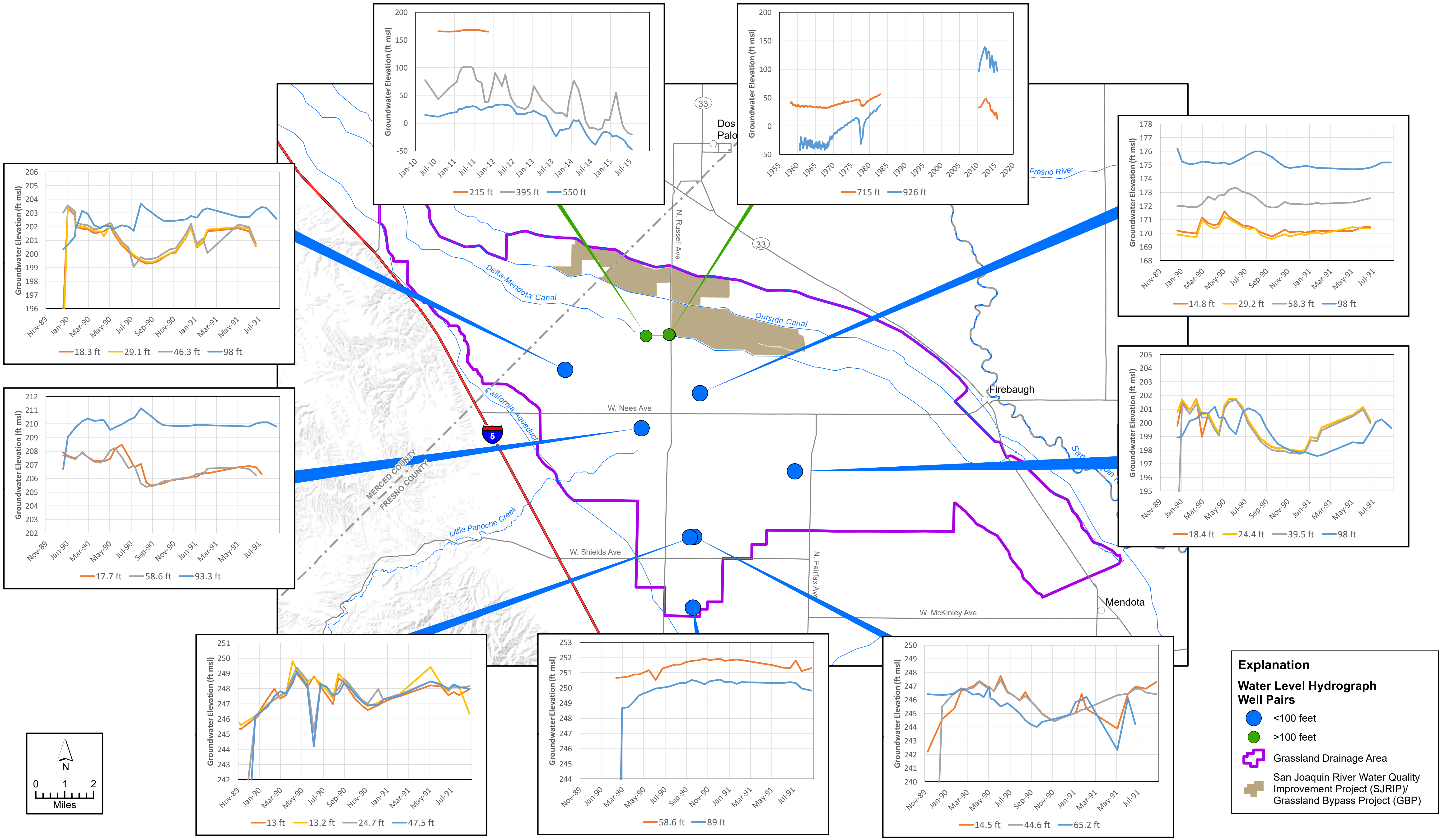

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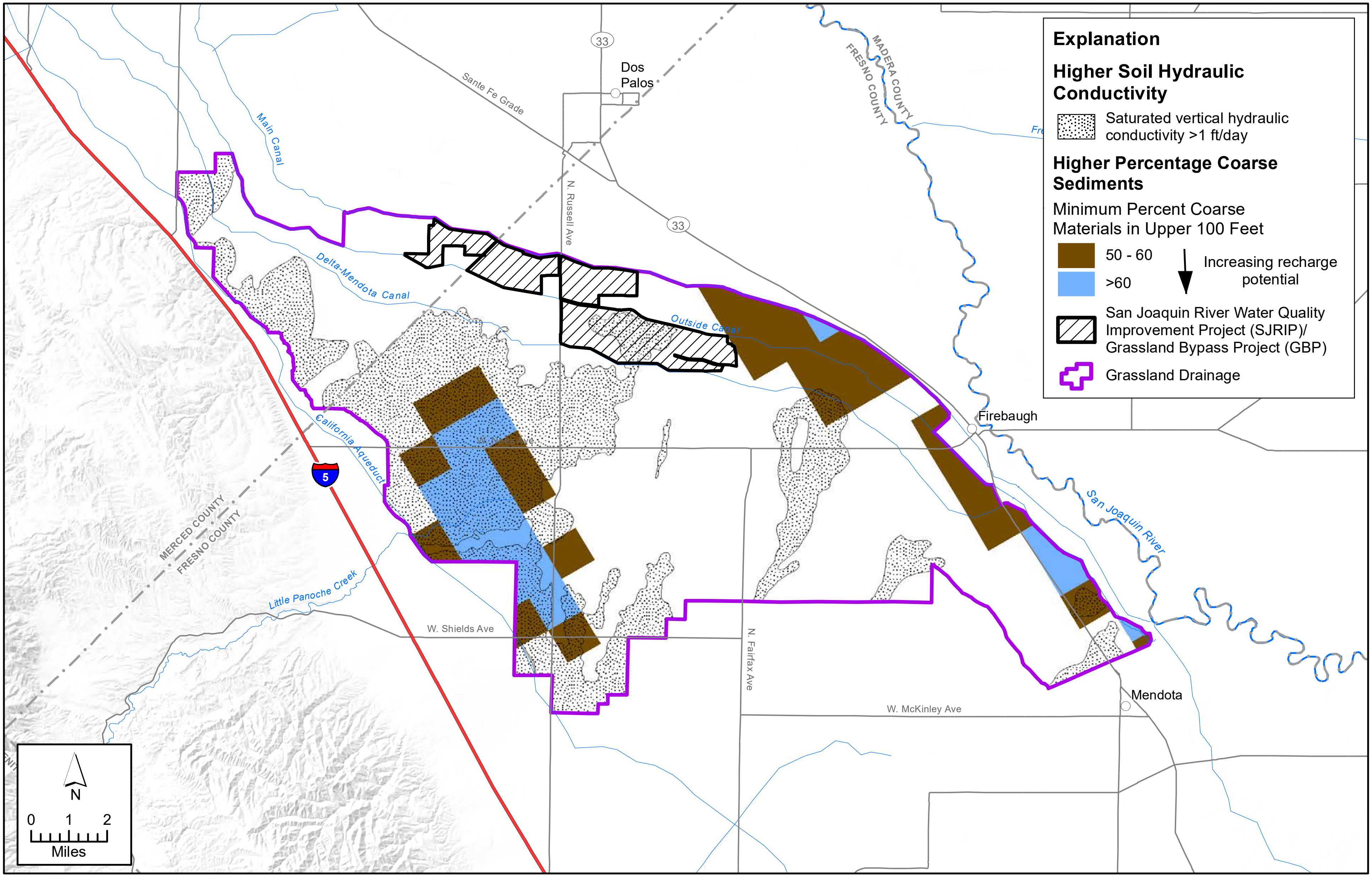
FIGURE 3-17

Water Level Hydrograph Pairs

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-22 Areas with Higher Potential for Groundwater Recharge.mxd

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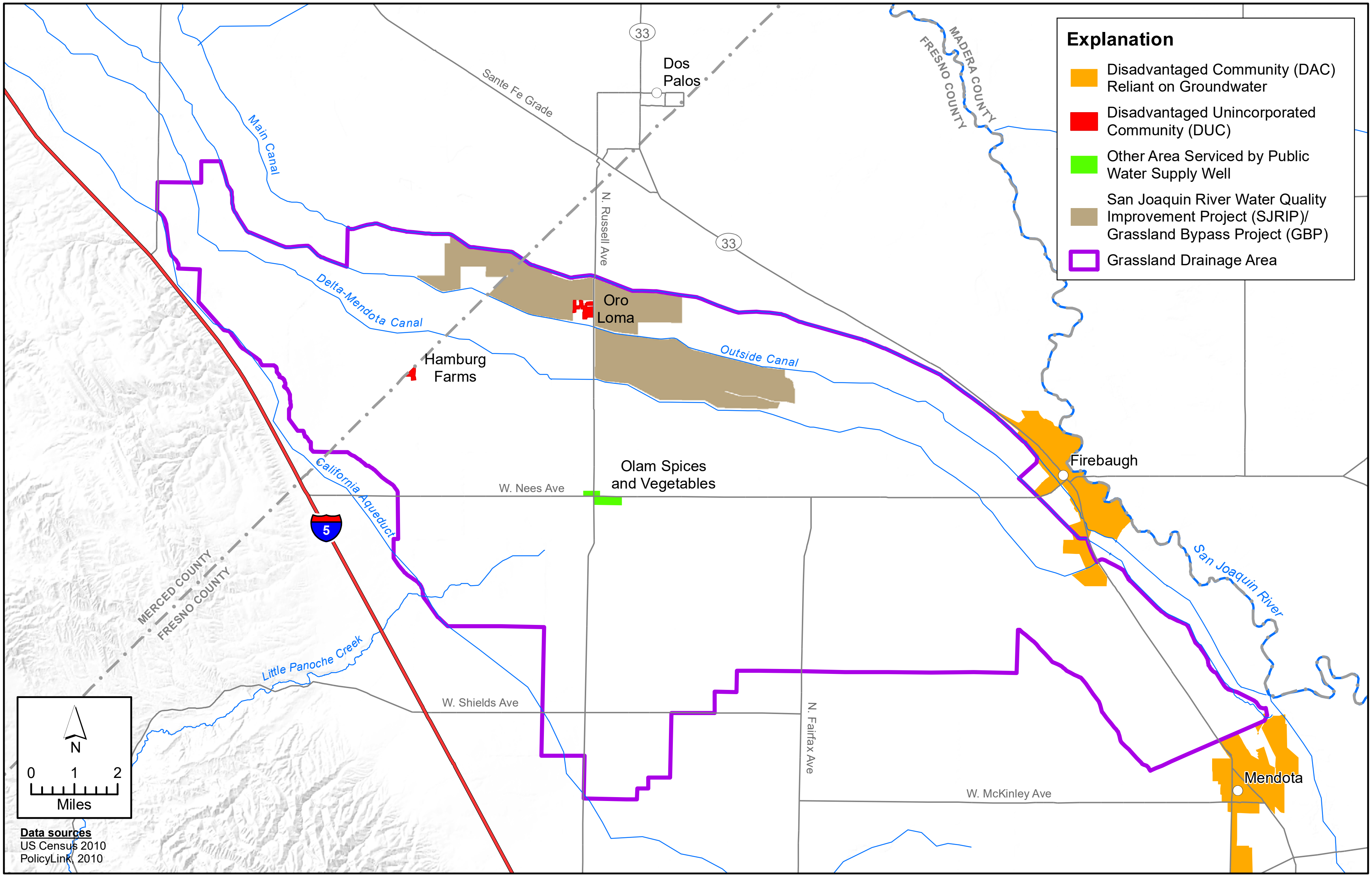
FIGURE 3-18
Map of Areas With Higher Potential for Groundwater Recharge
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-19 Communities Reliant on Groundwater.mxd

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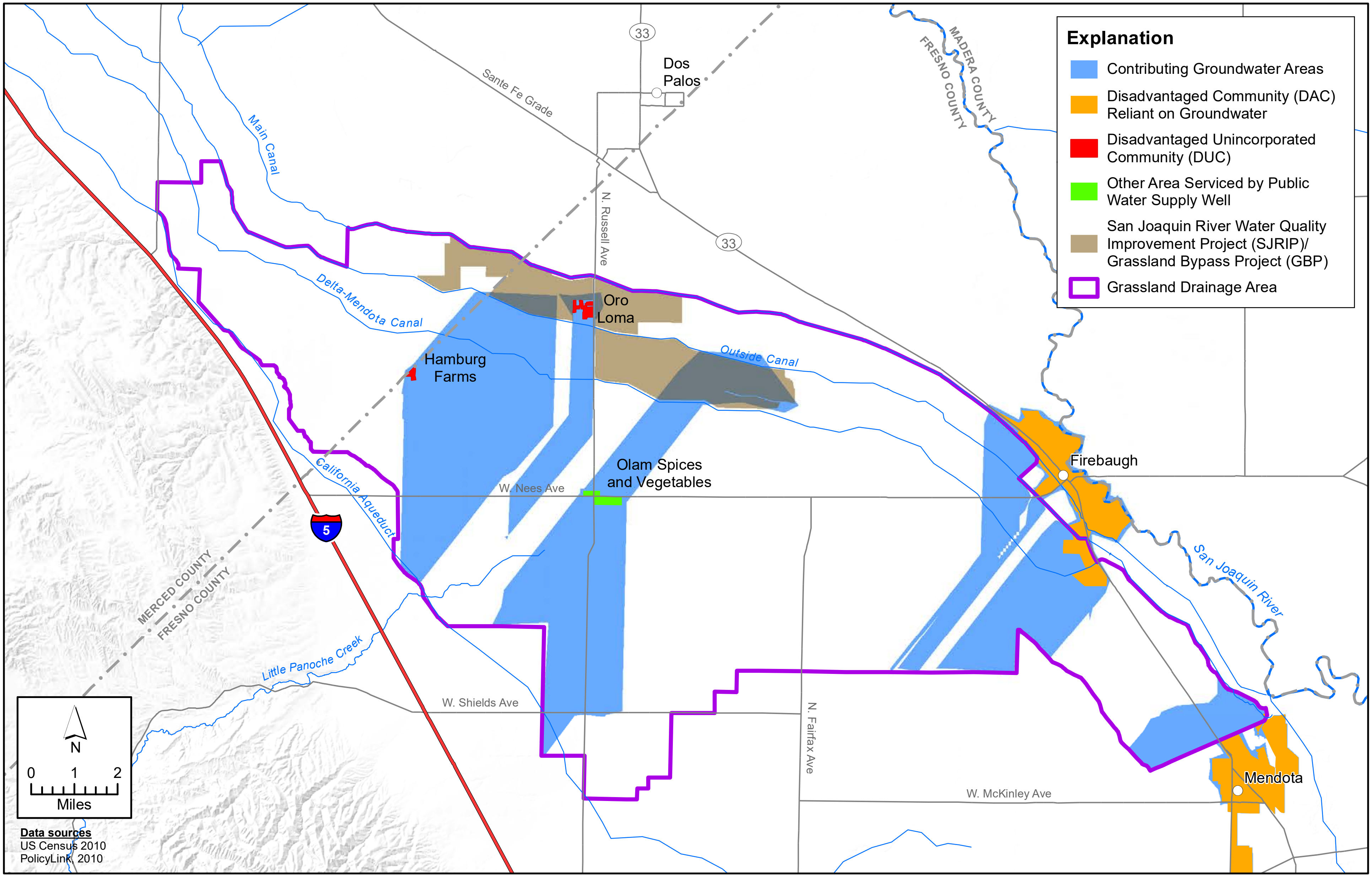
FIGURE 3-19

Map of Communities Reliant on Groundwater

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-20 Contributing Groundwater Areas for Communities Reliant on Groundwater.mxd

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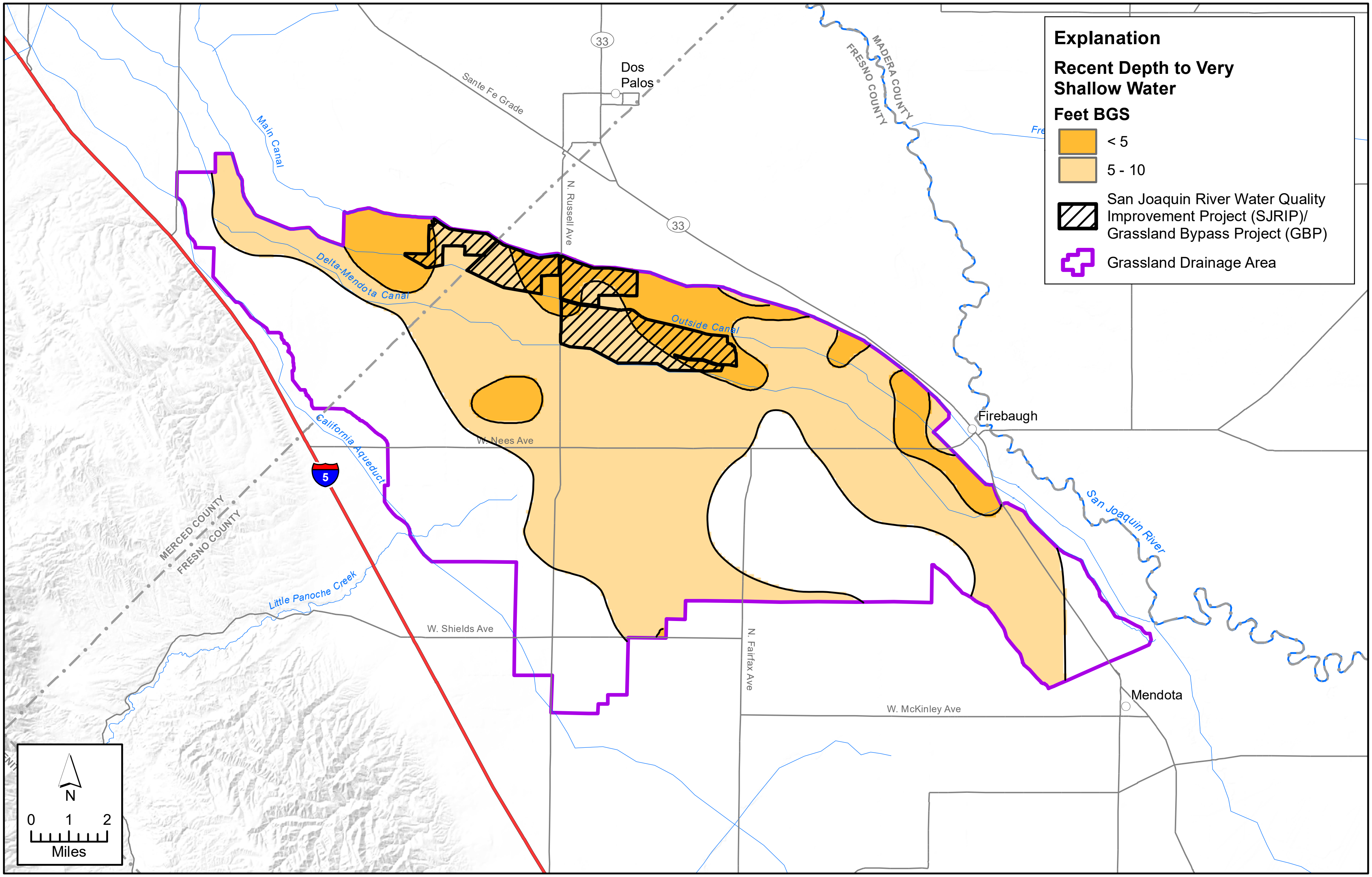
FIGURE 3-20
Map of Contributing Groundwater Areas for Communities Reliant on Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 3-22 Areas for Potential Evapoconcentration in Very Shallow Water.mxd

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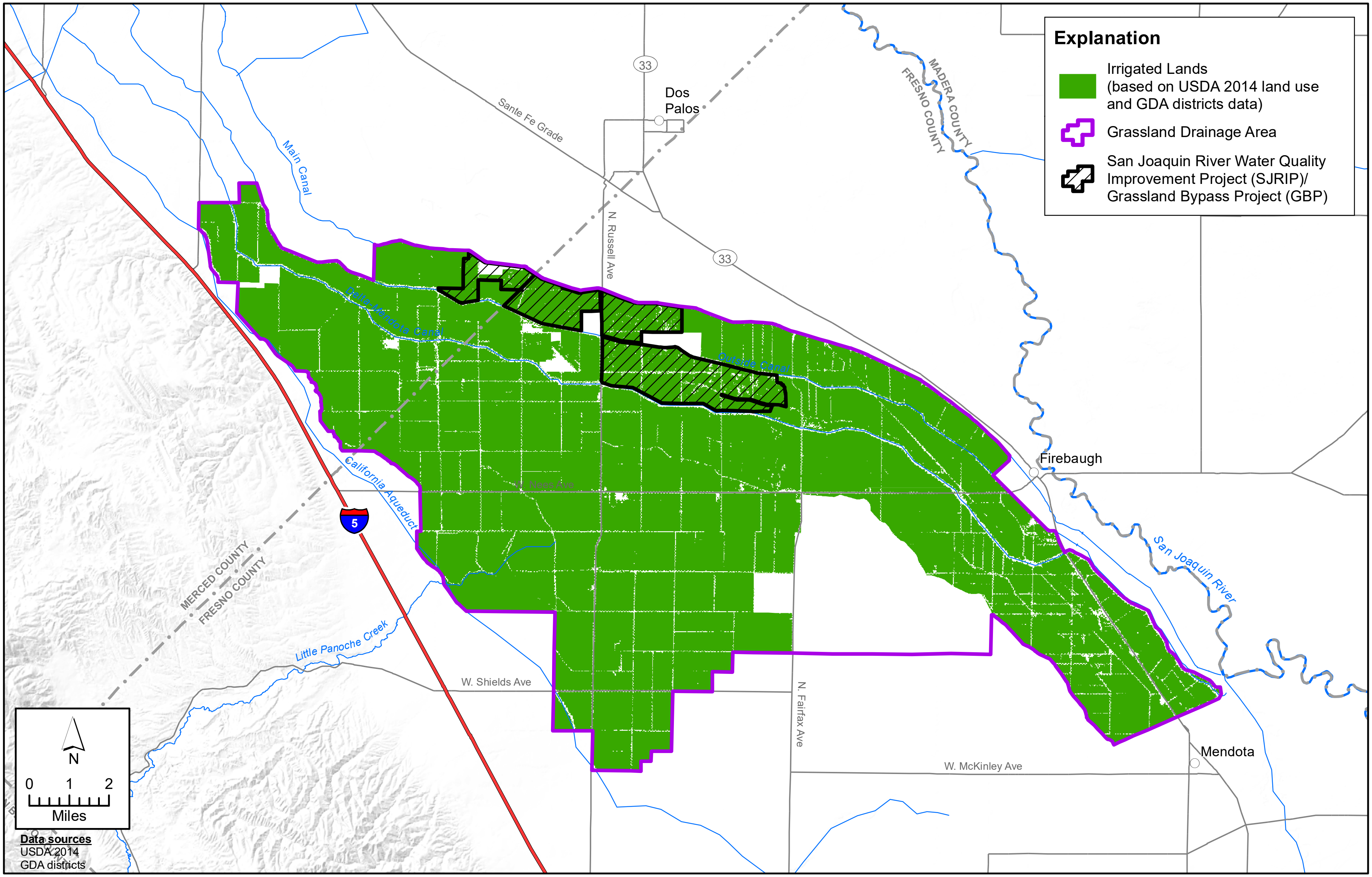
FIGURE 3-21
Areas for Potential Evapoconcentration: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 4-1 Map of Irrigated Areas.mxd

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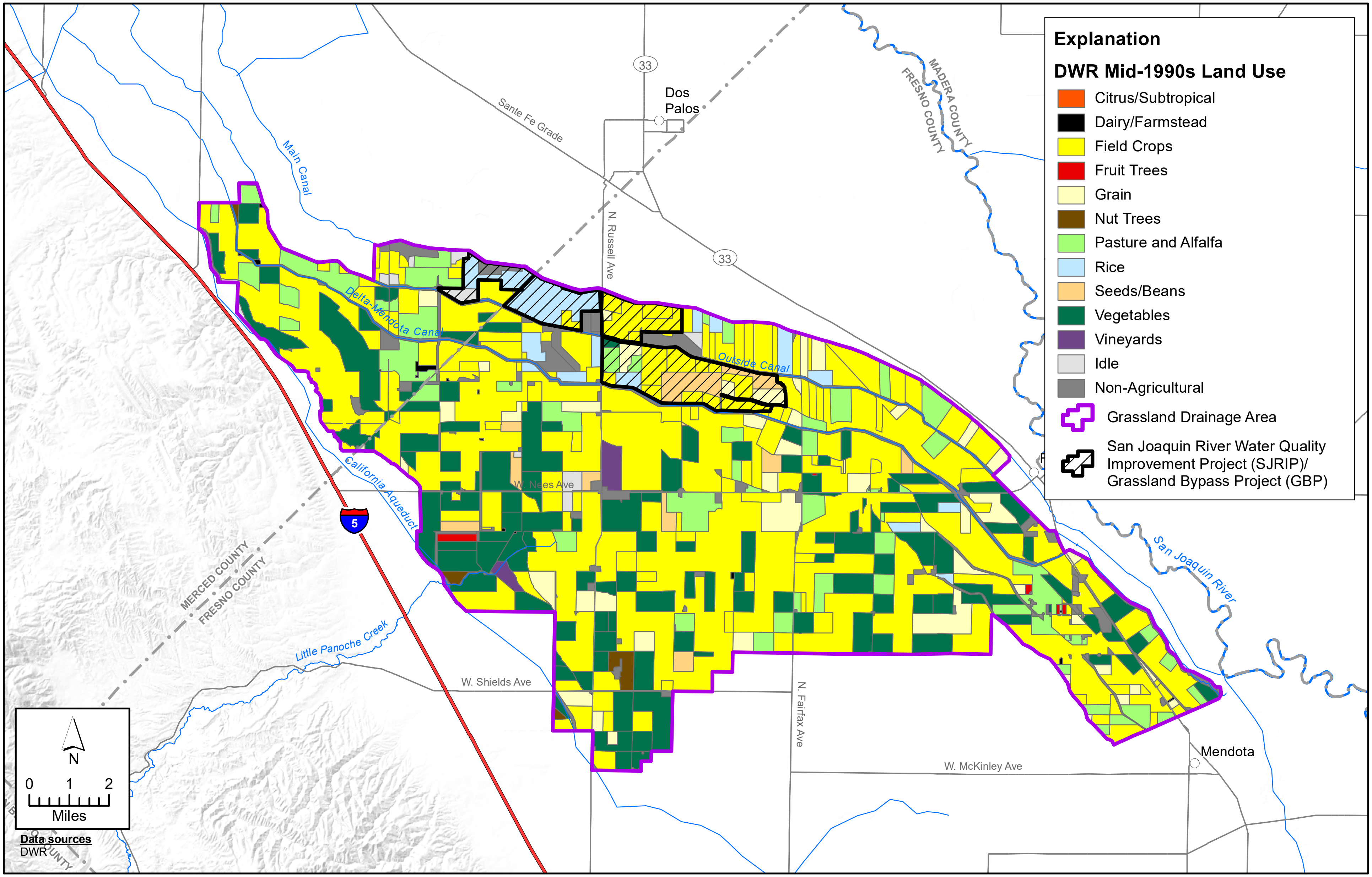
FIGURE 4-1

Map of Irrigated Lands

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 4-2 DWR Circa-1990 Land Use.mxd

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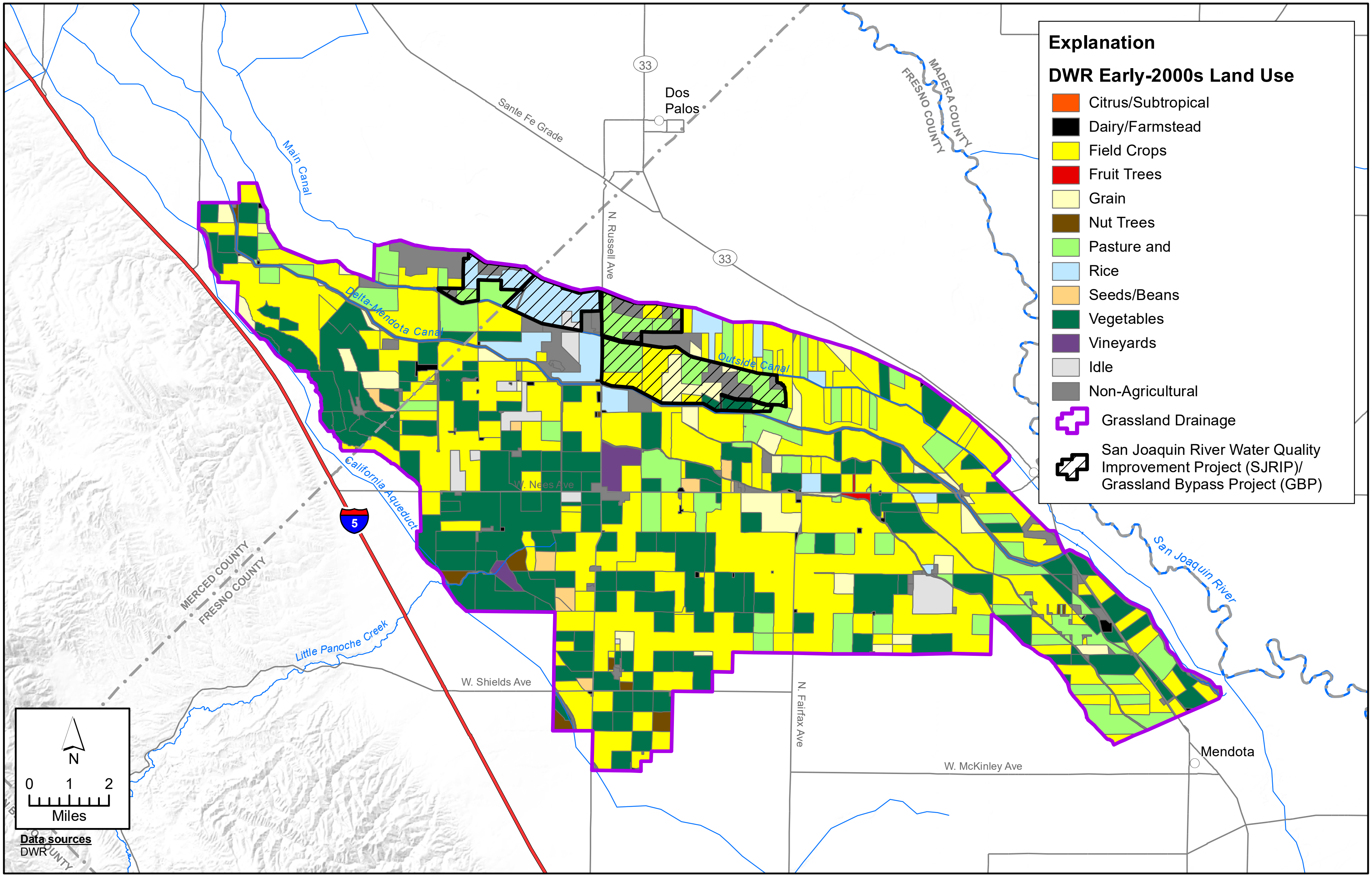
FIGURE 4-2

Map of DWR Mid-1990s Land Use

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 4-3 DWR Circa-2000 Land Use.mxd

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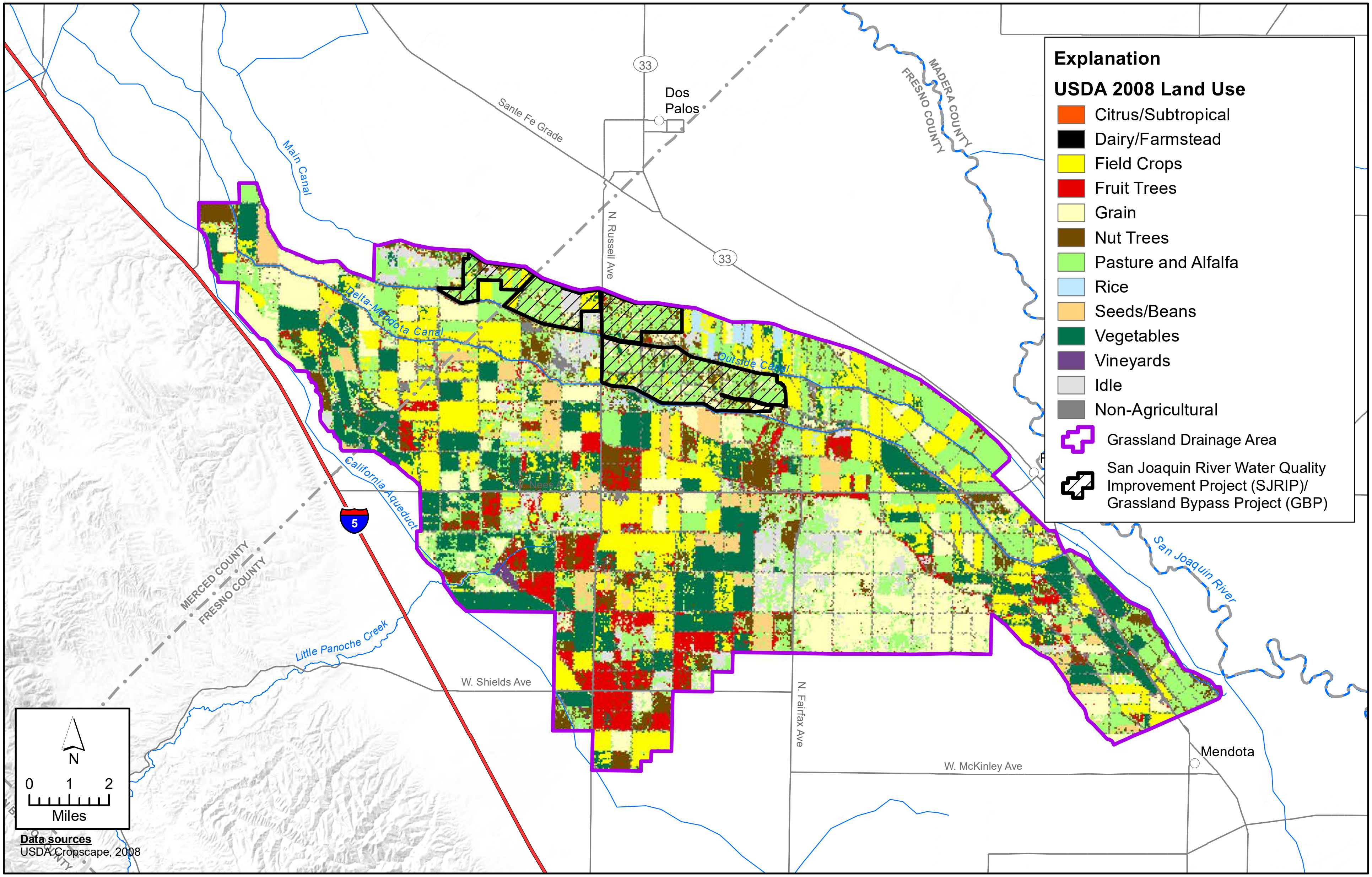
FIGURE 4-3

Map of DWR Early-2000s Land Use

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 4-4 USDA 2008 Land Use.mxd

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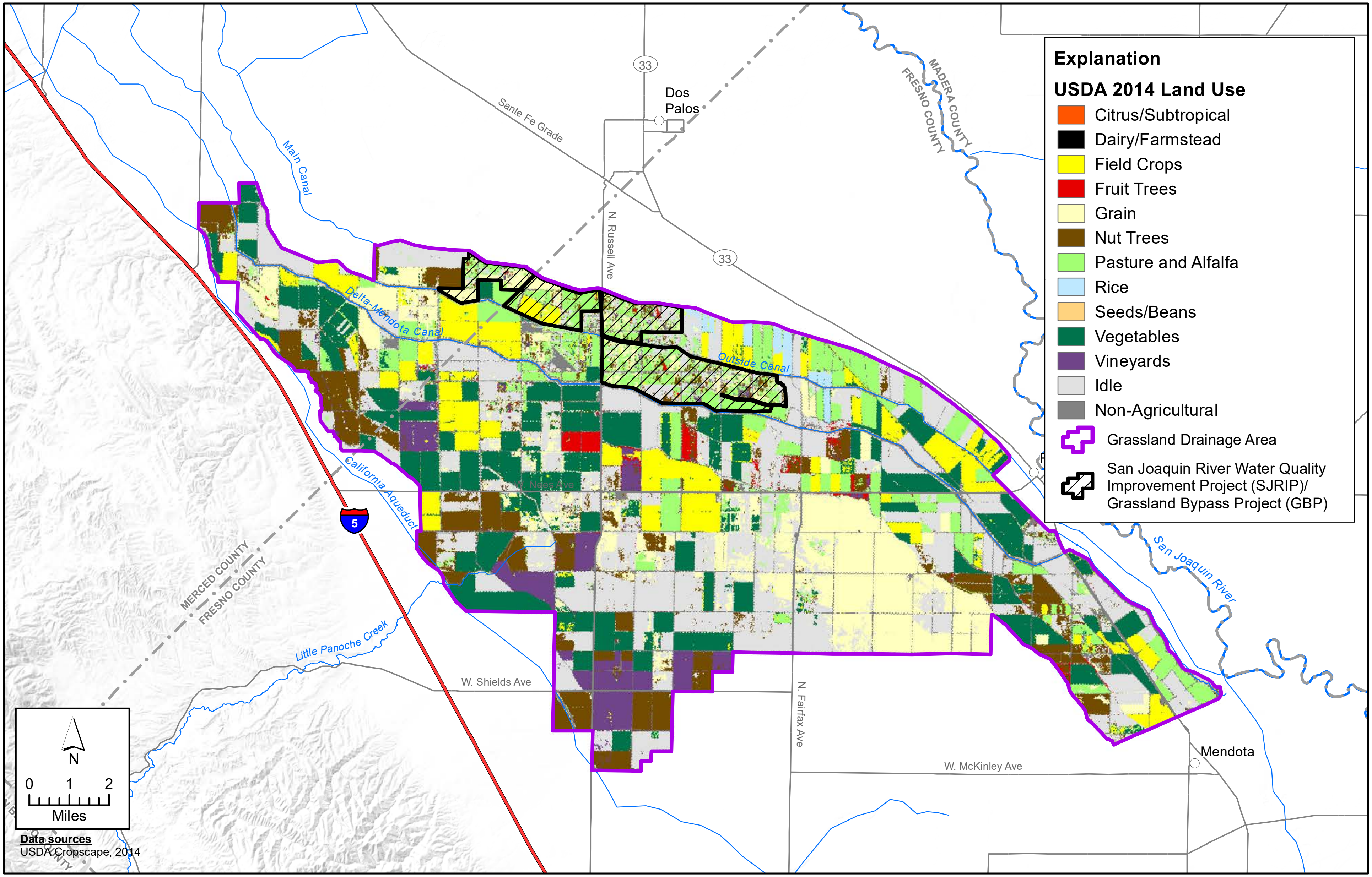
FIGURE 4-4

Map of USDA 2008 Land Use

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 4-5 USDA 2014 Land Use.mxd

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FIGURE 4-5

Map of USDA 2014 Land Use

Grassland Drainage Area
Groundwater Quality Assessment Report

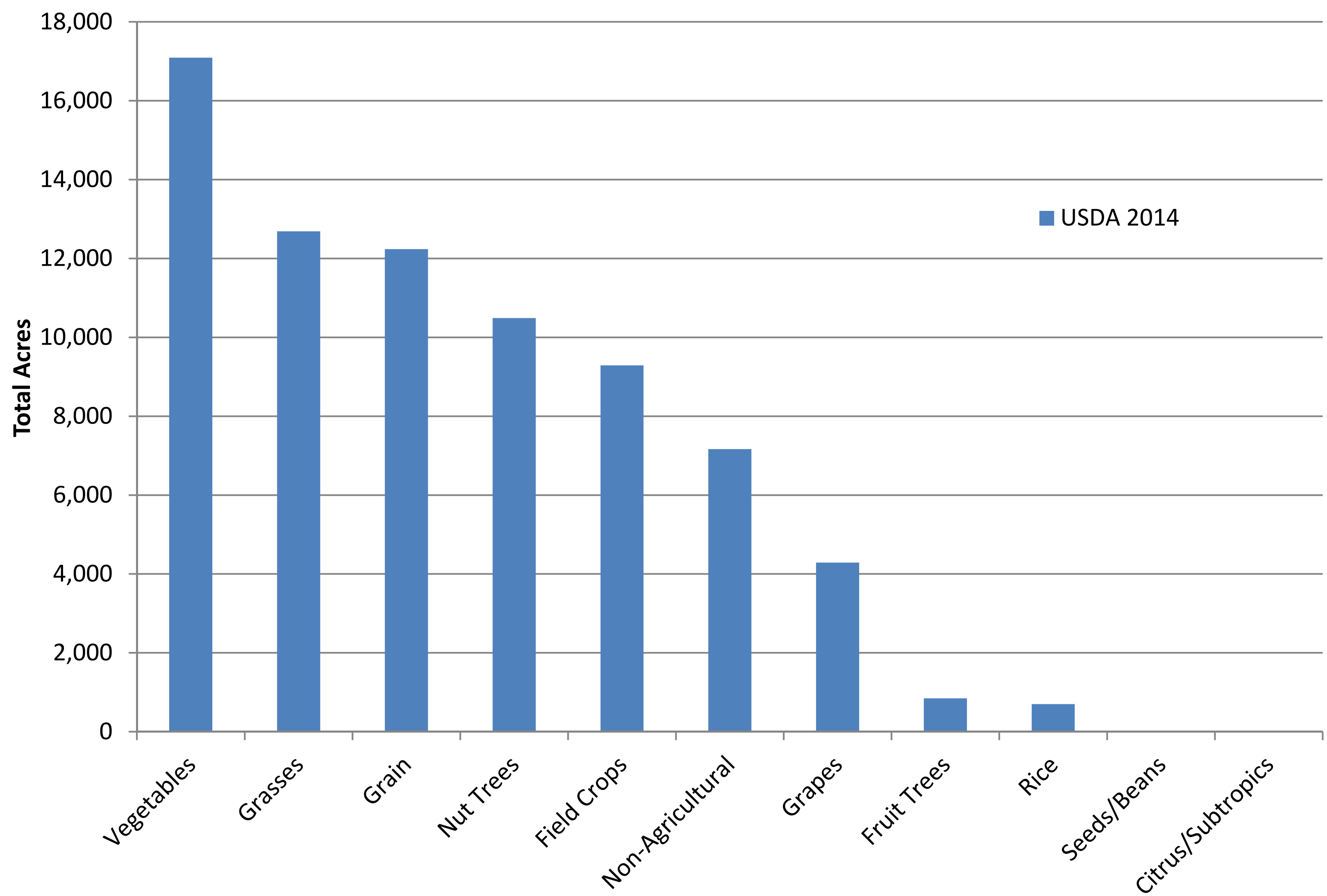

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FIGURE 4-6

Top Crop Categories in 2014 by Acreage Within the GDA

Grassland Drainage Area
Groundwater Quality Assessment Report

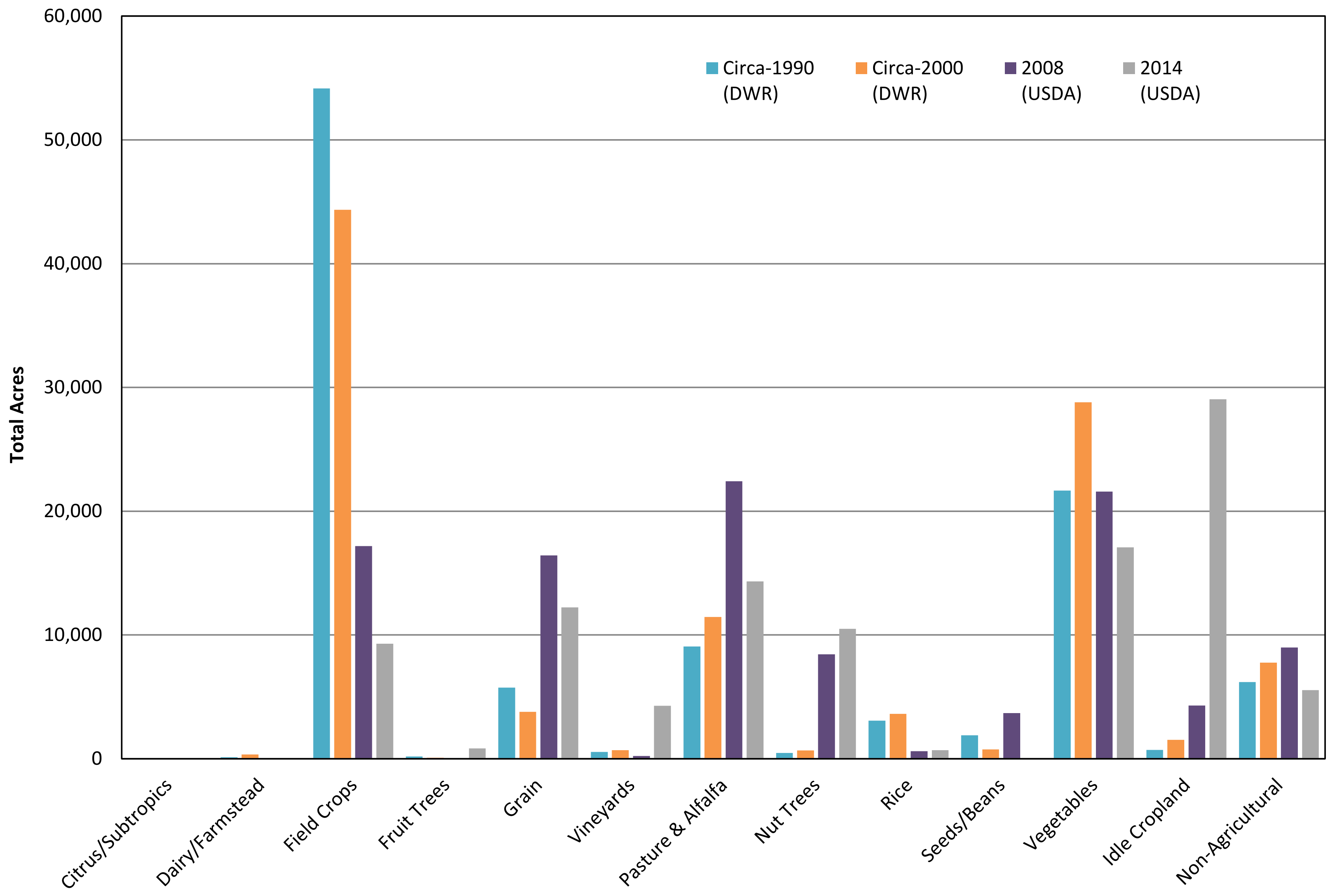

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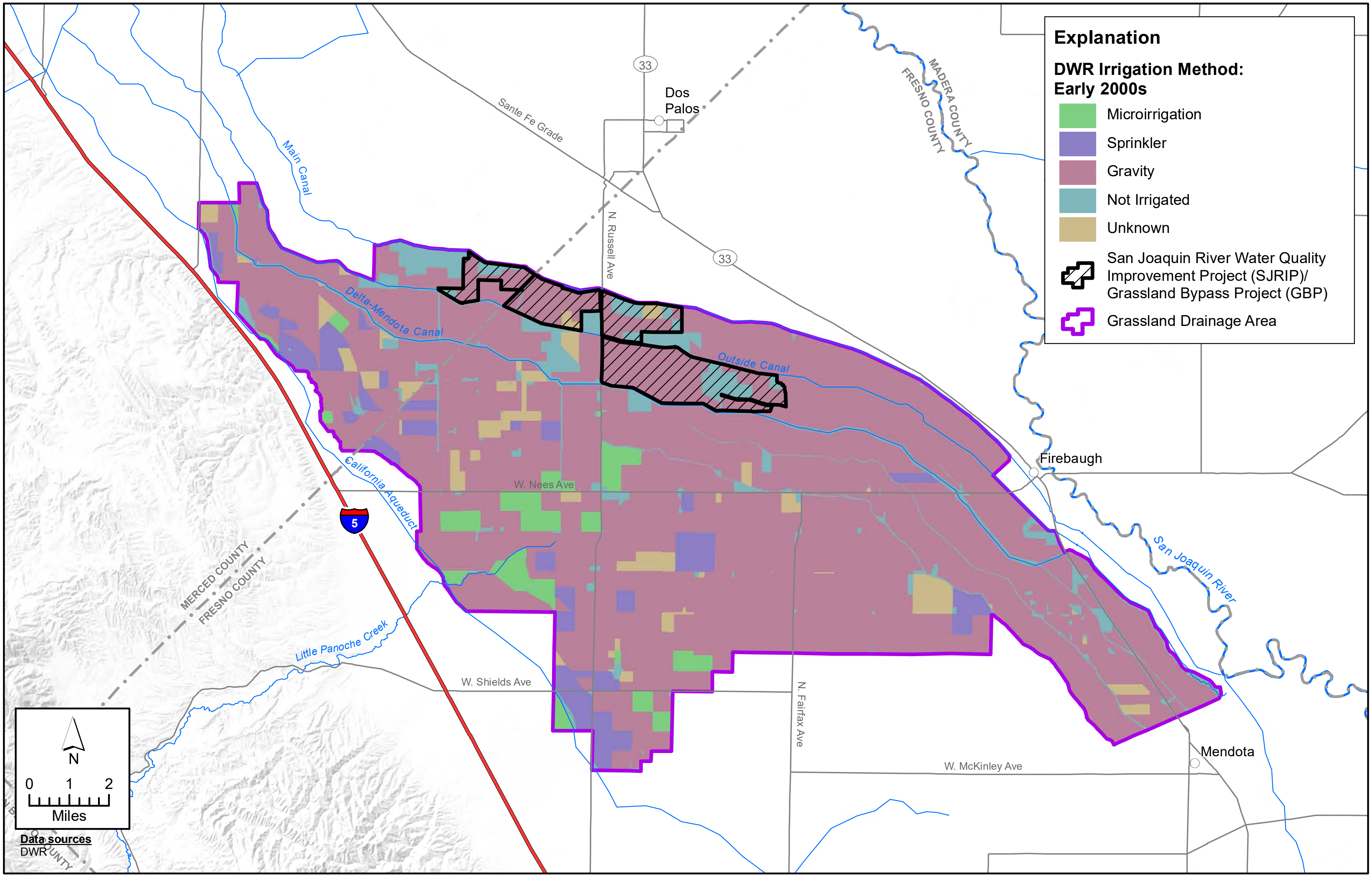
FIGURE 4-7

Changes in Land Use Within the GDA

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 4-8 DWR Irrigation.mxd

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FIGURE 4-8

Map of DWR Early 2000s Irrigation Methods

Grassland Drainage Area
Groundwater Quality Assessment Report

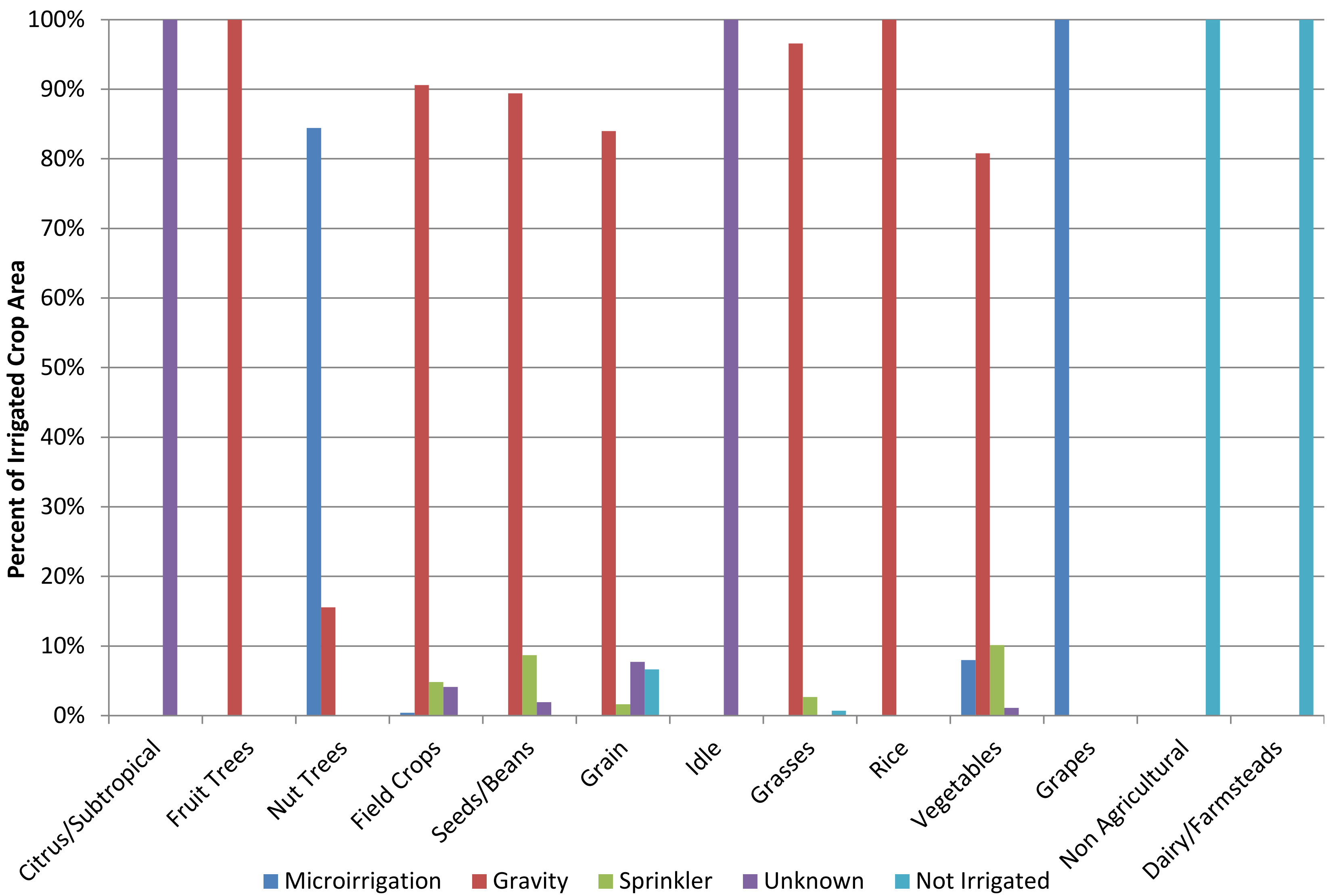

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FIGURE 4-9

Irrigation Method Circa-2000 by Crop Within the GDA

Grassland Drainage Area
Groundwater Quality Assessment Report

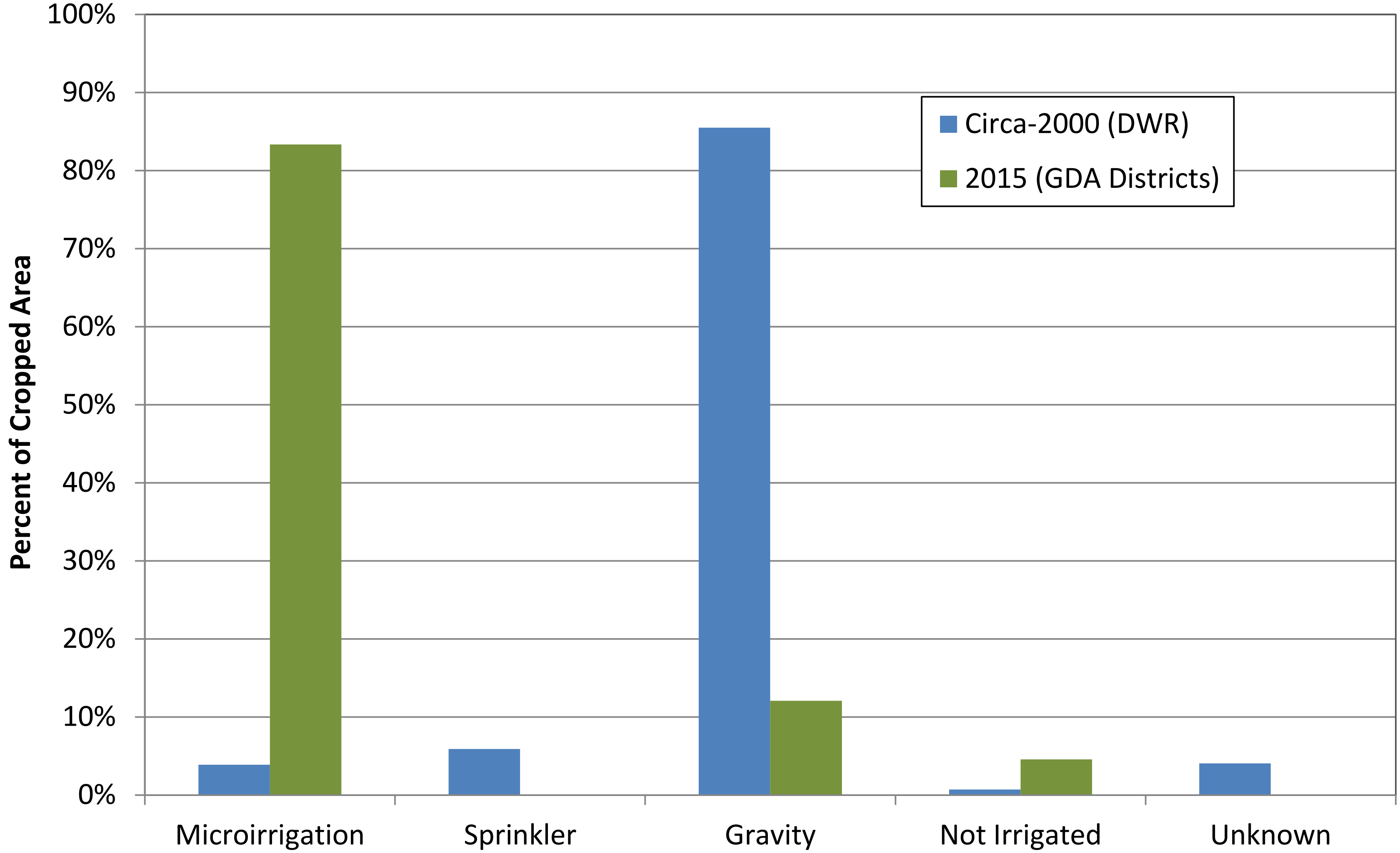

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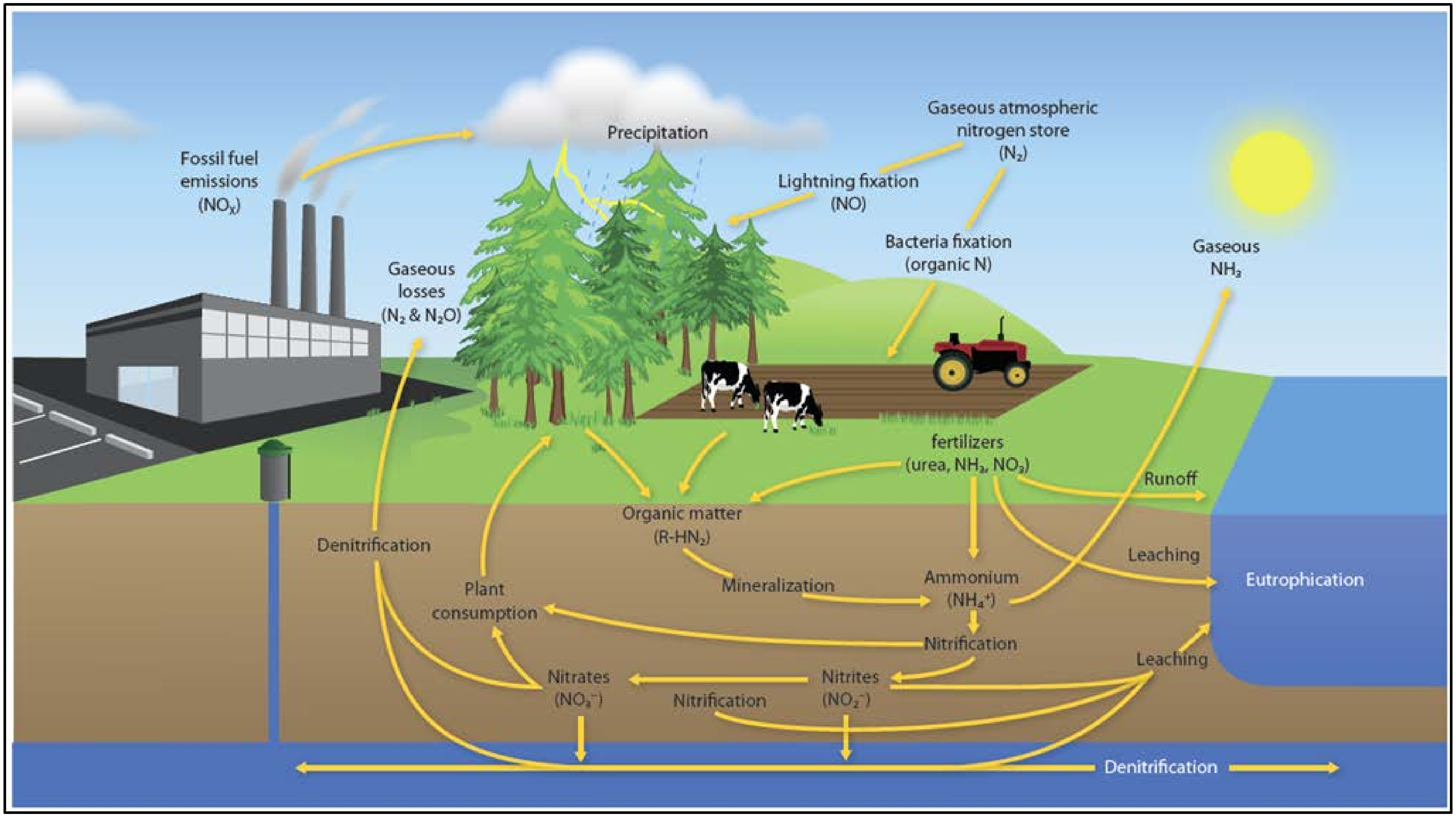
FIGURE 4-10

Irrigation Method by Year Within the GDA

Grassland Drainage Area
Groundwater Quality Assessment Report



From Rosenstock et al., 2013, courtesy of *Southwest Hydrology*

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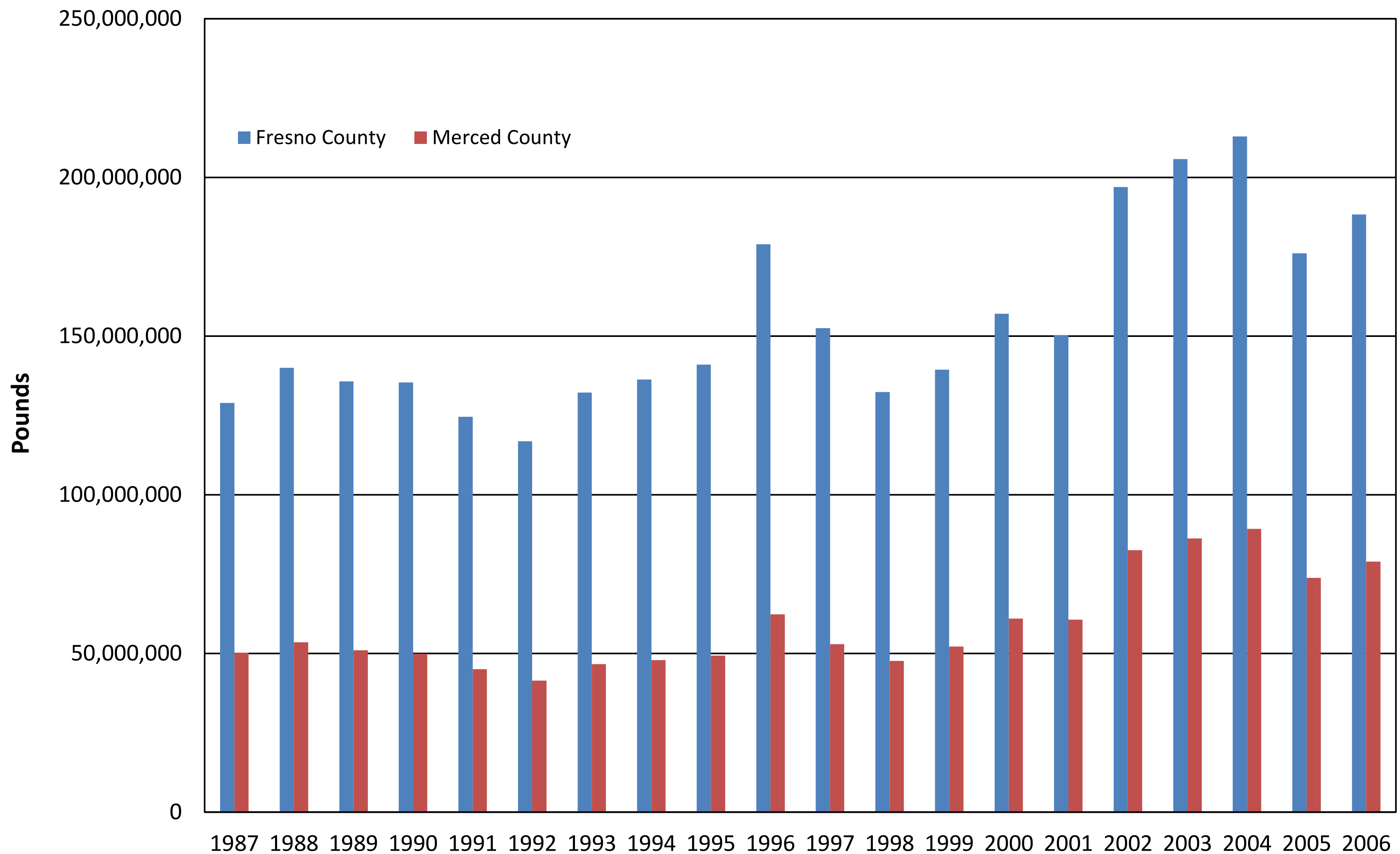
FIGURE 4-11

Nitrogen Cycle

Grassland Drainage Area
Groundwater Quality Assessment Report



Data from Gronberg and Spahr (2012)

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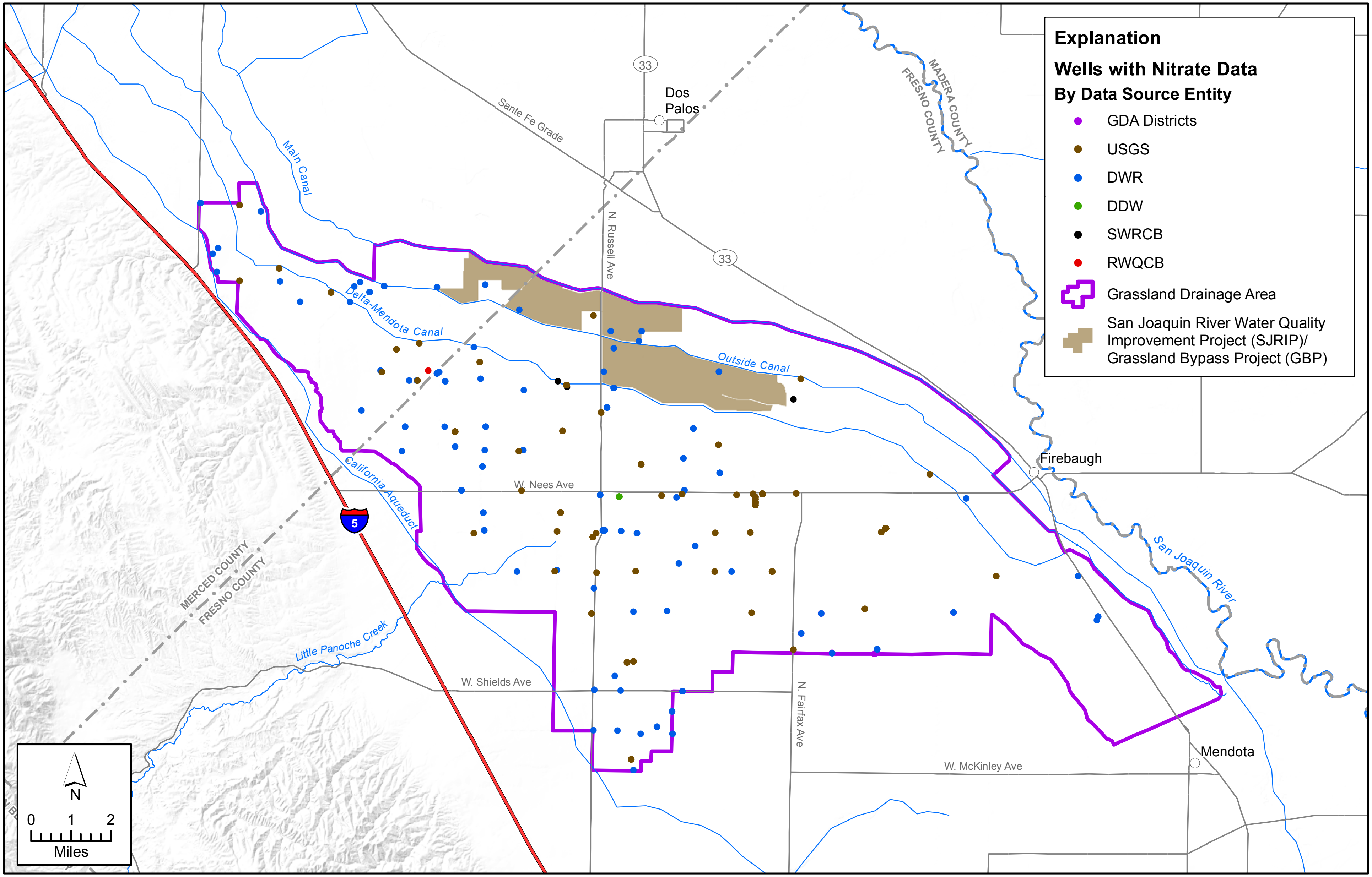
FIGURE 4-12

Regional Trends in Farm Nitrogen Fertilizer Use by County

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 5-1 Groundwater Quality Data by Source Nitrate.mxd

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FIGURE 5-1
Map of Groundwater Quality Data by Source: Nitrate

Grassland Drainage Area
Groundwater Quality Assessment Report

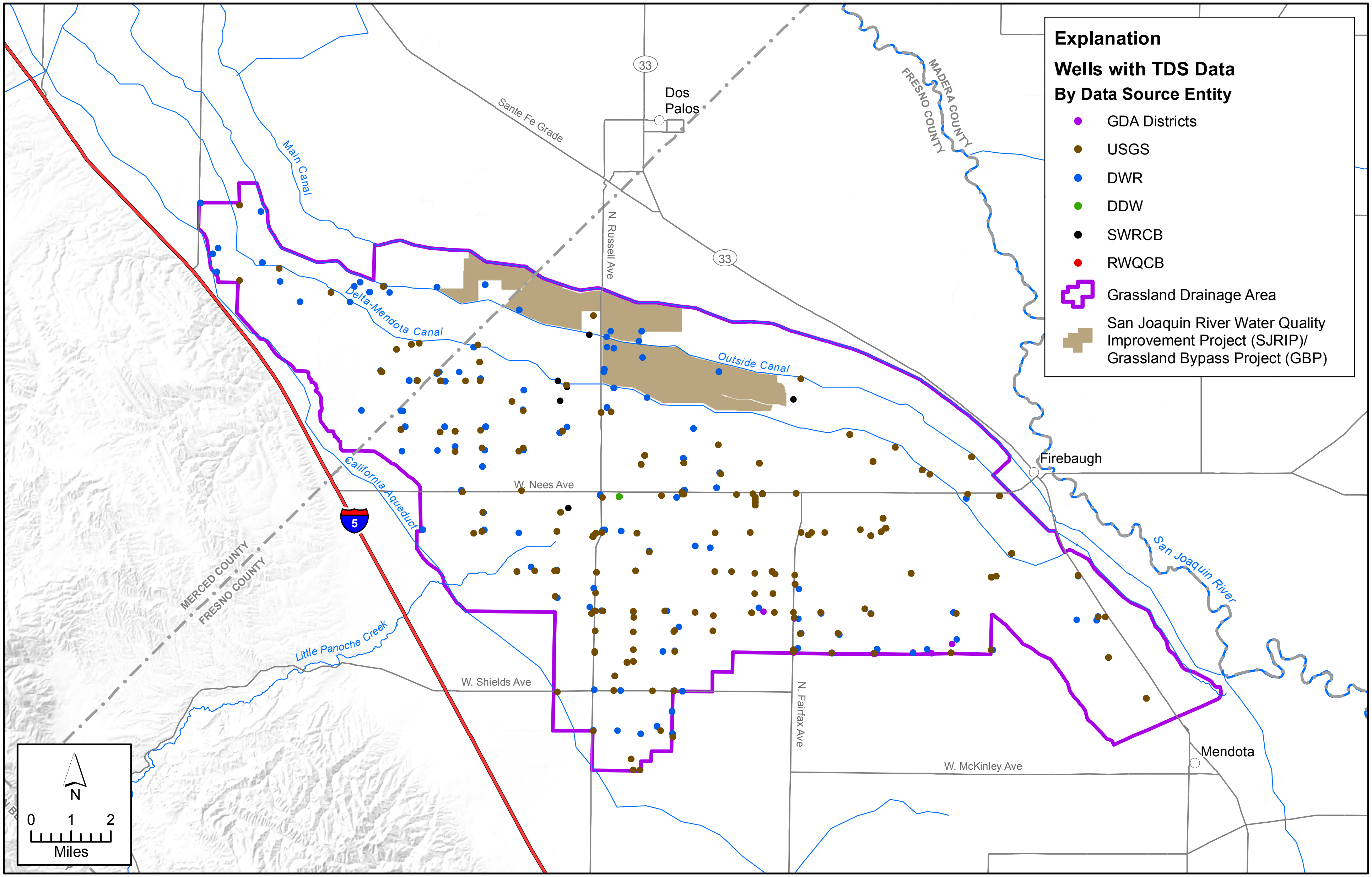

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FIGURE 5-2
Map of Groundwater Quality Data by Source: TDS

Grassland Drainage Area
Groundwater Quality Assessment Report

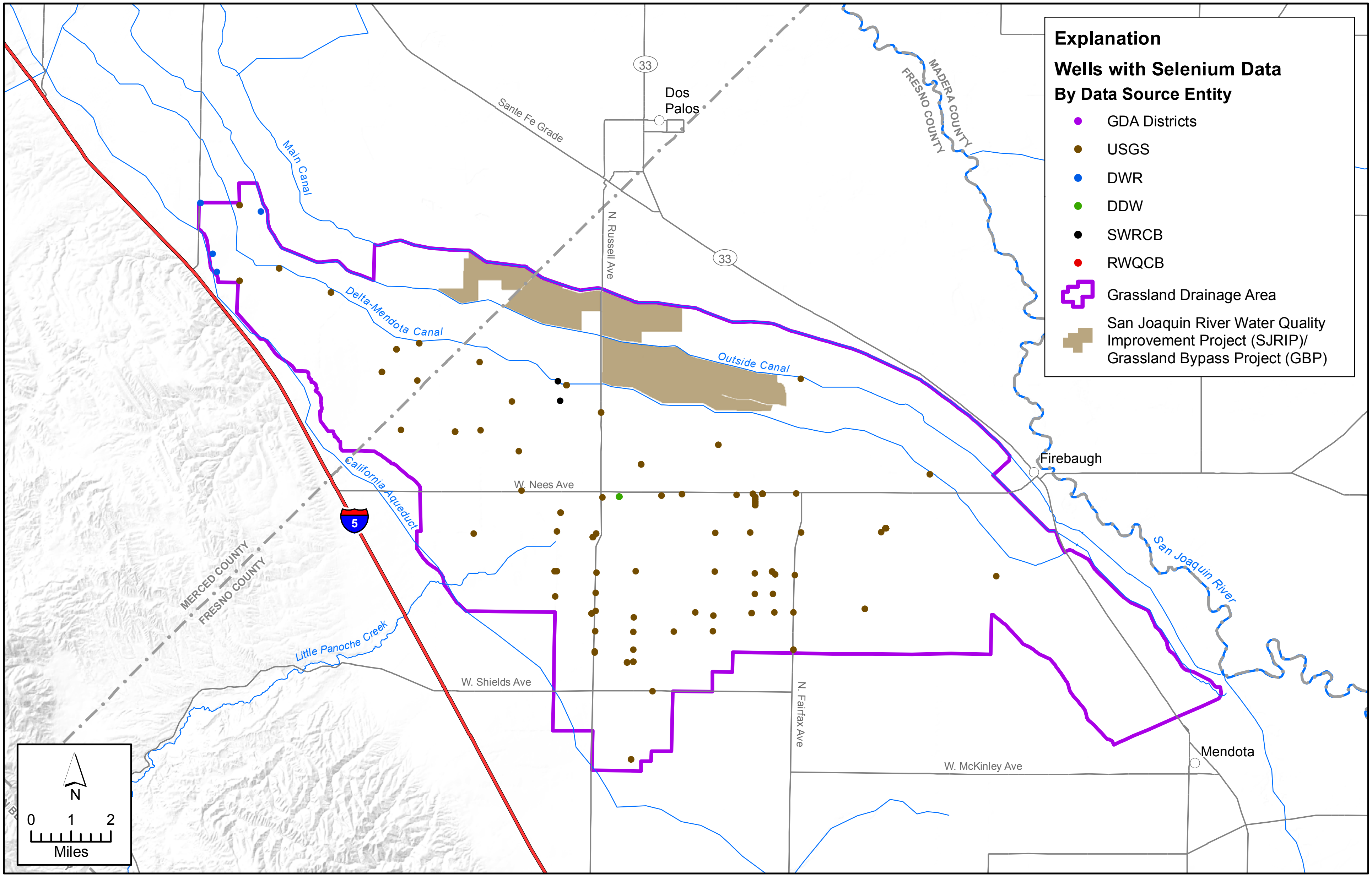

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FIGURE 5-3
Map of Groundwater Quality Data by Source: Selenium

Grassland Drainage Area
Groundwater Quality Assessment Report

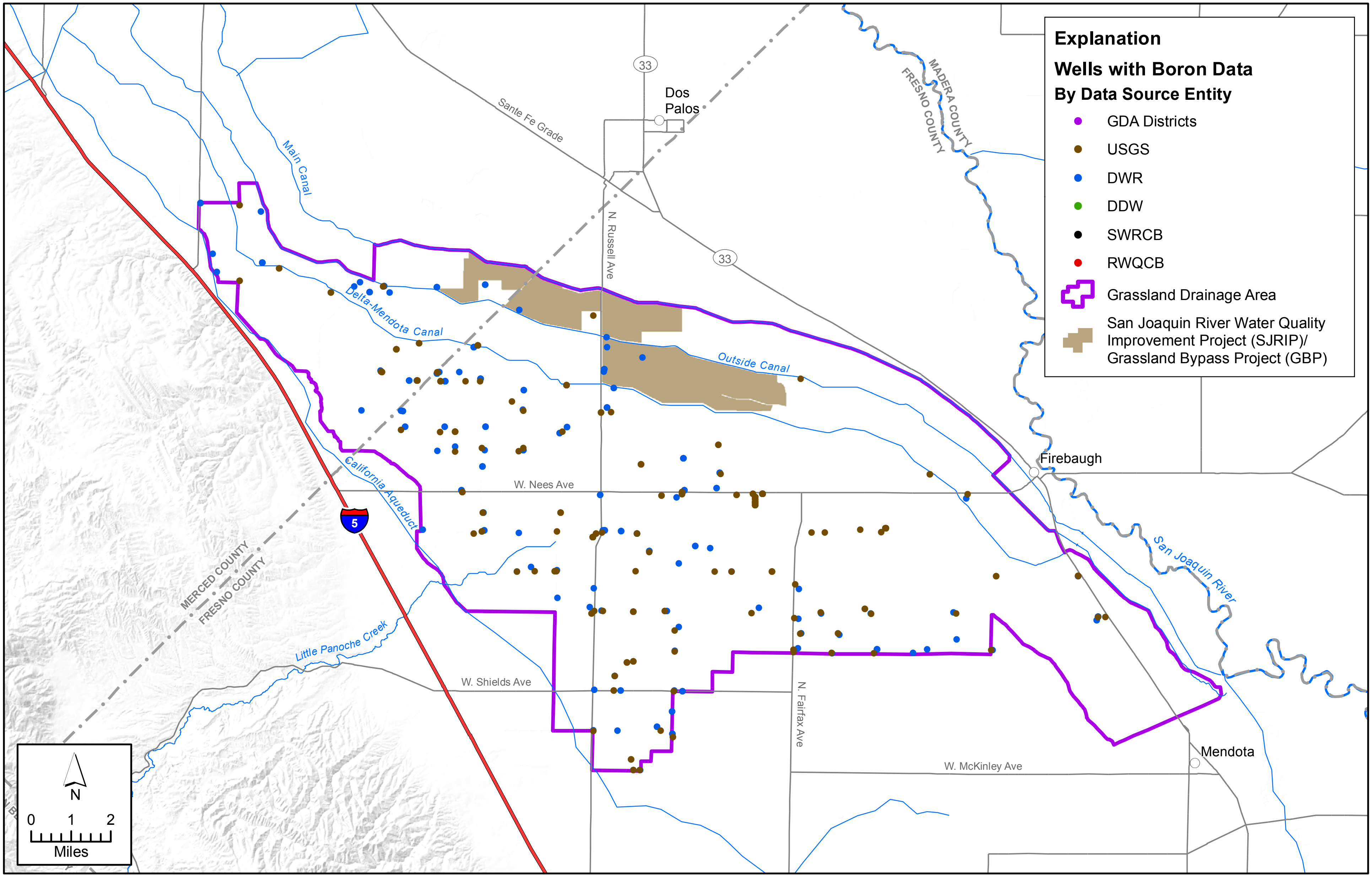

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FIGURE 5-4
Map of Groundwater Quality Data by Source: Boron

Grassland Drainage Area
Groundwater Quality Assessment Report

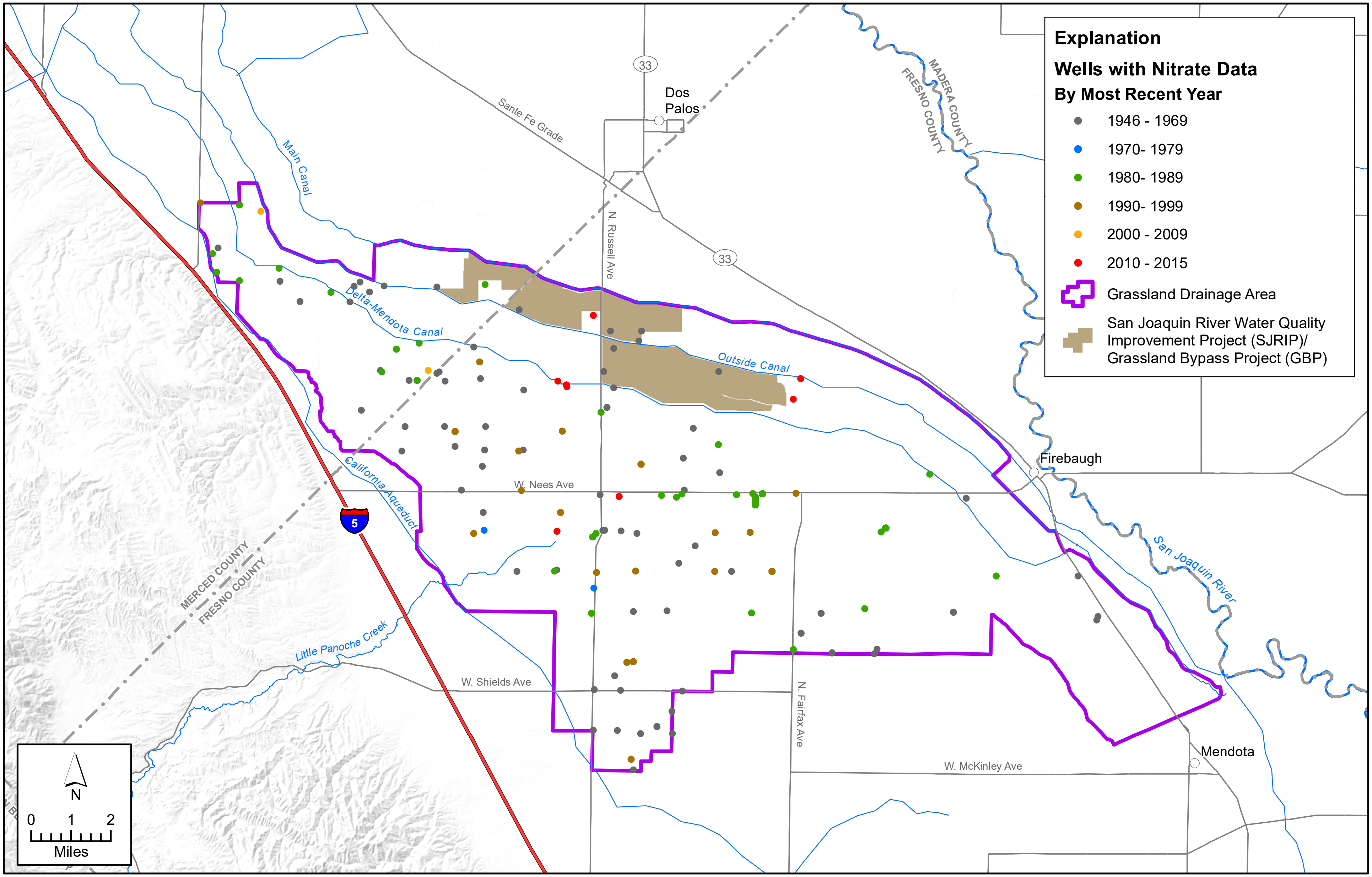

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FIGURE 5-5
Map of Groundwater Quality Data by Most Recent Year: Nitrate

Grassland Drainage Area
Groundwater Quality Assessment Report

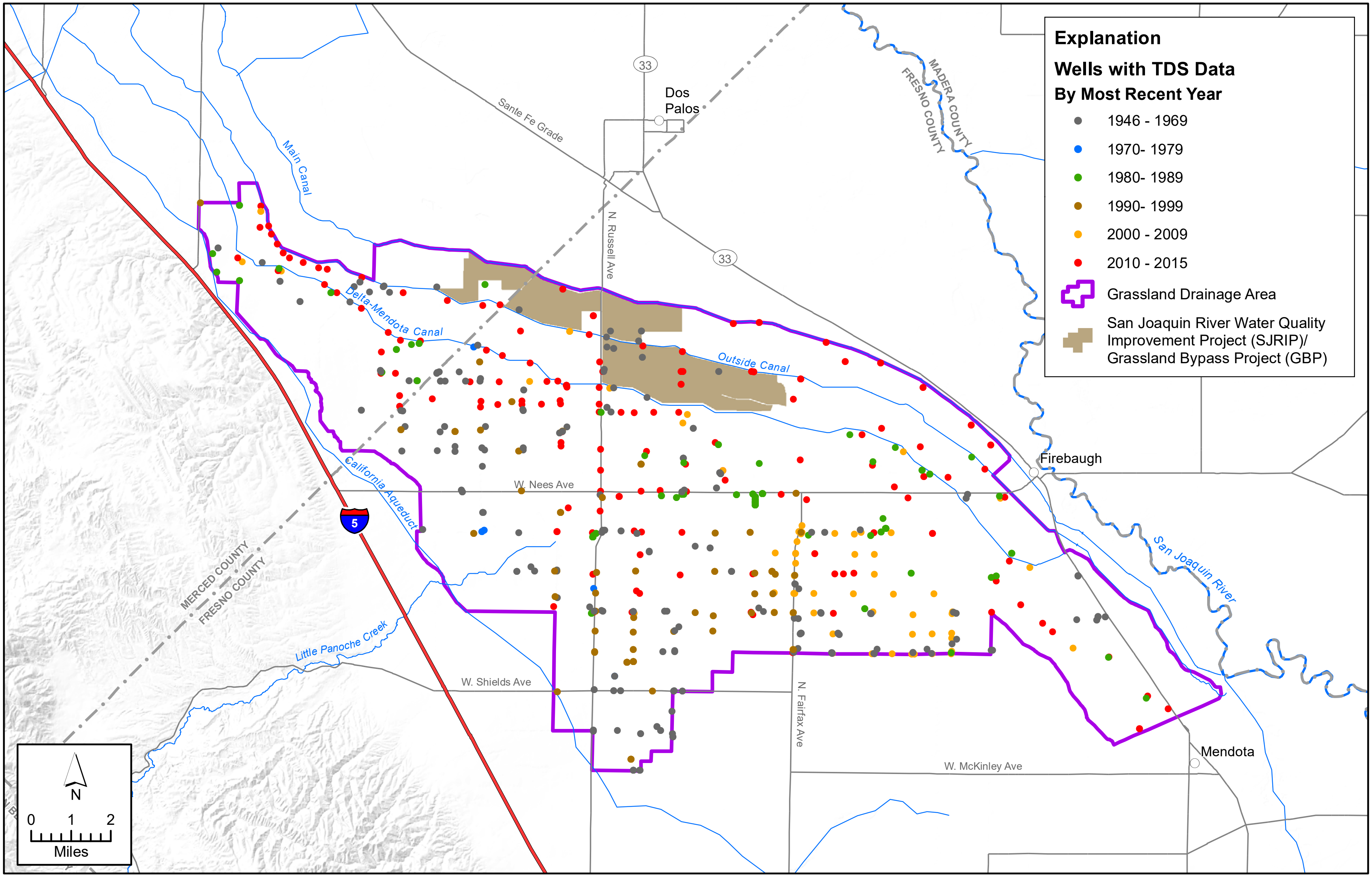

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FIGURE 5-6
Map of Groundwater Quality Data by Most Recent Year: TDS

Grassland Drainage Area
Groundwater Quality Assessment Report

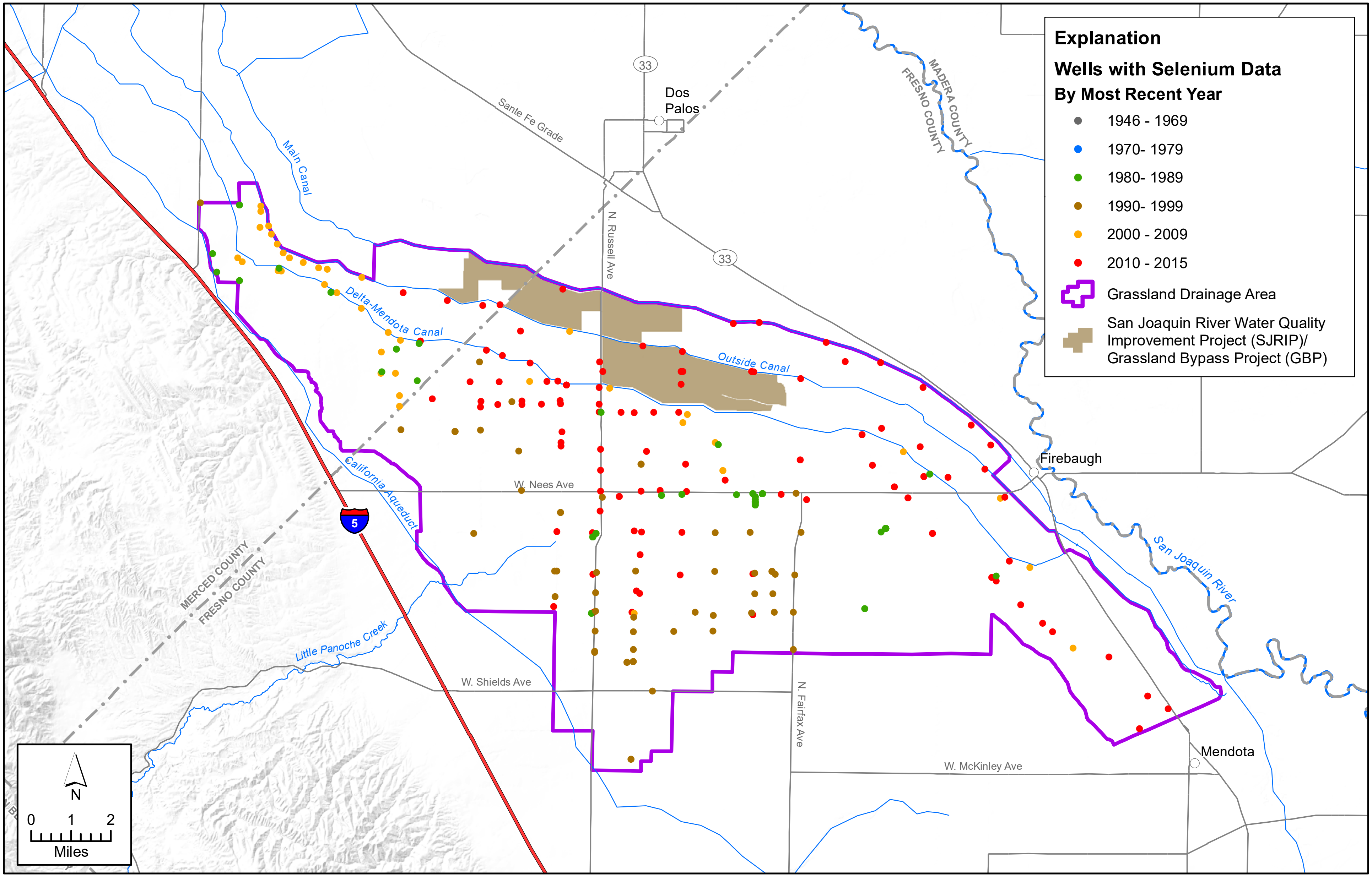

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FIGURE 5-7
Map of Groundwater Quality Data by Most Recent Year: Selenium

Grassland Drainage Area
Groundwater Quality Assessment Report

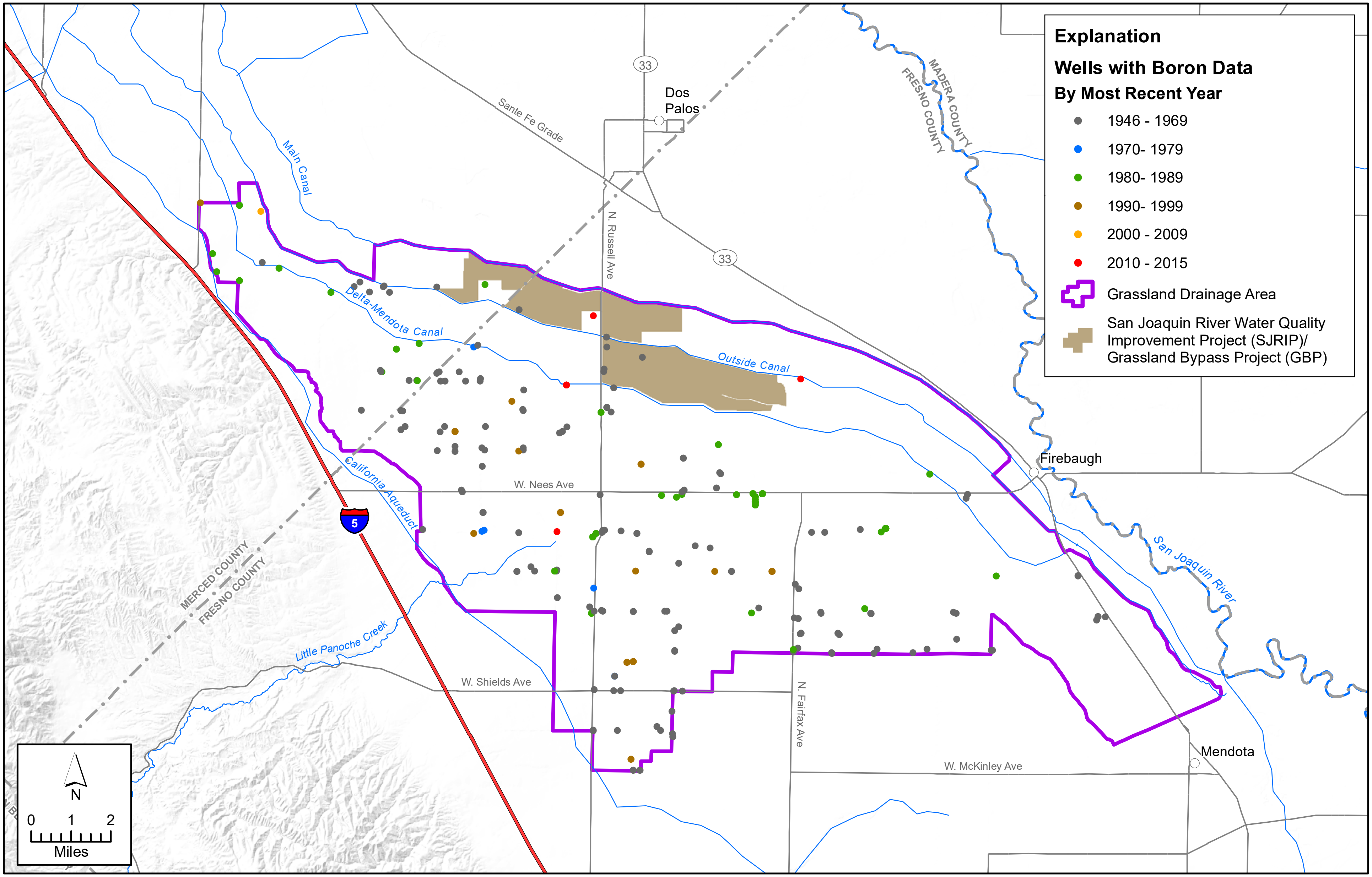

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FIGURE 5-8
Map of Groundwater Quality Data by Most Recent Year: Boron

Grassland Drainage Area
Groundwater Quality Assessment Report

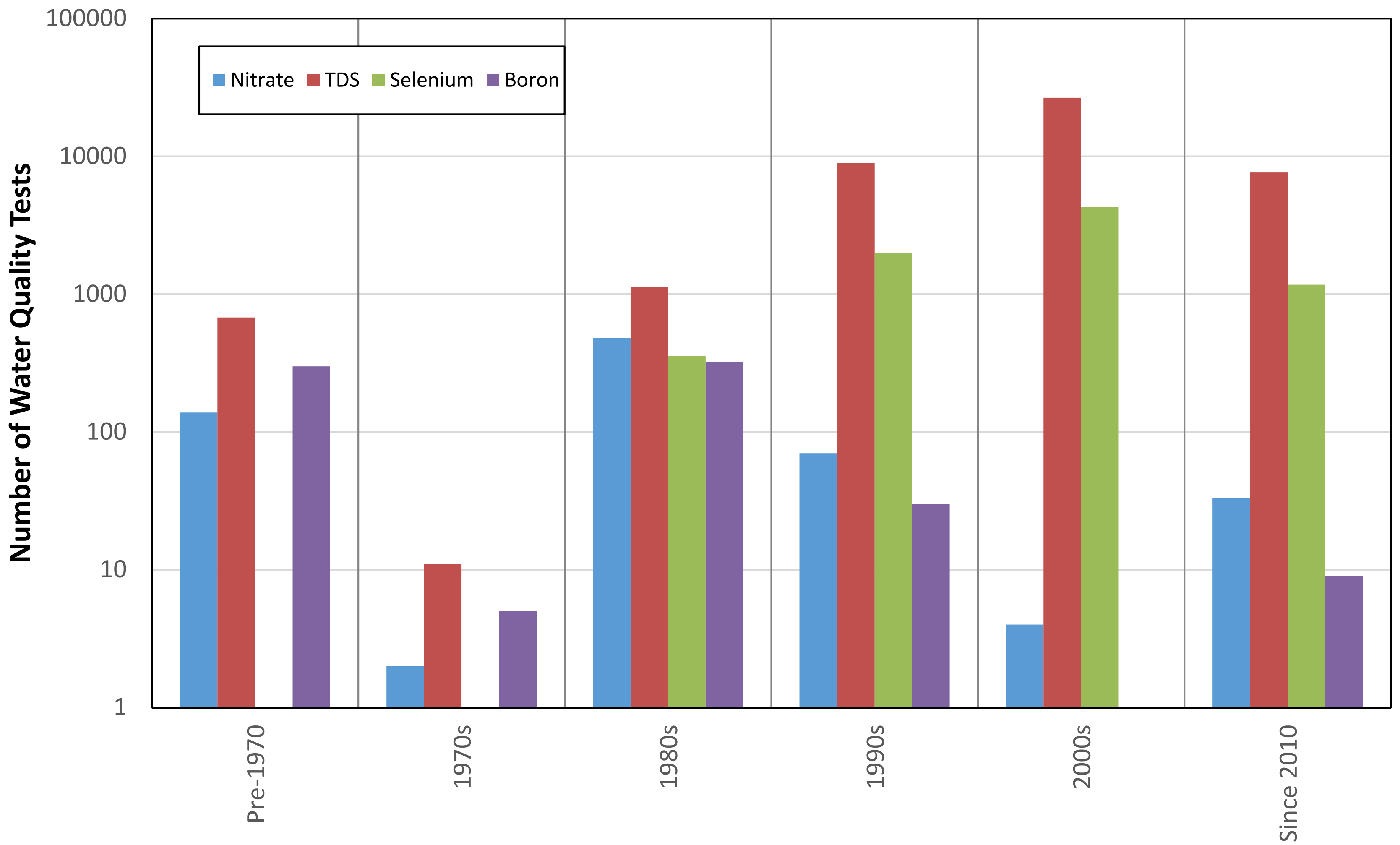

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FIGURE 5-9

Number of Water Quality Tests by Decade

Grassland Drainage Area
Groundwater Quality Assessment Report

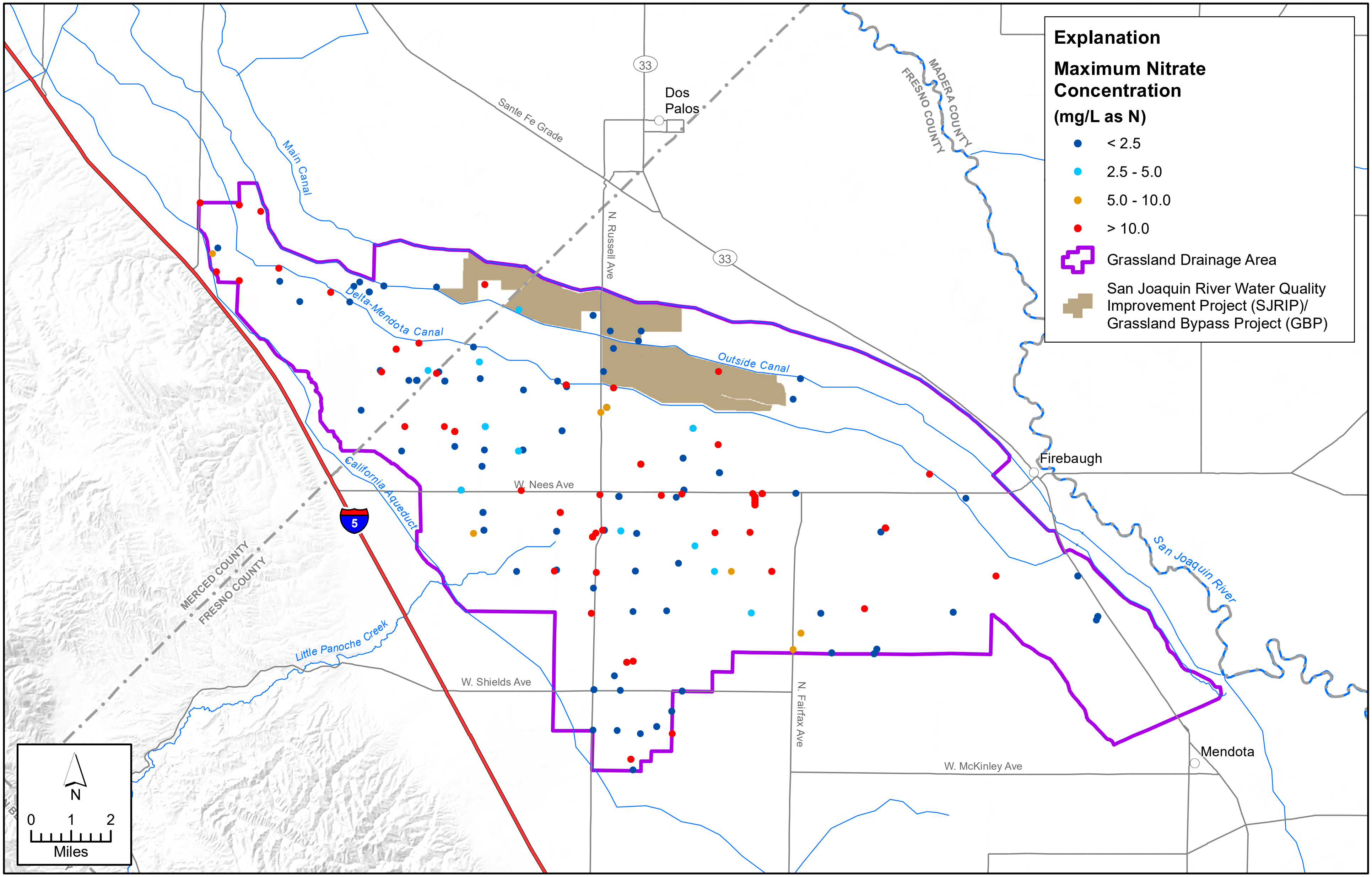

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FIGURE 5-10
Map of Maximum Nitrate Concentrations: All Drain and Well Data
Grassland Drainage Area
Groundwater Quality Assessment Report

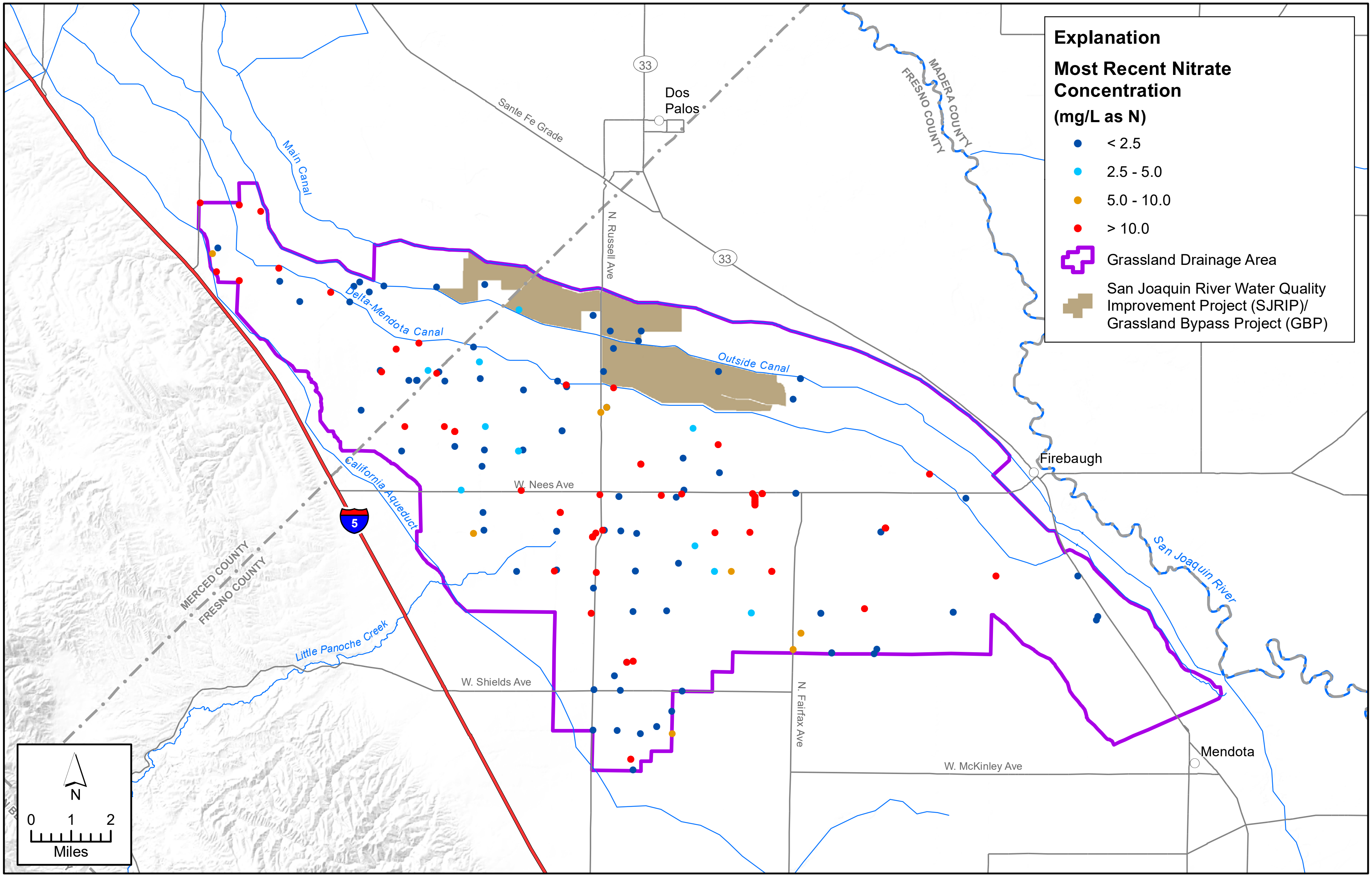

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FIGURE 5-11
Map of Most Recent Nitrate Concentrations: All Drain and Well Data
Grassland Drainage Area
Groundwater Quality Assessment Report

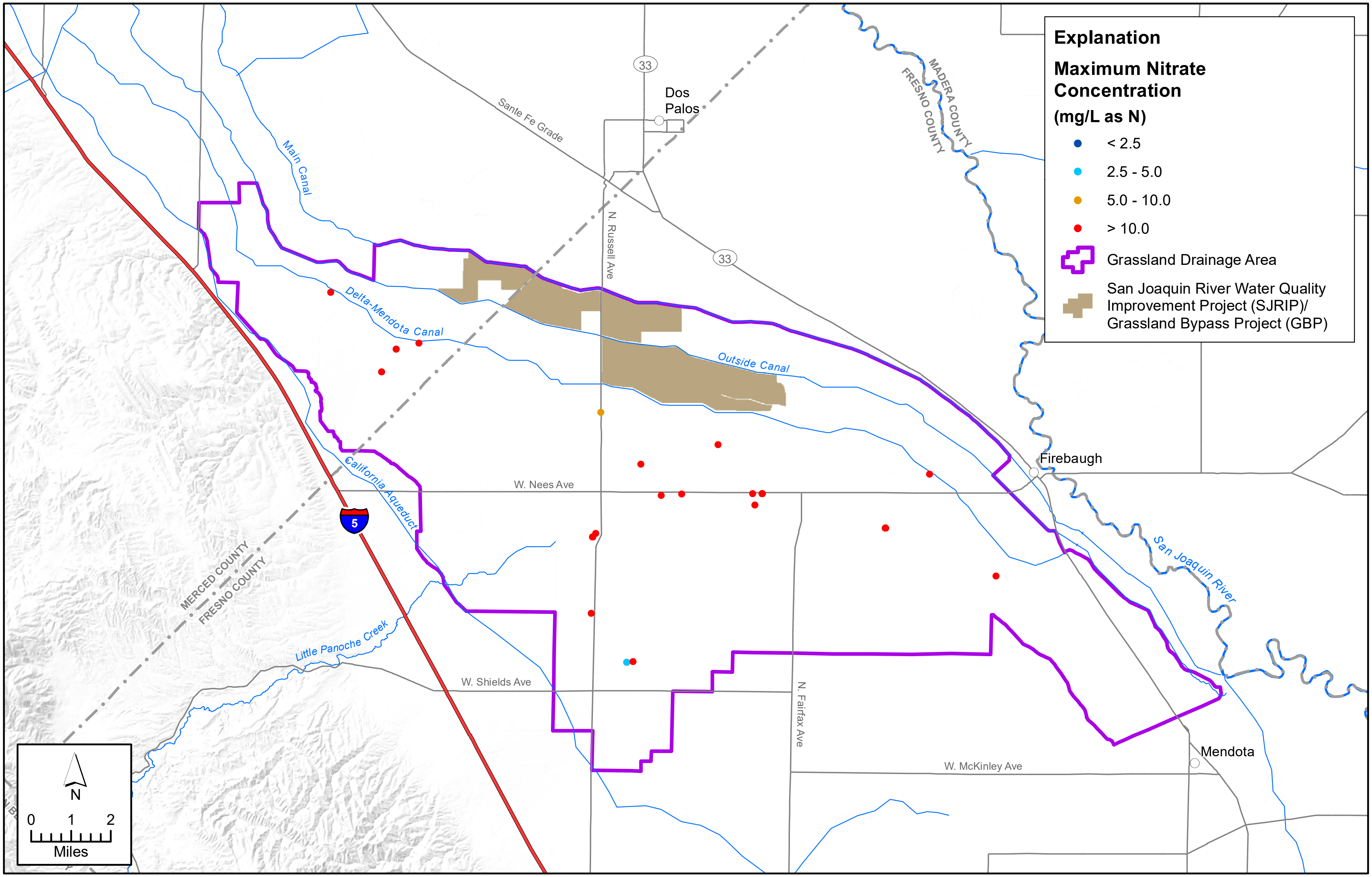

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FIGURE 5-12
Map of Maximum Nitrate Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

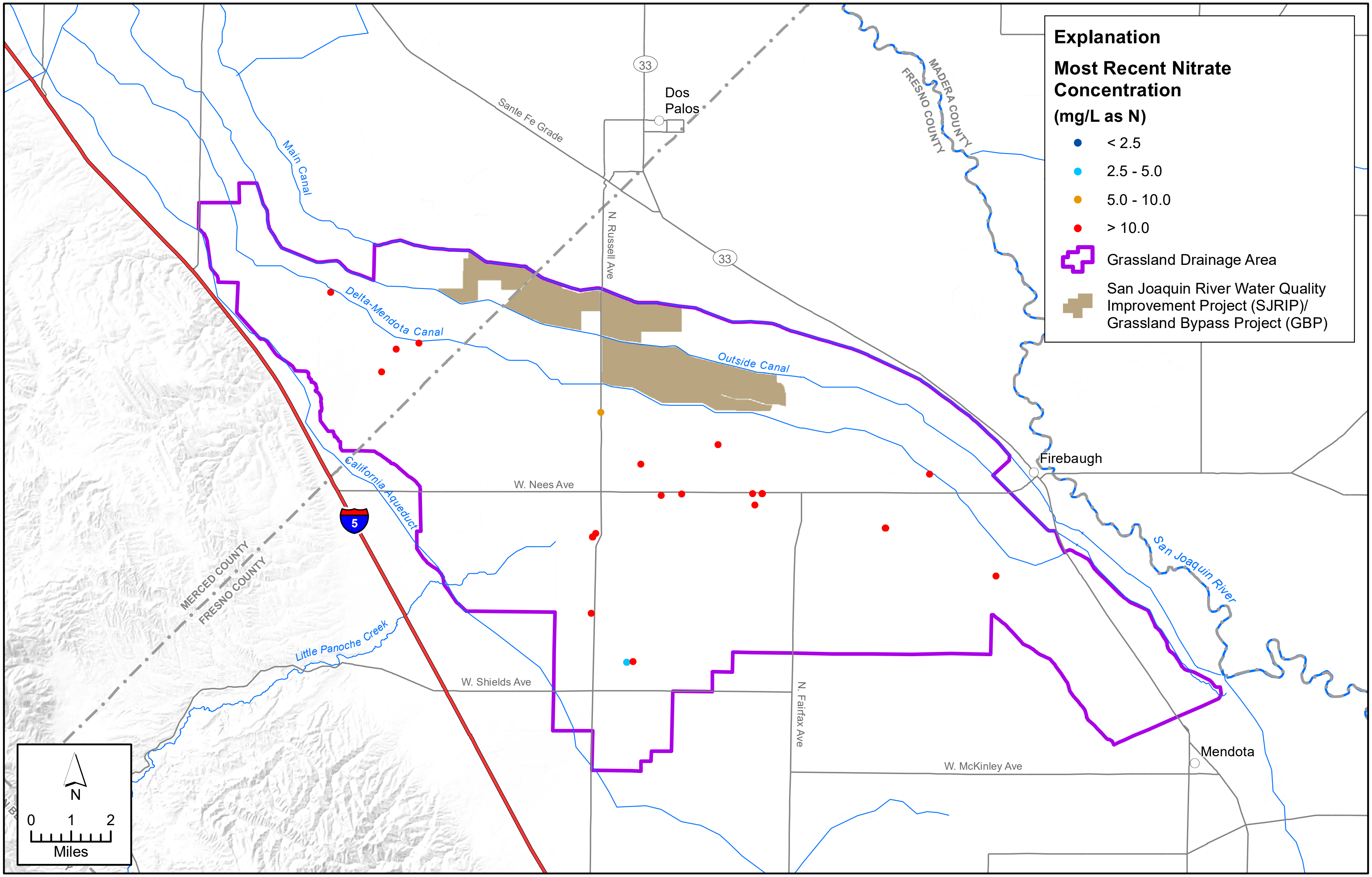

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FIGURE 5-13
Map of Most Recent Nitrate Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

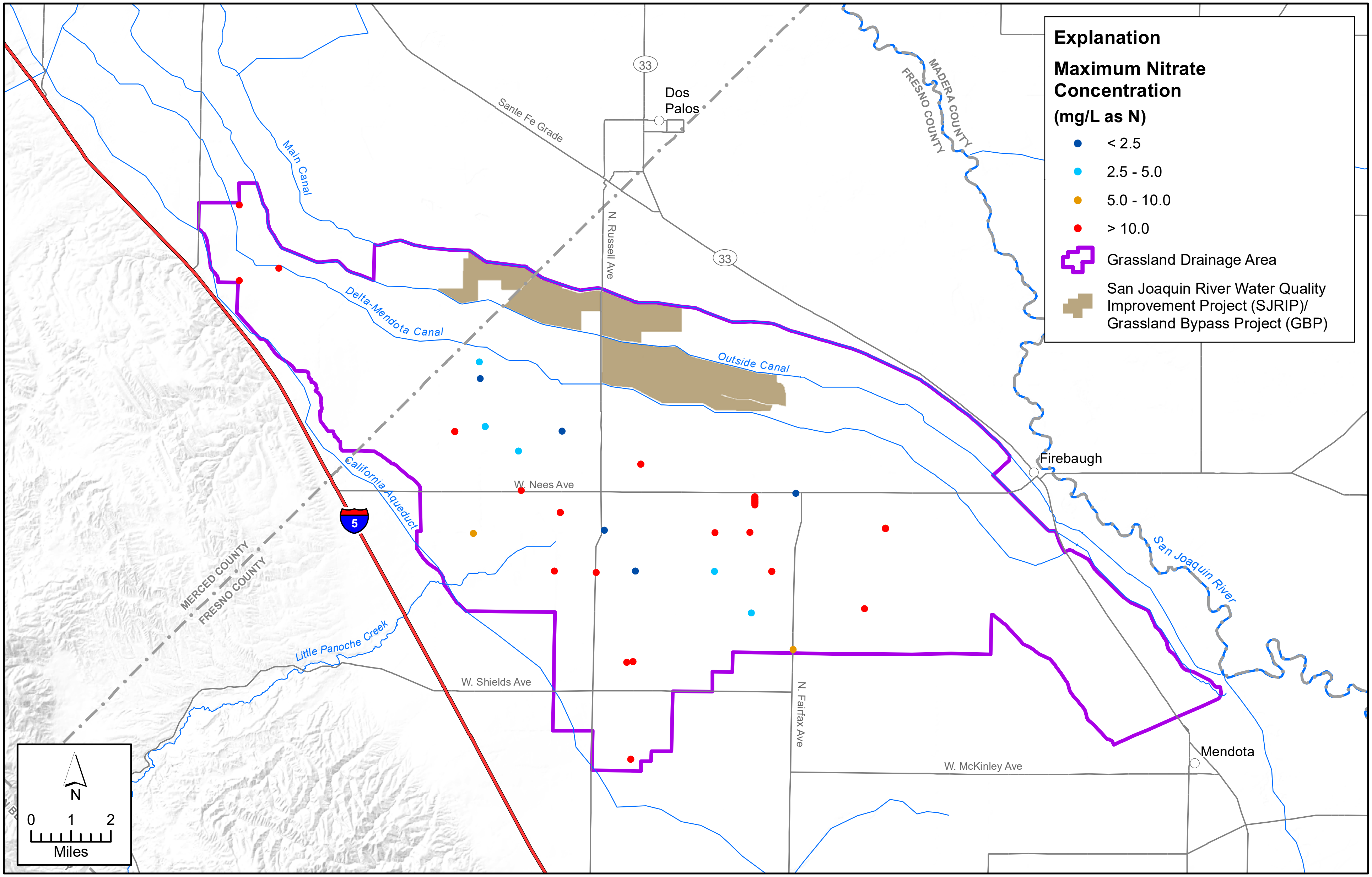

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FIGURE 5-14
Map of Maximum Nitrate Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

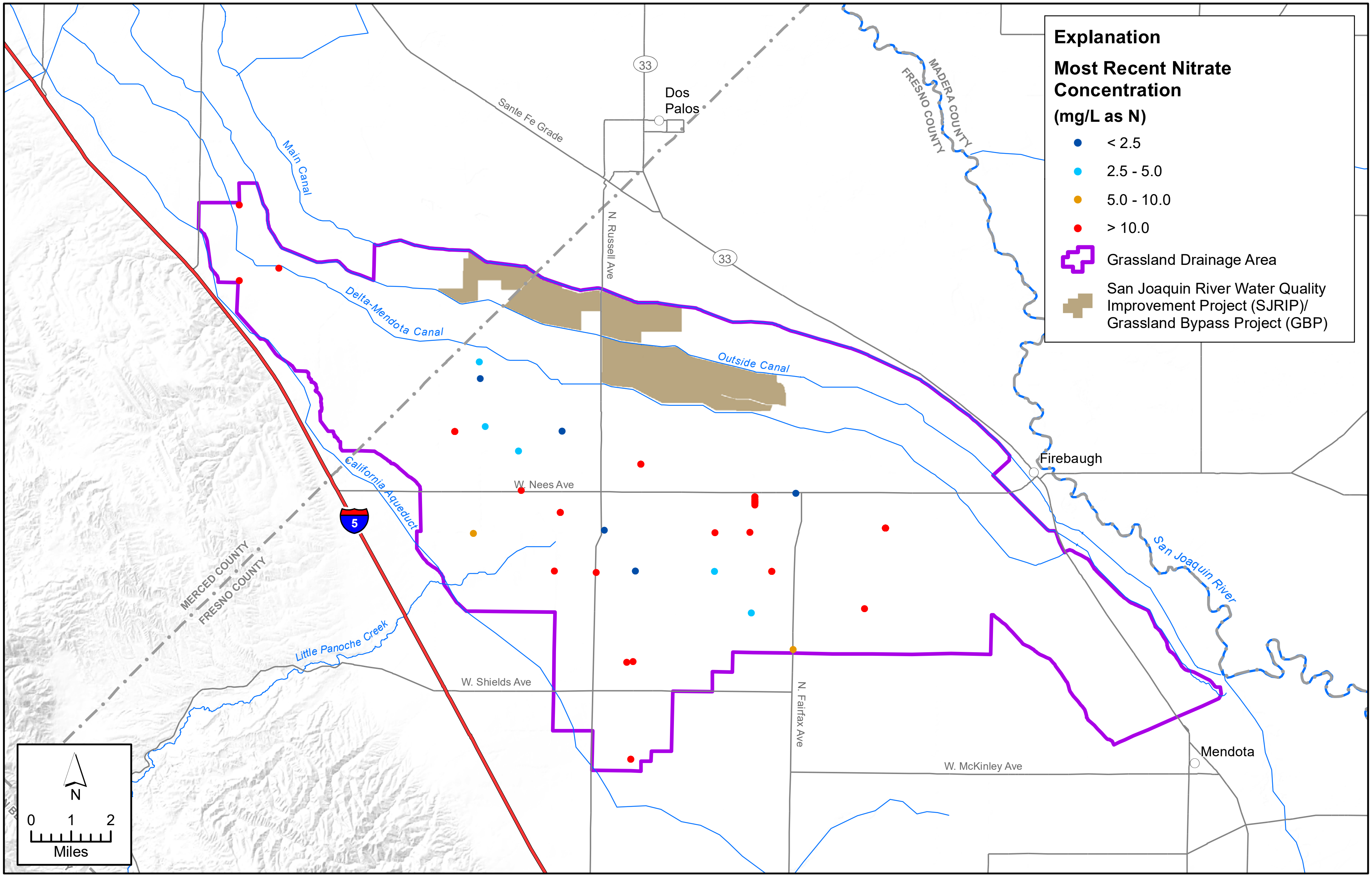

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FIGURE 5-15
Map of Most Recent Nitrate Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

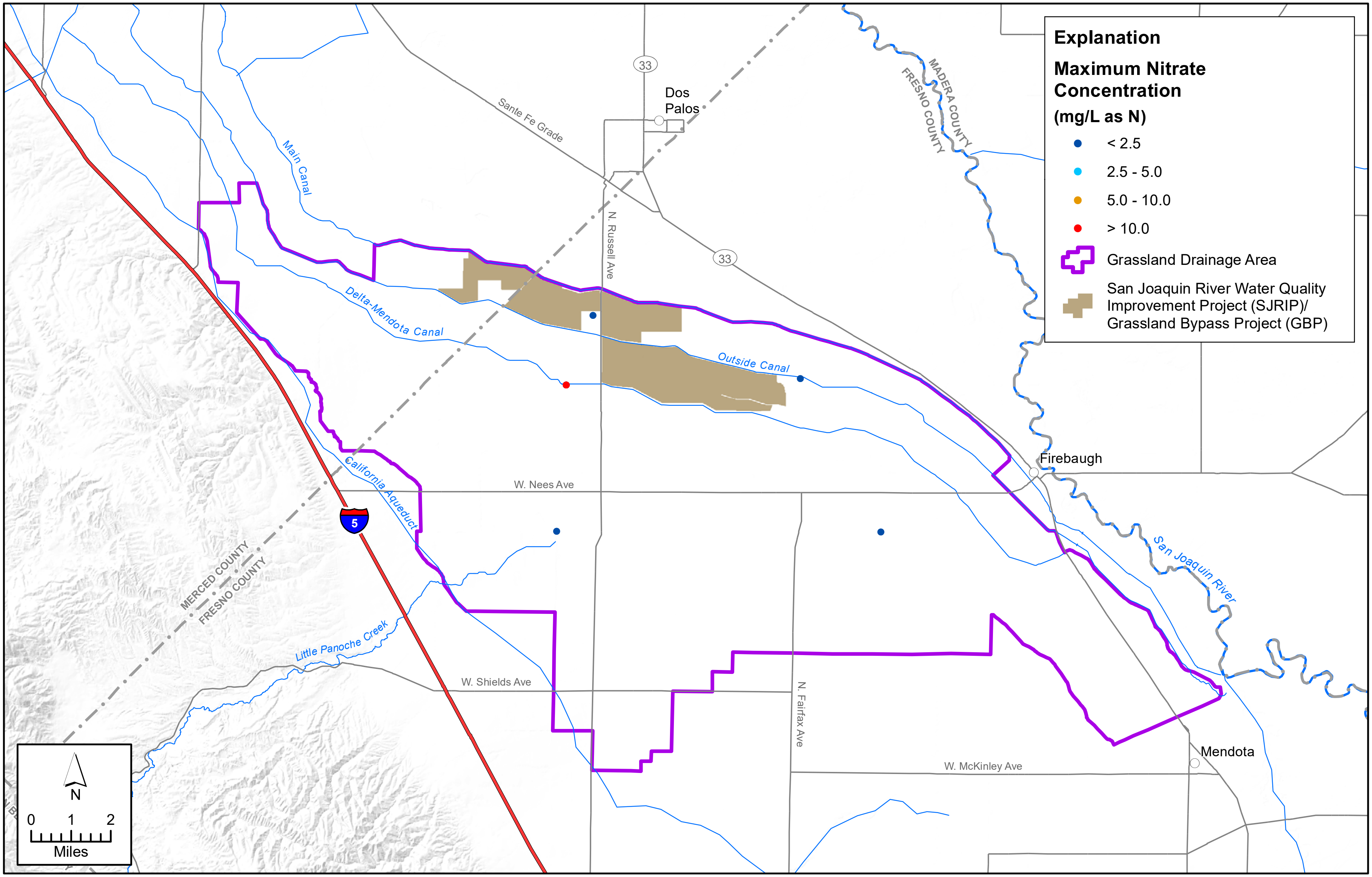

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FIGURE 5-16
Map of Maximum Nitrate Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

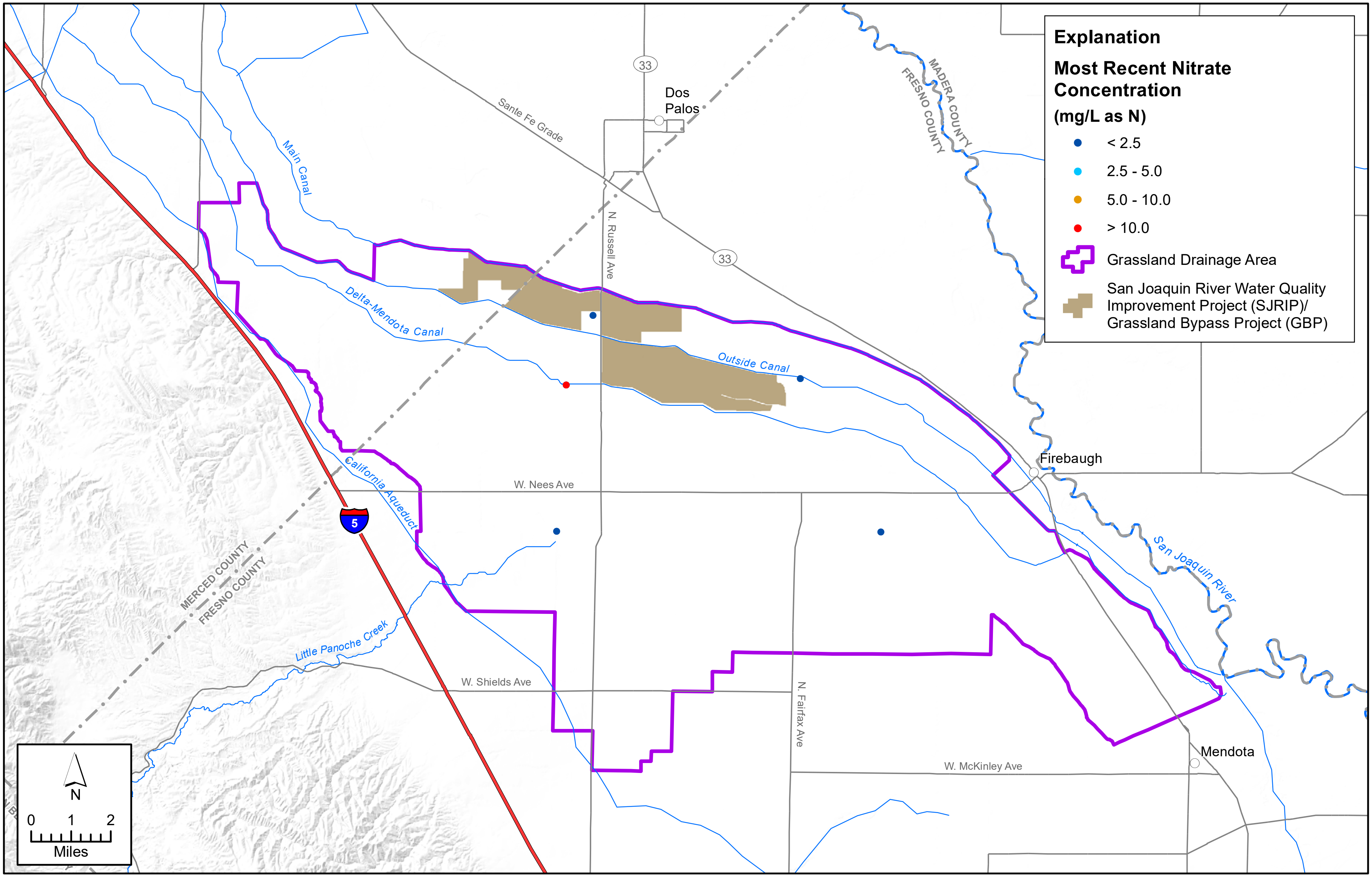

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FIGURE 5-17
Map of Most Recent Nitrate Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

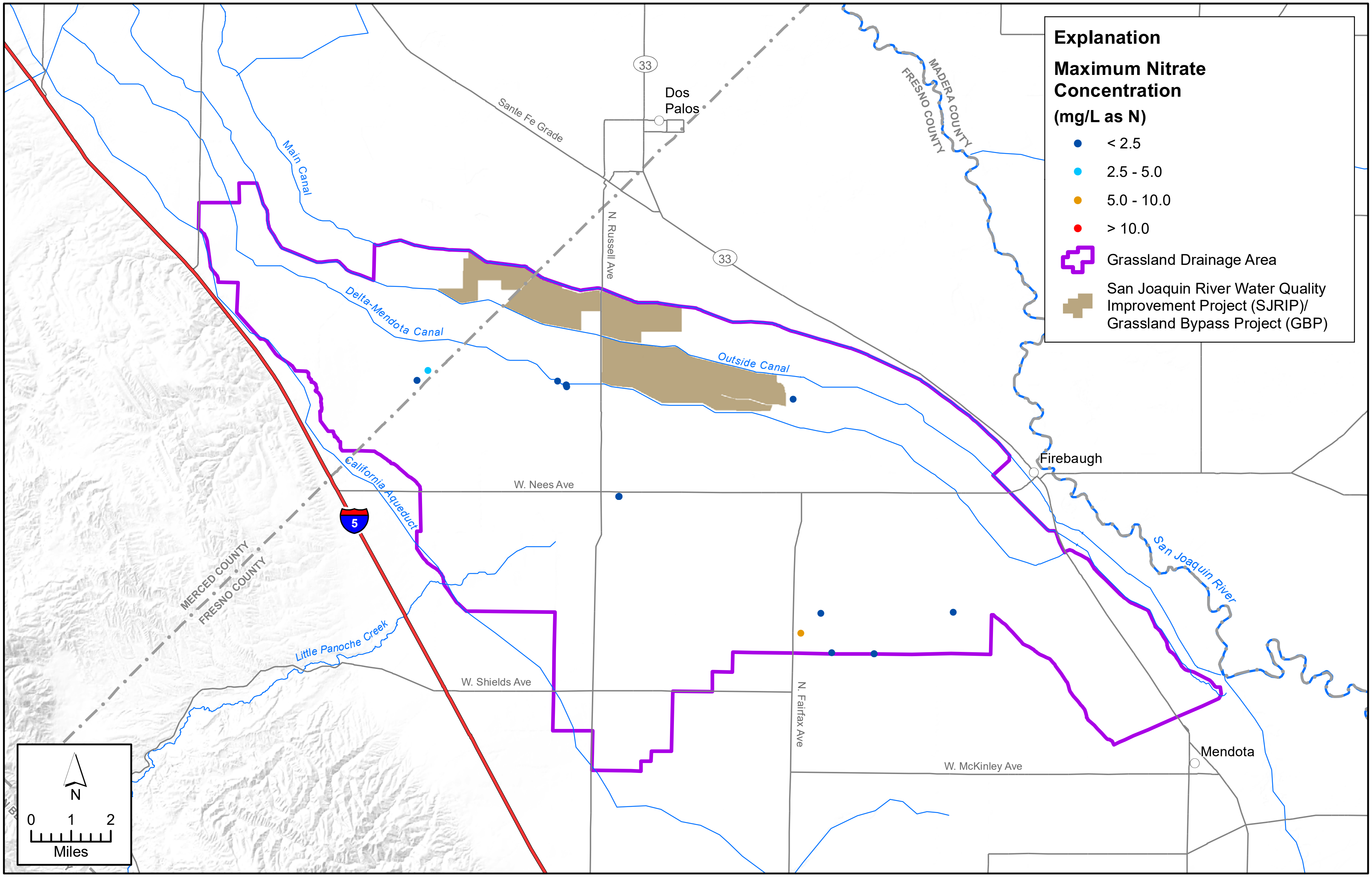

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FIGURE 5-18
Map of Maximum Nitrate Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

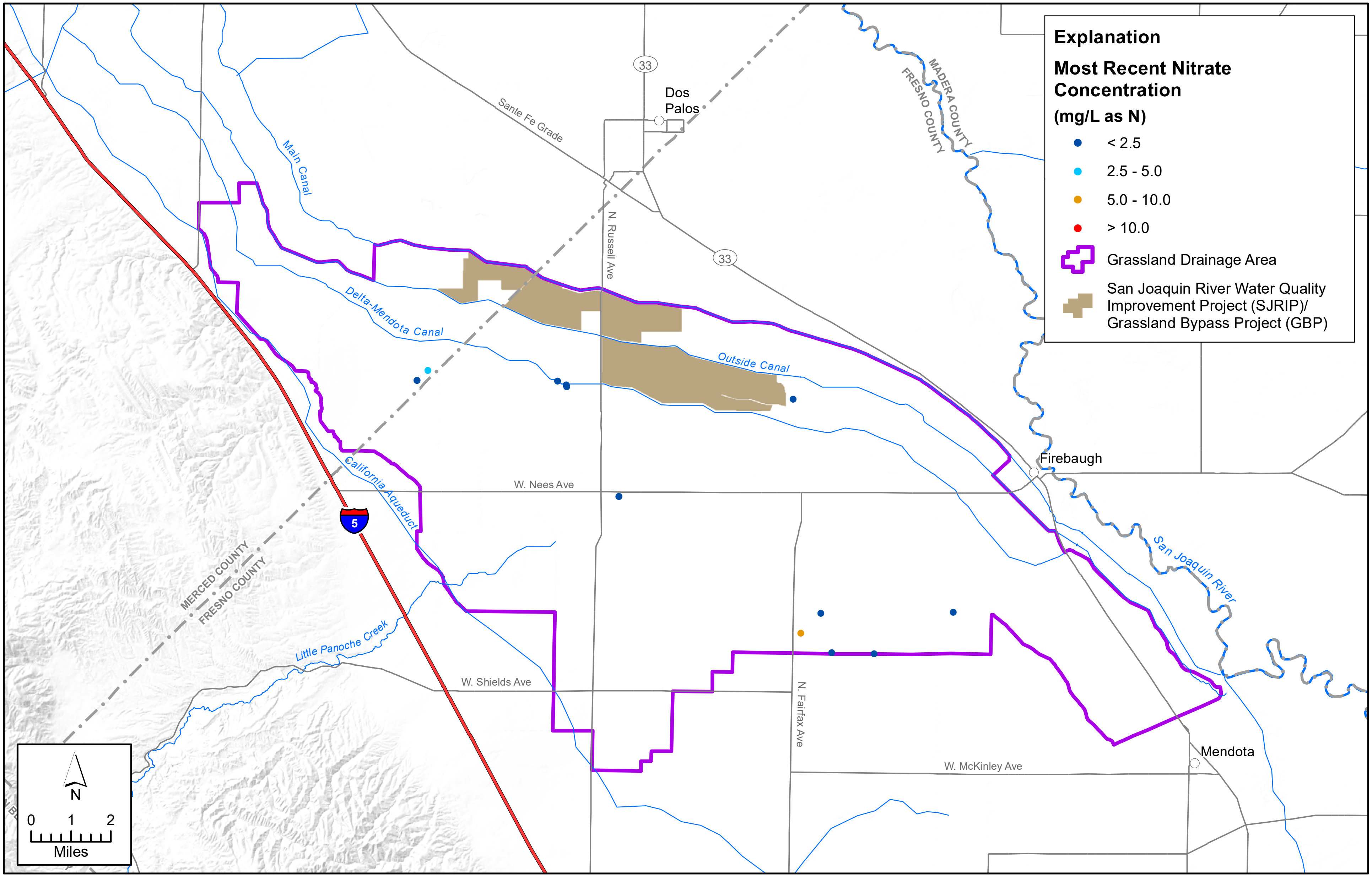

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FIGURE 5-19
Map of Most Recent Nitrate Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

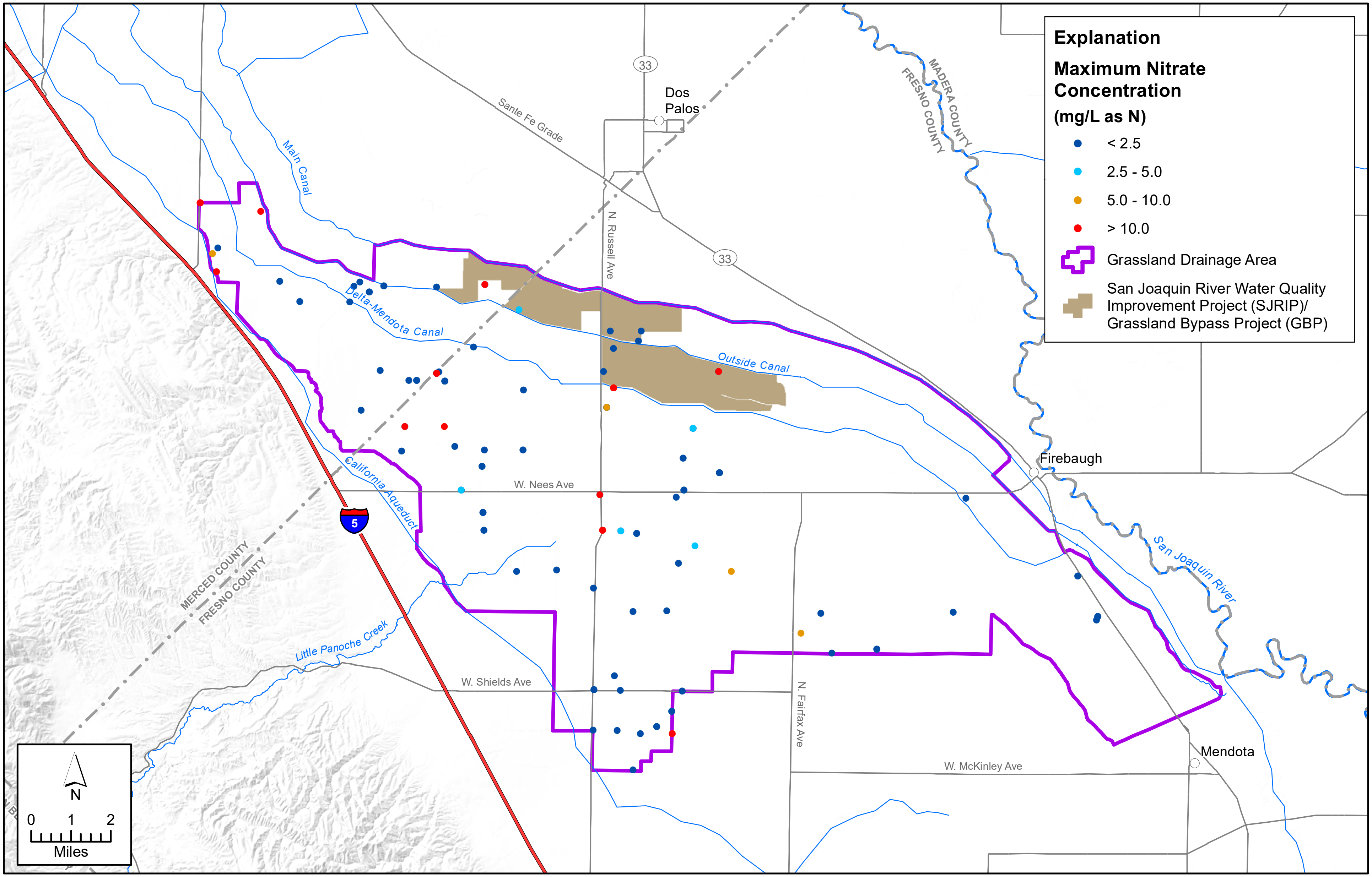

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FIGURE 5-20
Map of Maximum Nitrate Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

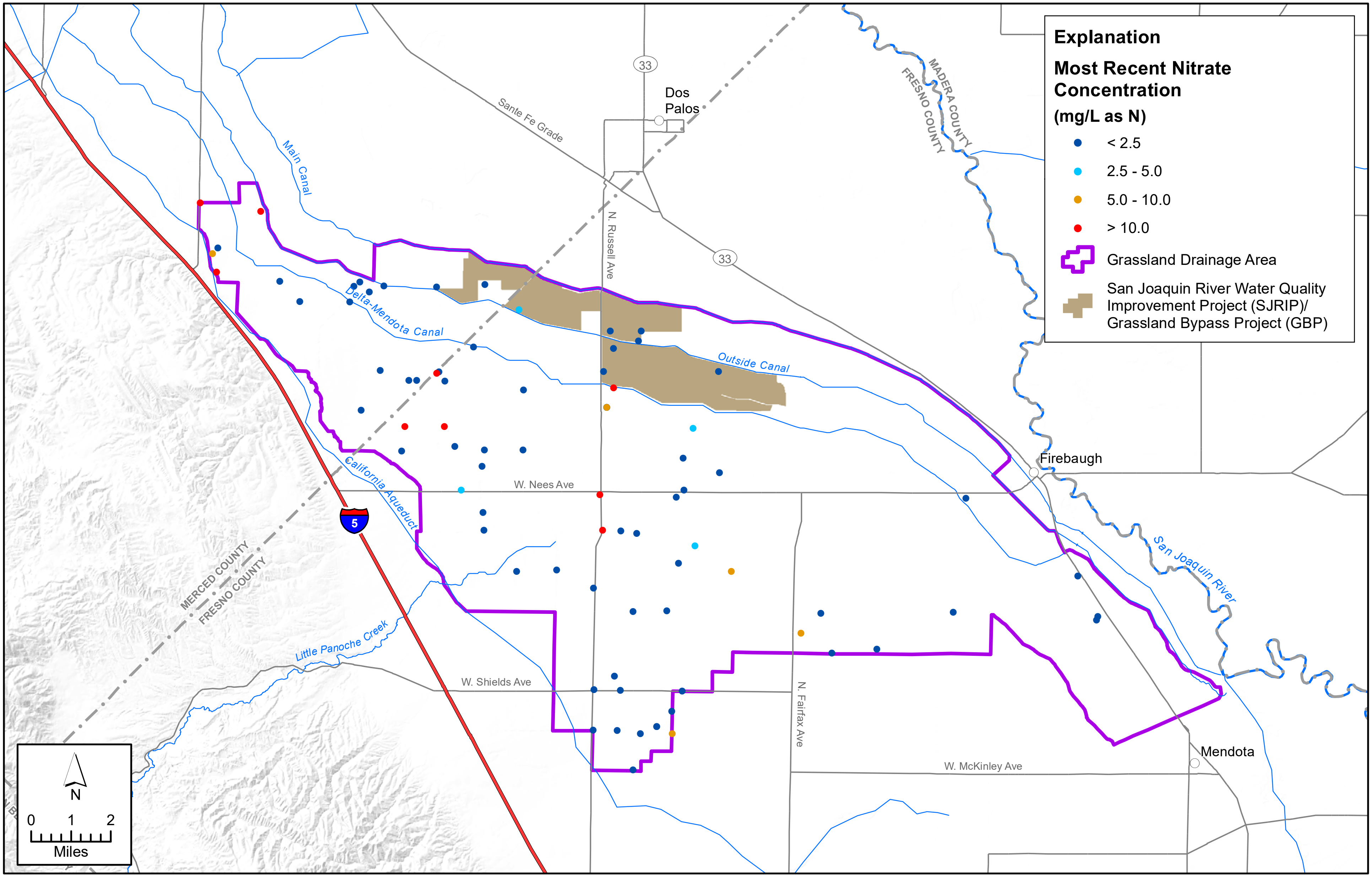

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FIGURE 5-21
Map of Most Recent Nitrate Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

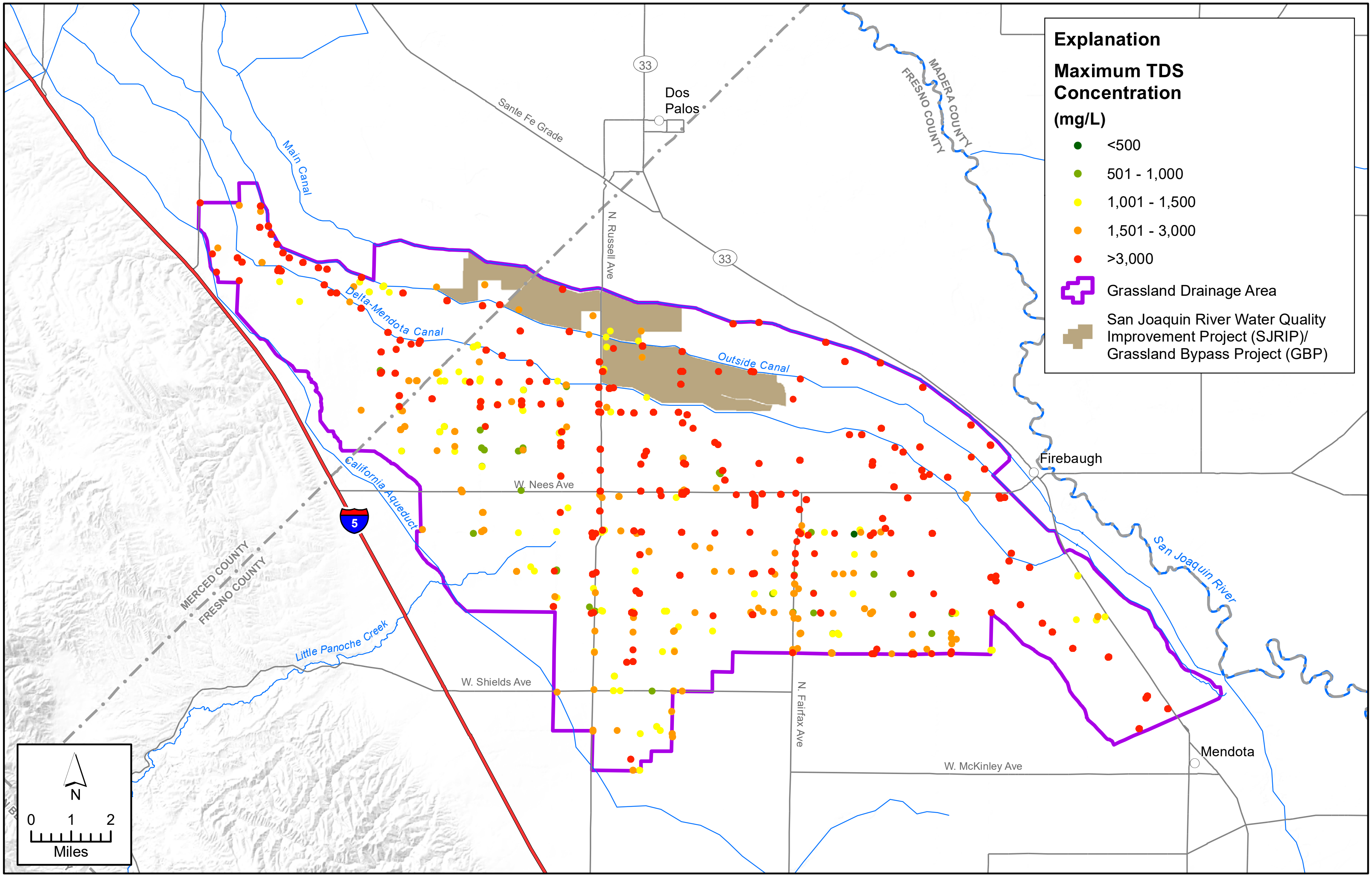

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FIGURE 5-22
Map of Maximum TDS Concentrations: All Drain and Well Data

Grassland Drainage Area
Groundwater Quality Assessment Report

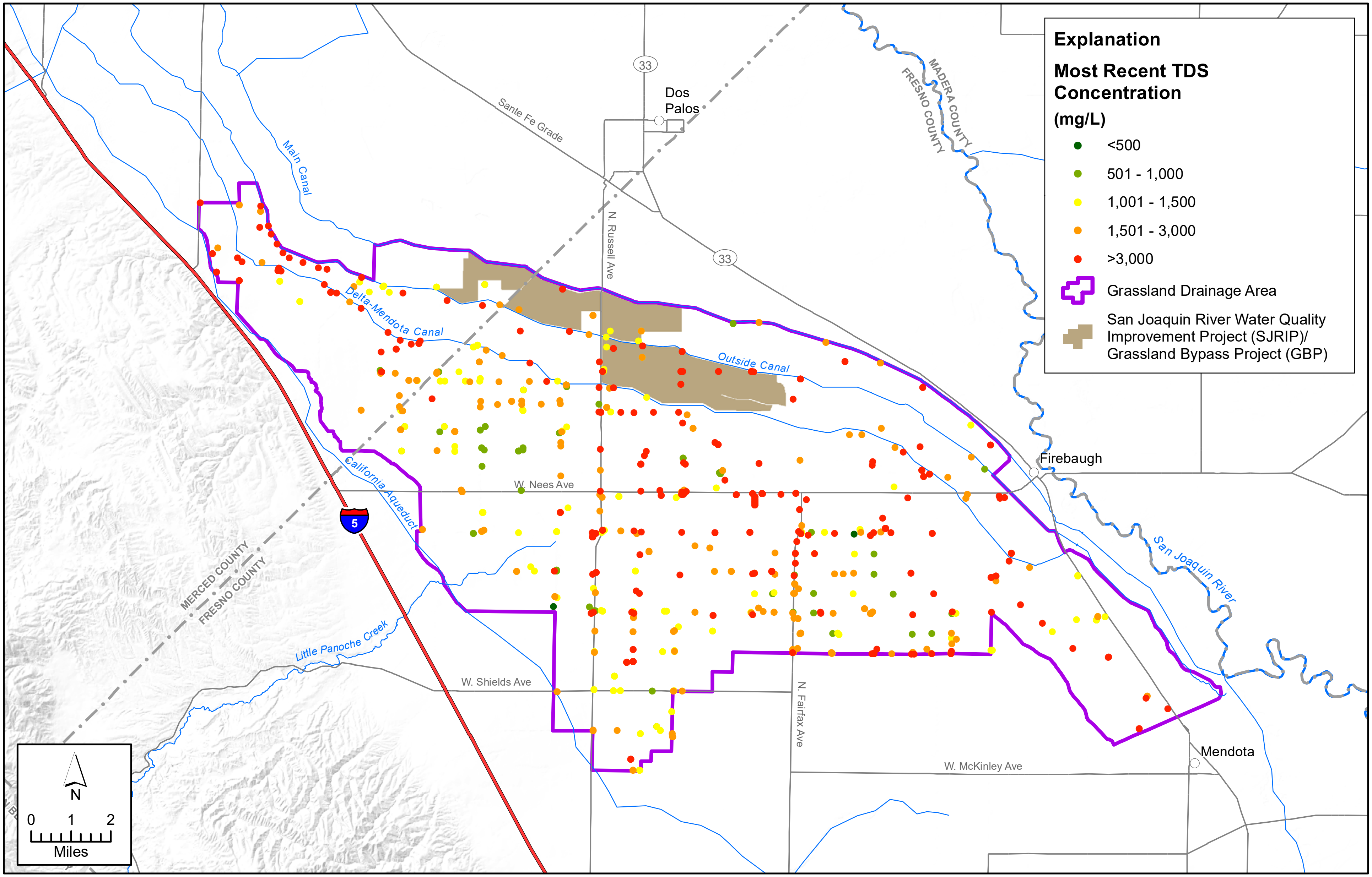

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FIGURE 5-23
Map of Most Recent TDS Concentrations: All Drain and Well Data
Grassland Drainage Area
Groundwater Quality Assessment Report

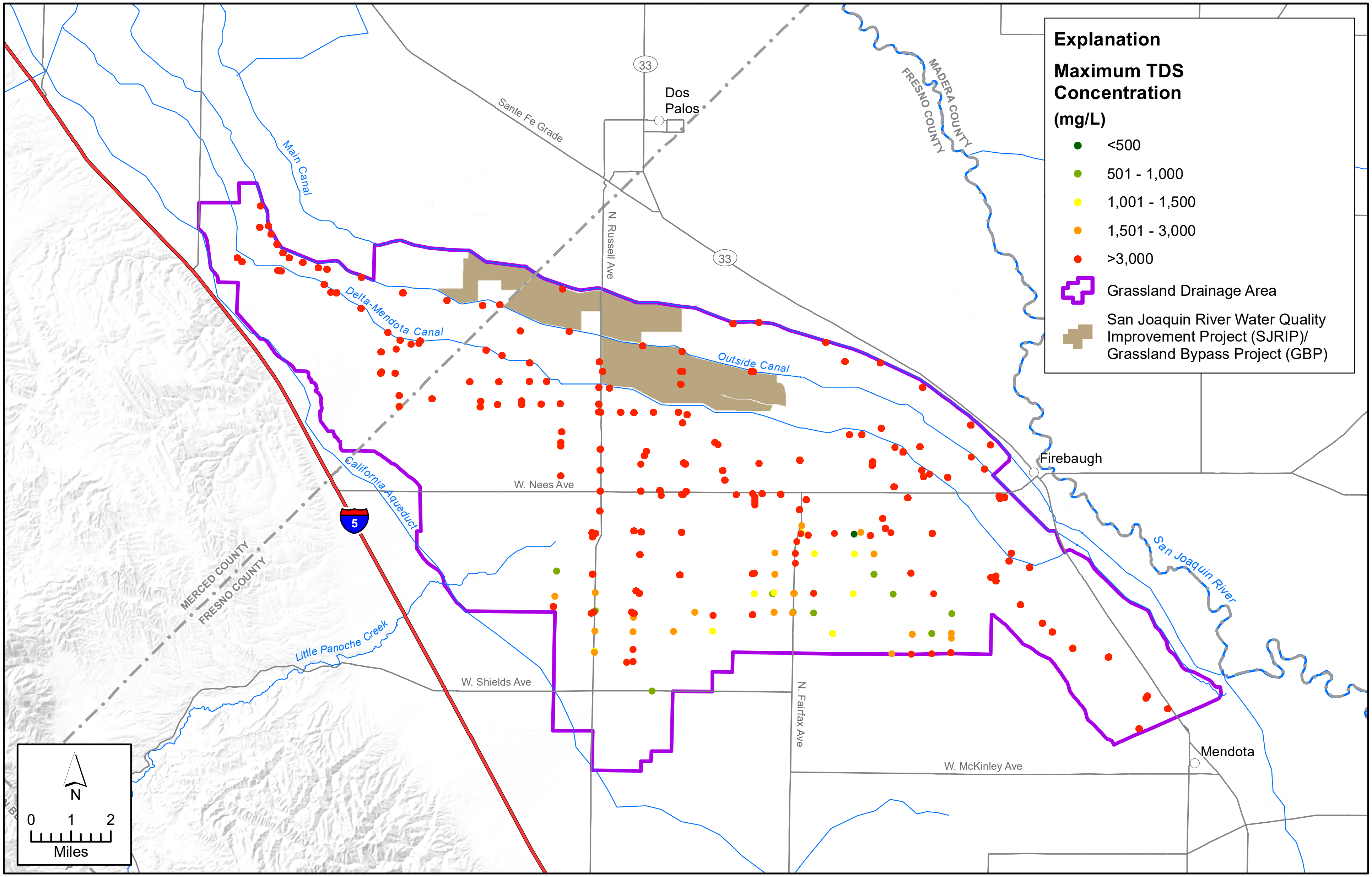

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FIGURE 5-24
Map of Maximum TDS Concentrations: Very Shallow Water
Grassland Drainage Area Groundwater Quality Assessment Report

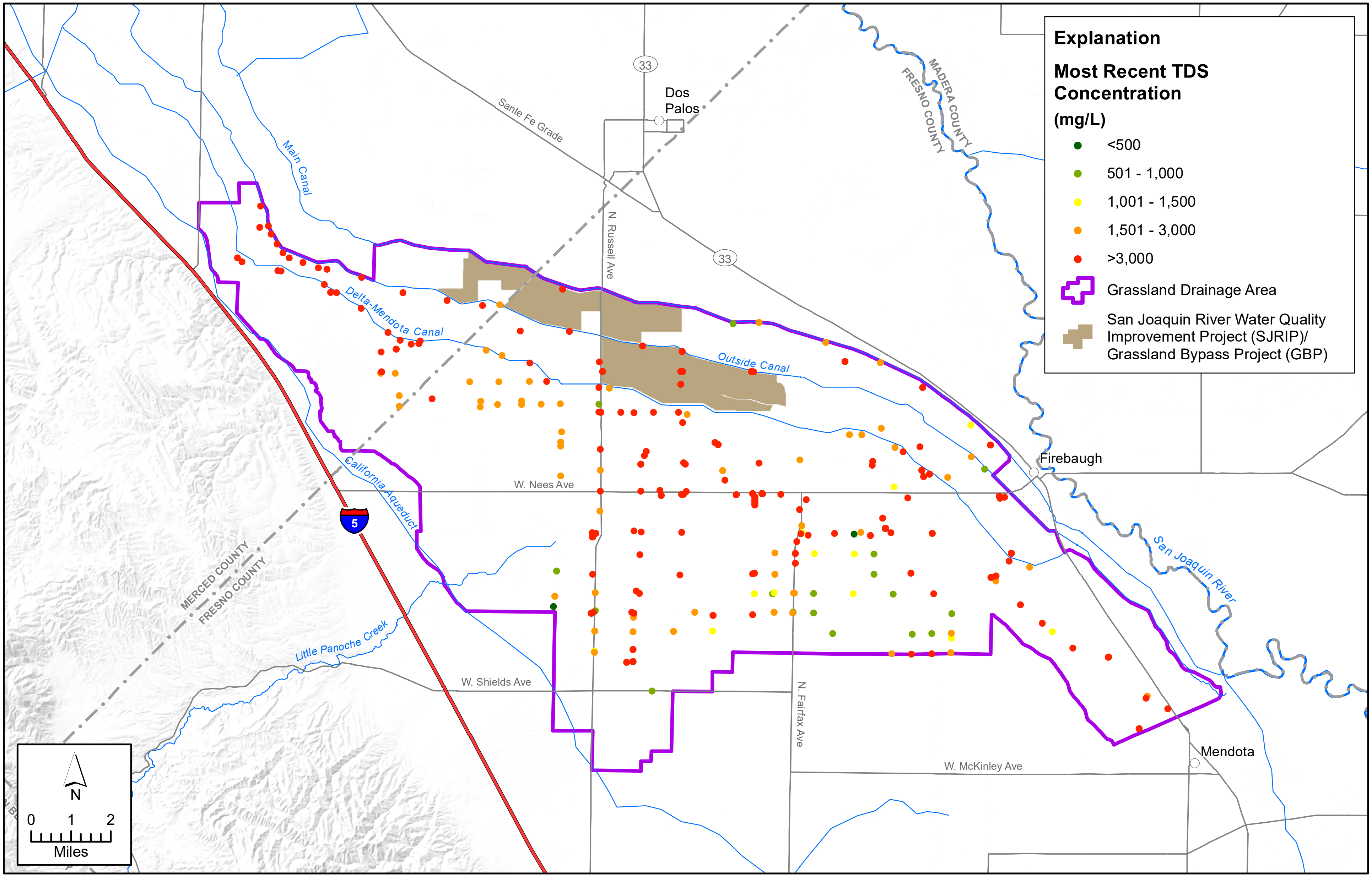

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FIGURE 5-25
Map of Most Recent TDS Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

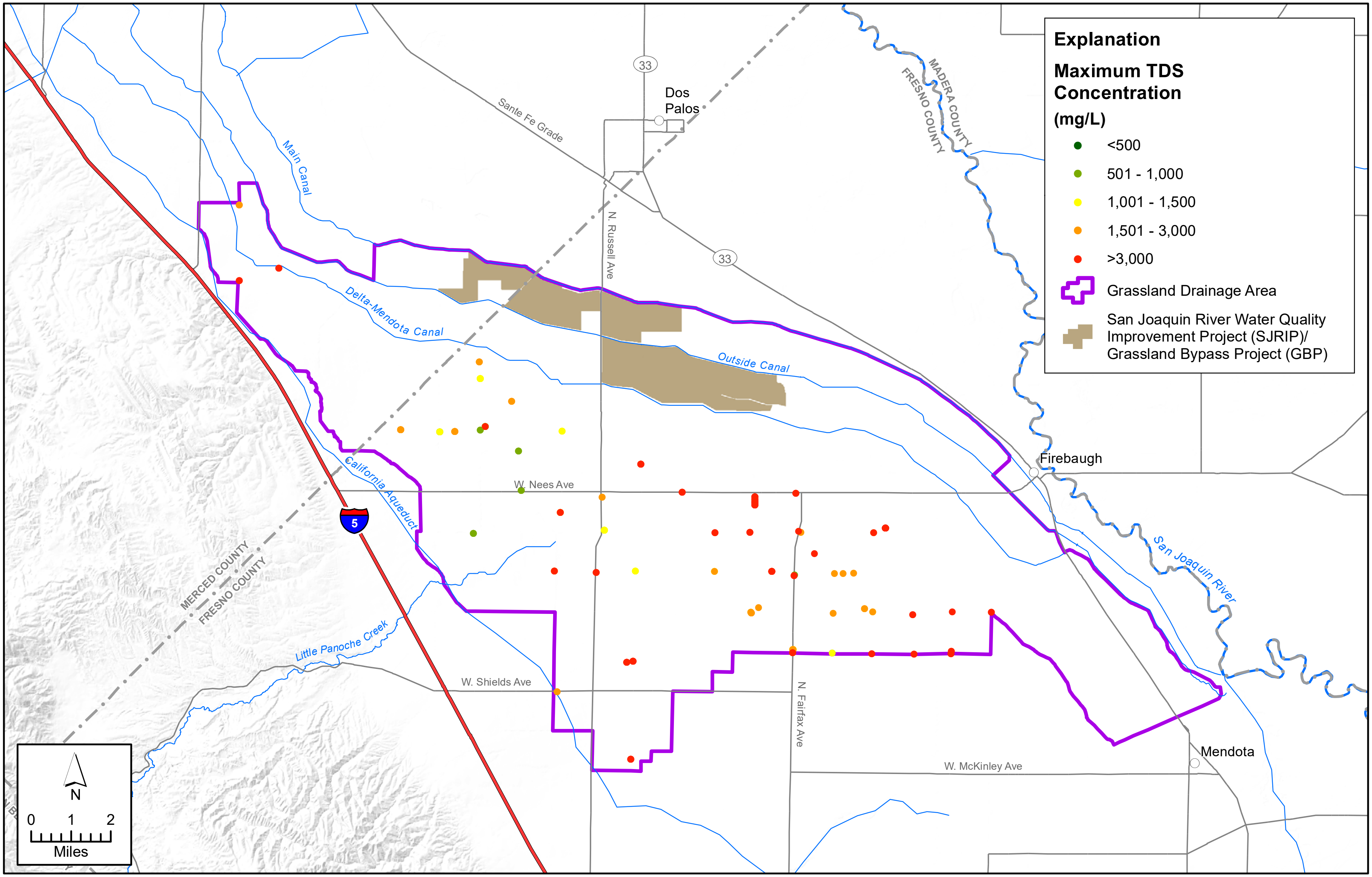

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FIGURE 5-26
Map of Maximum TDS Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

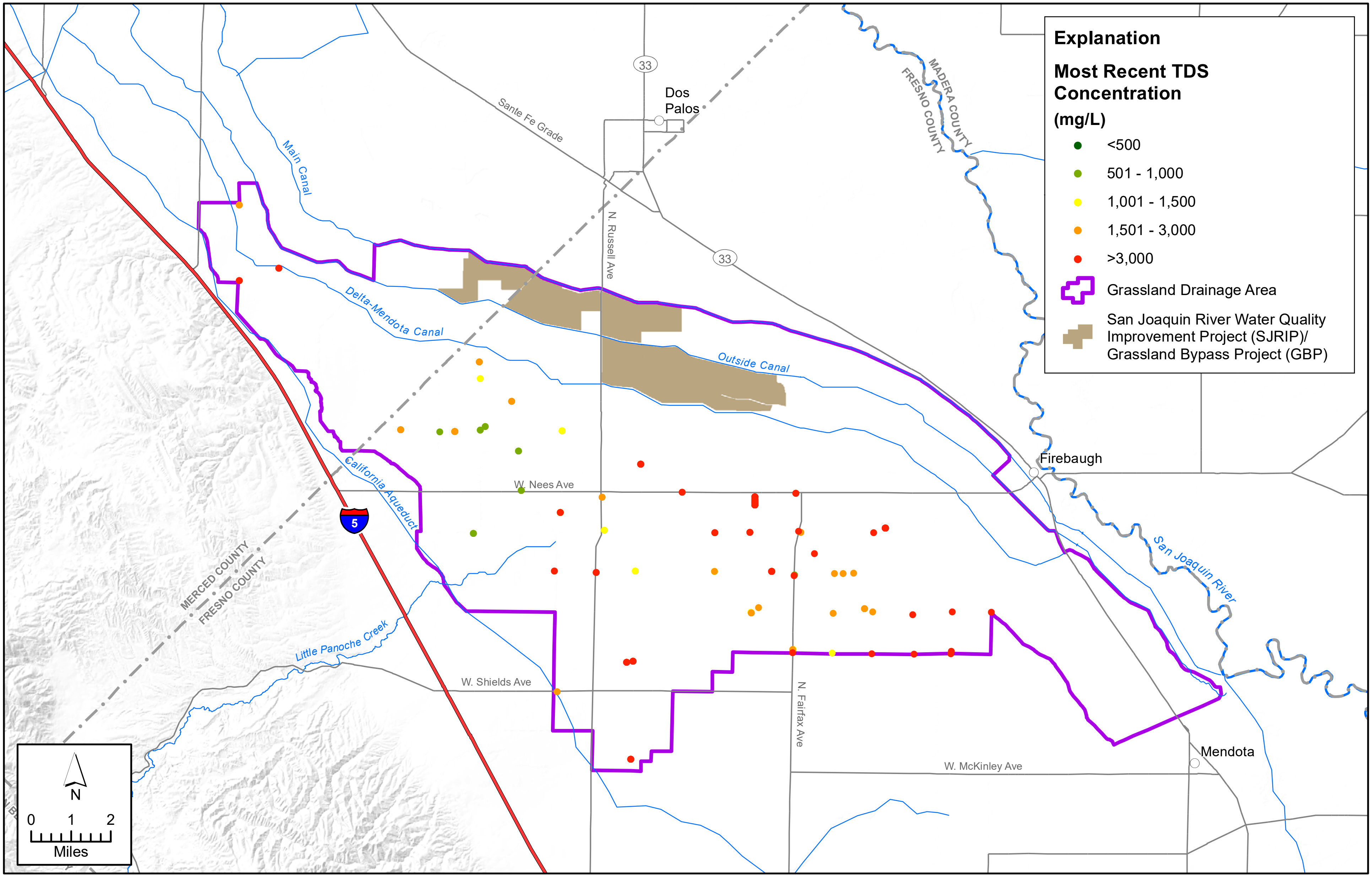

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FIGURE 5-27
Map of Most Recent TDS Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

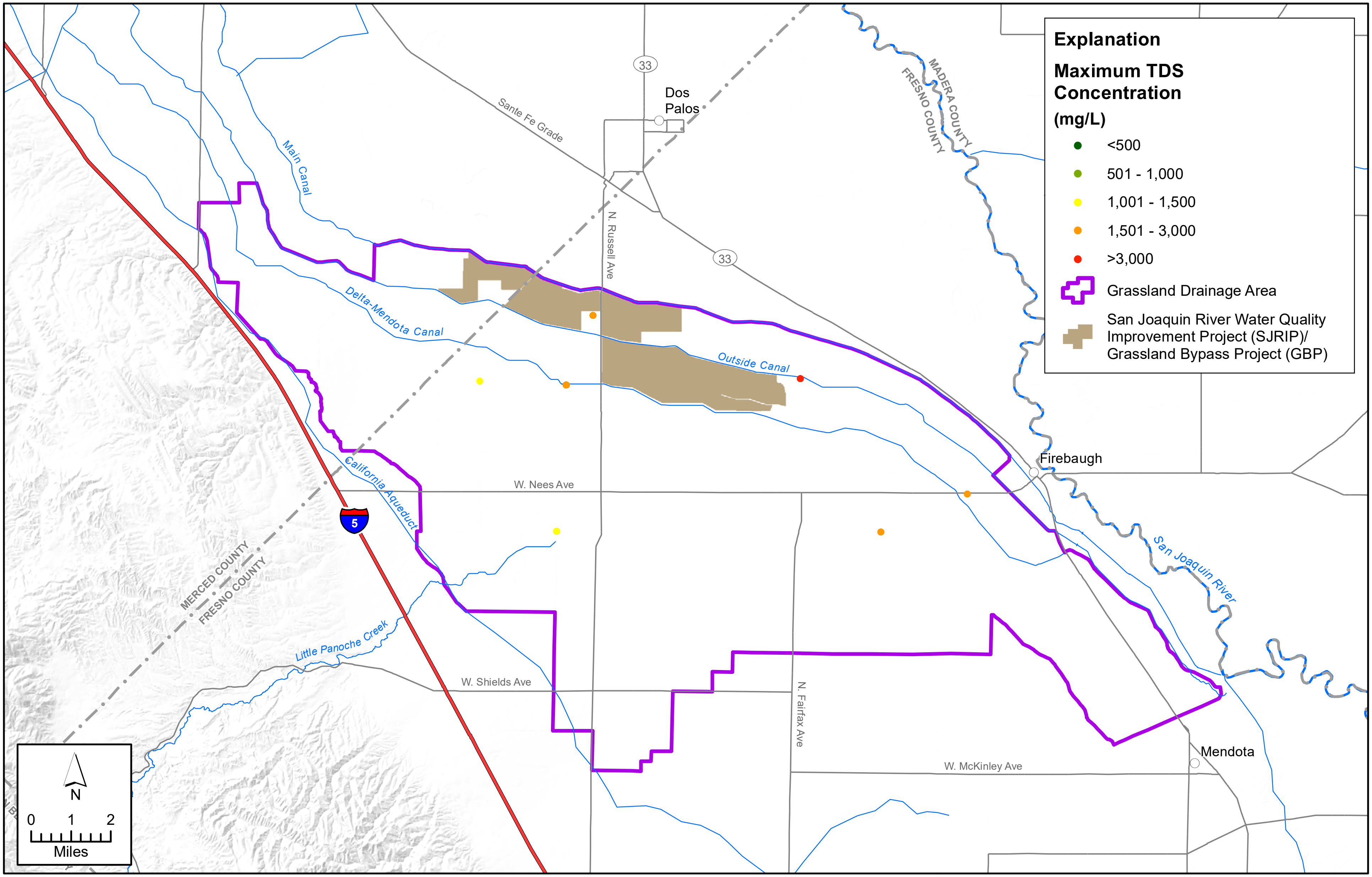

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FIGURE 5-28
Map of Maximum TDS Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

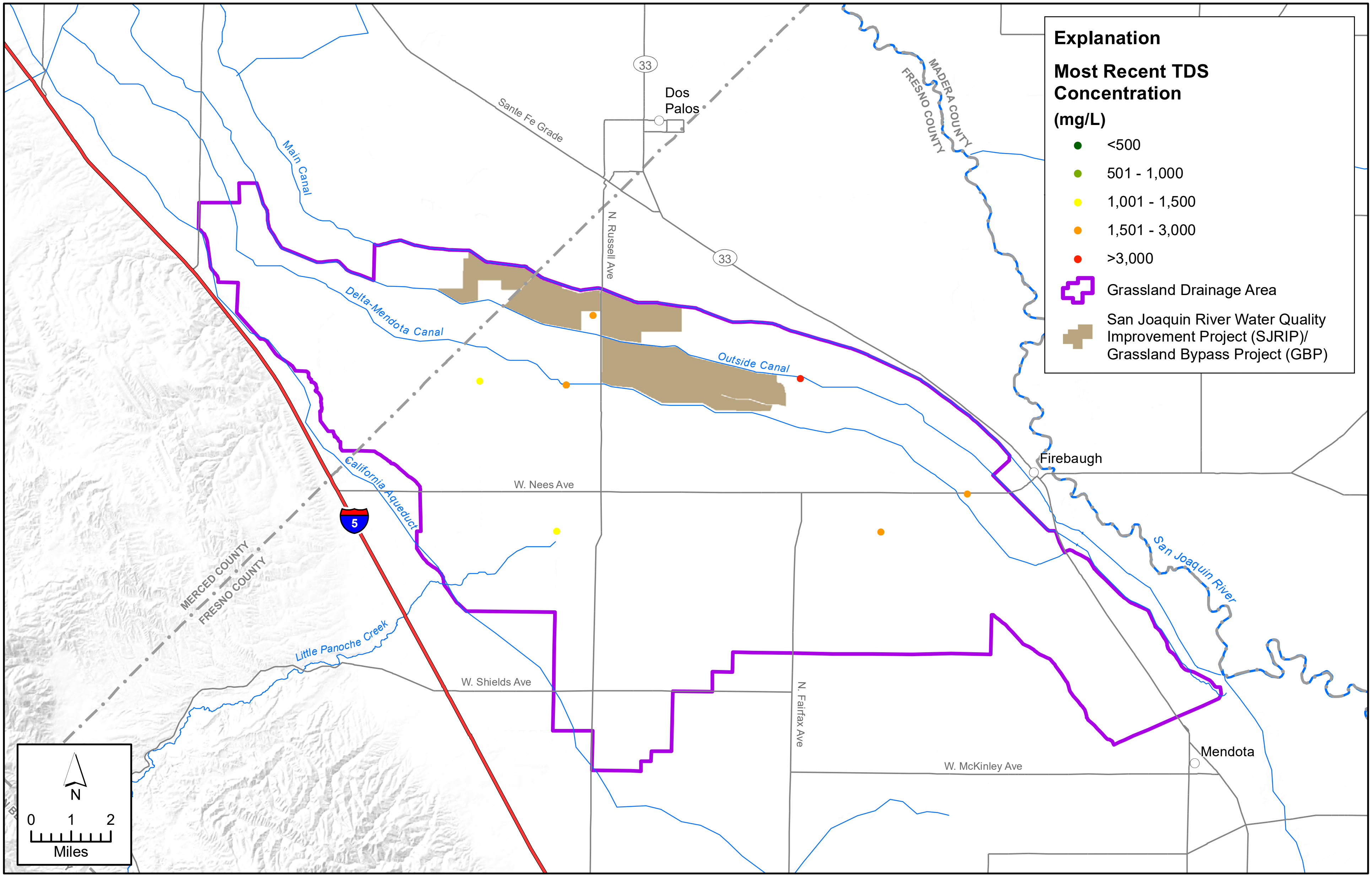

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FIGURE 5-29
Map of Most Recent TDS Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

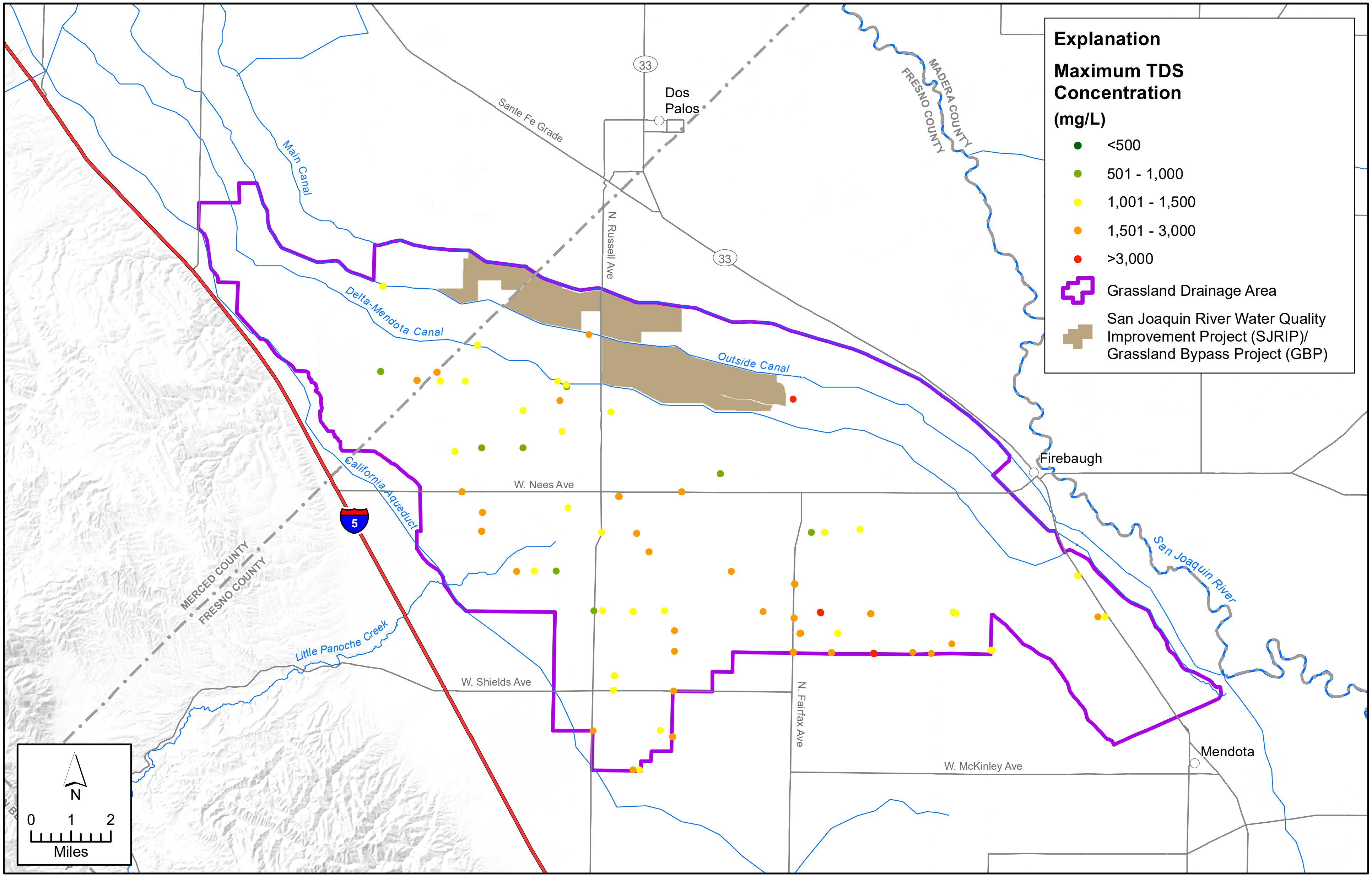

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FIGURE 5-30
Map of Maximum TDS Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

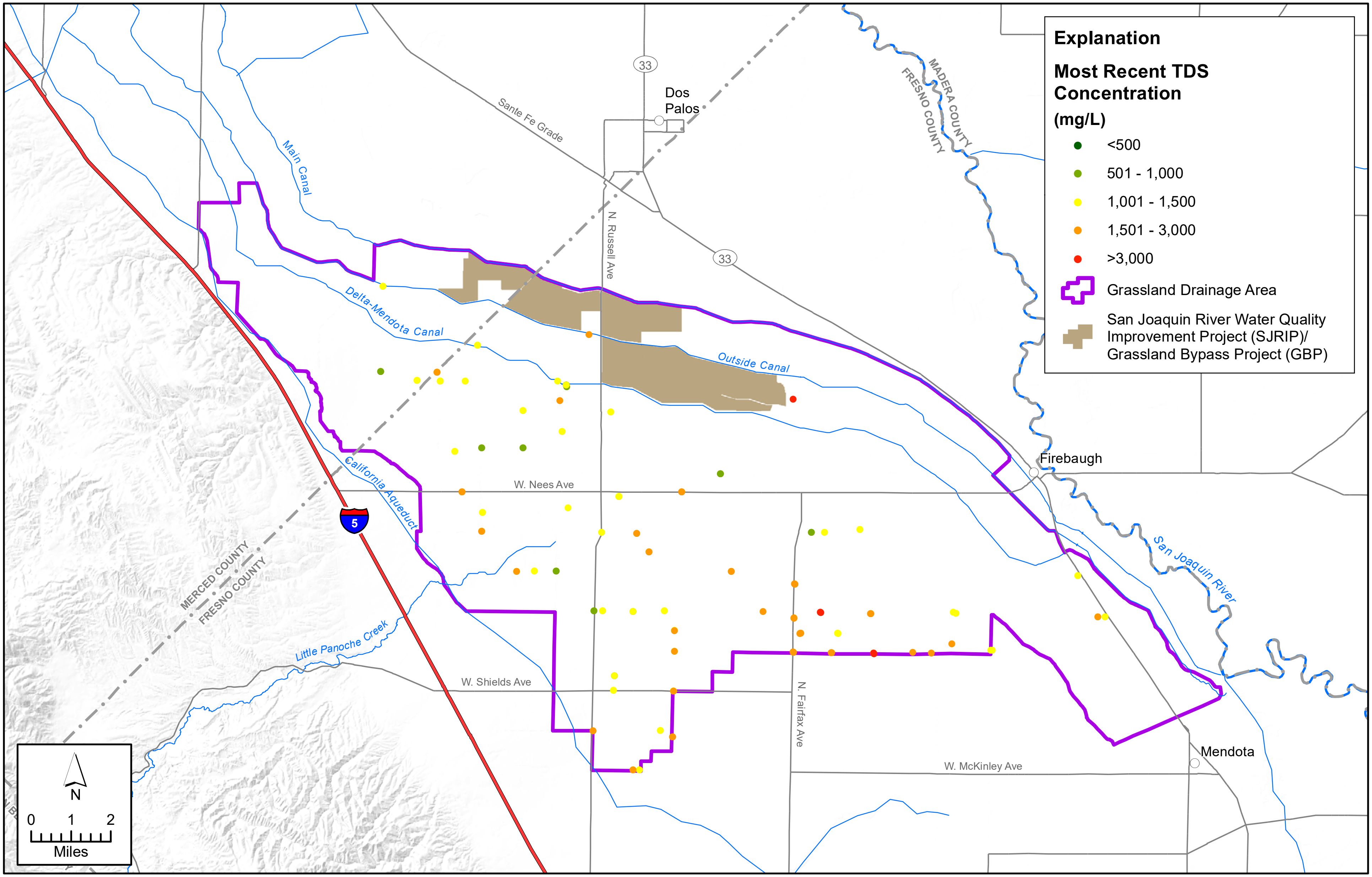

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FIGURE 5-31
Map of Most Recent TDS Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

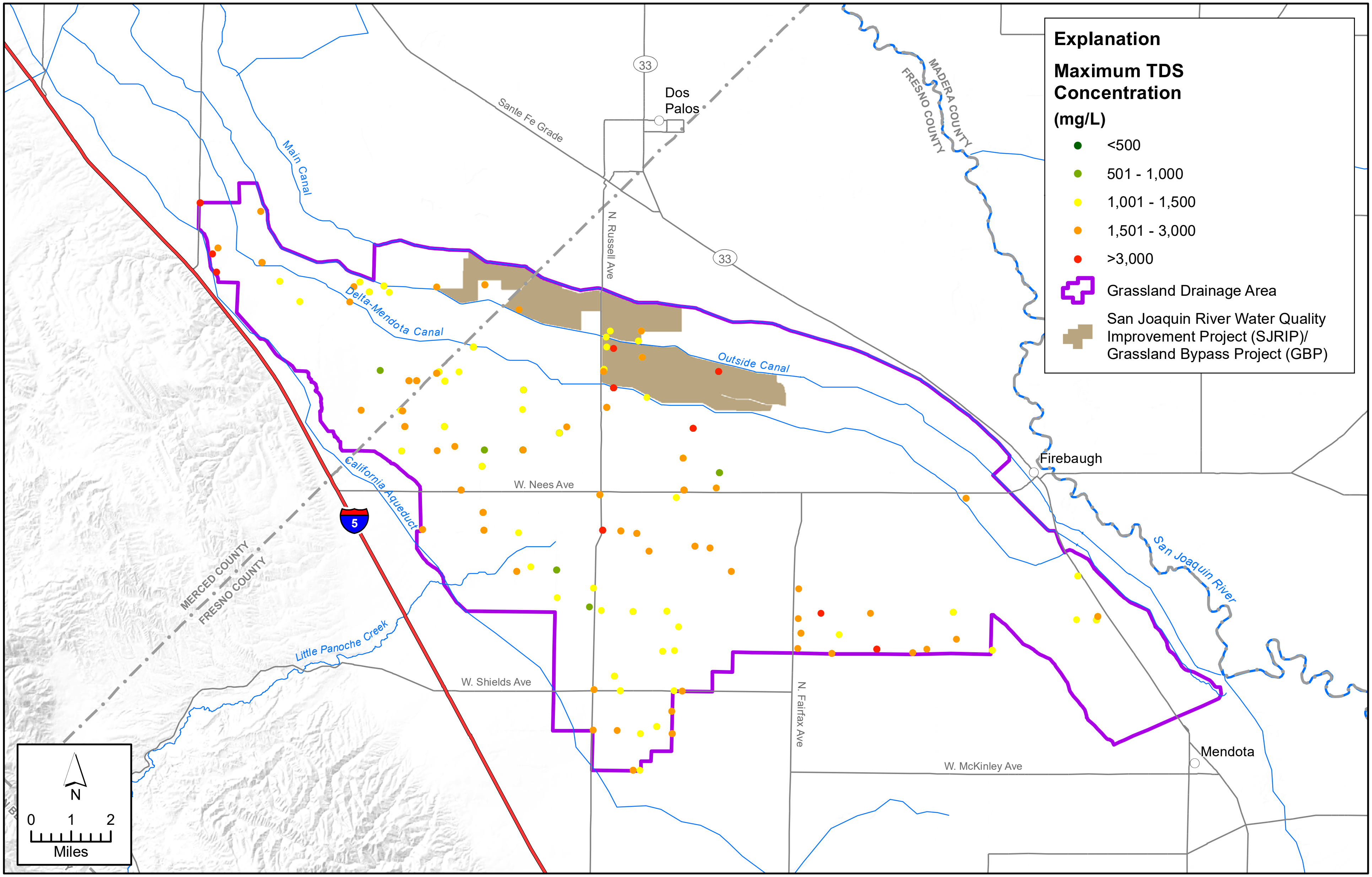

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FIGURE 5-32
Map of Maximum TDS Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

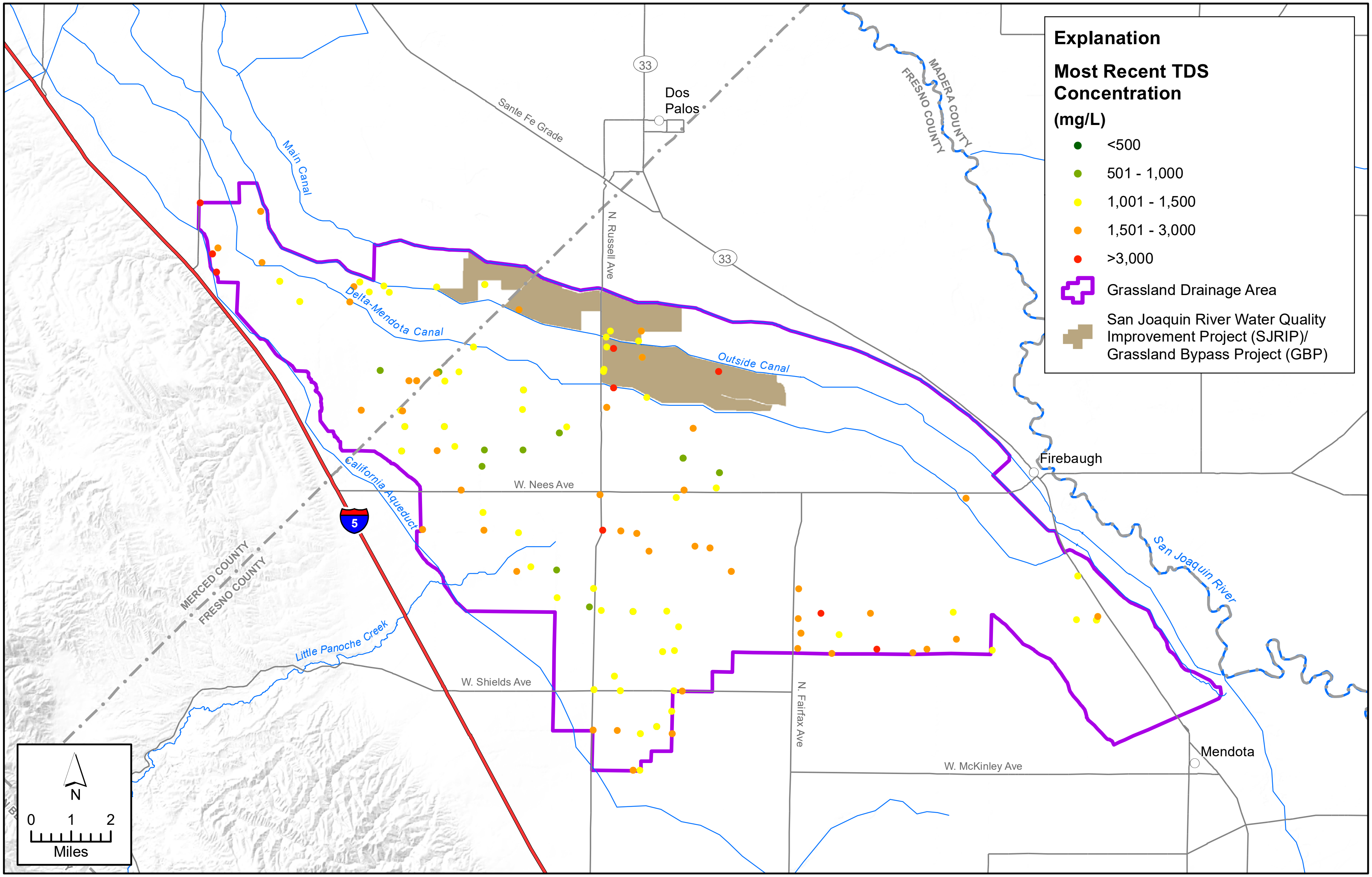

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FIGURE 5-33
Map of Most Recent TDS Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

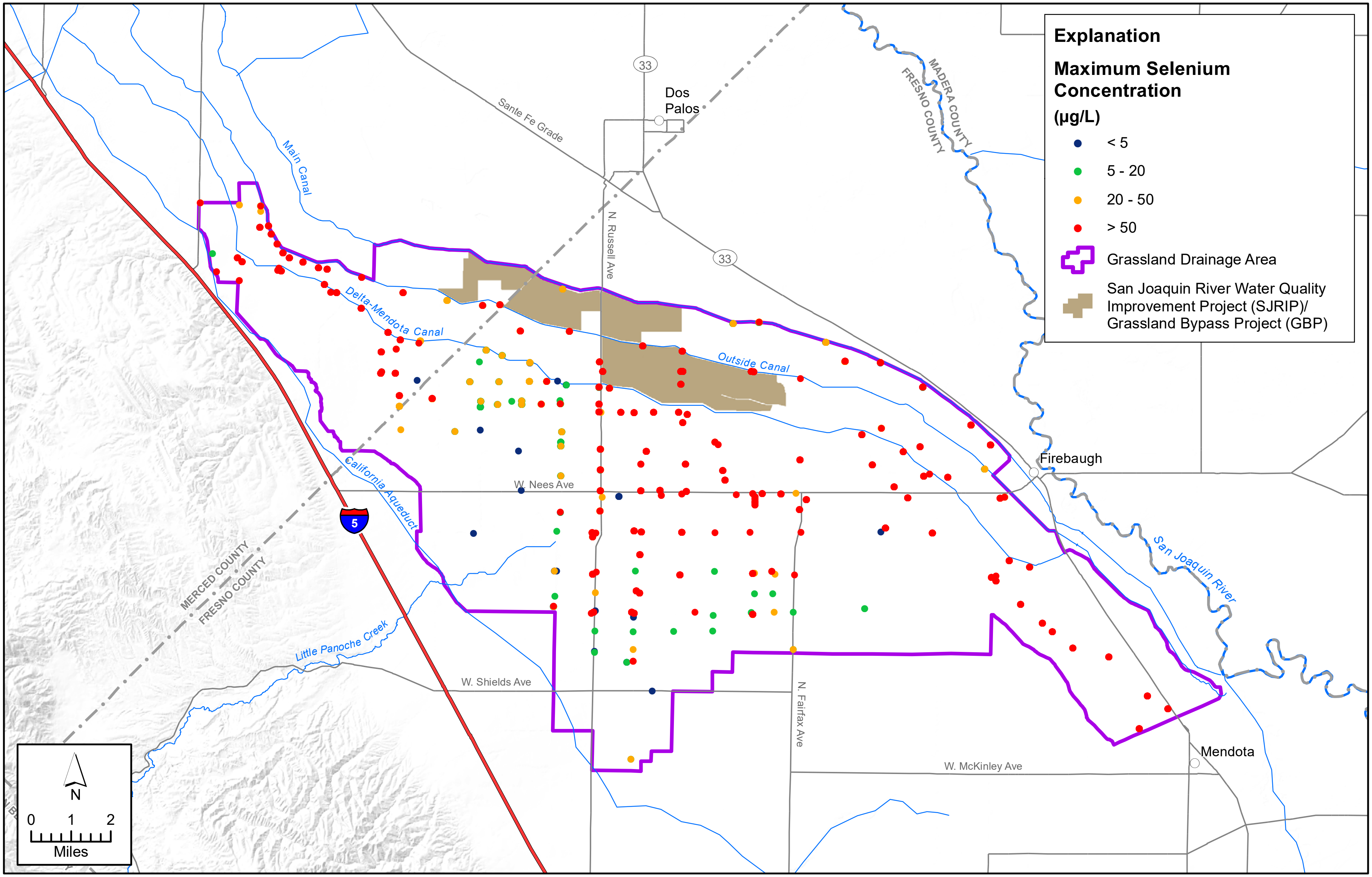

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FIGURE 5-34
Map of Maximum Selenium Concentrations: All Drain and Well Data
Grassland Drainage Area
Groundwater Quality Assessment Report

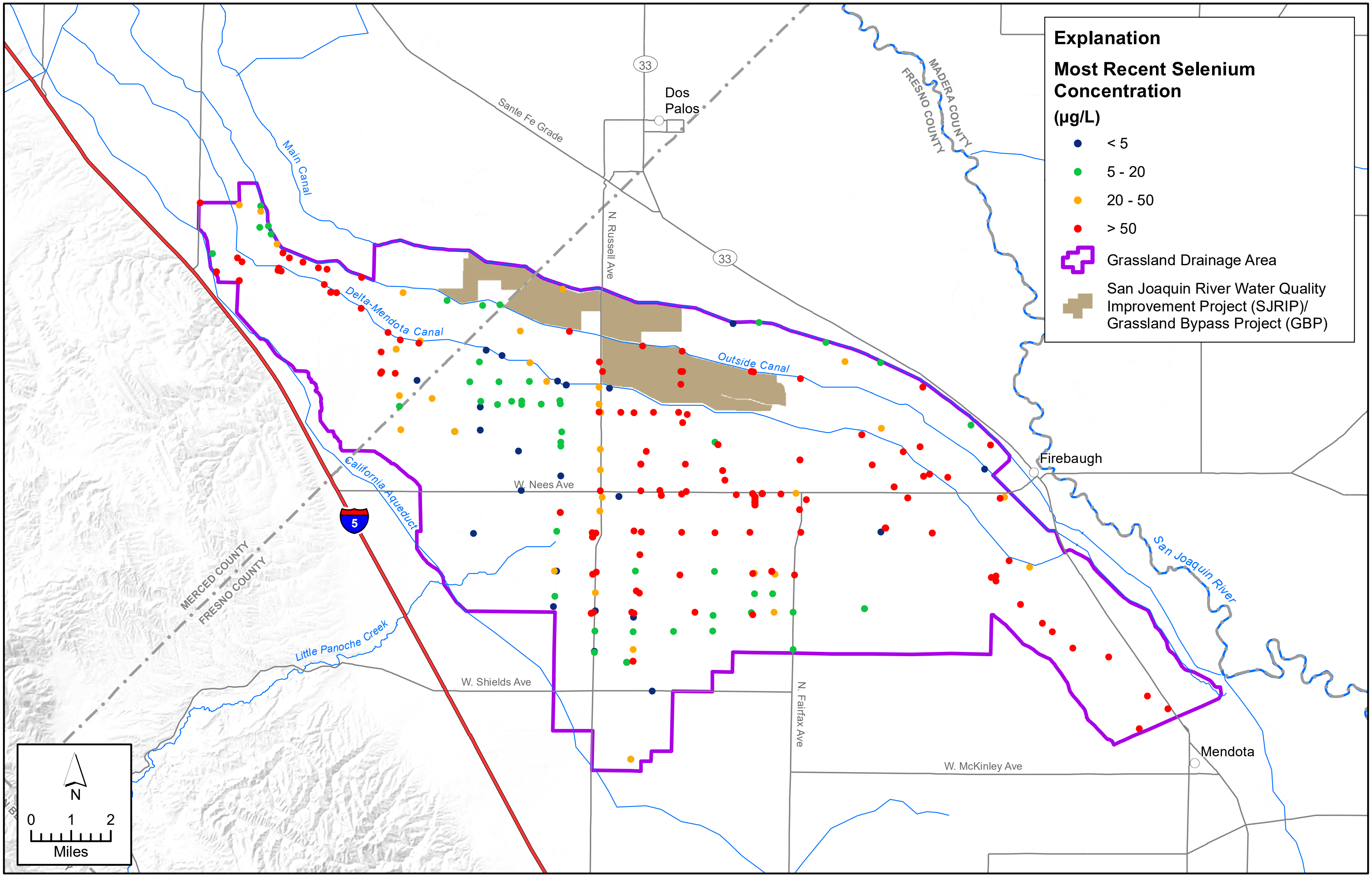

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FIGURE 5-35
Map of Most Recent Selenium Concentrations: All Drain and Well Data
Grassland Drainage Area
Groundwater Quality Assessment Report

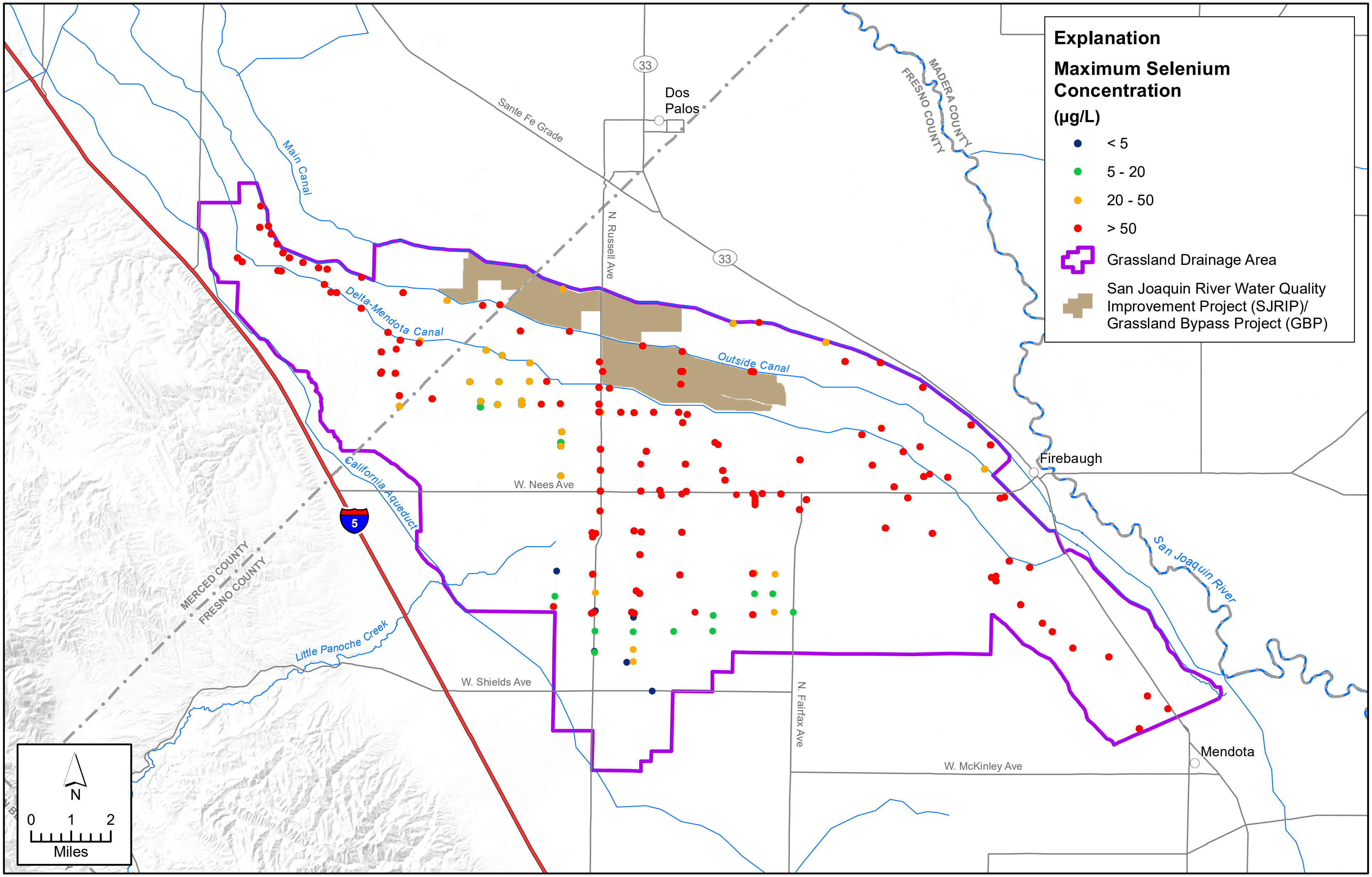

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FIGURE 5-36
Map of Maximum Selenium Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

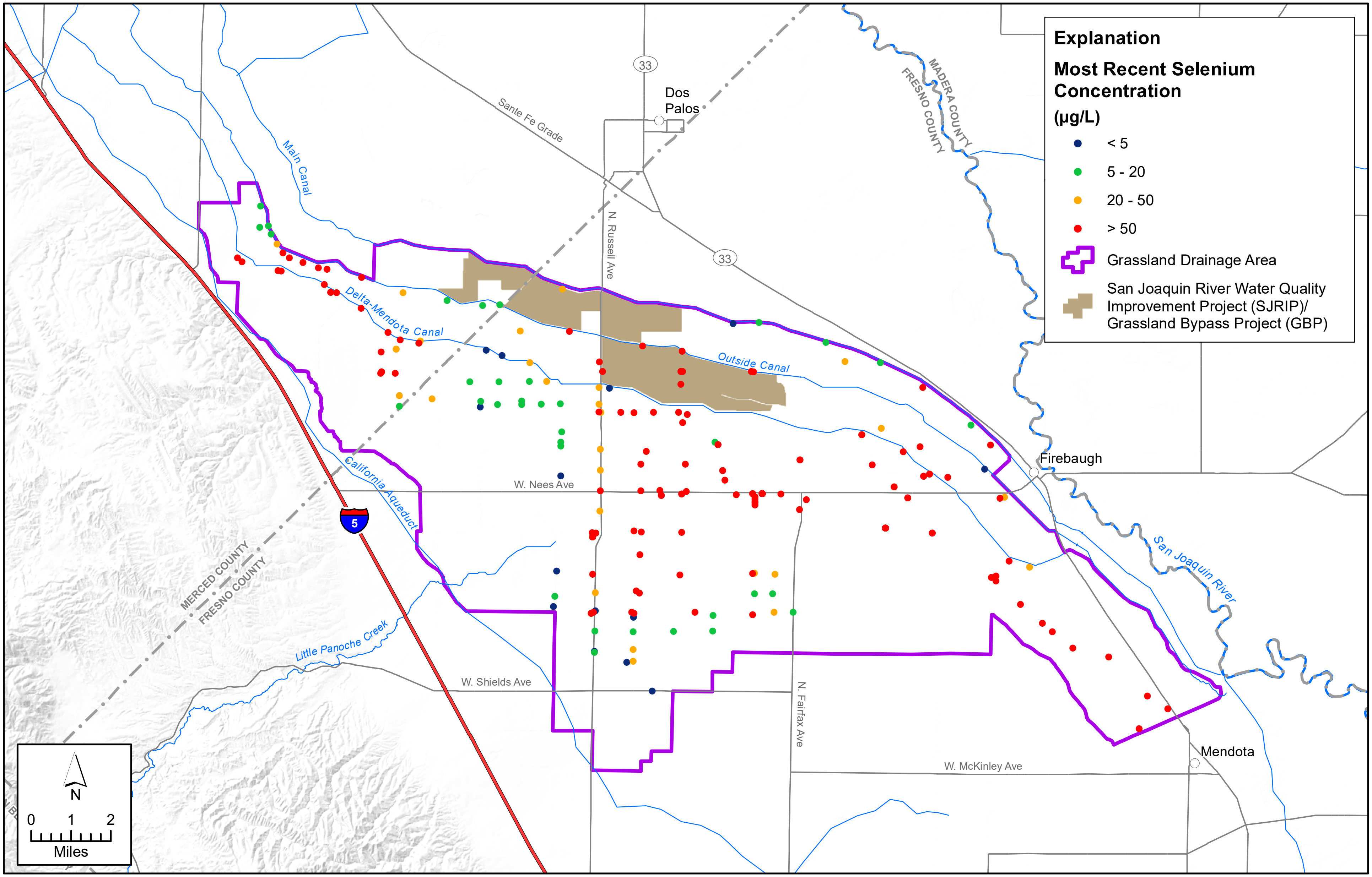

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FIGURE 5-37
Map of Most Recent Selenium Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

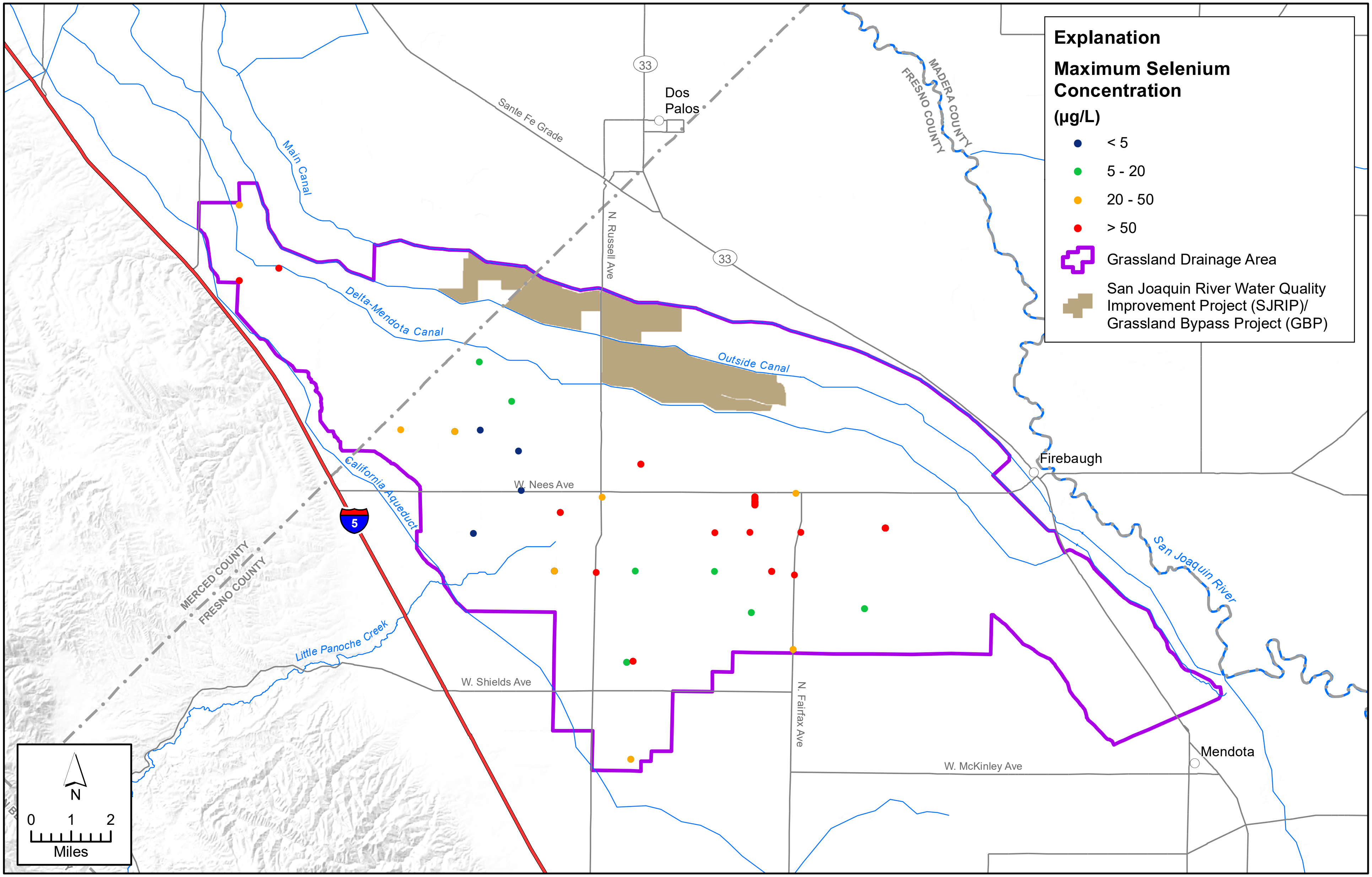

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FIGURE 5-38
Map of Maximum Selenium Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

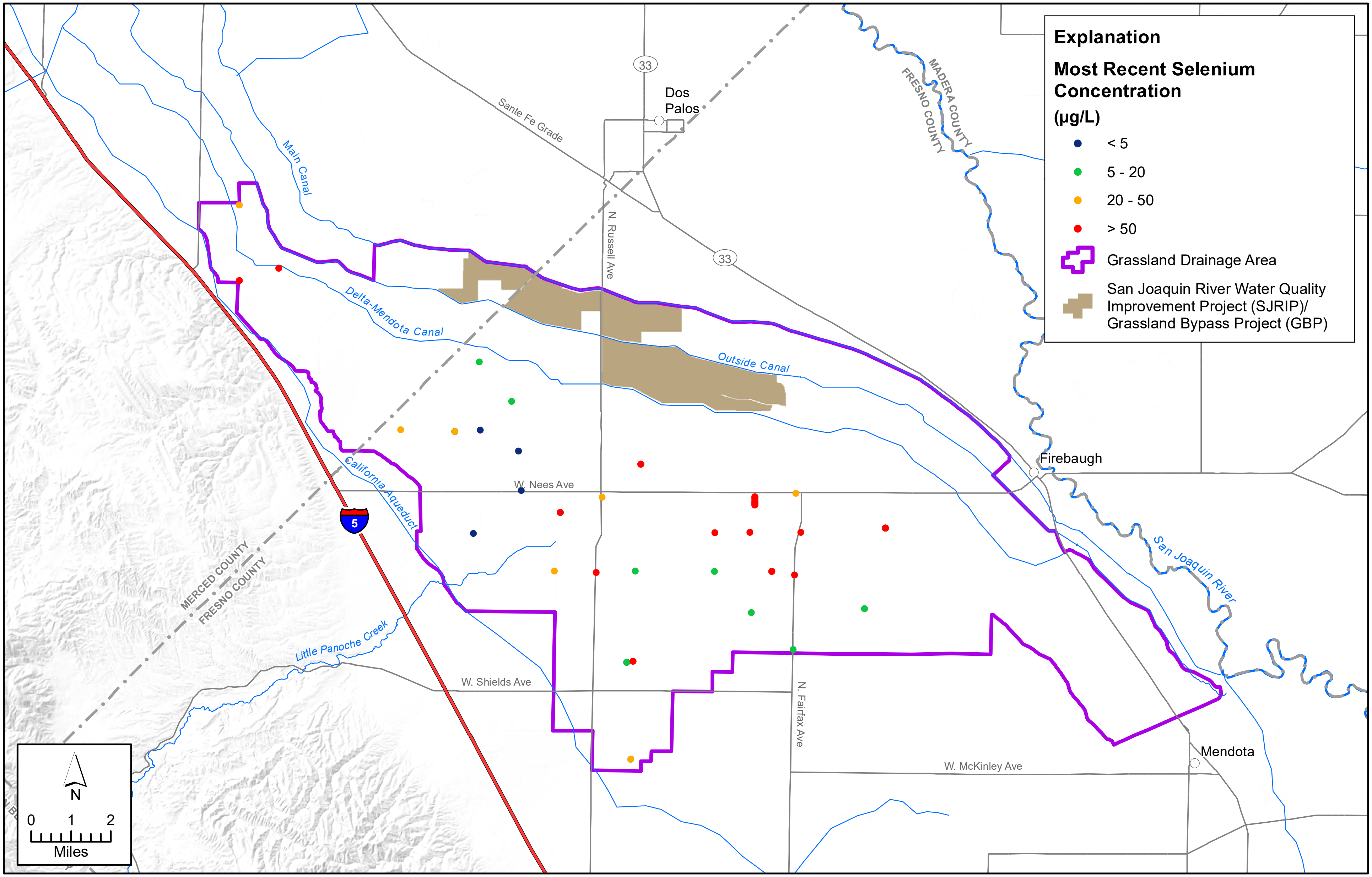

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FIGURE 5-39
Map of Most Recent Selenium Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

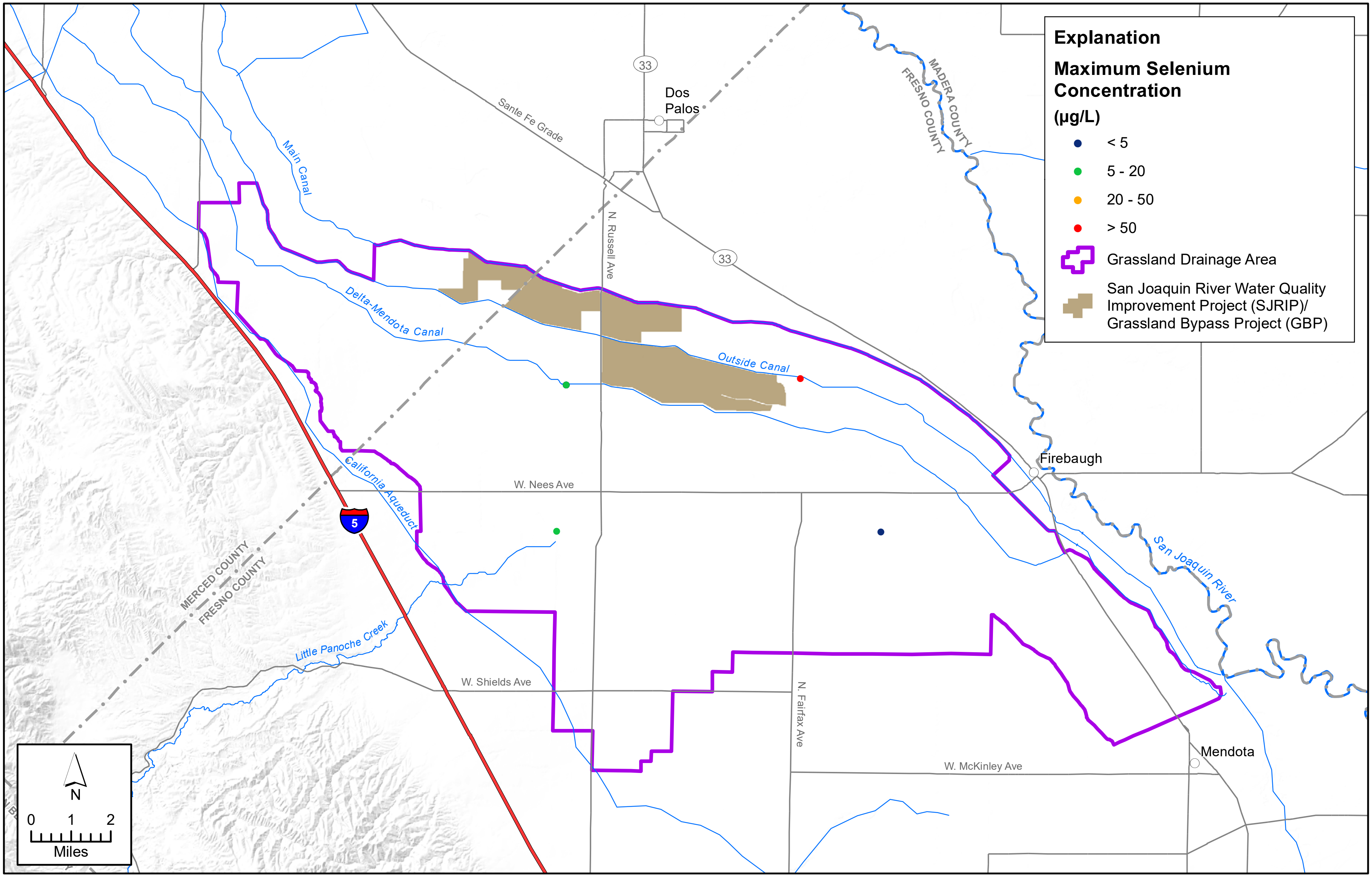

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FIGURE 5-40
Map of Maximum Selenium Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

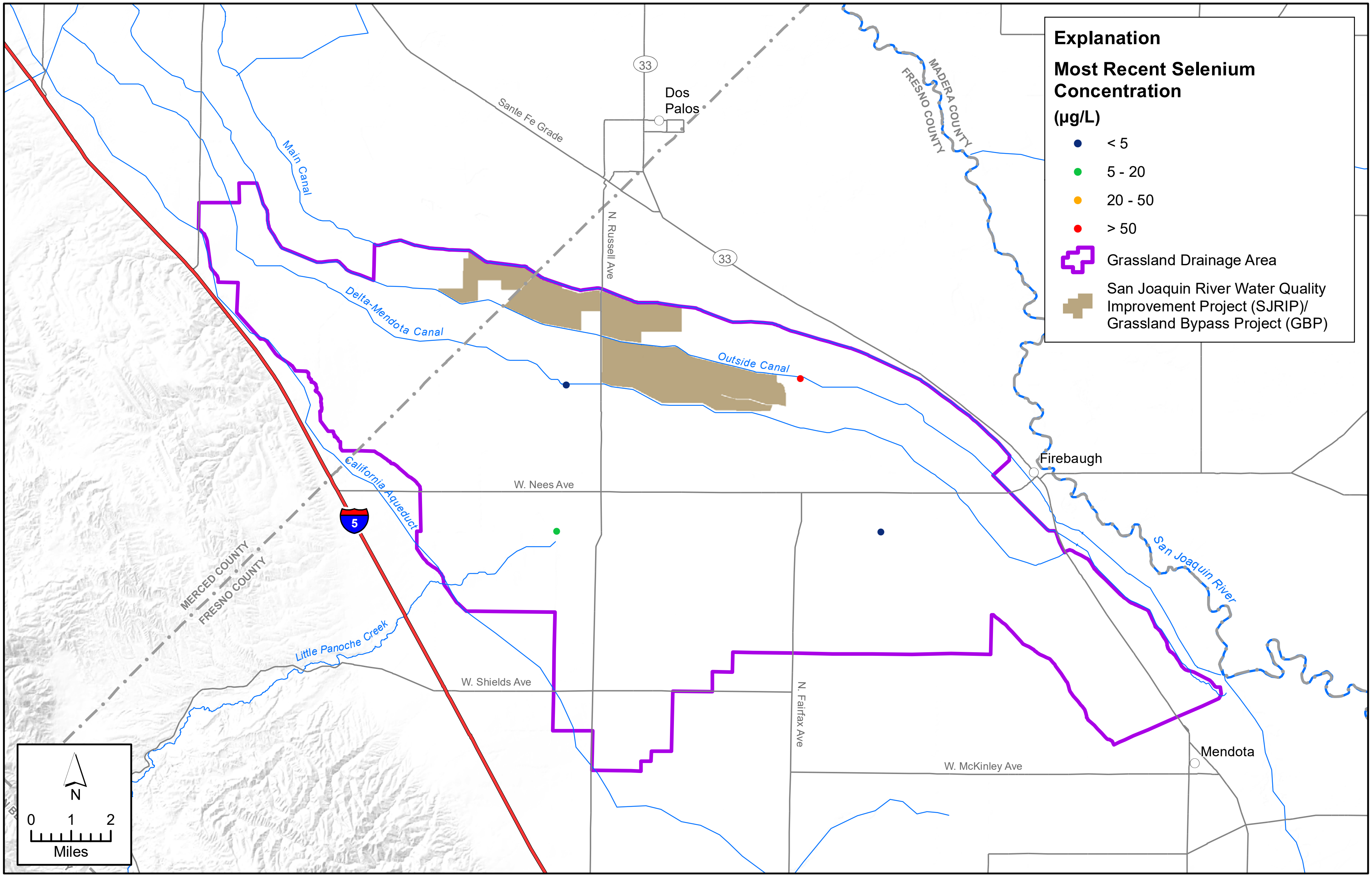

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FIGURE 5-41
Map of Most Recent Selenium Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

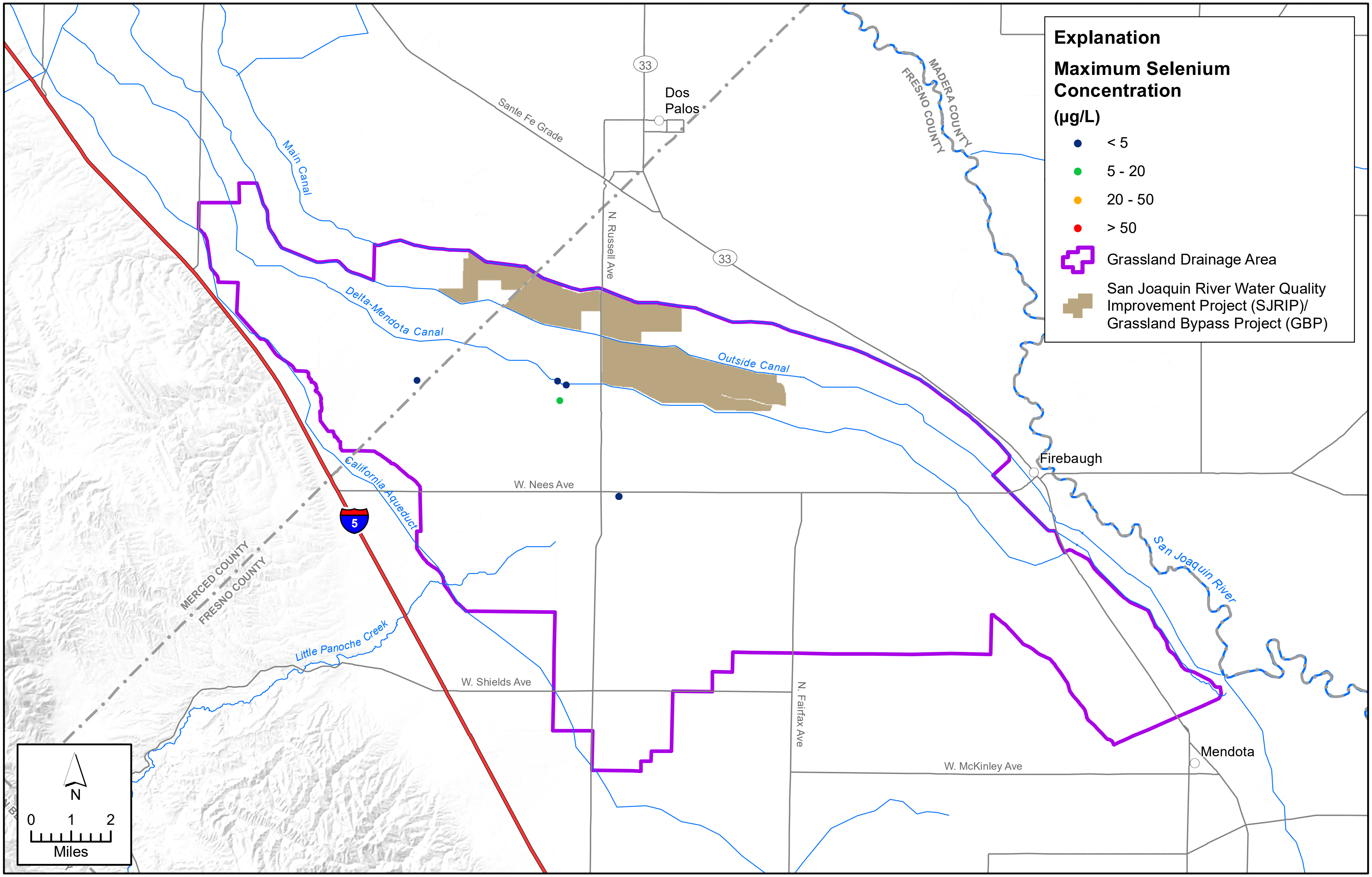

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FIGURE 5-42
Map of Maximum Selenium Concentrations: Lower Aquifer

Grassland Drainage Area
Groundwater Quality Assessment Report

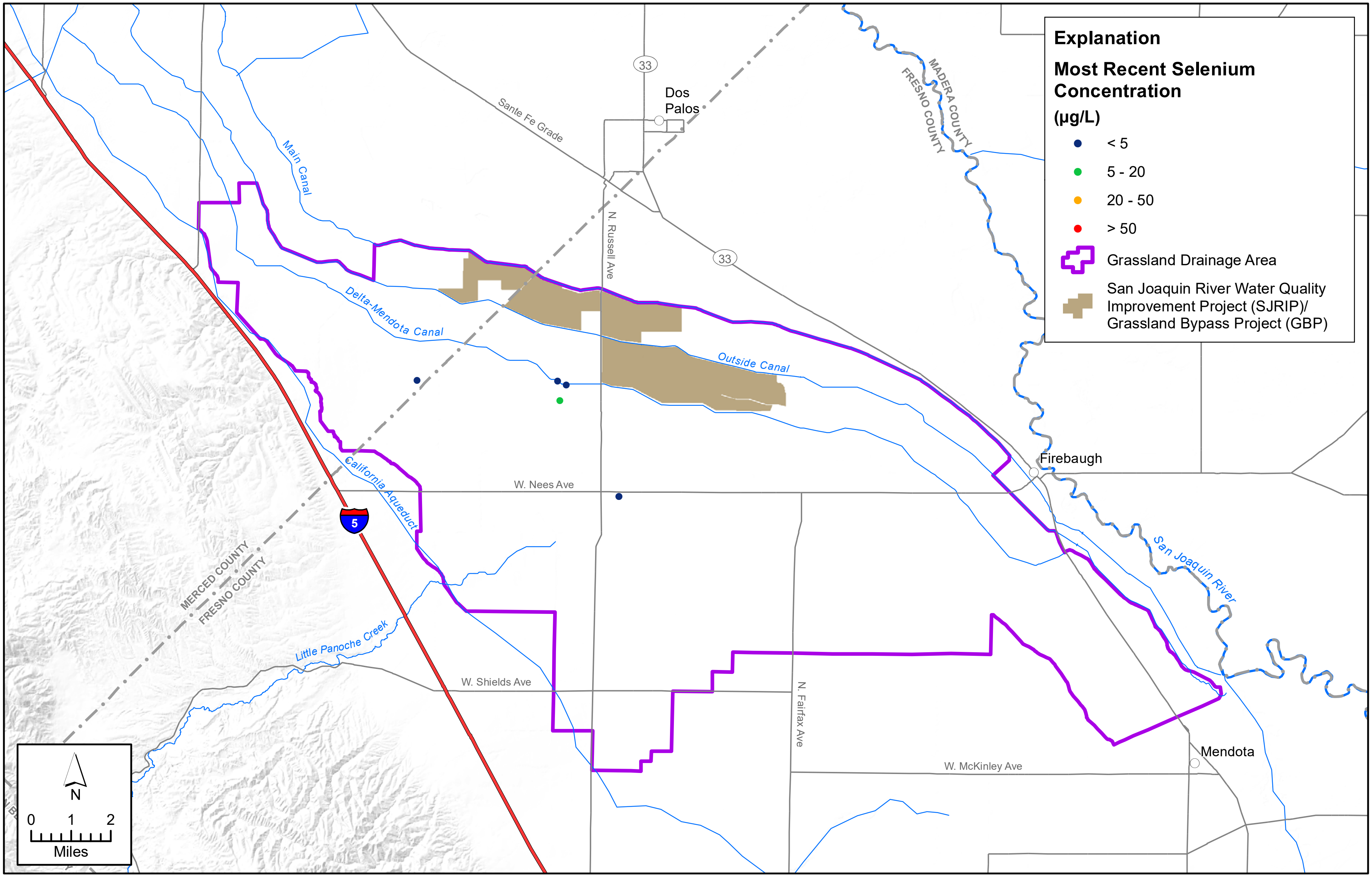

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FIGURE 5-43
Map of Most Recent Selenium Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

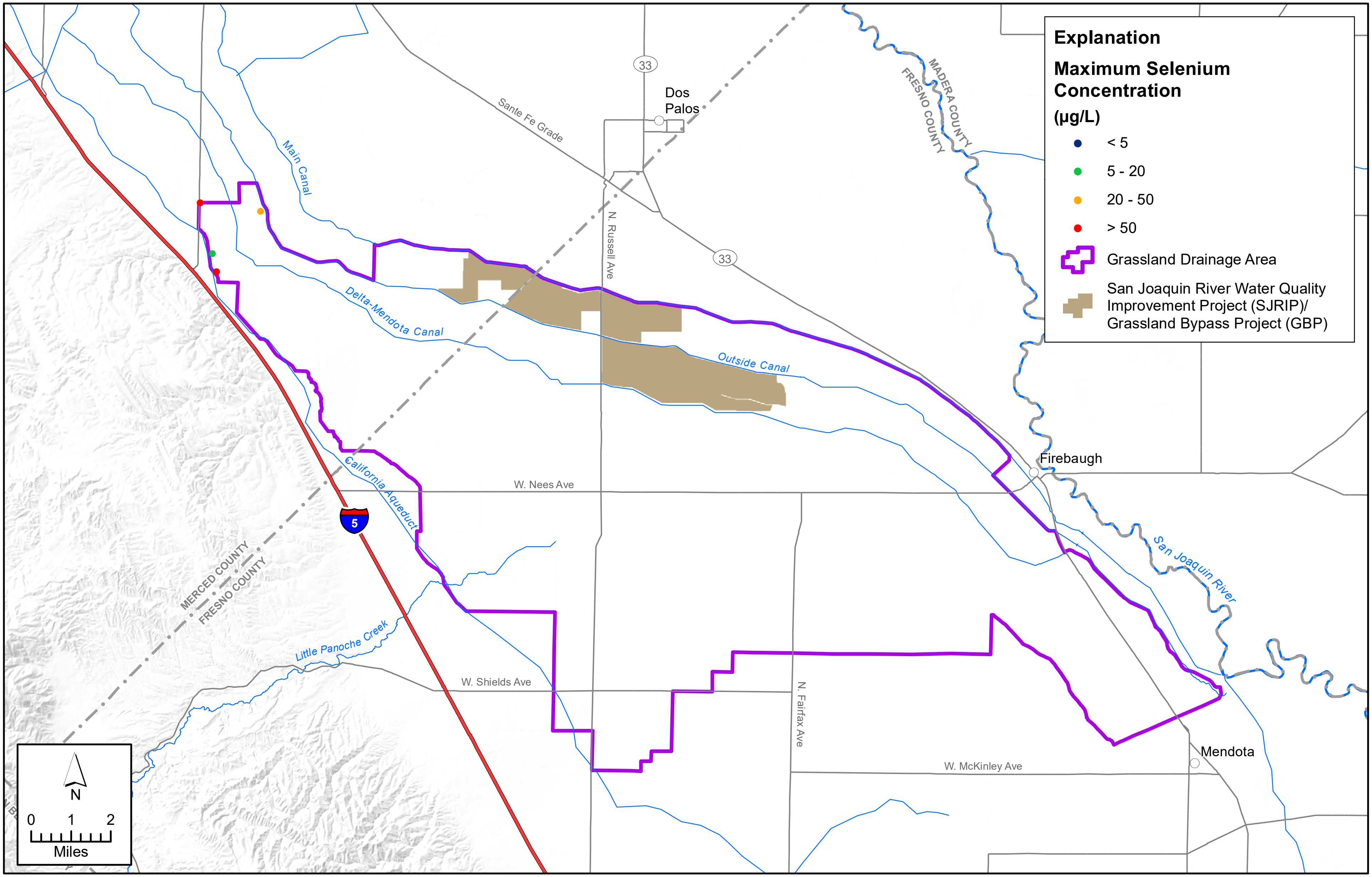

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FIGURE 5-44
Map of Maximum Selenium Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

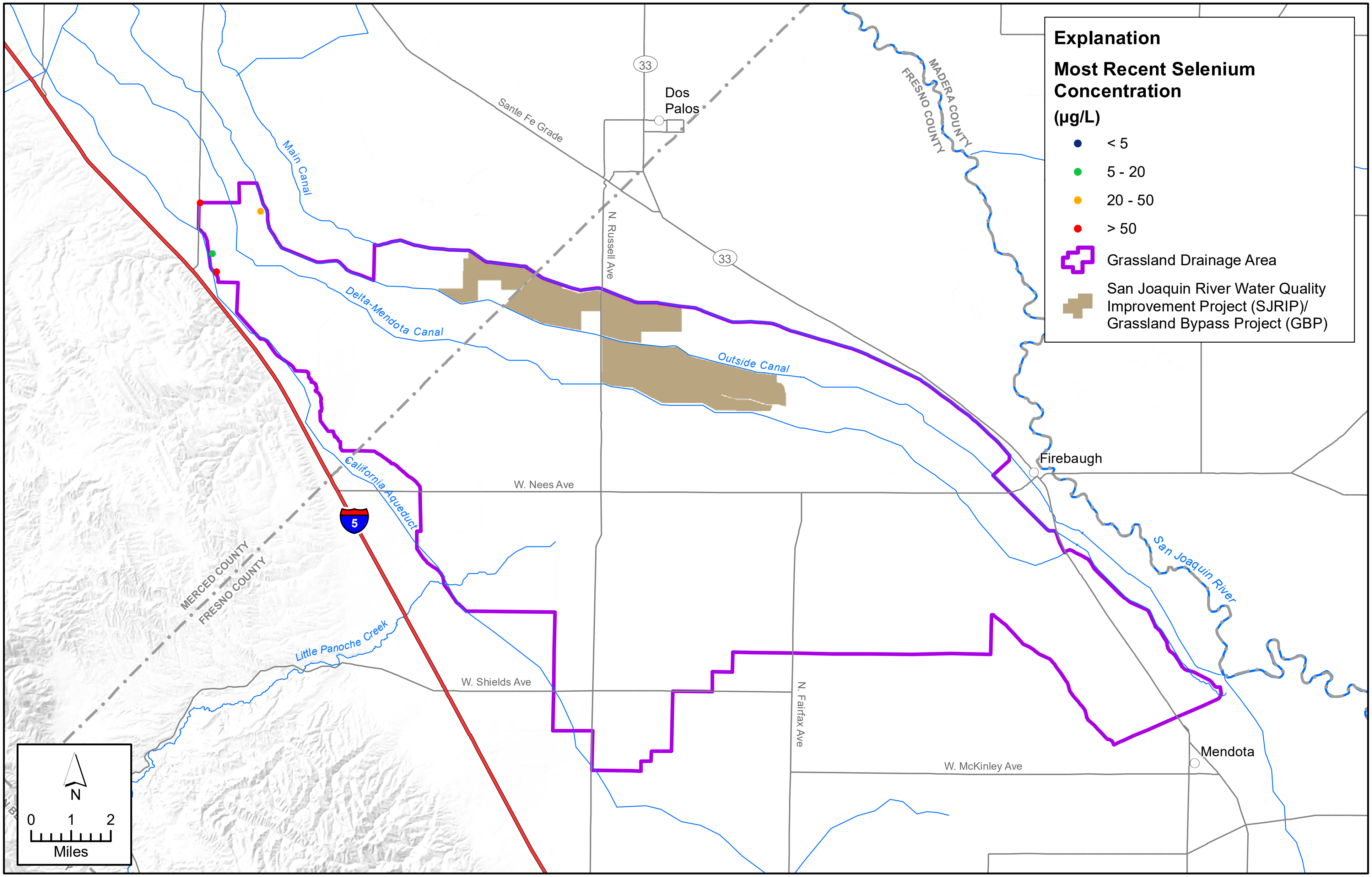

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FIGURE 5-45
Map of Most Recent Selenium Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

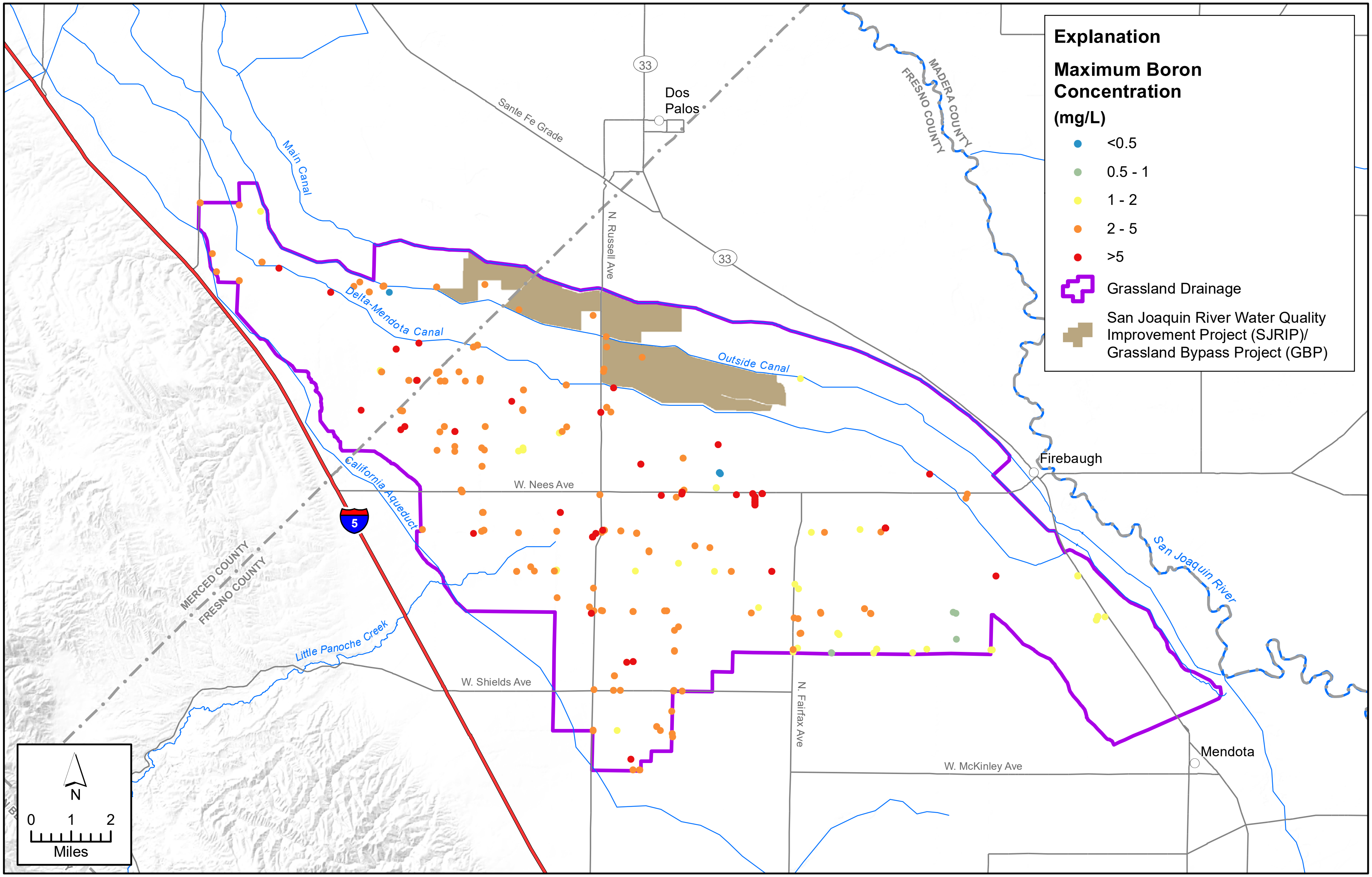

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FIGURE 5-46
Map of Maximum Boron Concentrations: All Drain and Well Data

Grassland Drainage Area
Groundwater Quality Assessment Report

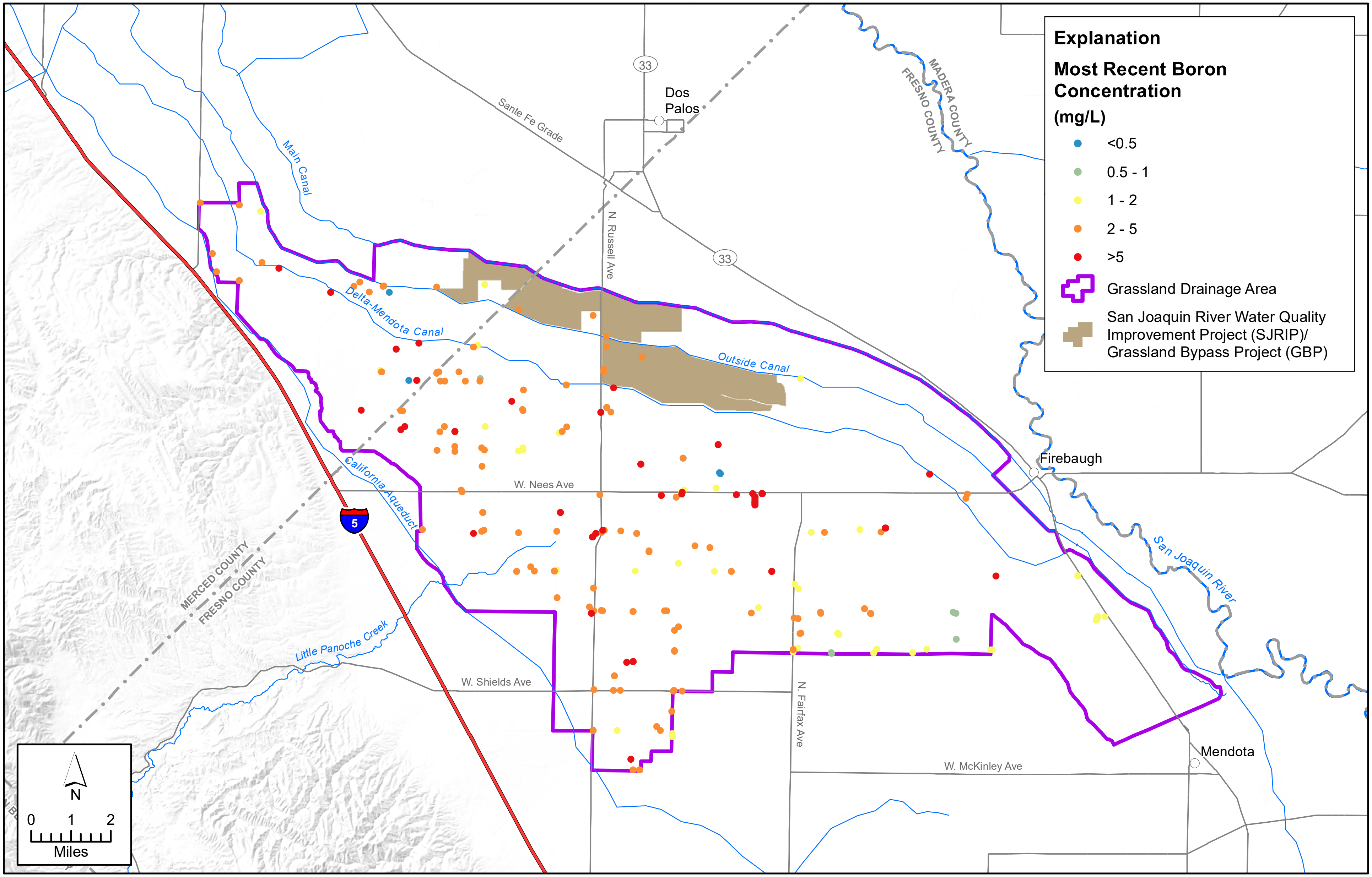

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FIGURE 5-47
Map of Most Recent Boron Concentrations: All Drain and Well Data
Grassland Drainage Area
Groundwater Quality Assessment Report

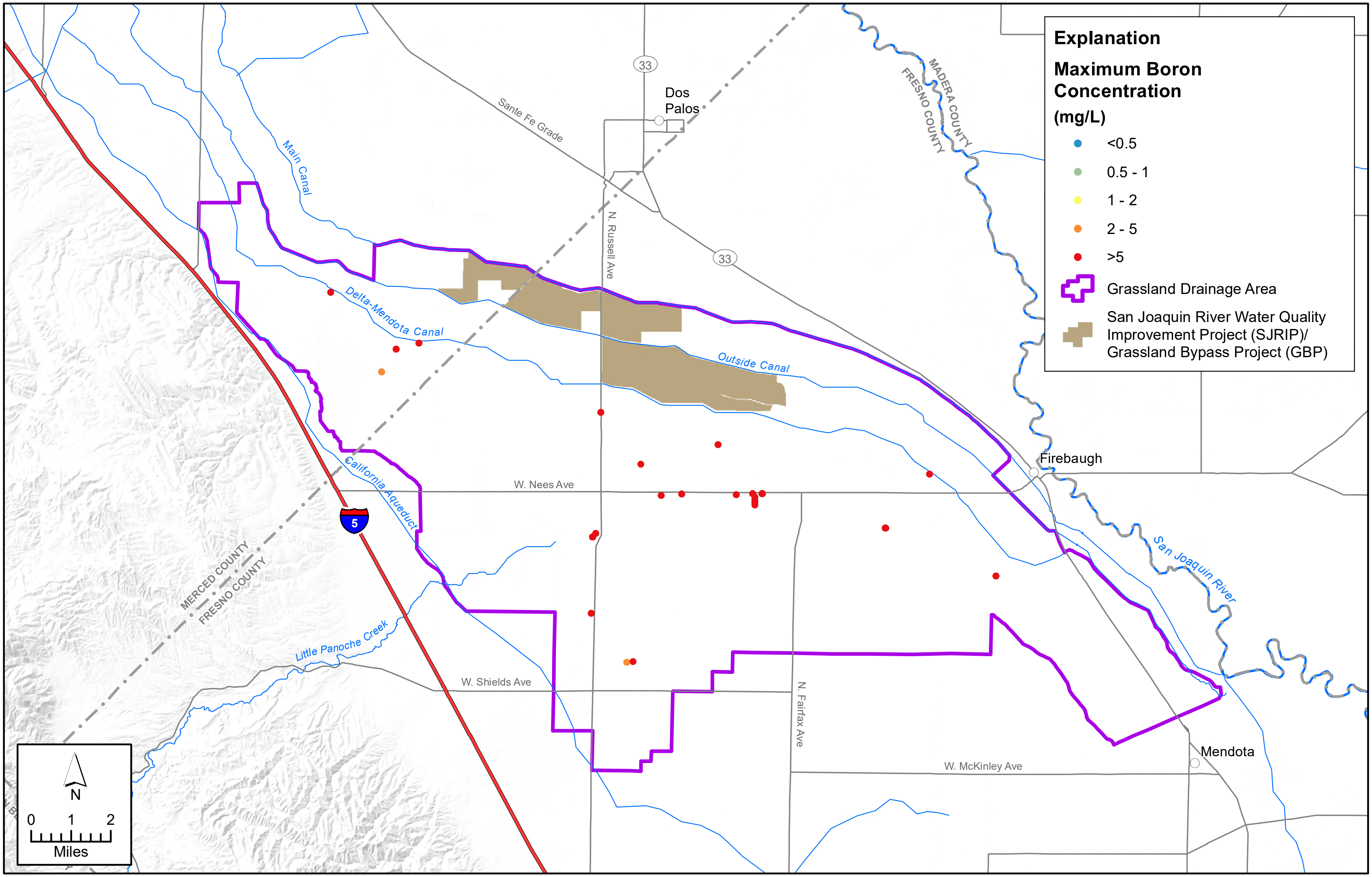

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FIGURE 5-48
Map of Maximum Boron Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

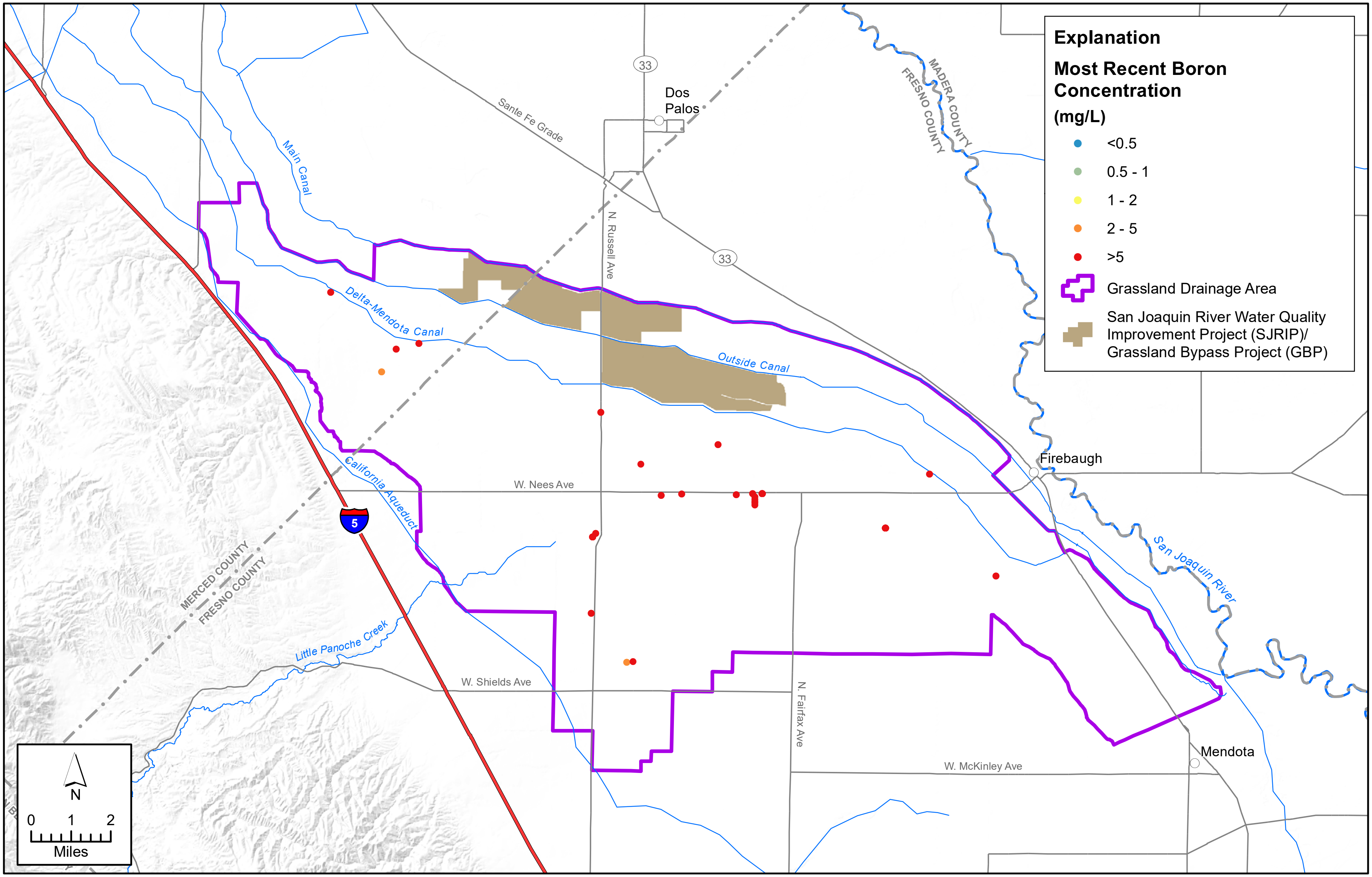

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FIGURE 5-49
Map of Most Recent Boron Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

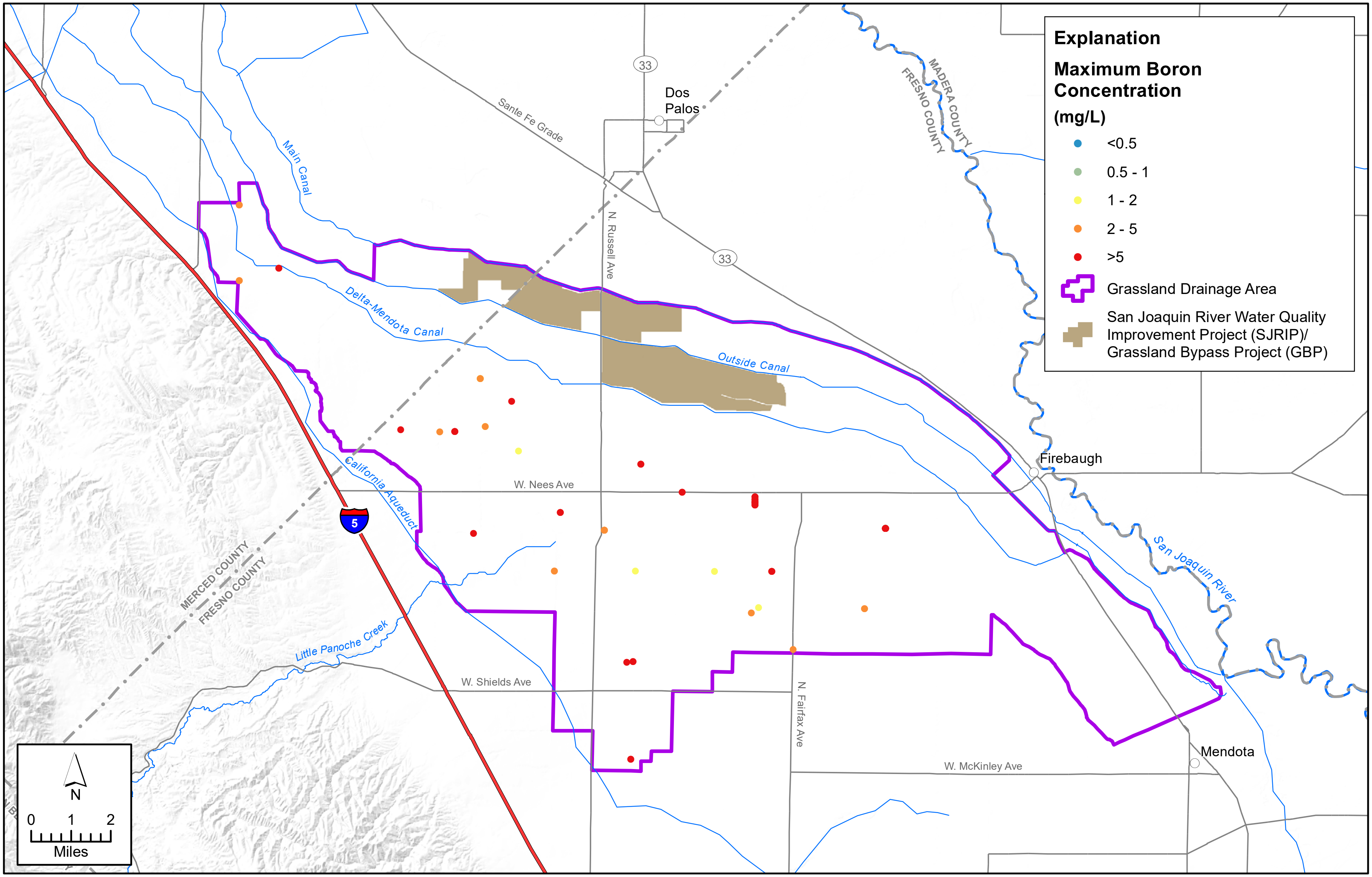

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FIGURE 5-50
Map of Maximum Boron Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

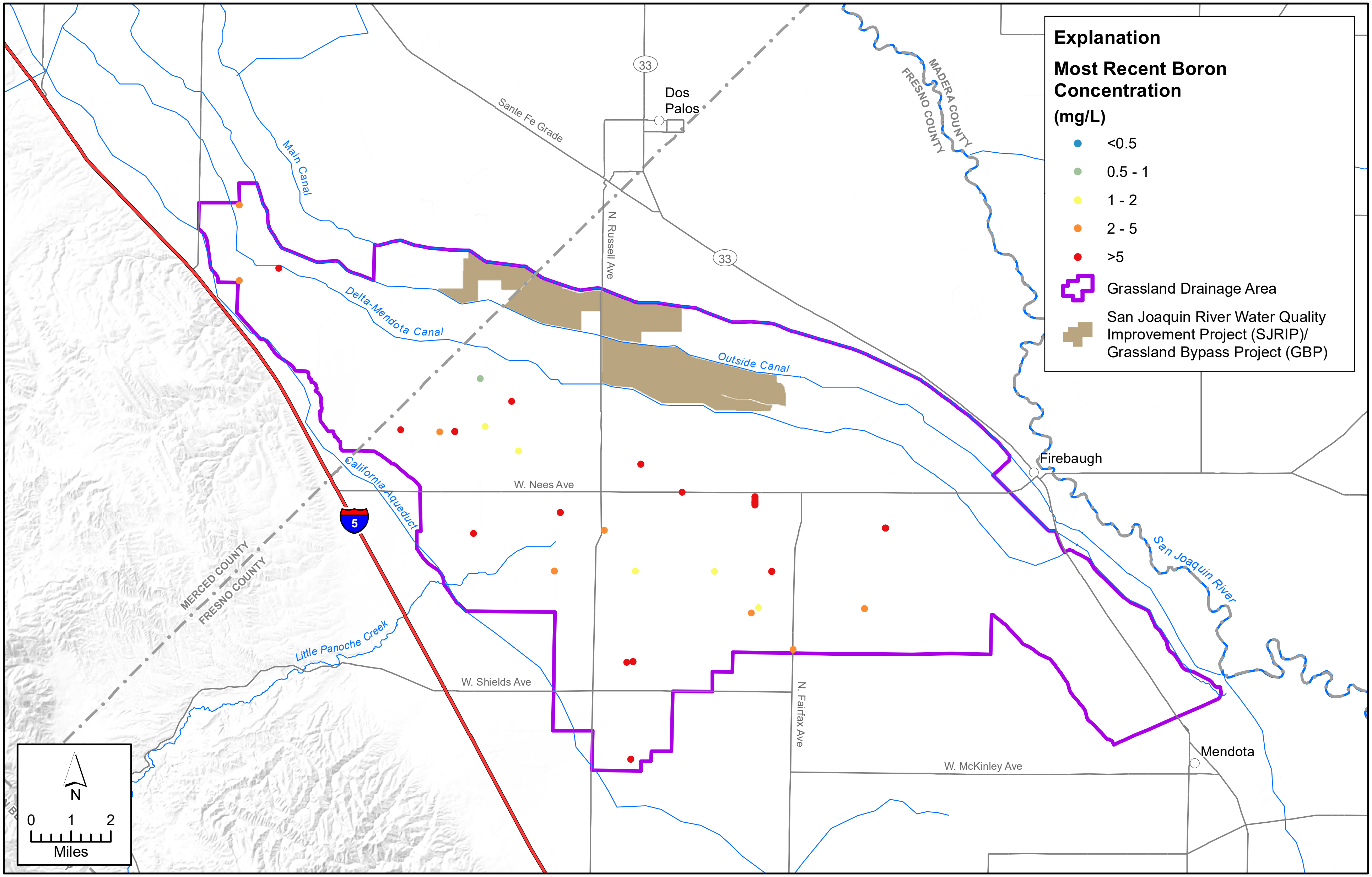

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FIGURE 5-51
Map of Most Recent Boron Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

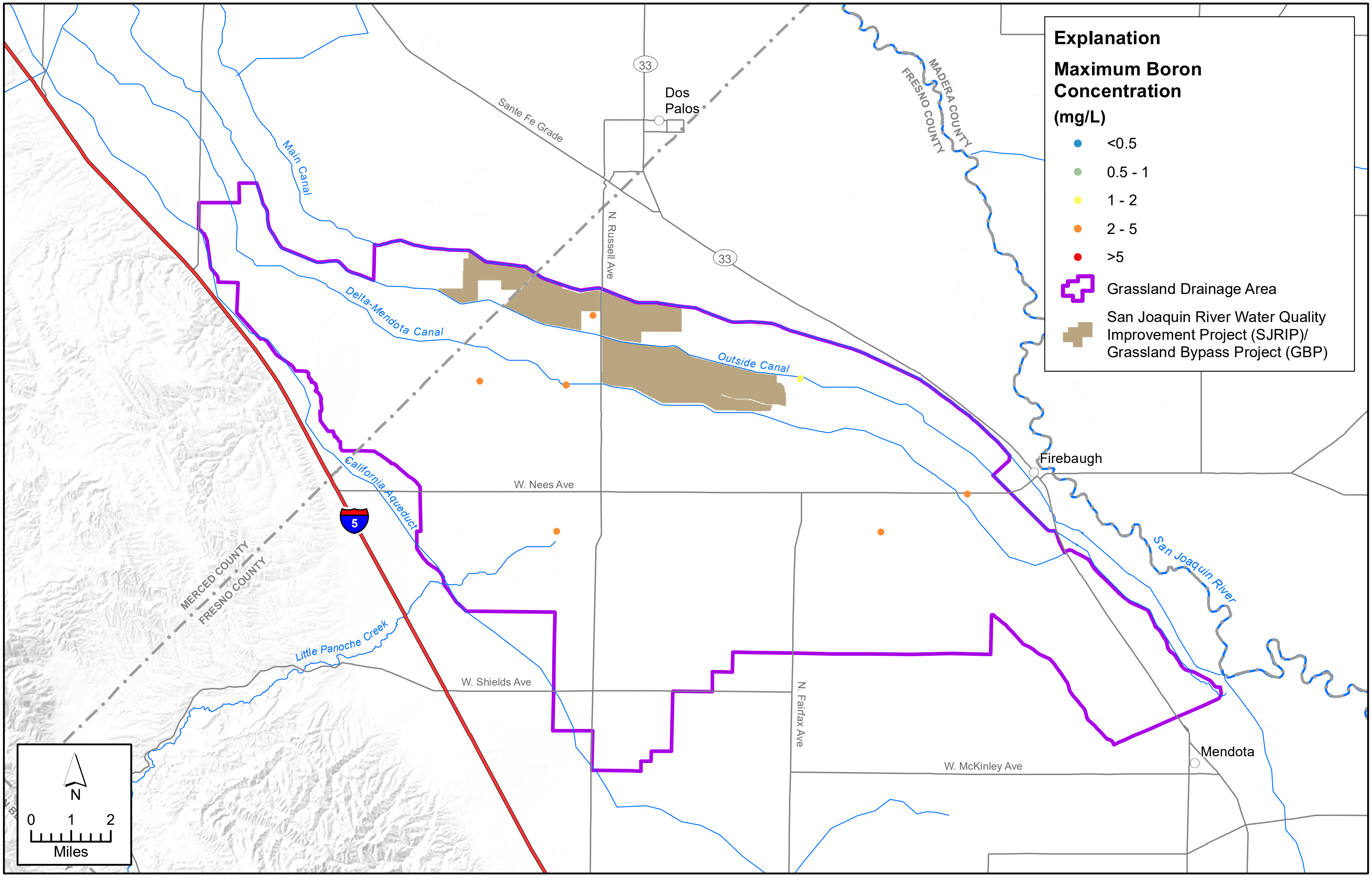

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FIGURE 5-52
Map of Maximum Boron Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

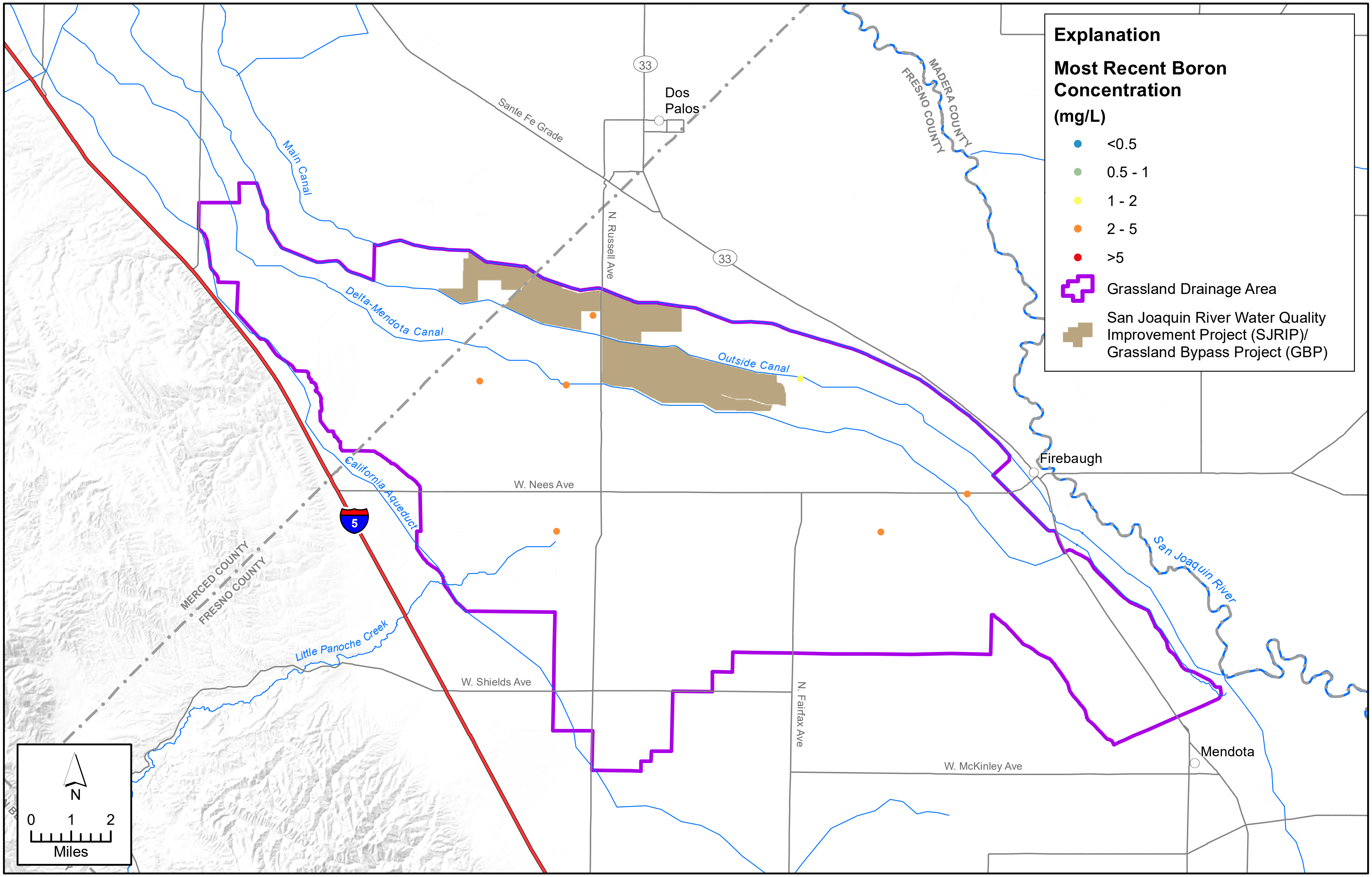

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FIGURE 5-53
Map of Most Recent Boron Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

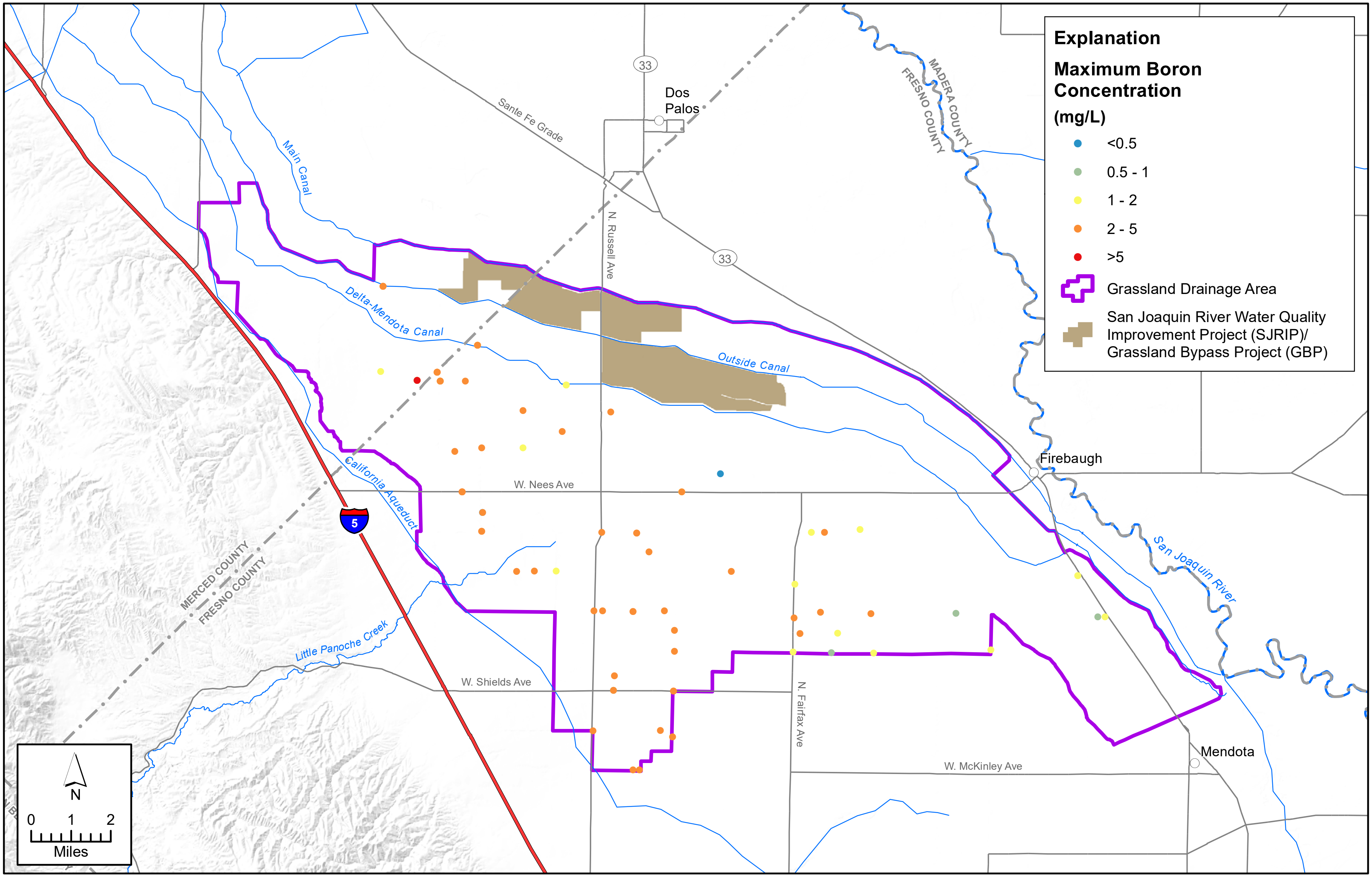

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FIGURE 5-54
Map of Maximum Boron Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

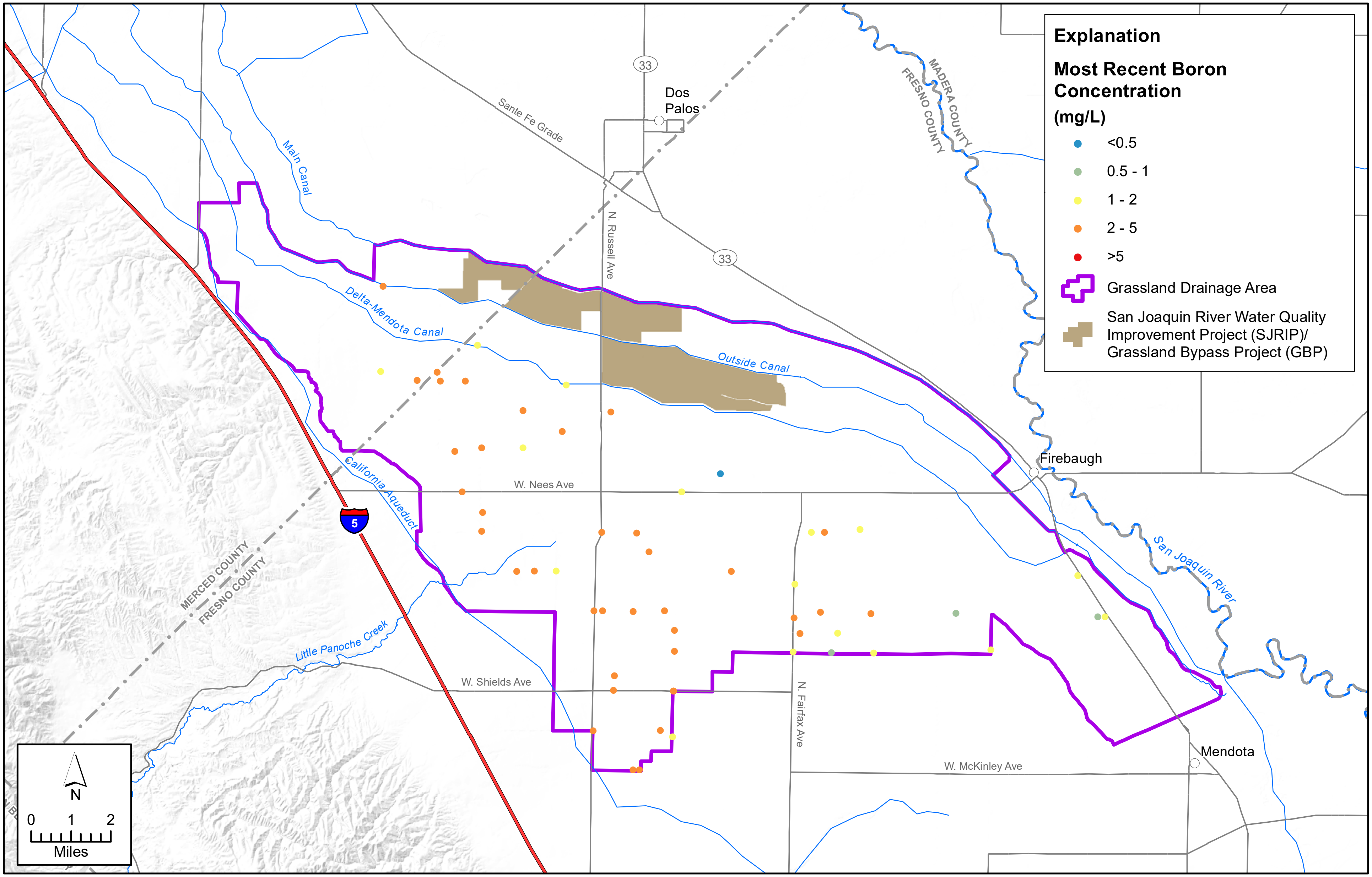

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FIGURE 5-55
Map of Most Recent Boron Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

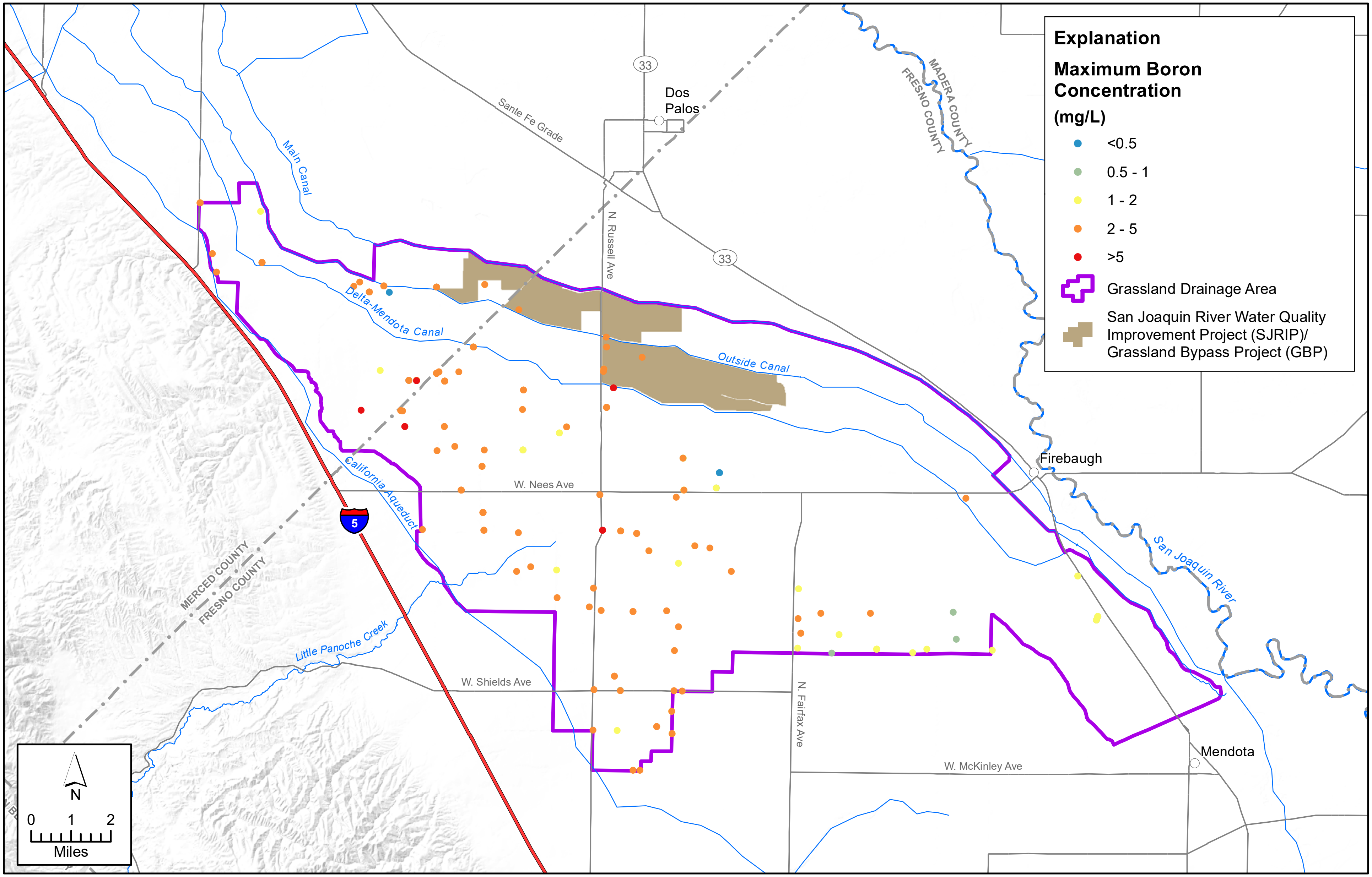

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FIGURE 5-56
Map of Maximum Boron Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

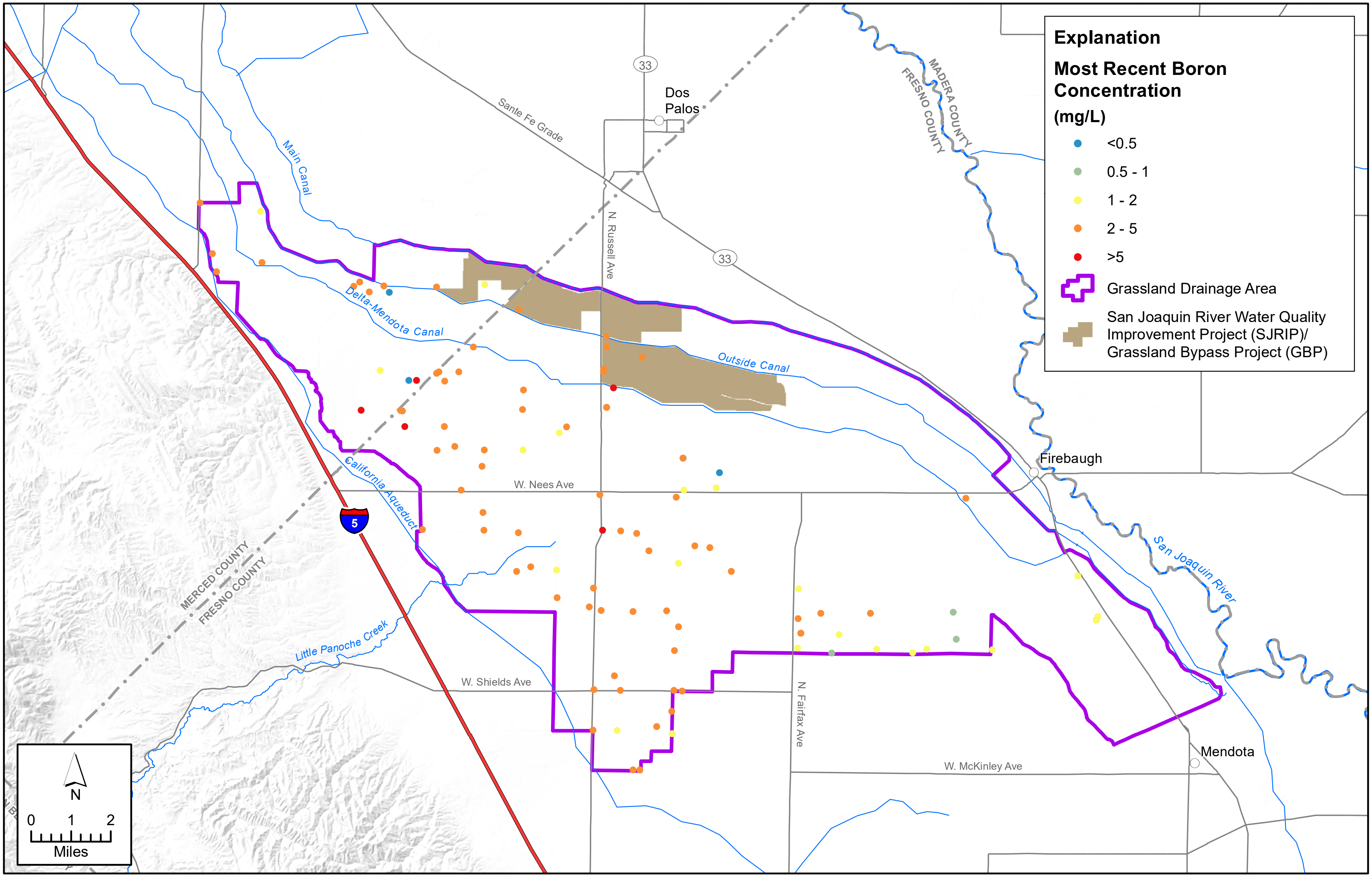

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FIGURE 5-57
Map of Most Recent Boron Concentrations: Wells of Unknown Depth
Grassland Drainage Area
Groundwater Quality Assessment Report

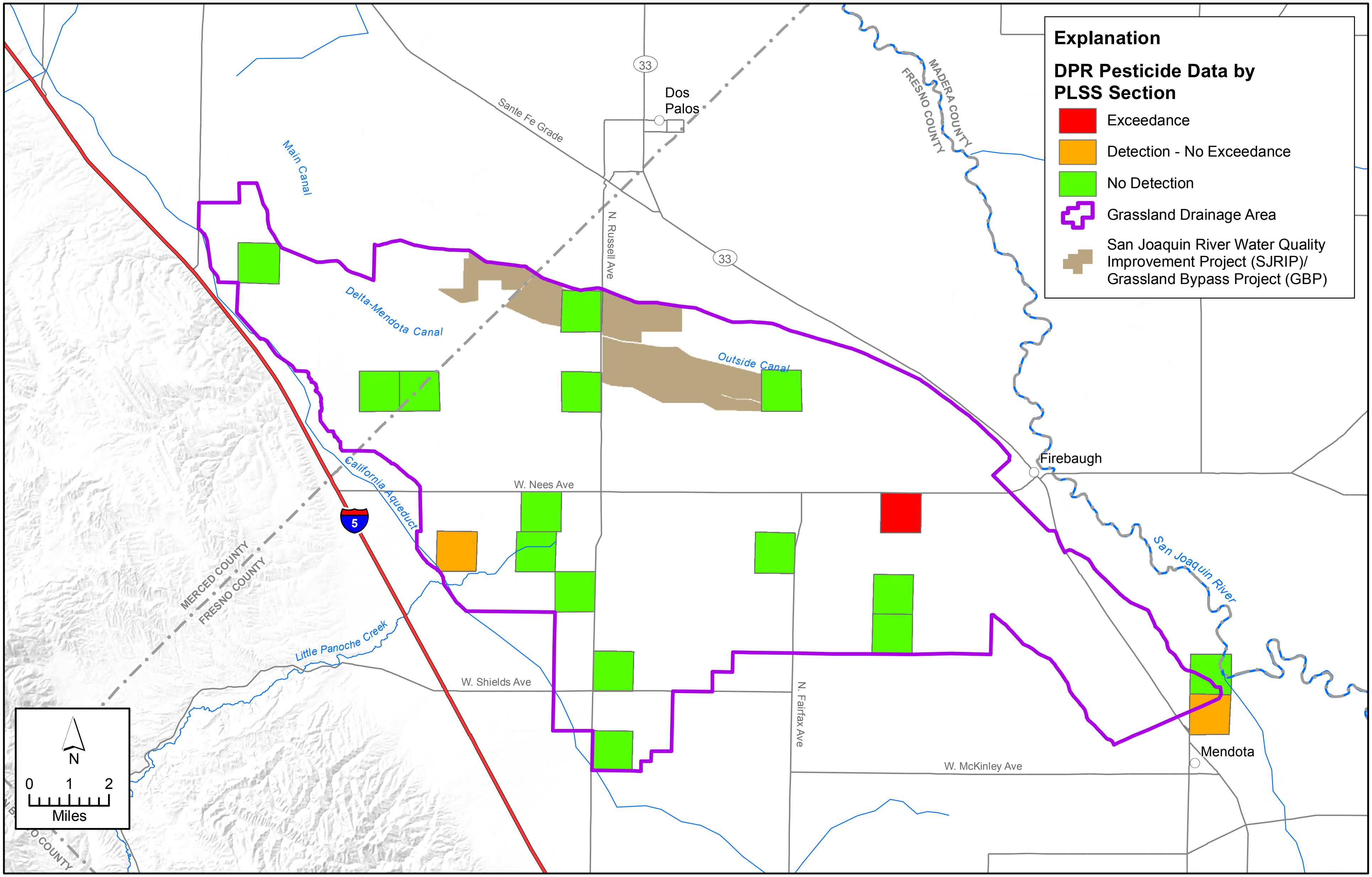

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FIGURE 5-58
Map of Pesticide Detections and Exceedances by Section
Grassland Drainage Area
Groundwater Quality Assessment Report

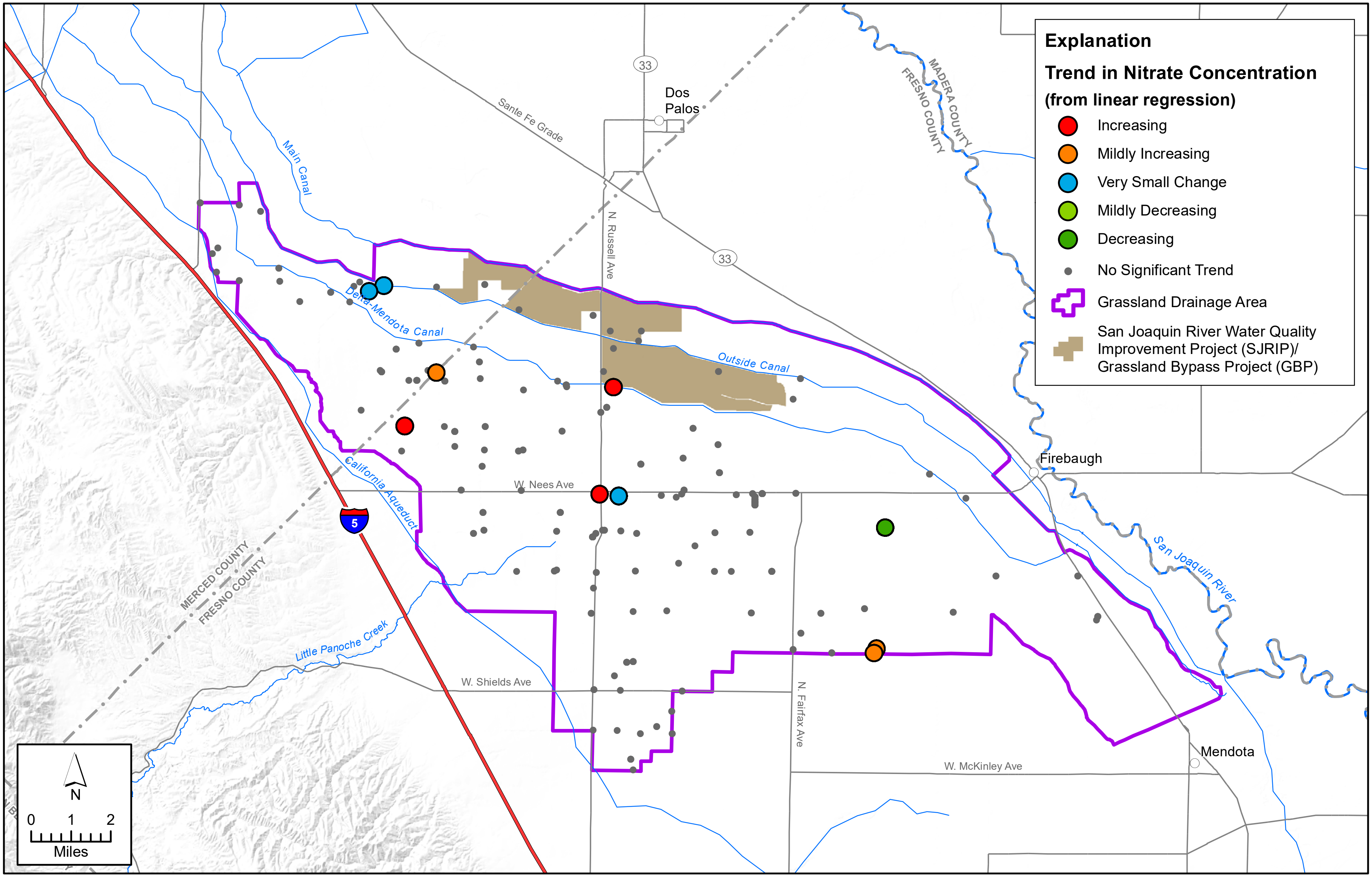

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FIGURE 5-59

Map of Significant Temporal Trends in Nitrate Concentrations: All Drain and Well Data

Grassland Drainage Area

Groundwater Quality Assessment Report

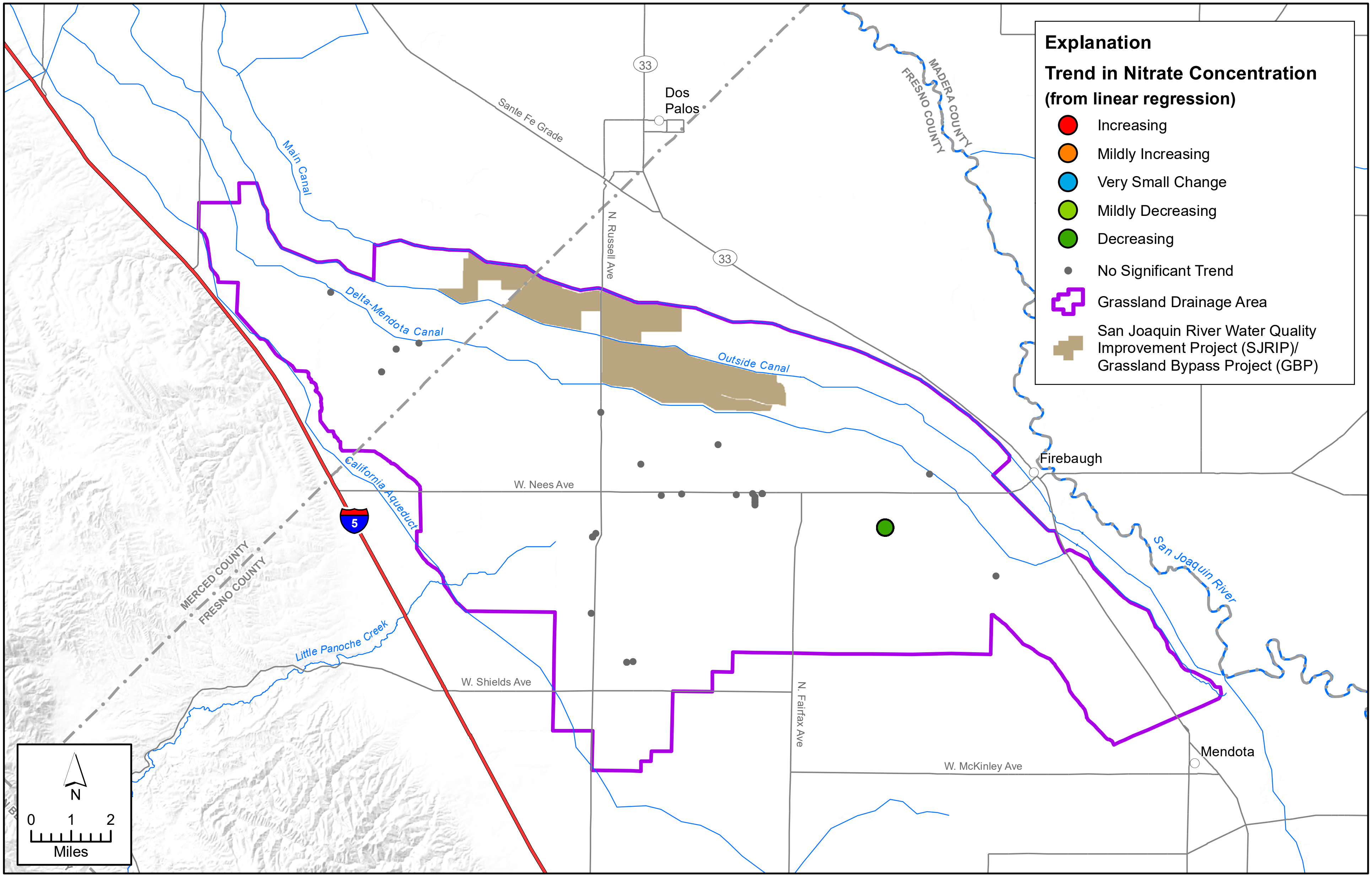

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FIGURE 5-60
Map of Significant Temporal Trends in Nitrate Concentrations: Very Shallow Water

Grassland Drainage Area
Groundwater Quality Assessment Report

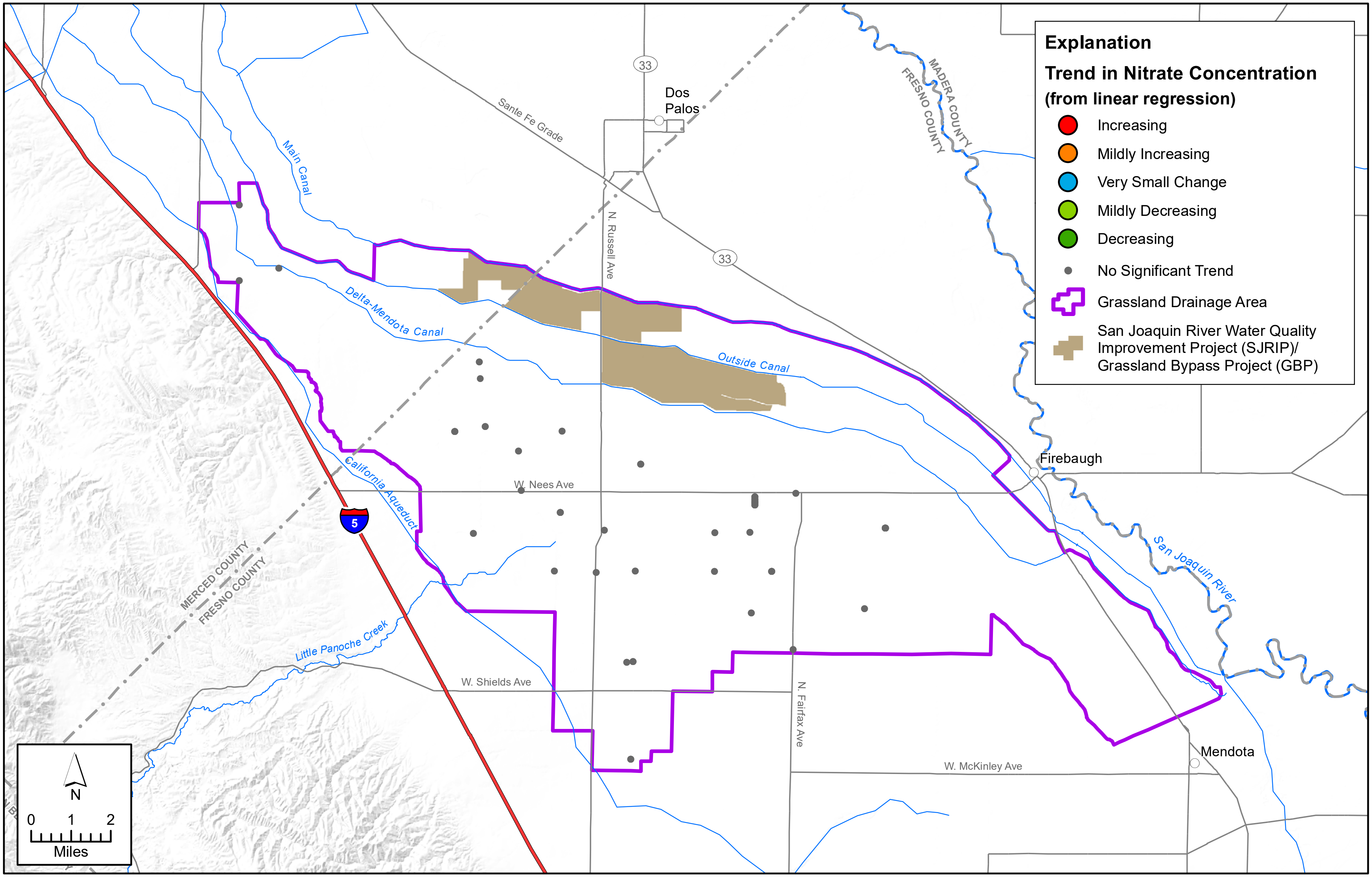

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FIGURE 5-61
Map of Significant Temporal Trends in Nitrate Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

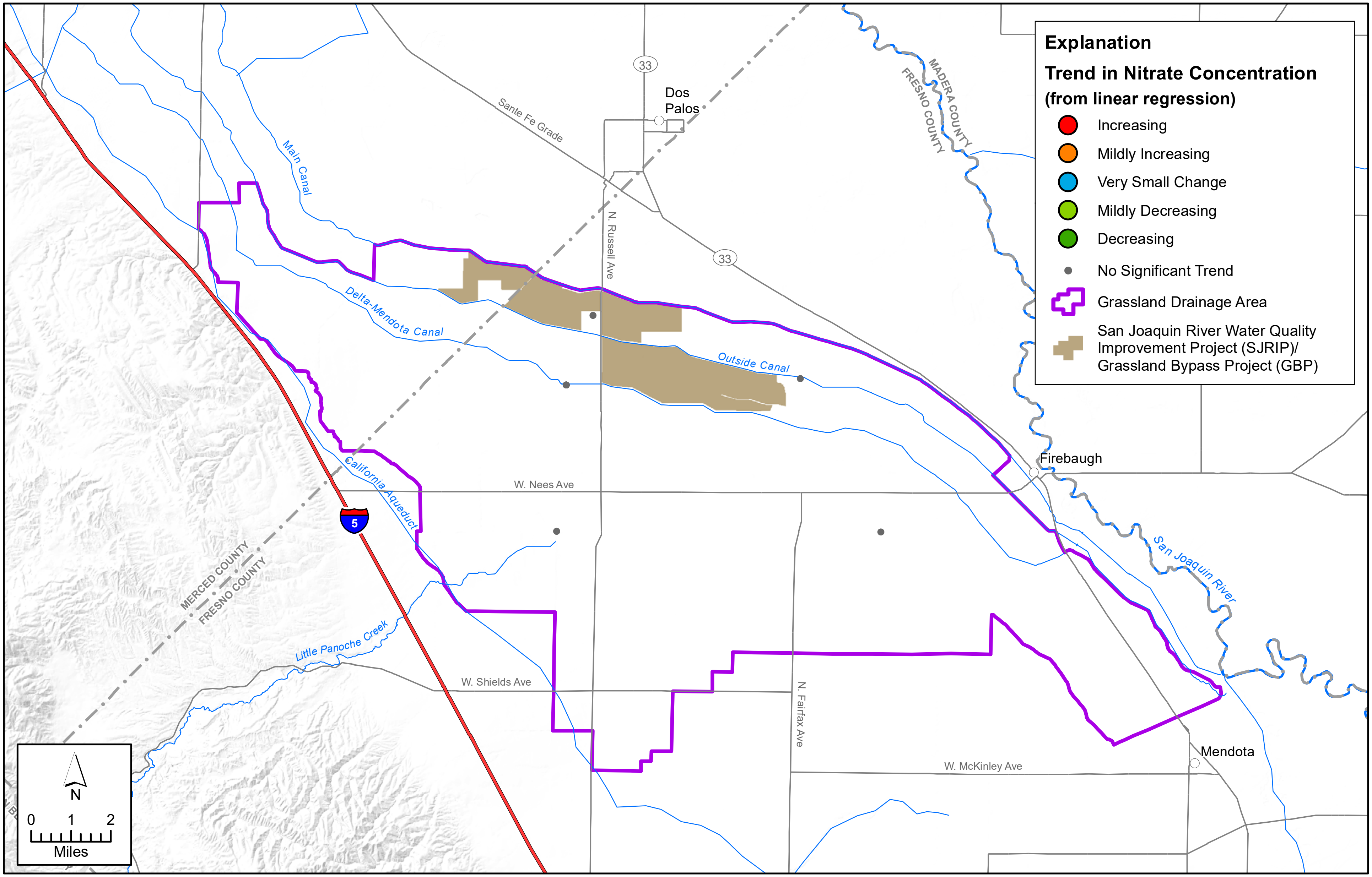

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FIGURE 5-62
Map of Significant Temporal Trends in Nitrate Concentrations: Upper Aquifer

Grassland Drainage Area
Groundwater Quality Assessment Report

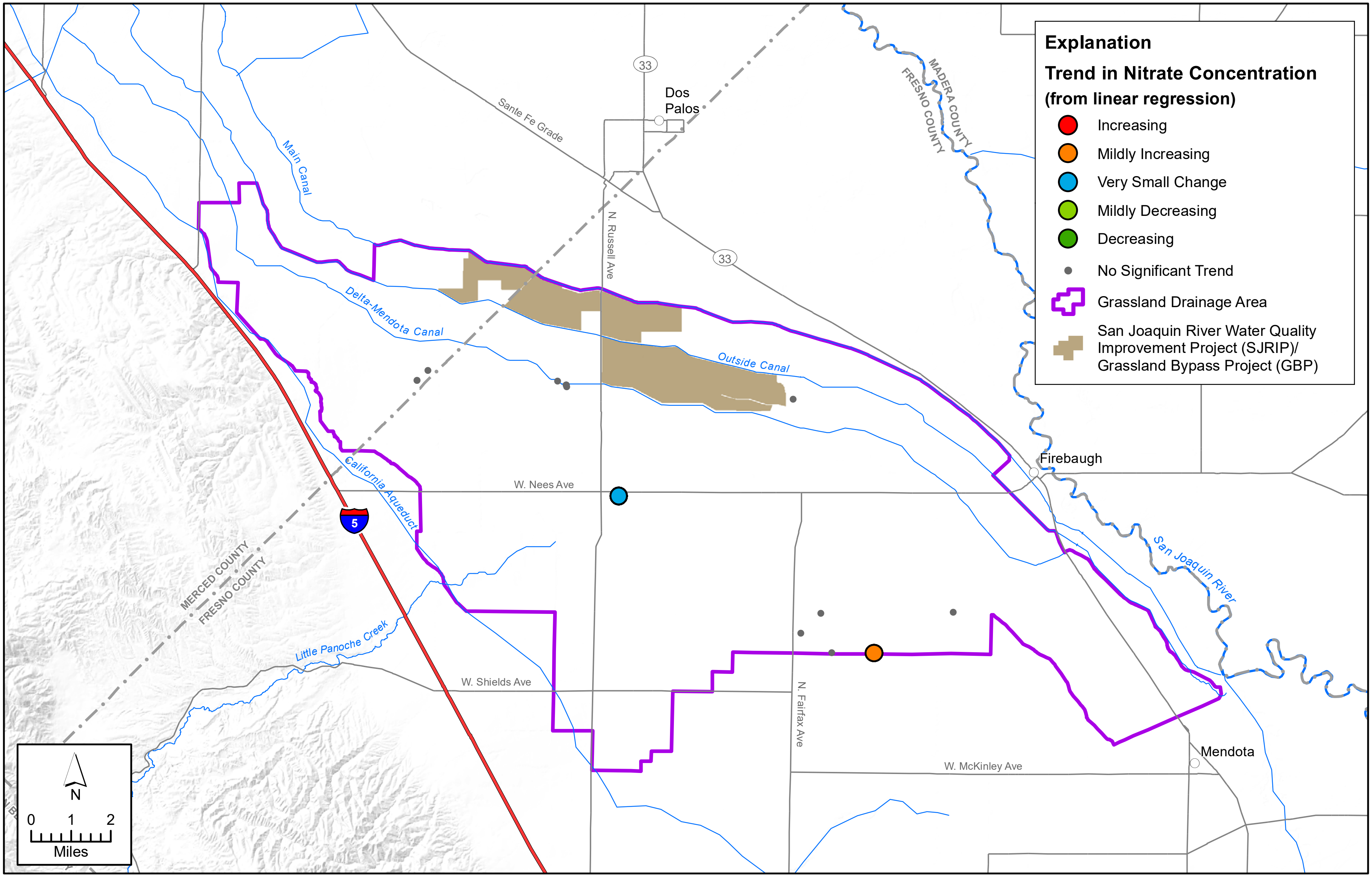

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FIGURE 5-63
Map of Significant Temporal Trends in Nitrate Concentrations: Lower Aquifer

Grassland Drainage Area
Groundwater Quality Assessment Report

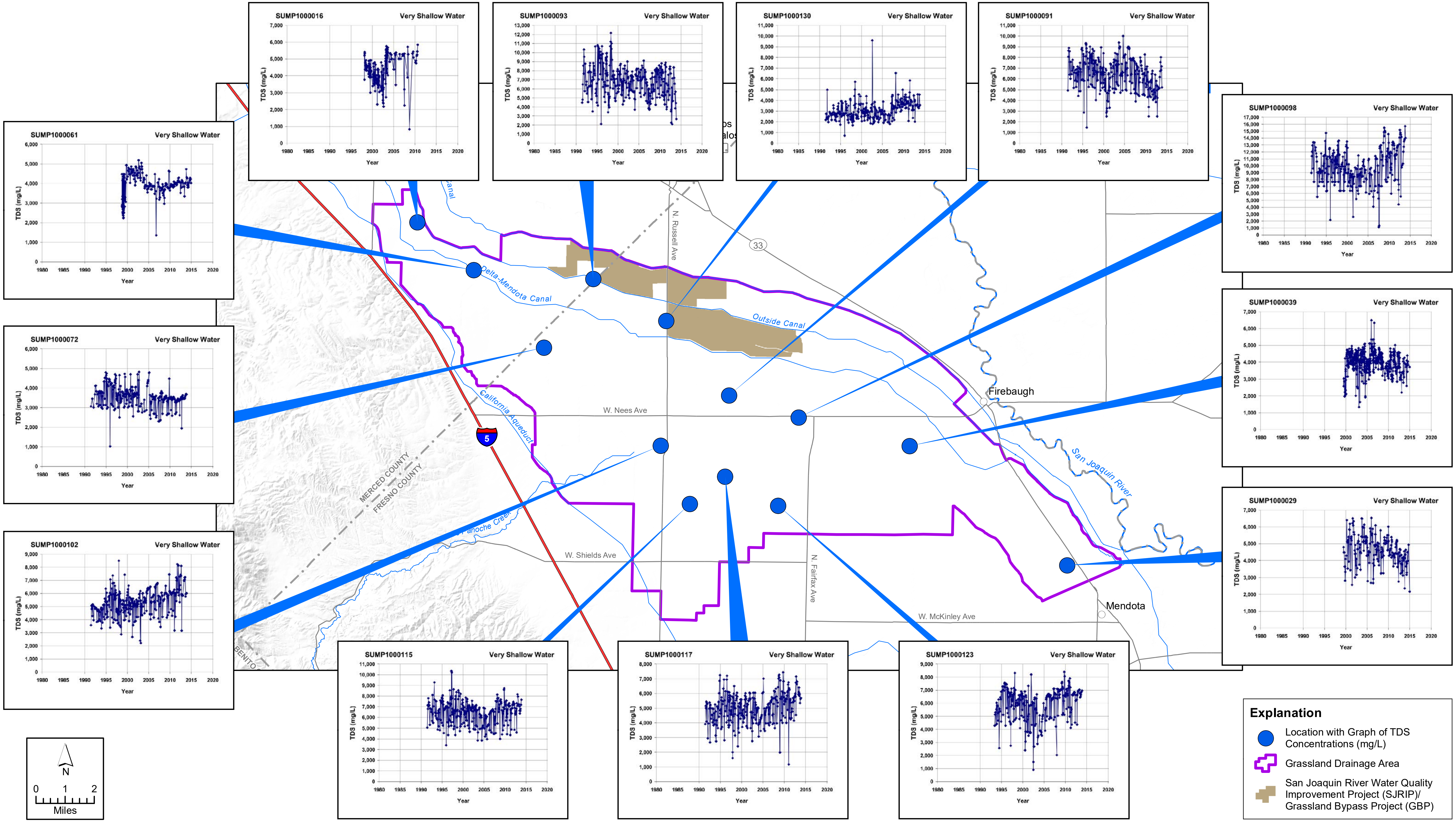

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FIGURE 5-64
Select Graphs of TDS Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

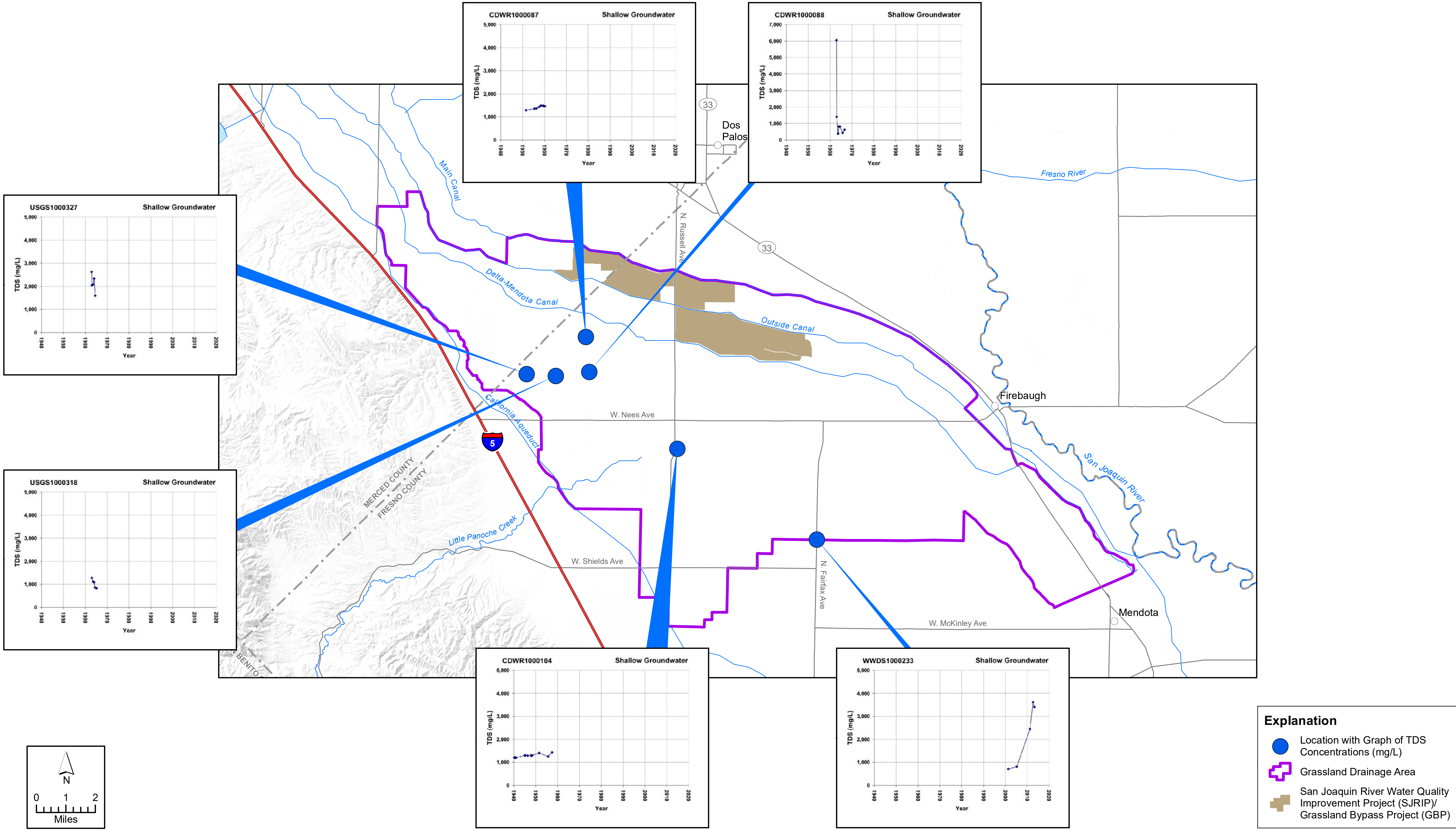

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FIGURE 5-65
Select Graphs of TDS Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

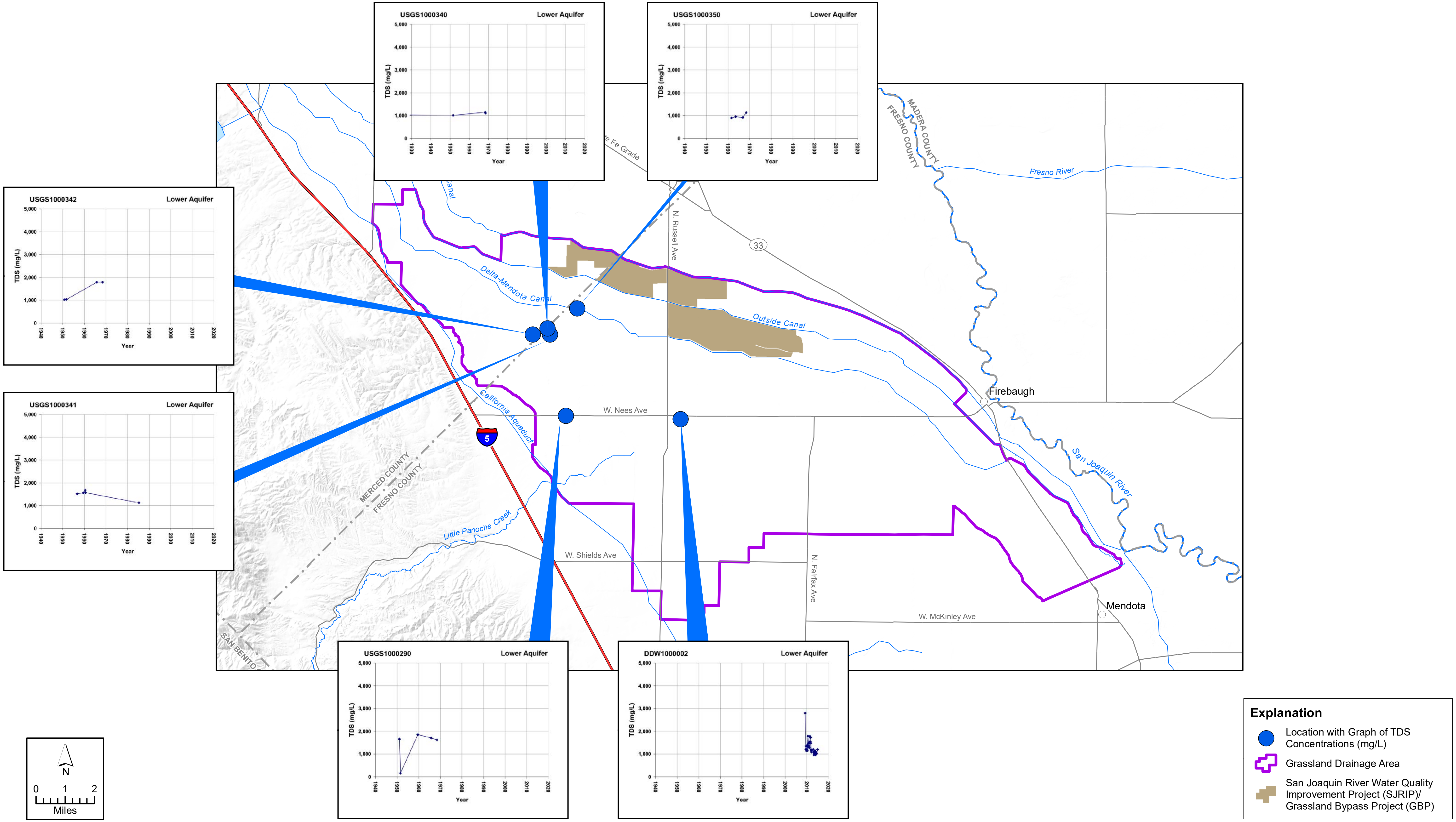

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FIGURE 5-66
Select Graphs of TDS Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

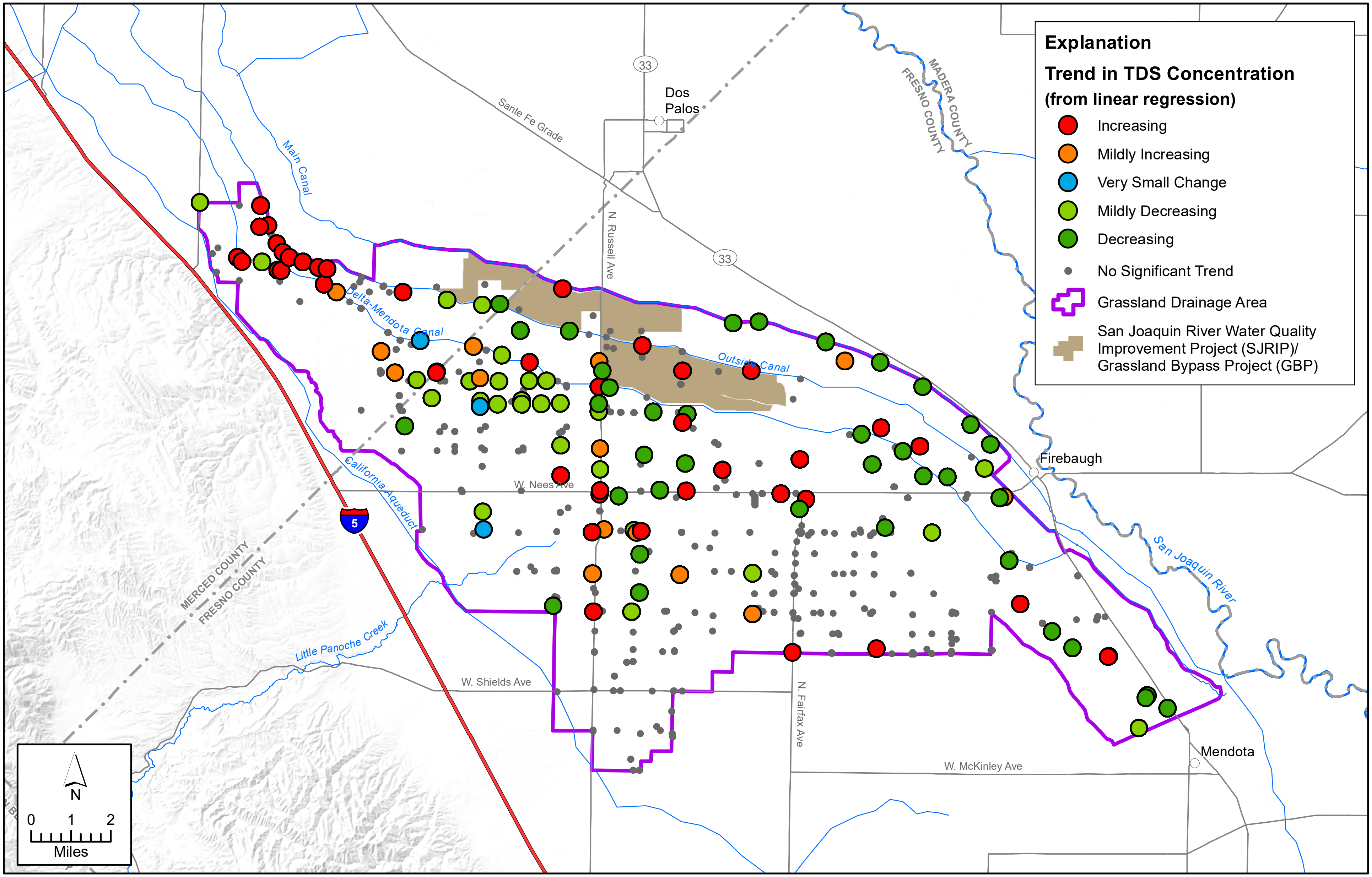

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FIGURE 5-67
Map of Significant Temporal Trends in TDS Concentrations: All Drain and Well Data
Grassland Drainage Area
Groundwater Quality Assessment Report

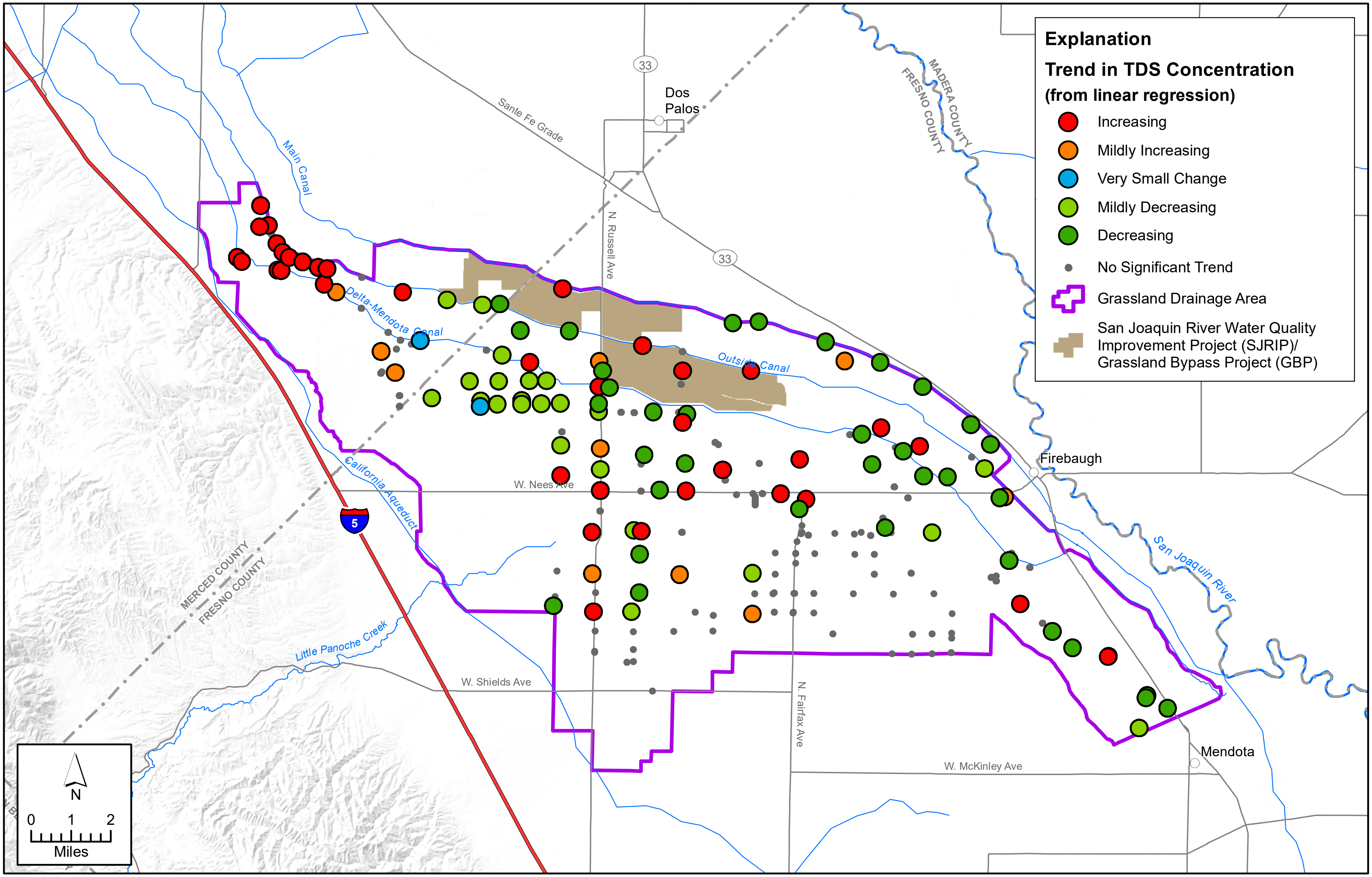

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FIGURE 5-68
Map of Significant Temporal Trends in TDS Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

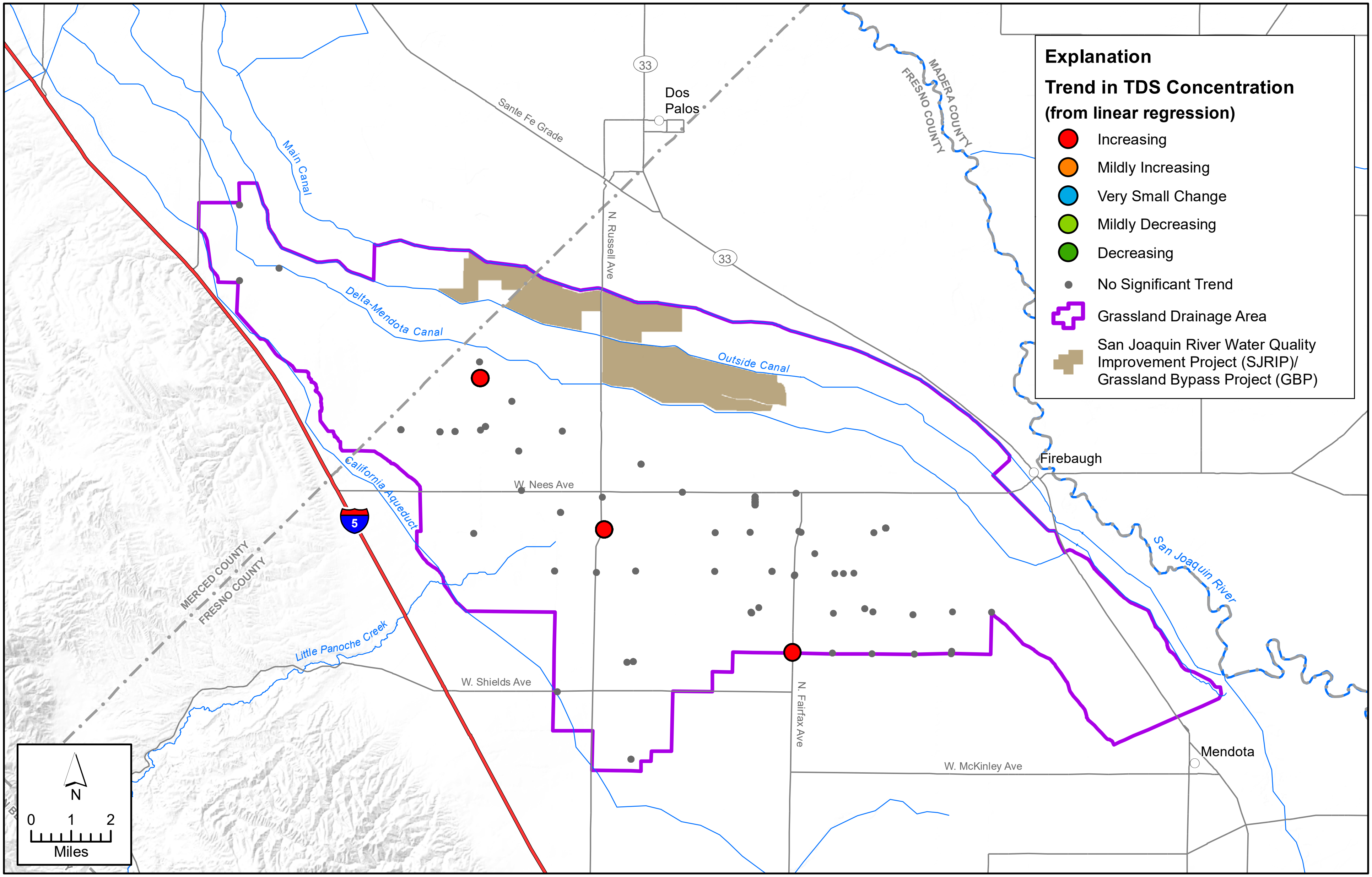

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FIGURE 5-69
Map of Significant Temporal Trends in TDS Concentrations: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

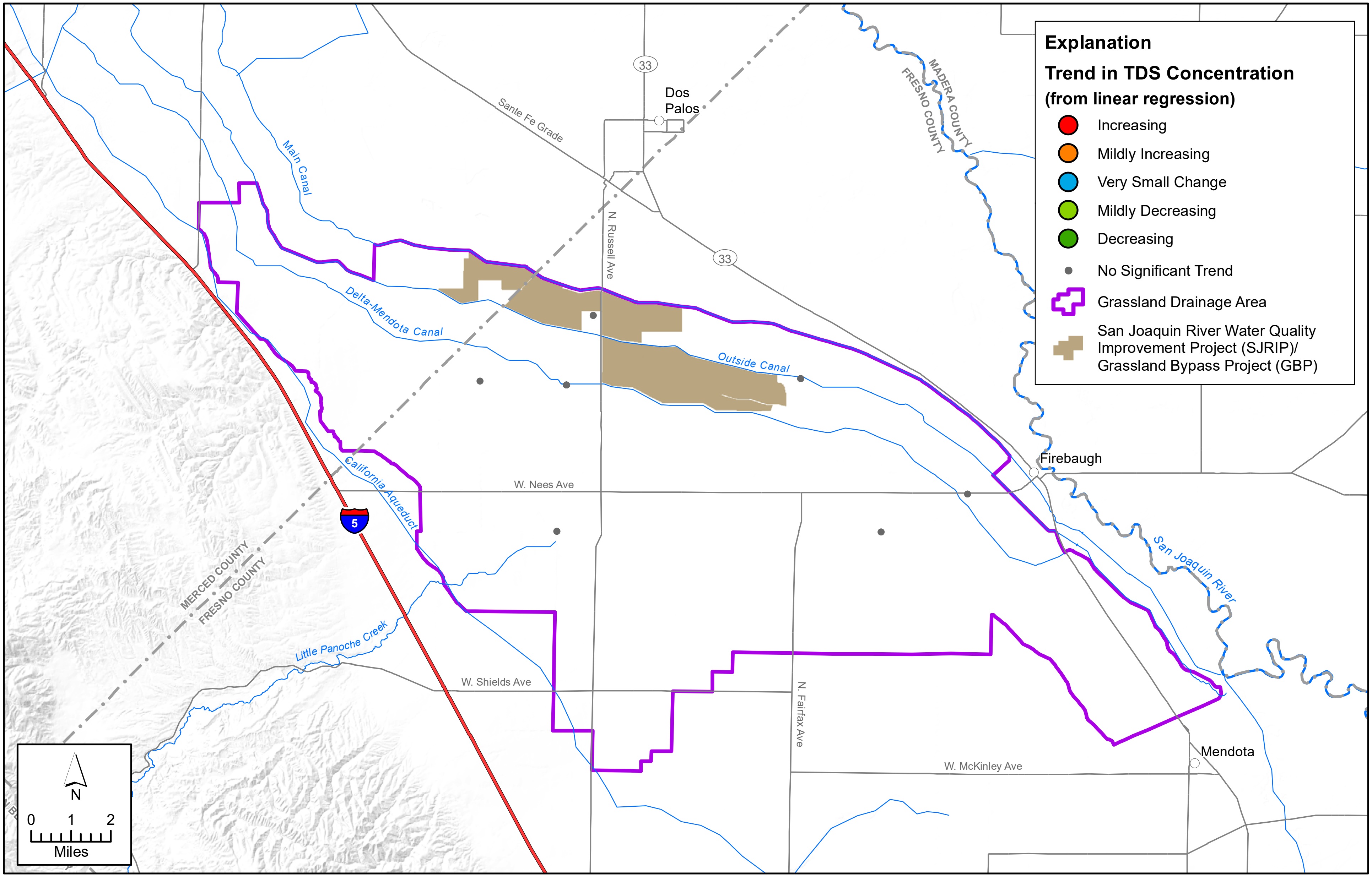

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FIGURE 5-70
Map of Significant Temporal Trends in TDS Concentrations: Upper Aquifer

Grassland Drainage Area
Groundwater Quality Assessment Report

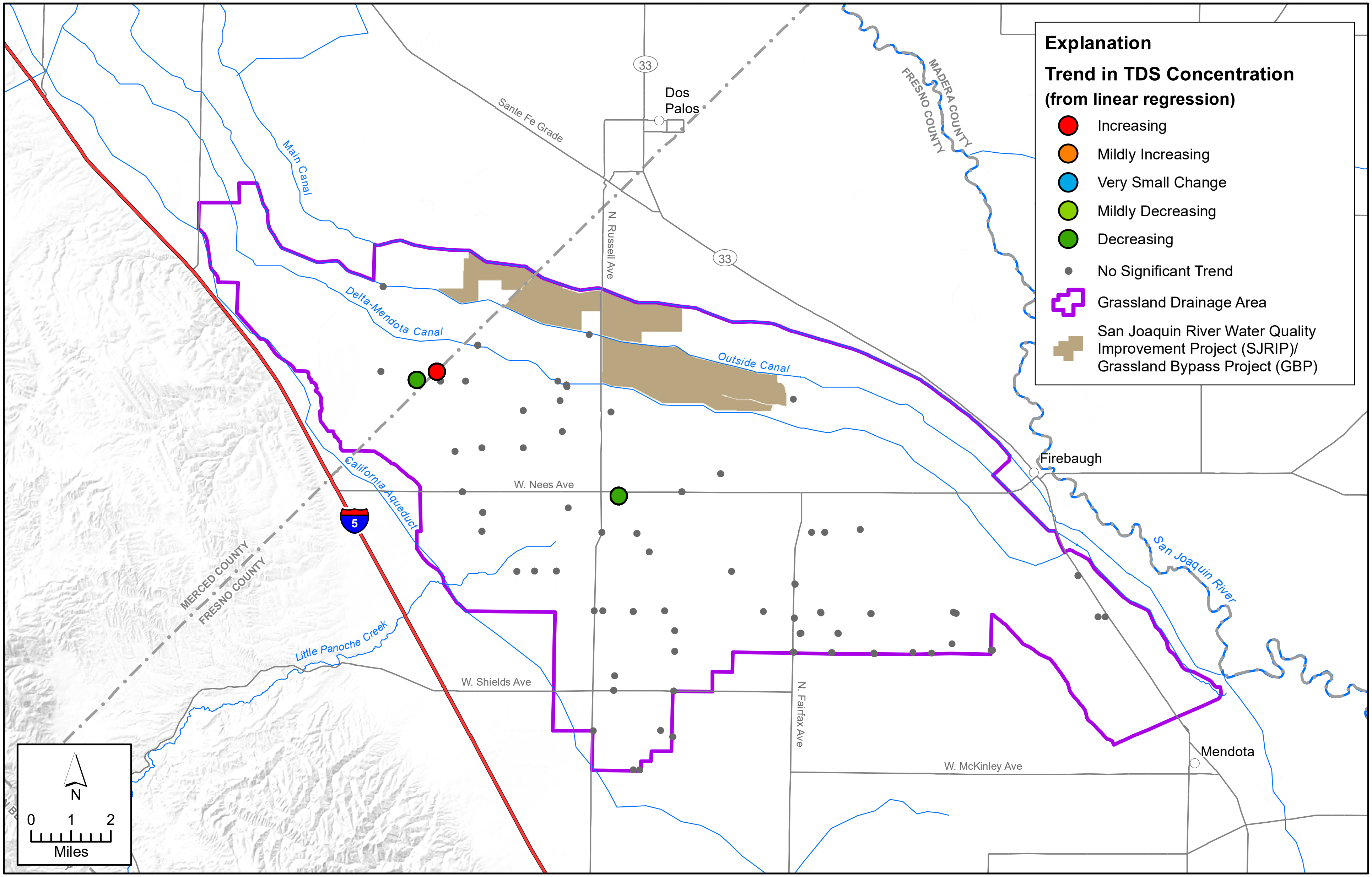

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FIGURE 5-71
Map of Significant Temporal Trends in TDS Concentrations: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

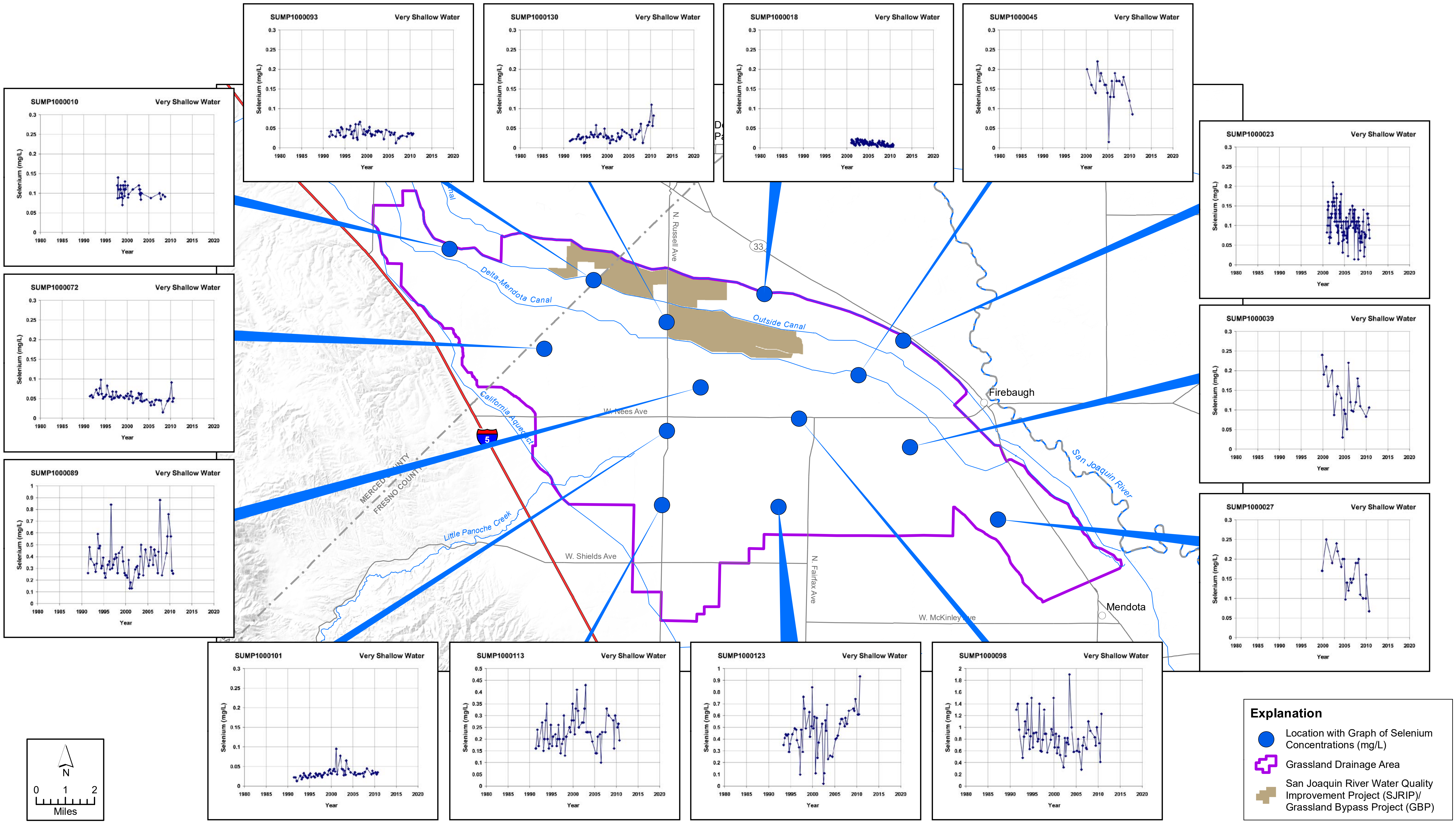

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FIGURE 5-72
Select Graphs of Selenium Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

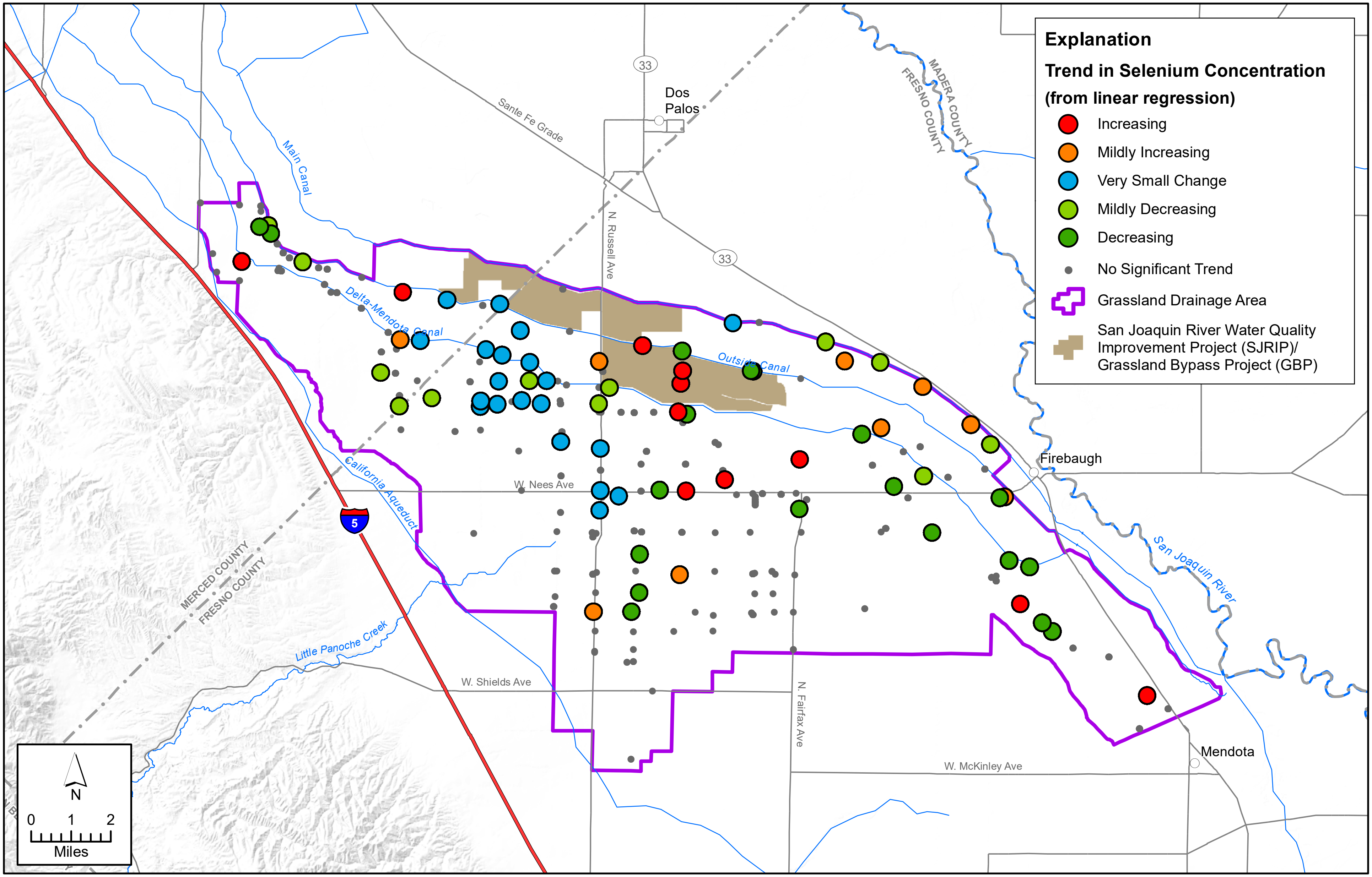

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FIGURE 5-73
Map of Significant Temporal Trends in Selenium Concentrations: All Drain and Well Data

Grassland Drainage Area
Groundwater Quality Assessment Report

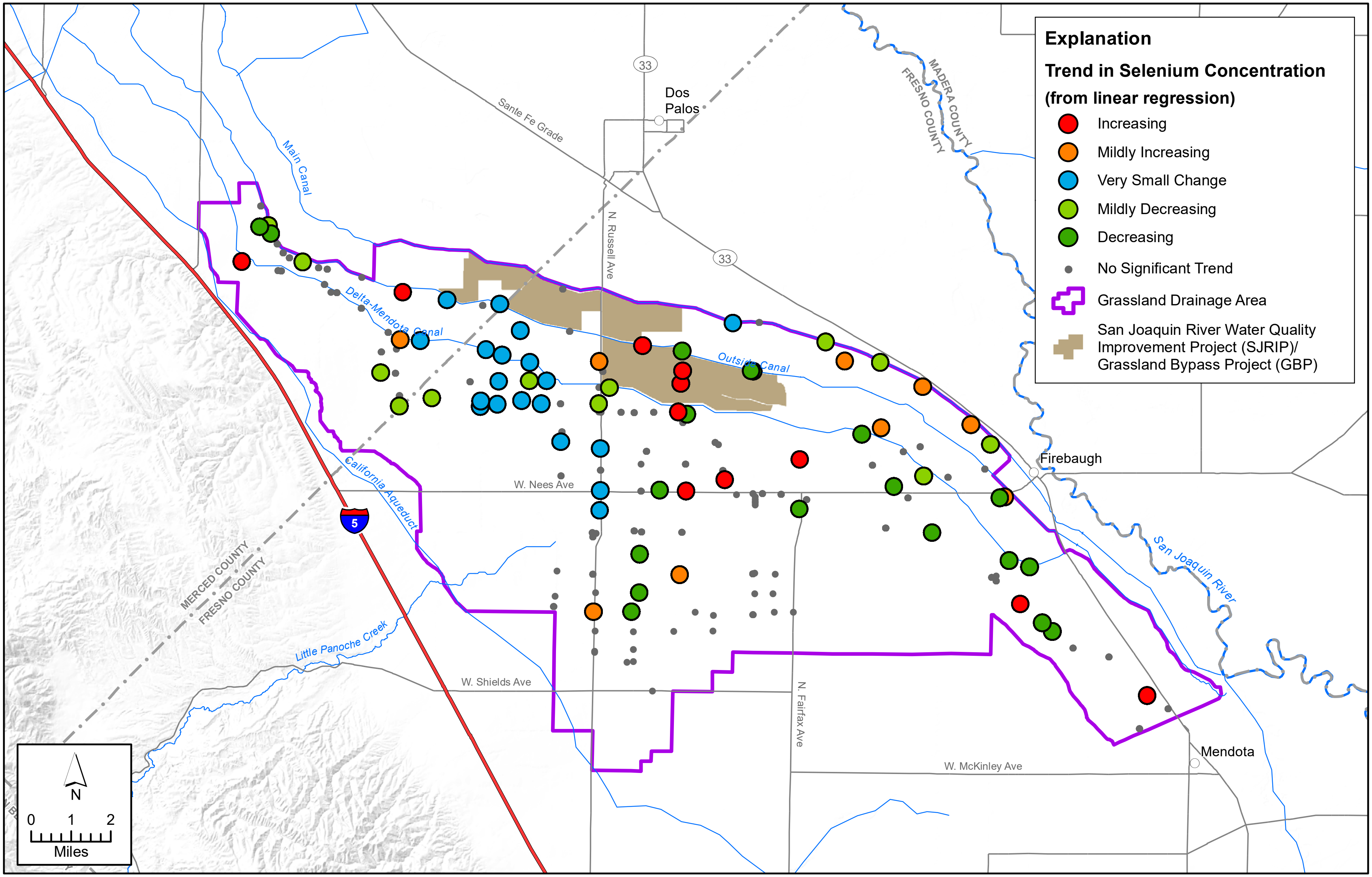

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FIGURE 5-74
Map of Significant Temporal Trends in Selenium Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

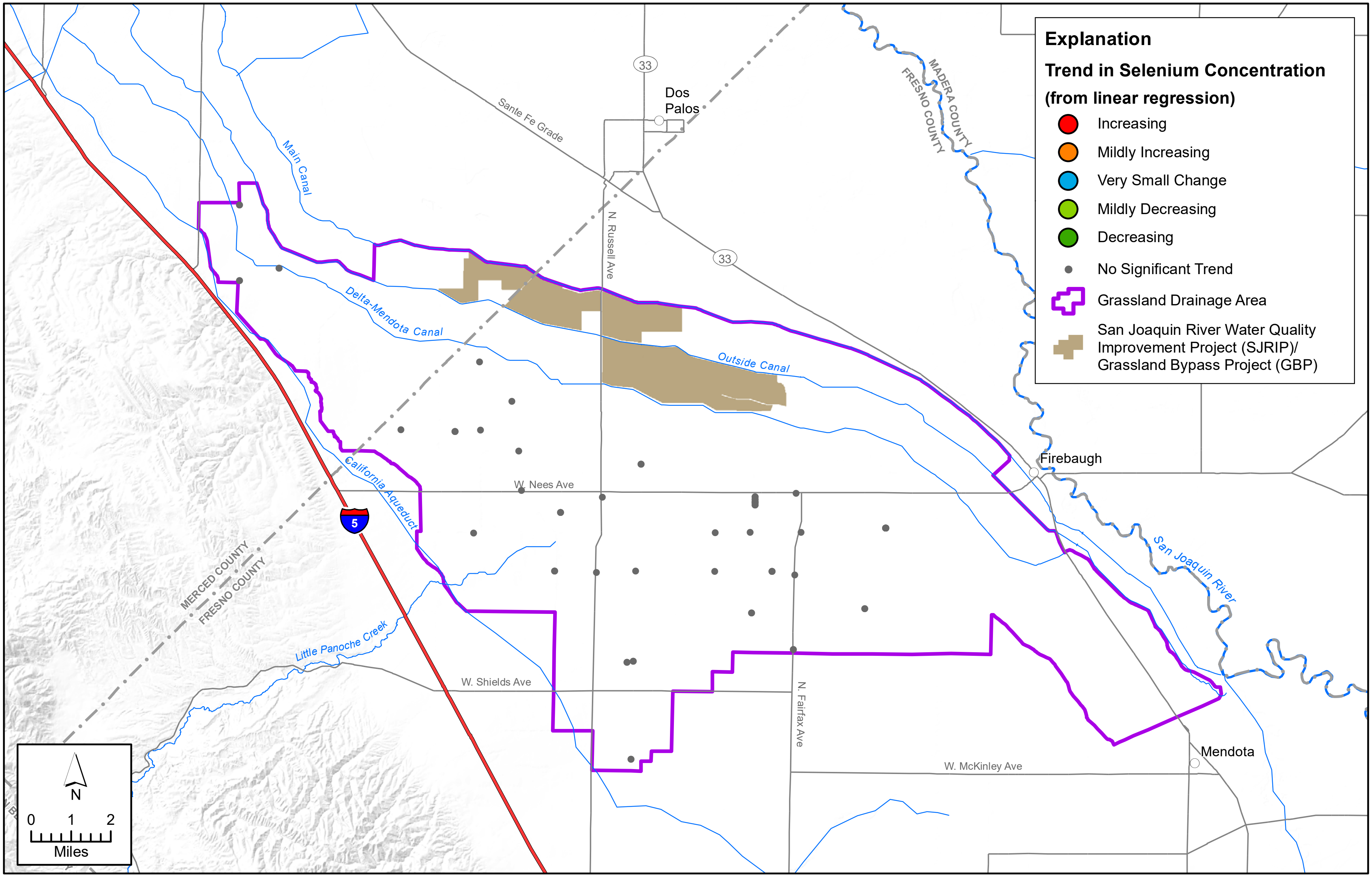

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FIGURE 5-75
Map of Significant Temporal Trends in Selenium Concentrations: Shallow Groundwater

Grassland Drainage Area
Groundwater Quality Assessment Report

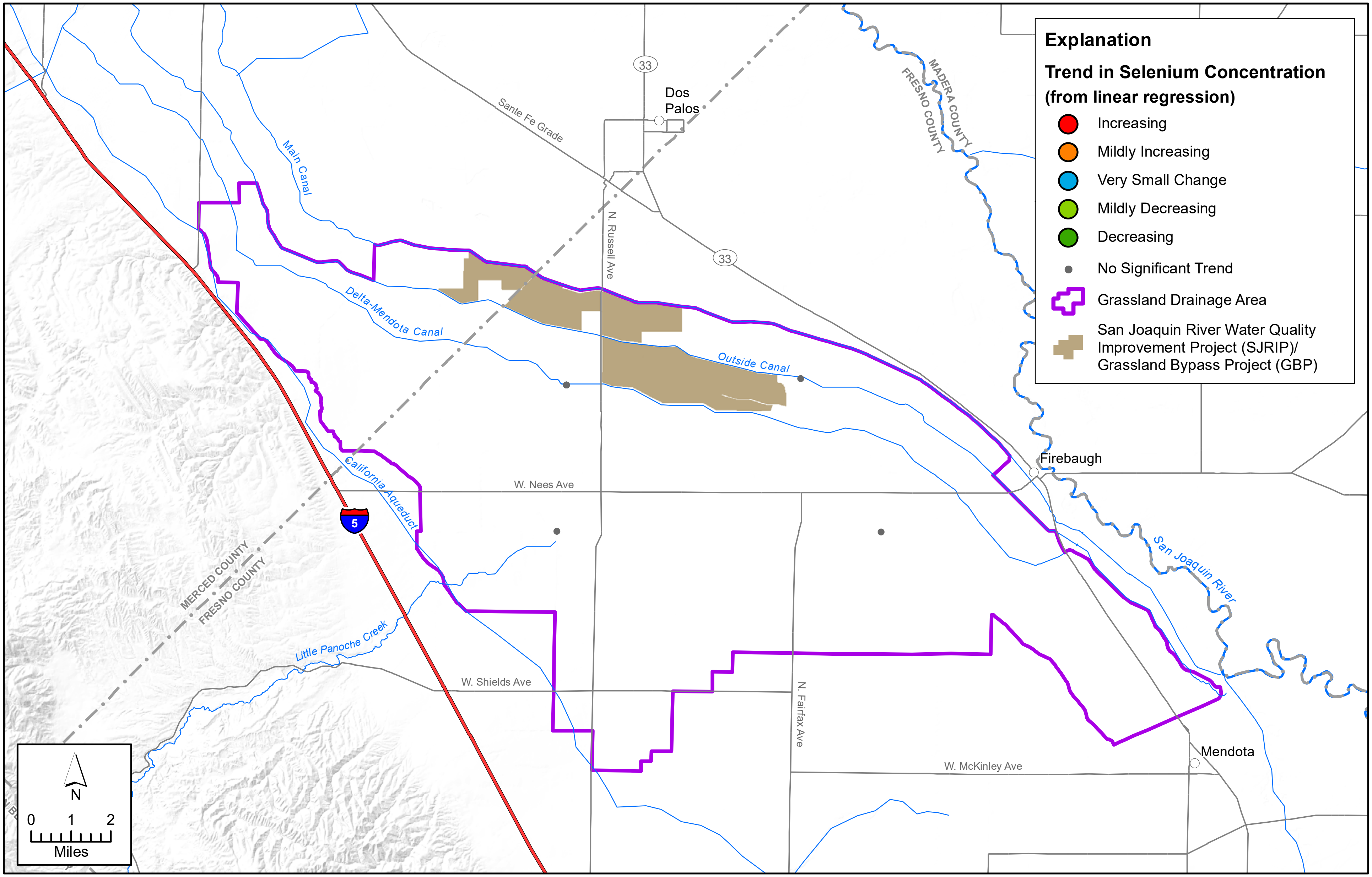

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FIGURE 5-76
Map of Significant Temporal Trends in Selenium Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

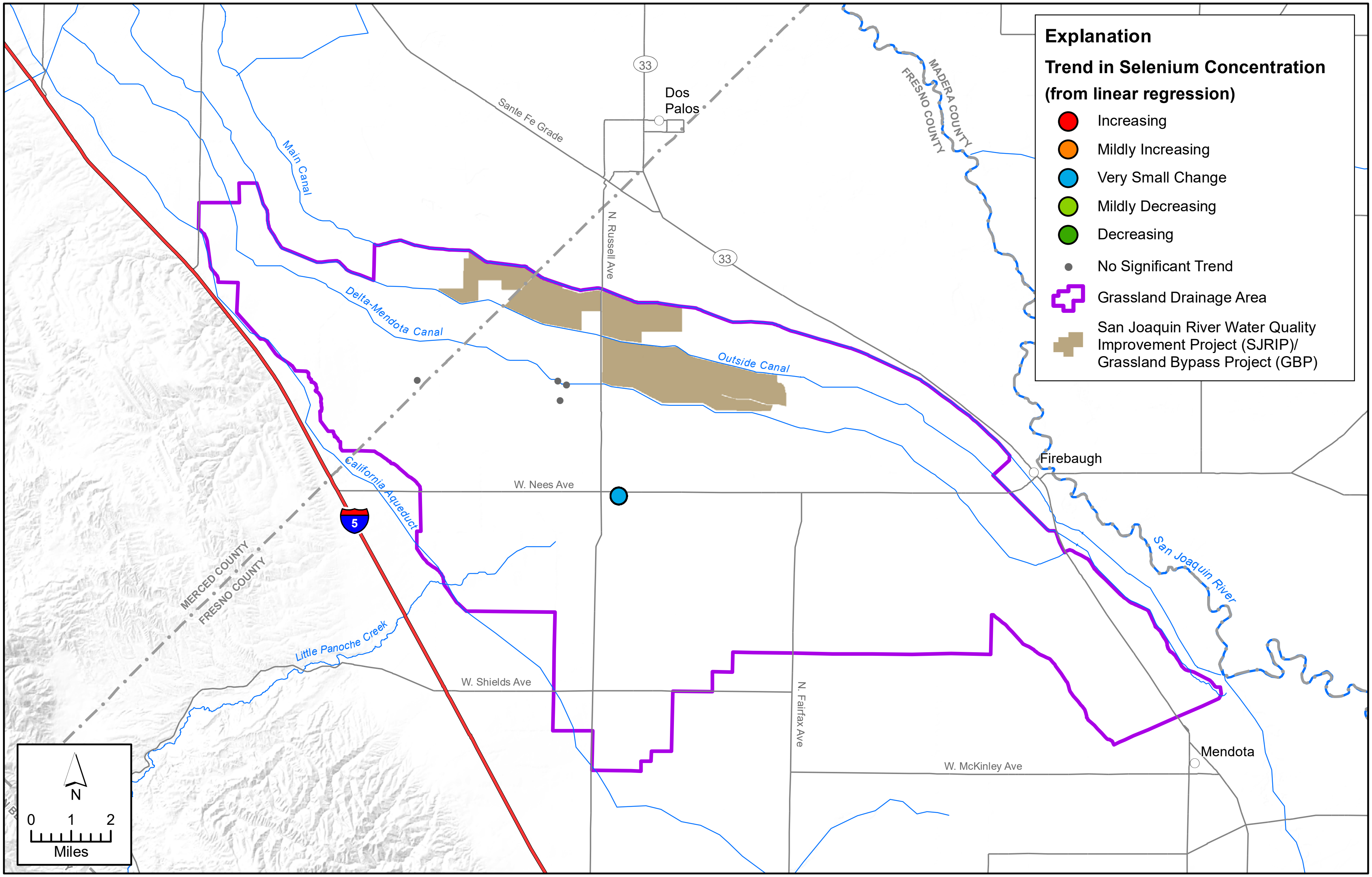

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FIGURE 5-77
Map of Significant Temporal Trends in Selenium Concentrations: Lower Aquifer

Grassland Drainage Area
Groundwater Quality Assessment Report

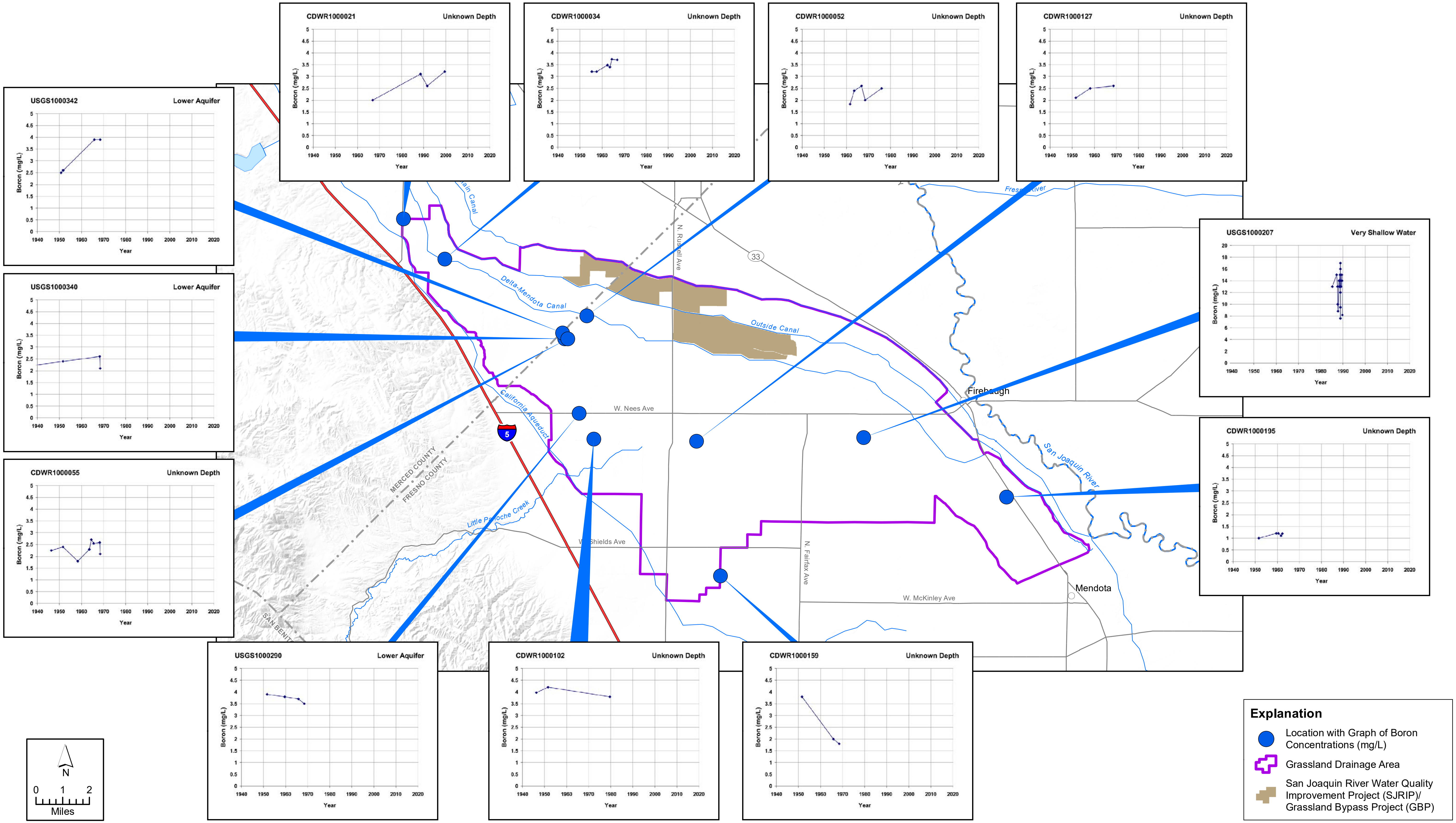

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FIGURE 5-78
Select Graphs of Boron Concentrations: Various Depths

Grassland Drainage Area
Groundwater Quality Assessment Report

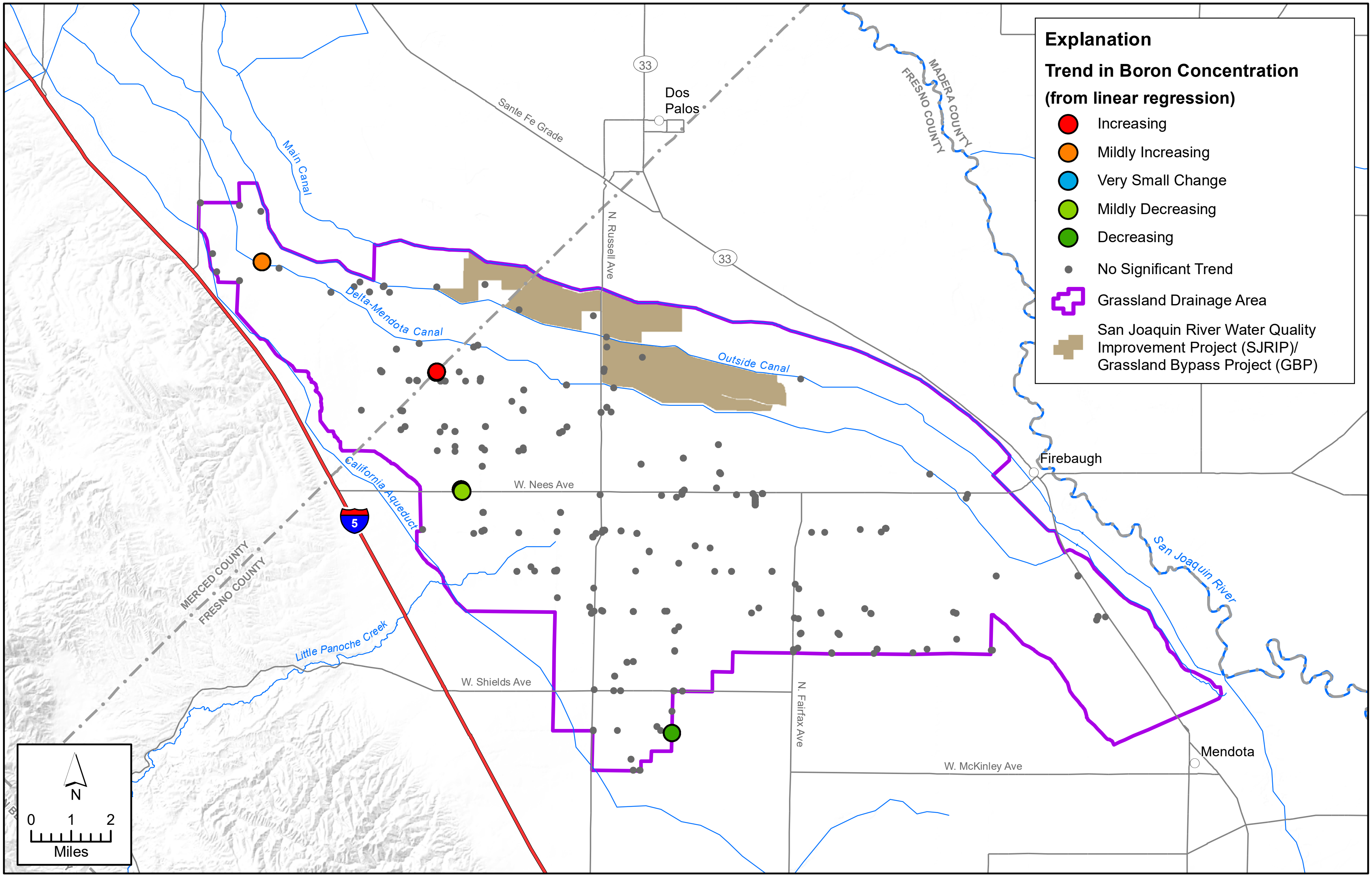

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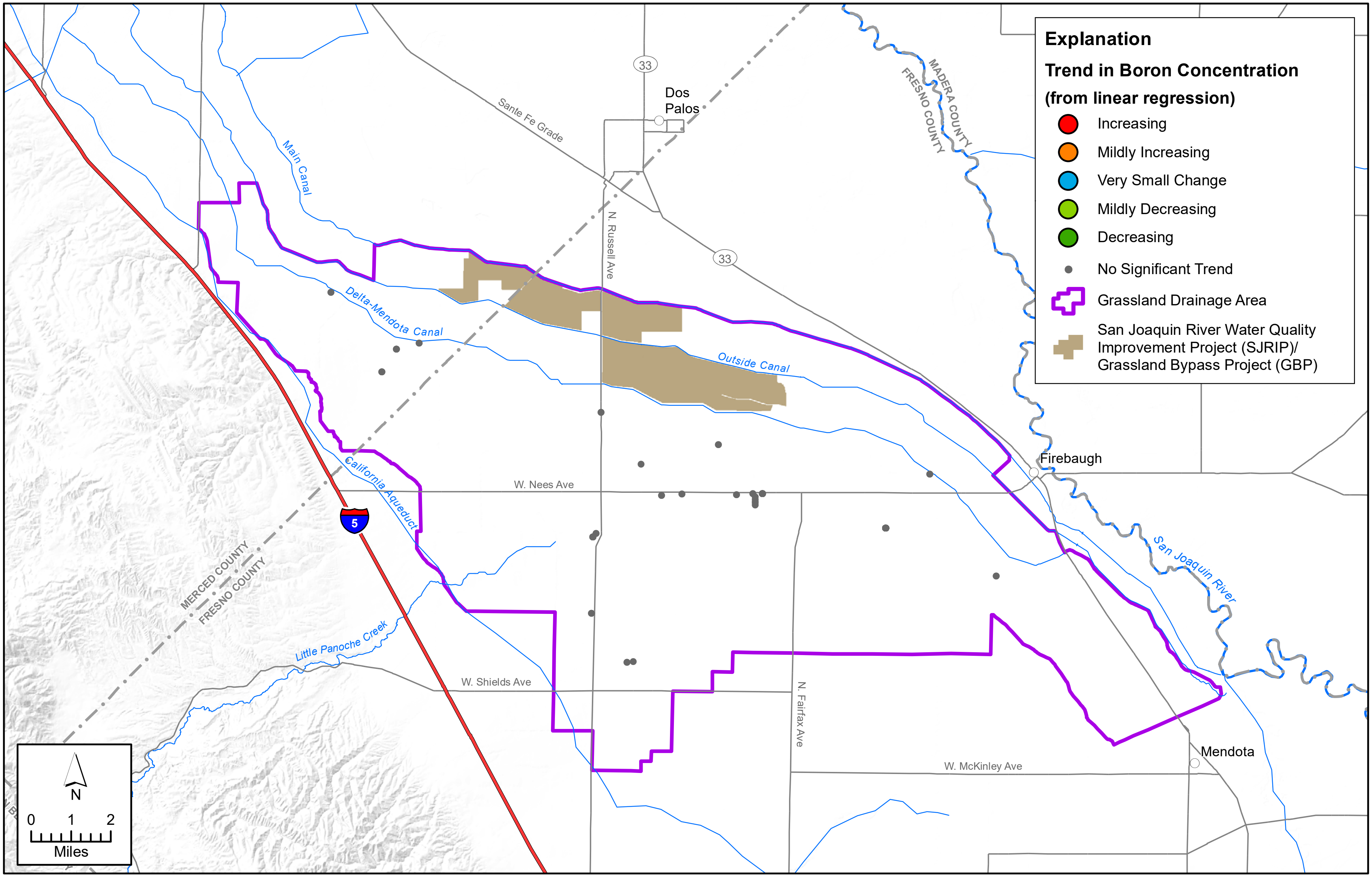
FIGURE 5-79
Map of Significant Temporal Trends in Boron Concentrations: All Drain and Well Data

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 5-80 Significant Trends in Boron Concentrations Very Shallow.mxd

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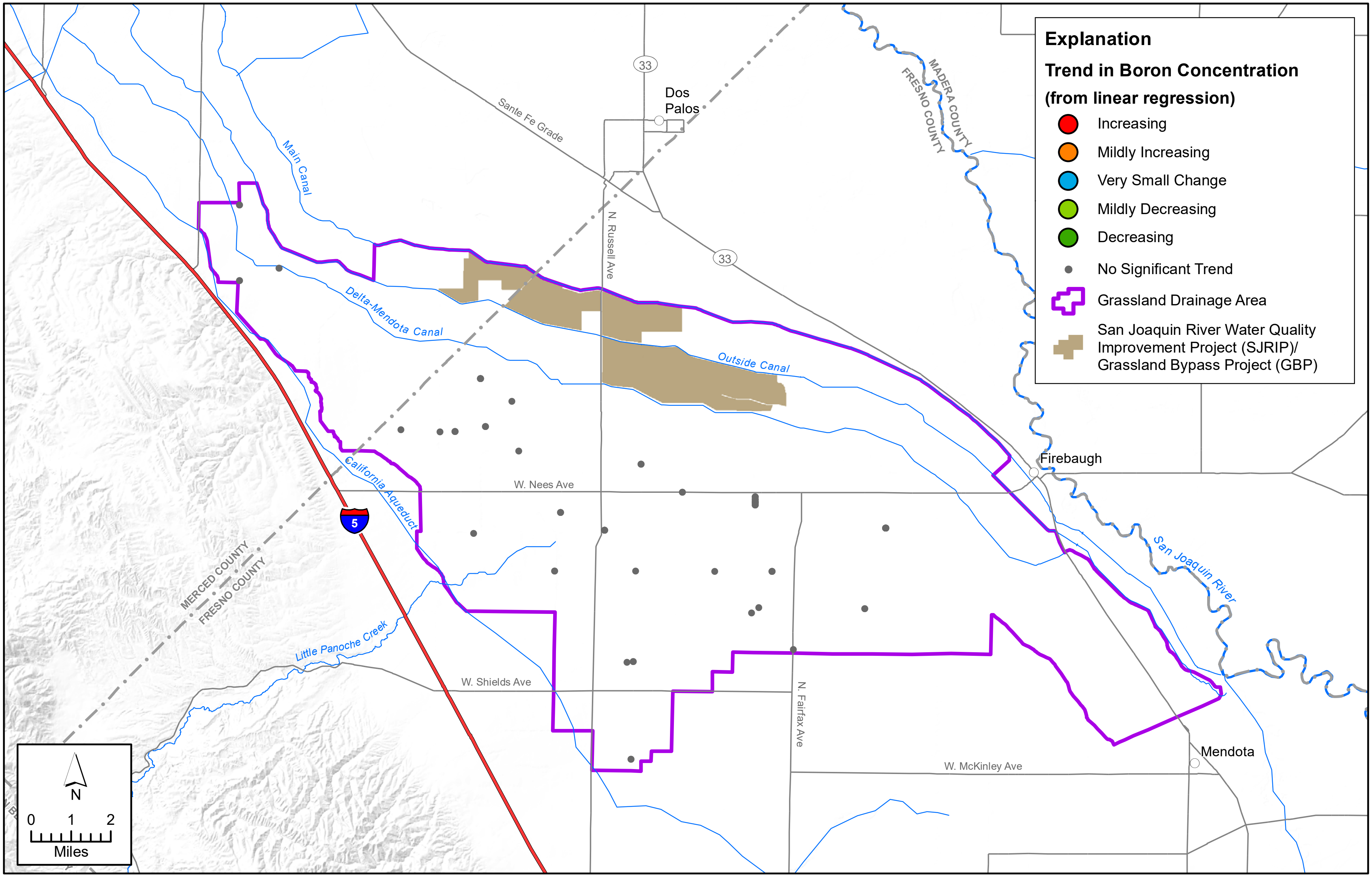
FIGURE 5-80
Map of Significant Temporal Trends in Boron Concentrations: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 5-81 Significant Trends in Boron Concentrations Shallow.mxd

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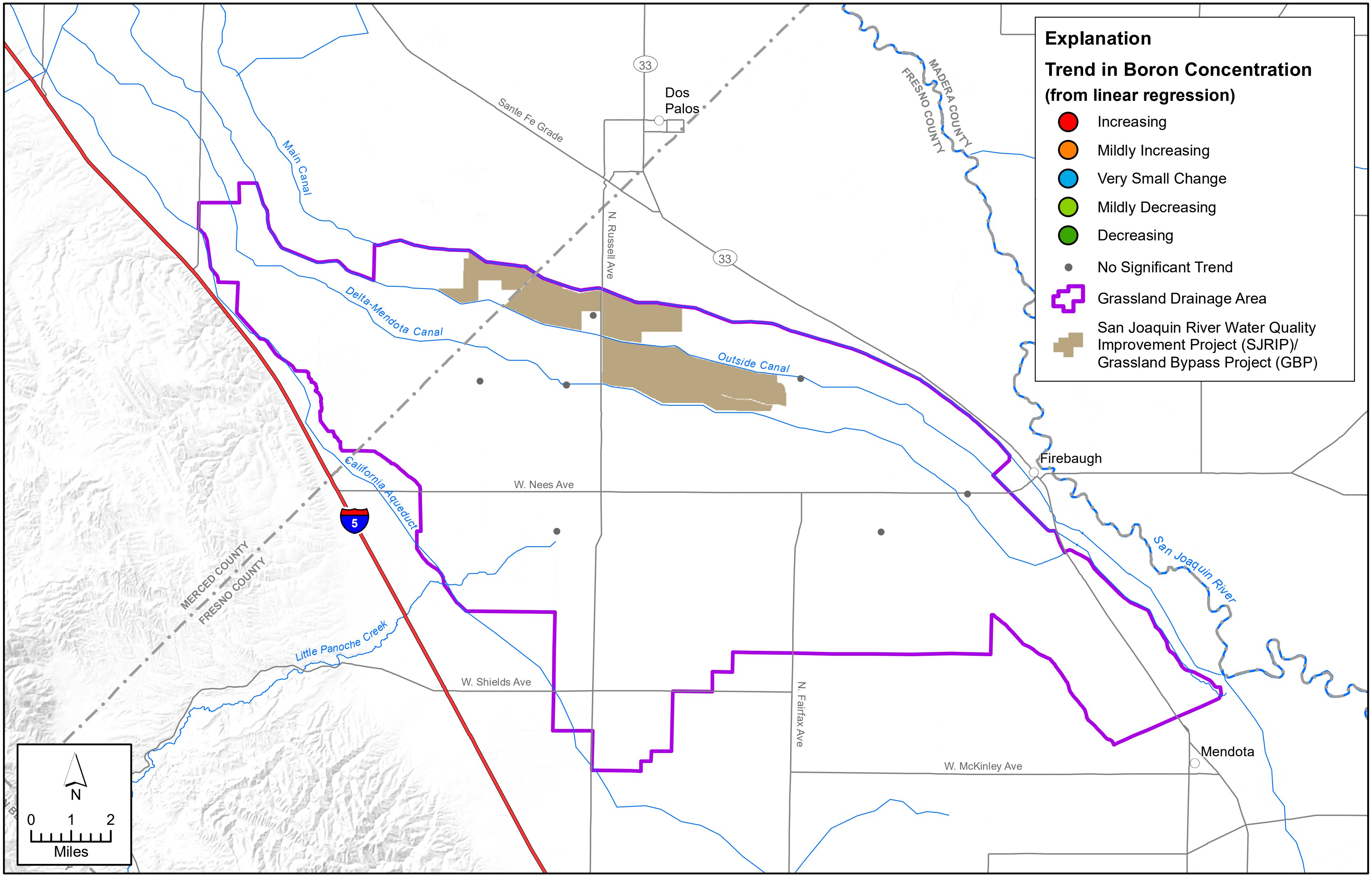
FIGURE 5-81

Map of Significant Temporal Trends in Boron Concentrations: Shallow Groundwater

Grassland Drainage Area

Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 5-82 Significant Trends in Boron Concentrations Upper Aquifer.mxd

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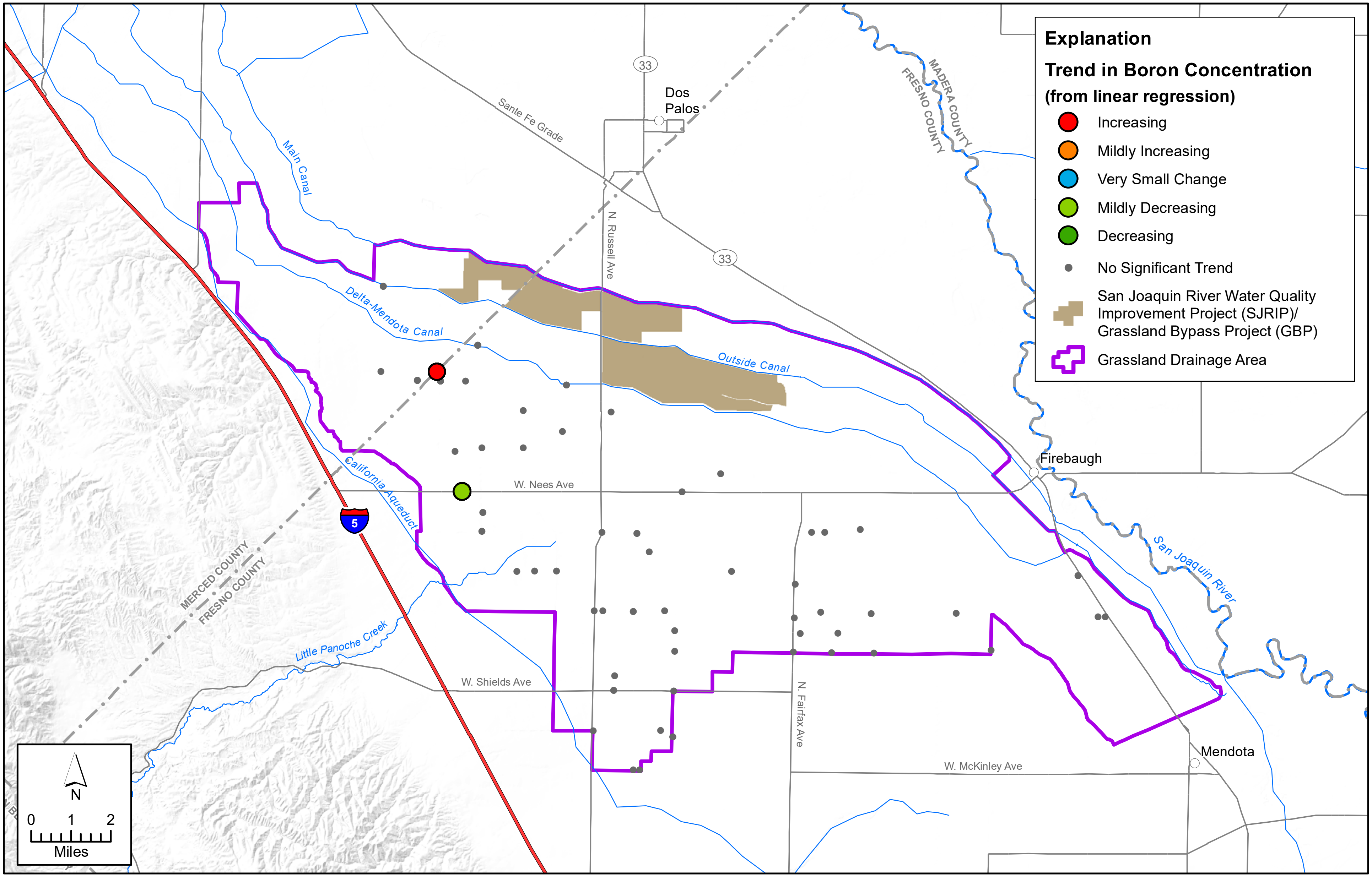
FIGURE 5-82
Map of Significant Temporal Trends in Boron Concentrations: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 5-83 Significant Trends in Boron Concentrations Lower Aquifer.mxd

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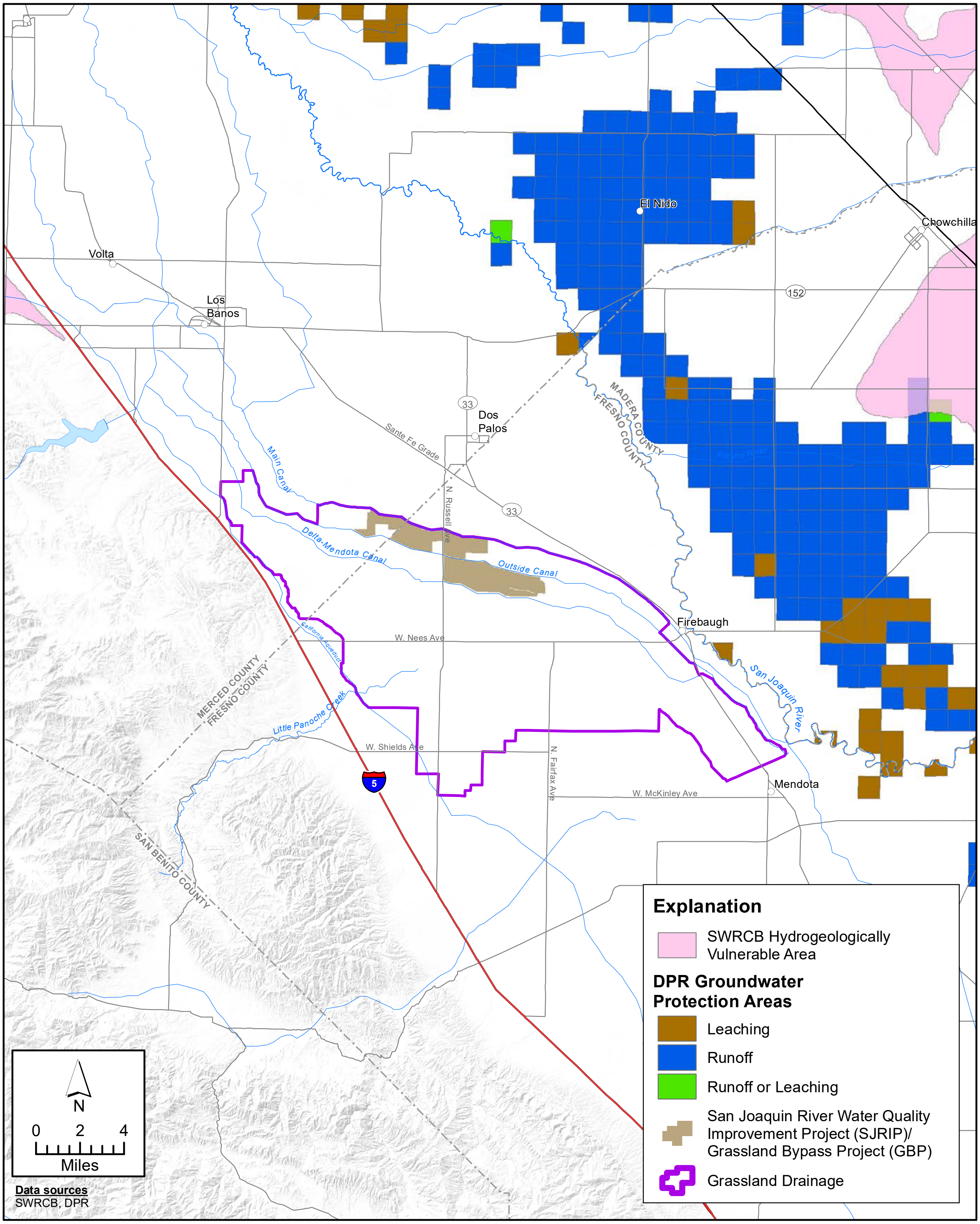
FIGURE 5-83

Map of Significant Temporal Trends in Boron Concentrations: Lower Aquifer

Grassland Drainage Area

Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-1 Map of SWRCB Hydrogeologically Vulnerable Areas and DPR Groundwater Protection Area.mxd

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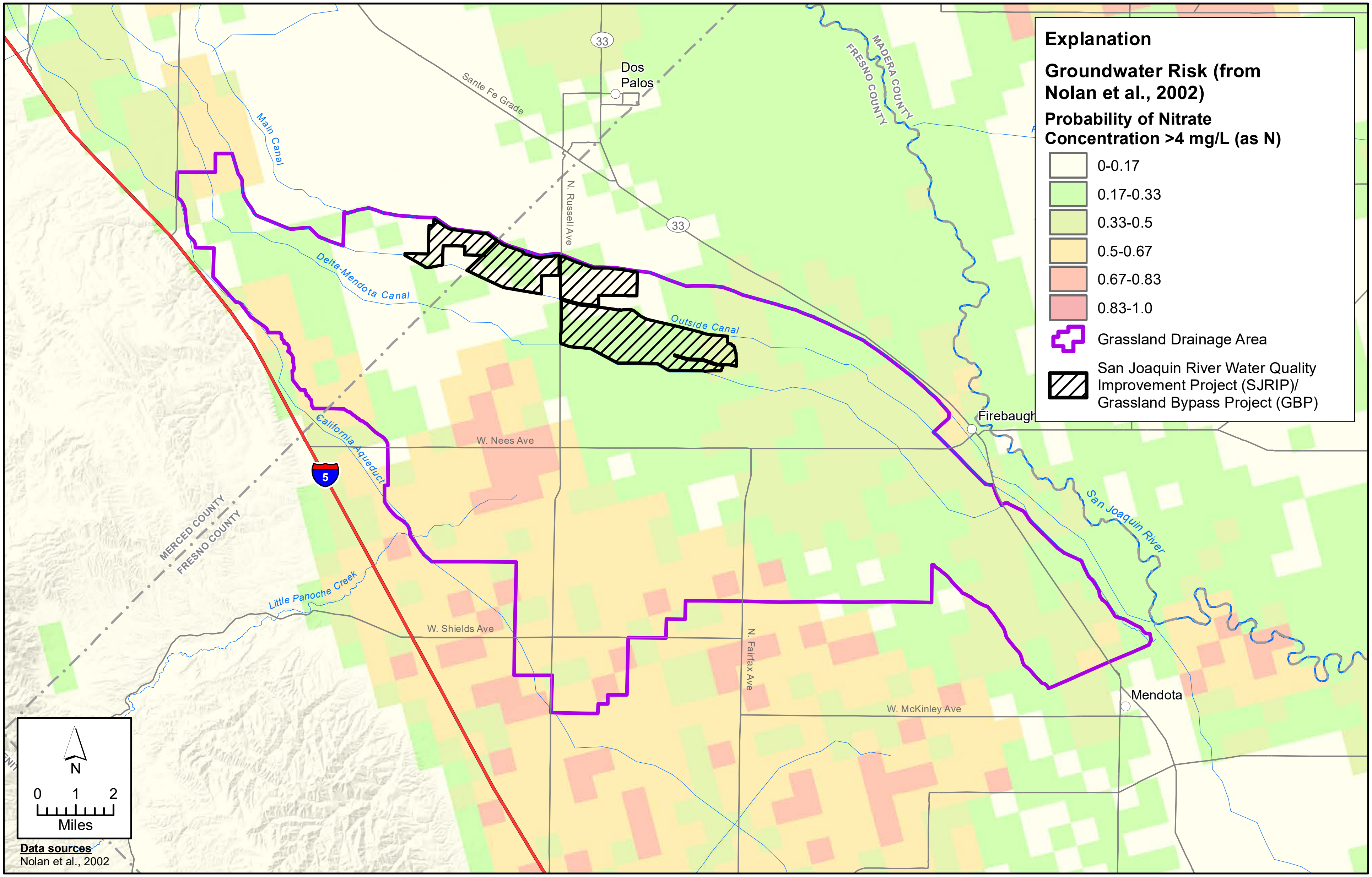
FIGURE 6-1
Map of SWRCB Hydrogeologically Vulnerable Areas and DPR Groundwater Protection Areas
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-3 Map of Groundwater Risk from Nolan et al 2002.mxd

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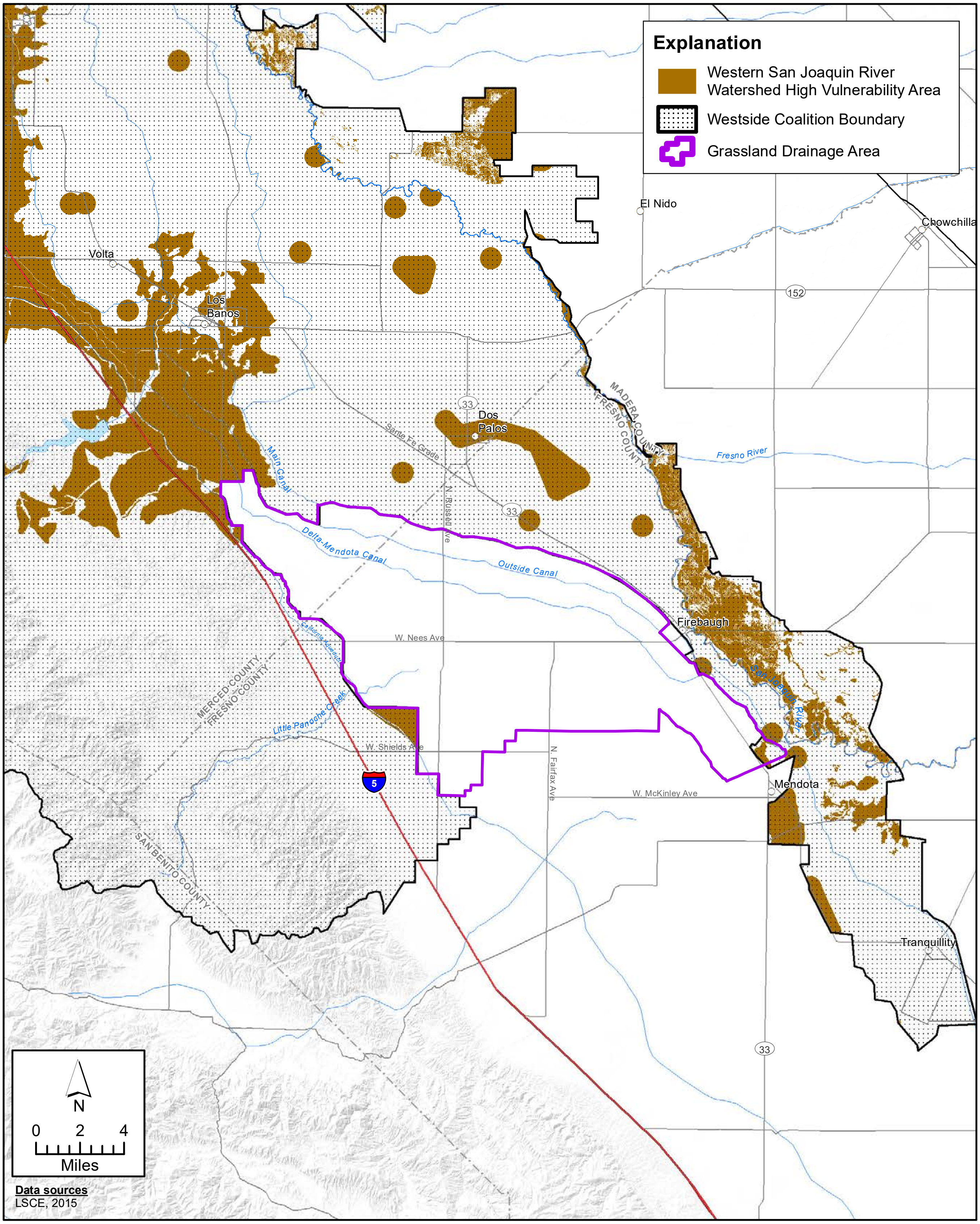
FIGURE 6-2
Map of Groundwater Risk Assessment from Nolan et al. (2002)
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-3 Map of Western San Joaquin River Watershed High Vulnerability Area.mxd

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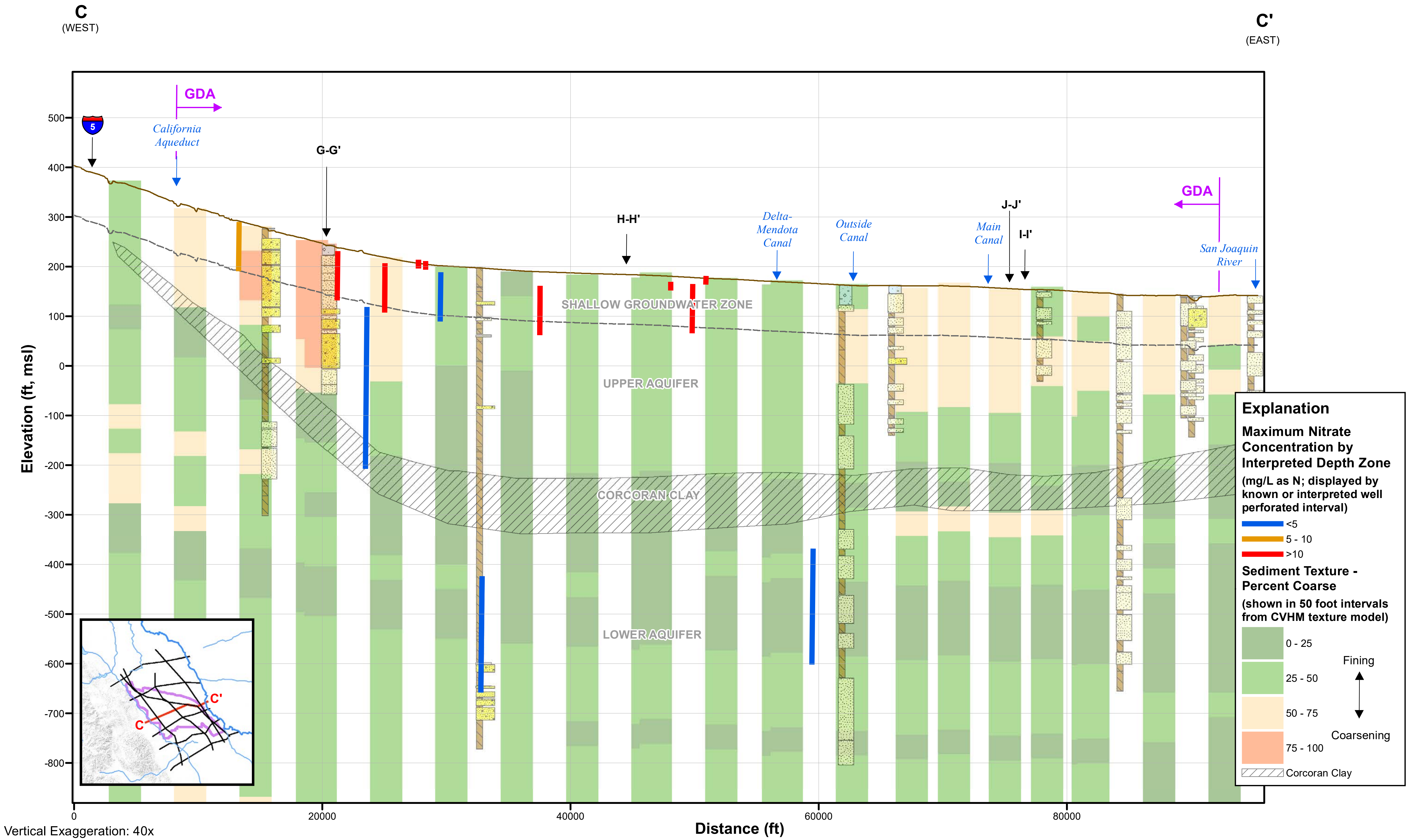
FIGURE 6-3
Map of Western San Joaquin River Watershed High Vulnerability Area in GDA Vicinity
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-4 Nitrate Concentrations by Depth Along Cross Section C.mxd

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FIGURE 6-4

Nitrate Concentrations by Depth Along Geologic Cross-Section C-C'

Grassland Drainage Area
Groundwater Quality Assessment Report

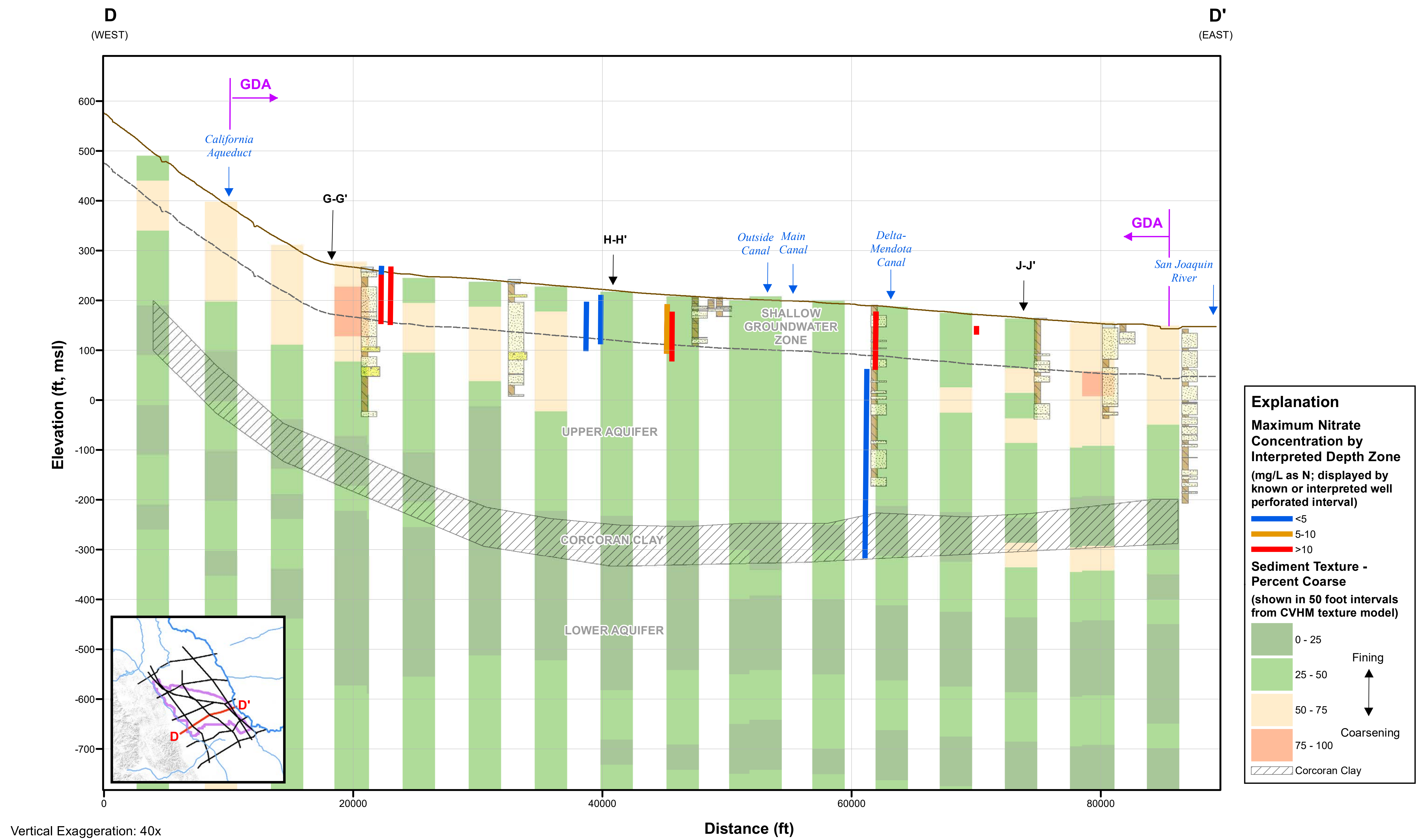

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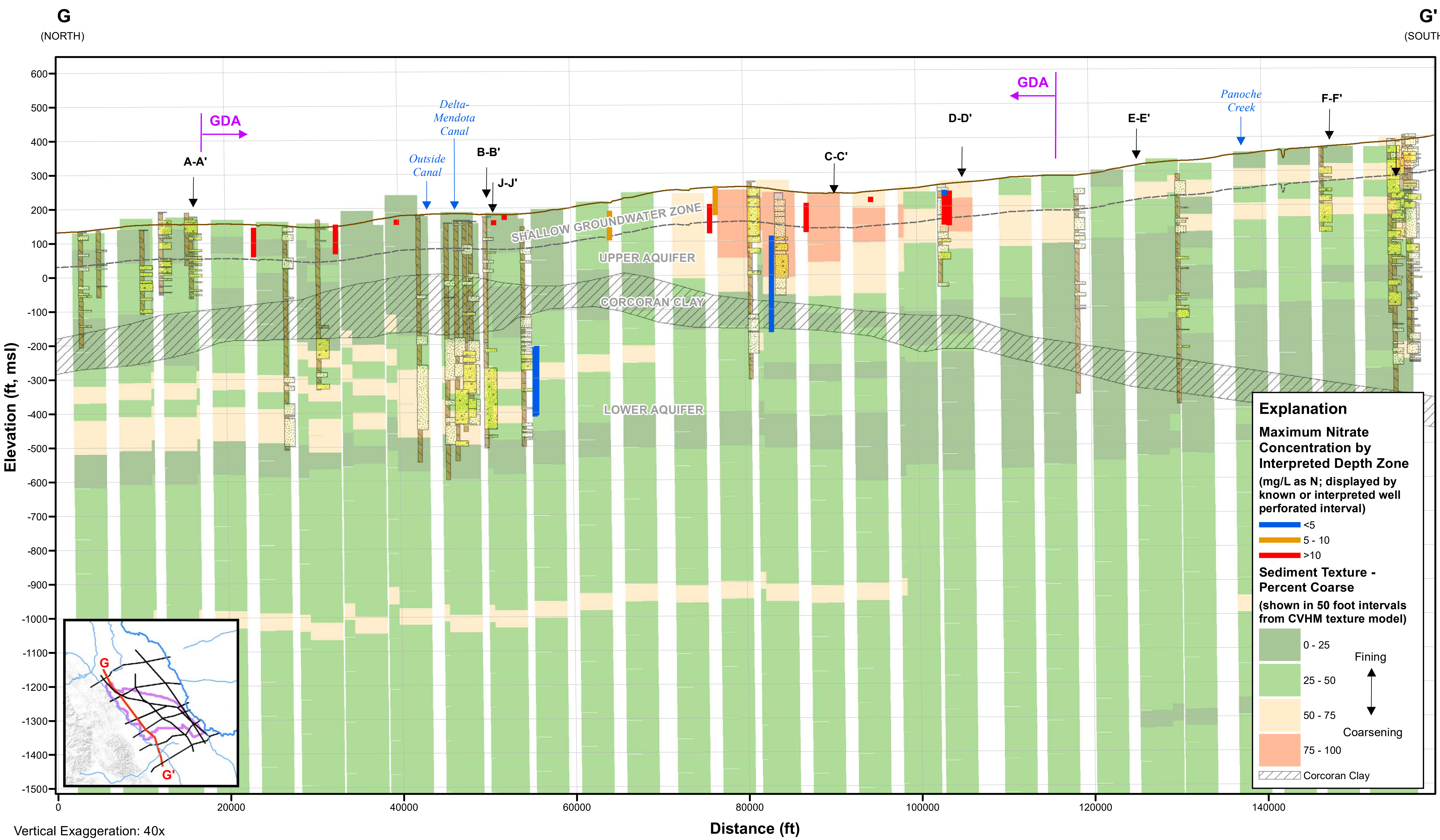
FIGURE 6-5

Nitrate Concentrations by Depth Along Geologic Cross-Section D-D'

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-6 Nitrate Concentrations by Depth Along Cross Section G.mxd

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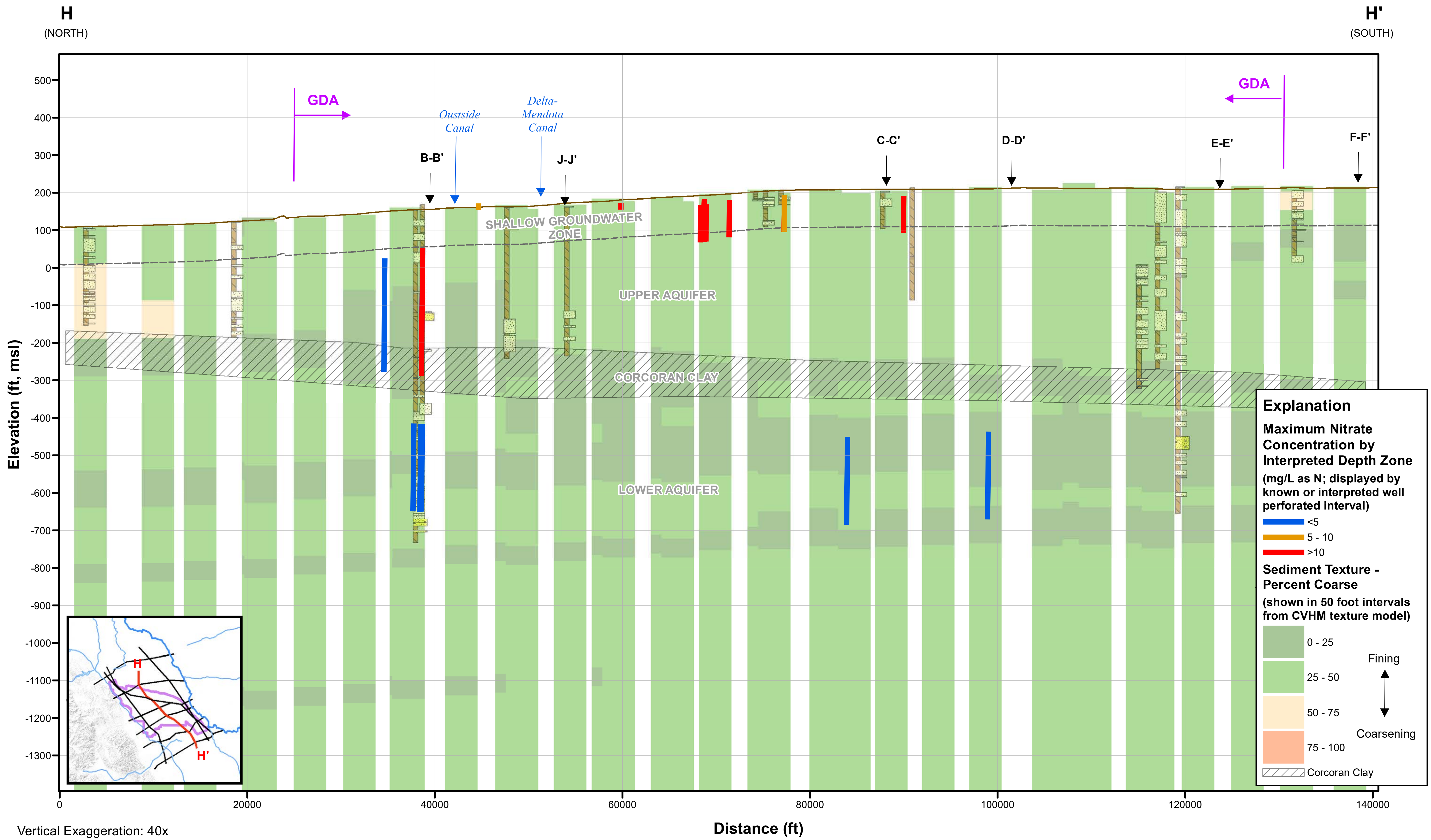
FIGURE 6-6

Nitrate Concentrations by Depth Along Geologic Cross-Section G-G'

Grassland Drainage Area
Groundwater Quality Assessment Report



Vertical Exaggeration: 40x

X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-7 Nitrate Concentrations by Depth Along Cross Section H.mxd

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FIGURE 6-7

Nitrate Concentrations by Depth Along Geologic Cross-Section H-H'

Grassland Drainage Area
Groundwater Quality Assessment Report

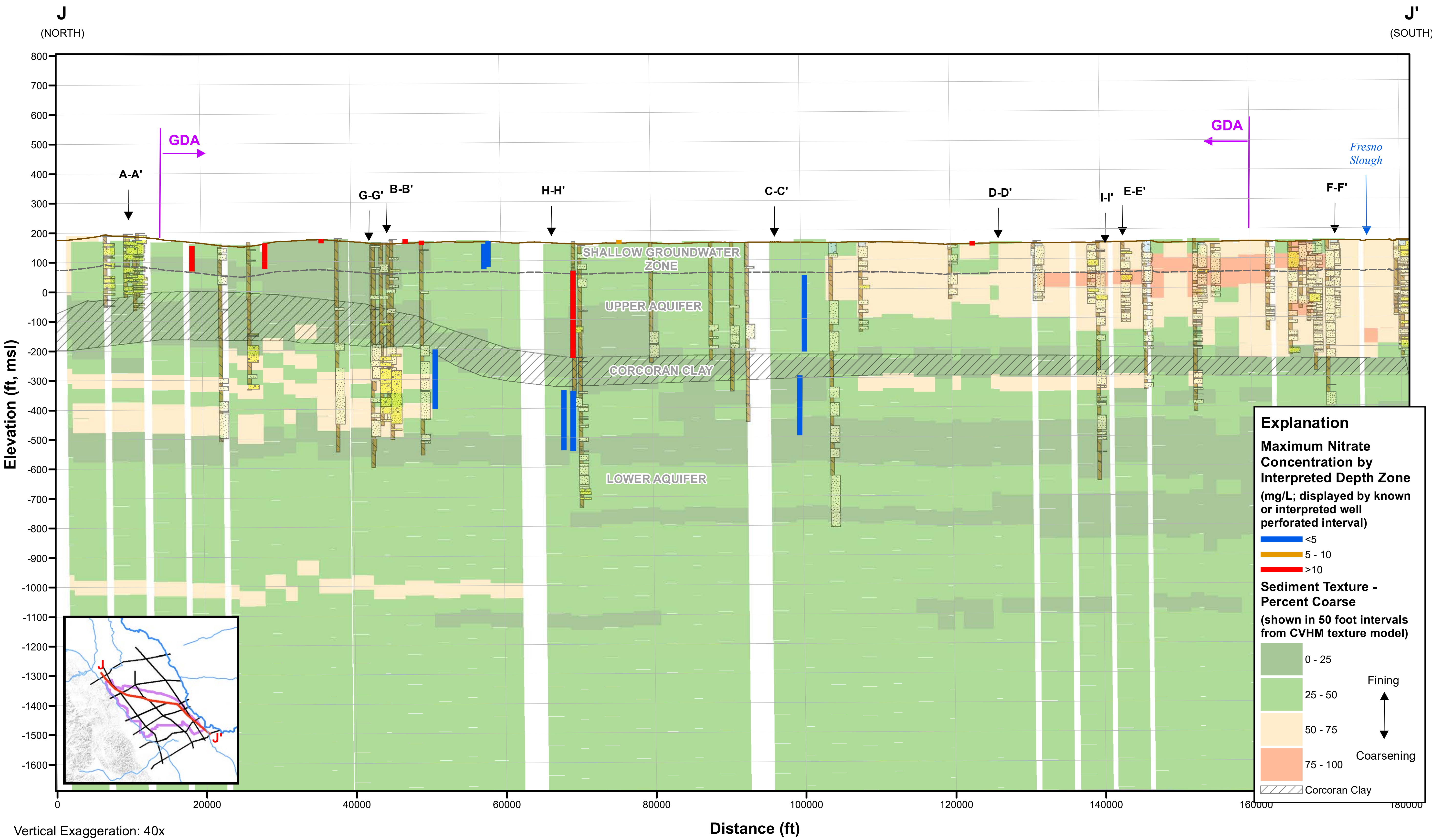

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FIGURE 6-8

Nitrate Concentrations by Depth Along Geologic Cross-Section J-J'

Grassland Drainage Area
Groundwater Quality Assessment Report

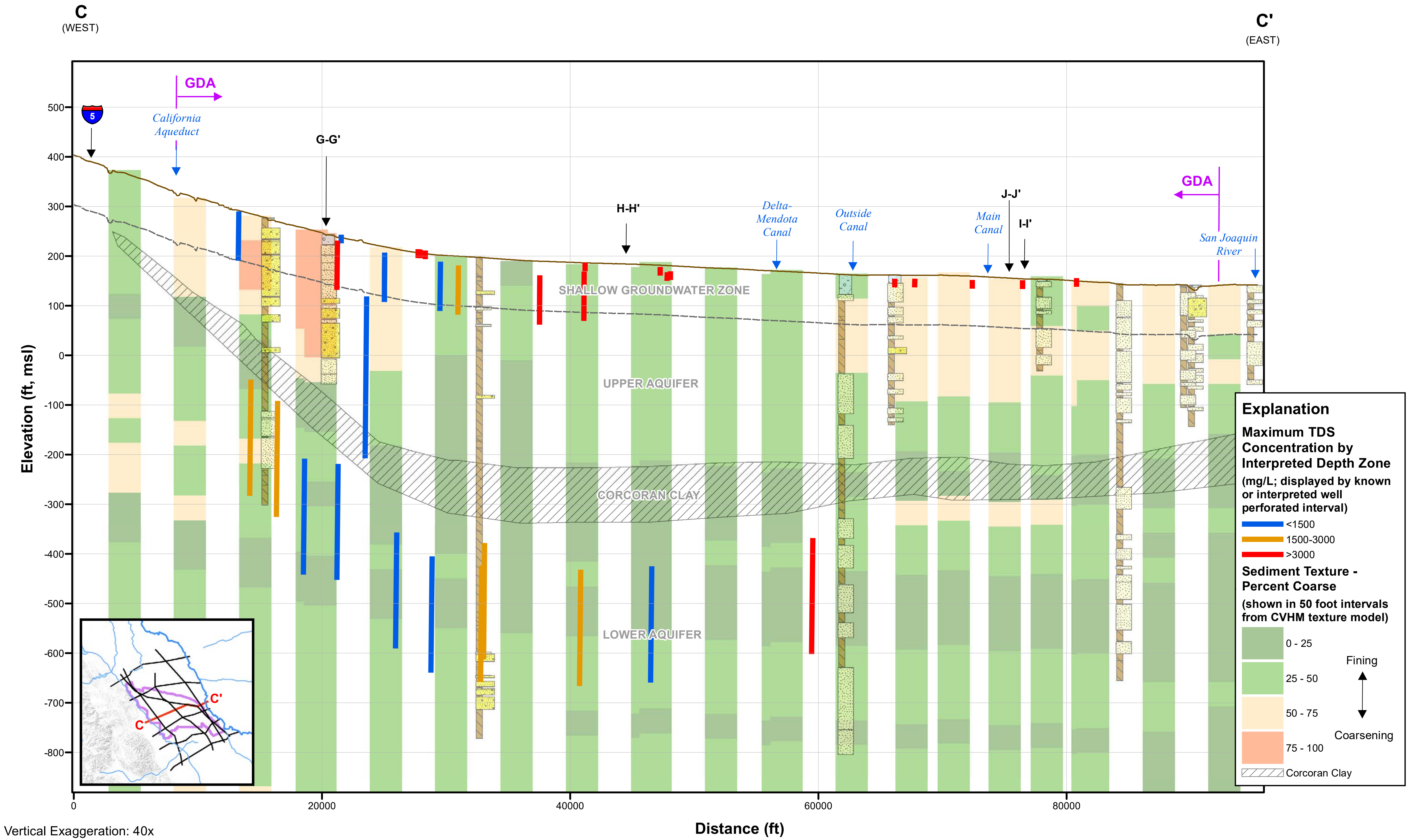

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FIGURE 6-9

TDS Concentrations by Depth Along Geologic Cross-Section C-C'

Grassland Drainage Area
Groundwater Quality Assessment Report

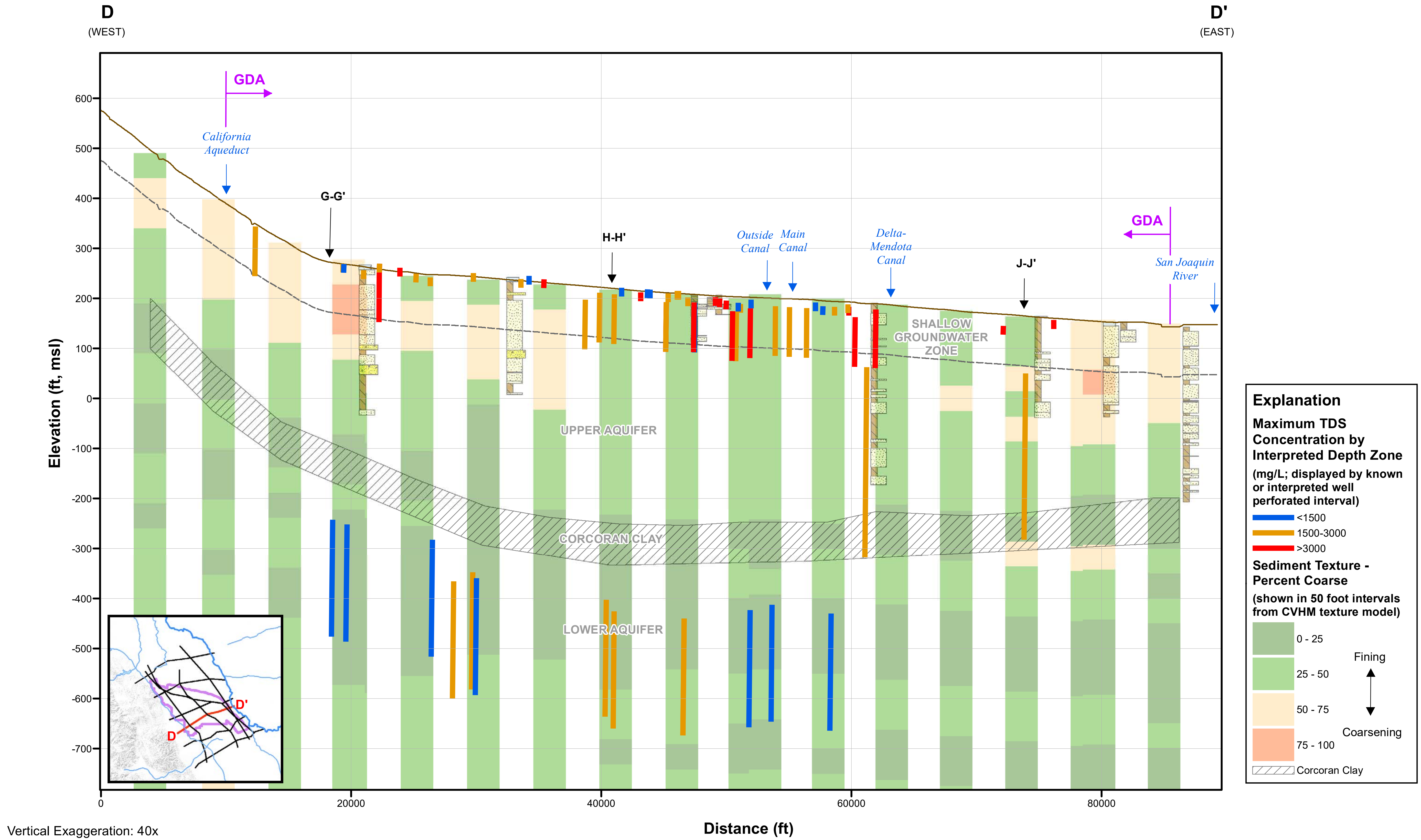

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FIGURE 6-10

TDS Concentrations by Depth Along Geologic Cross-Section D-D'

Grassland Drainage Area
Groundwater Quality Assessment Report

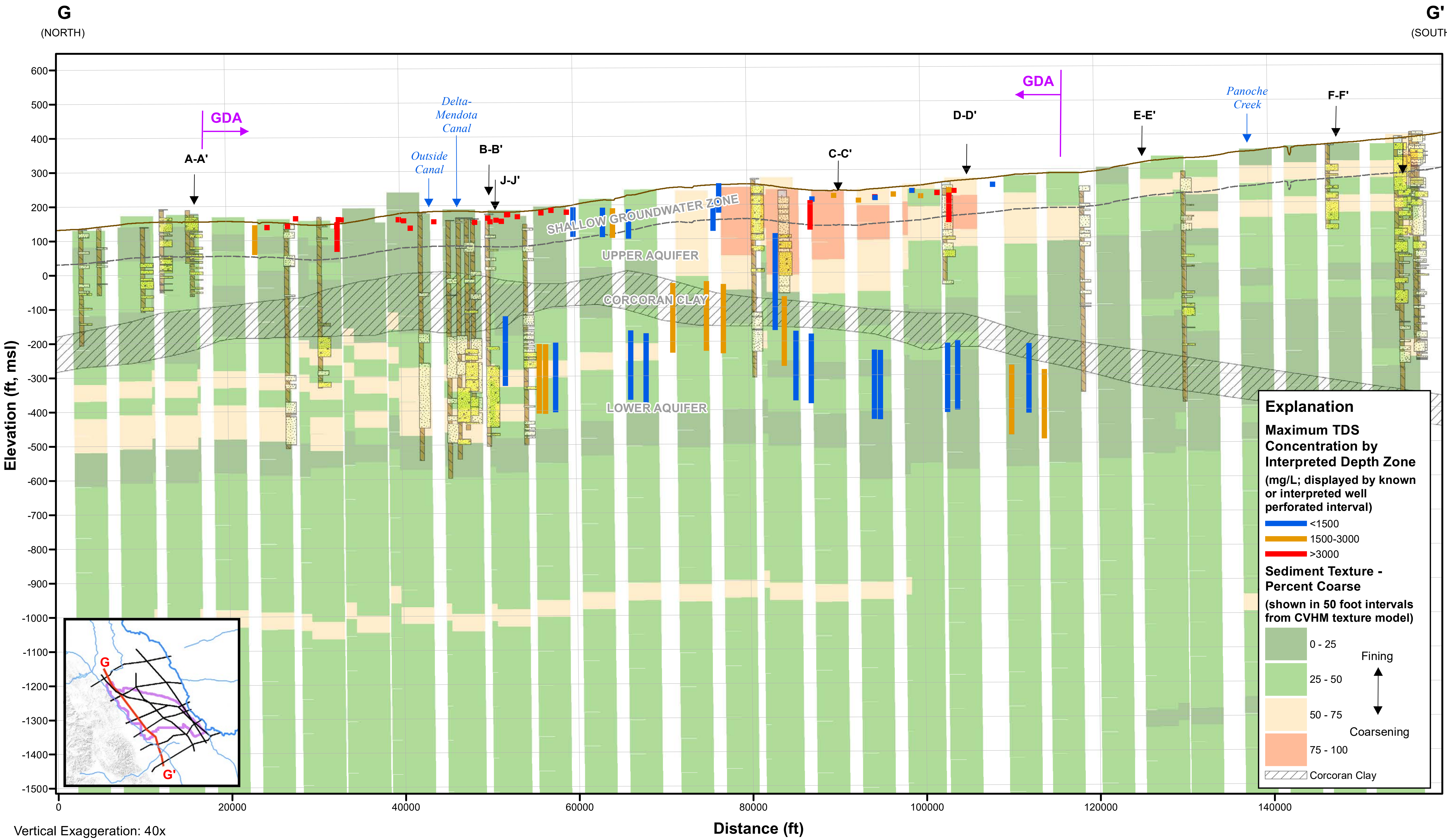

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FIGURE 6-11

TDS Concentrations by Depth Along Geologic Cross-Section G-G'

Grassland Drainage Area
Groundwater Quality Assessment Report

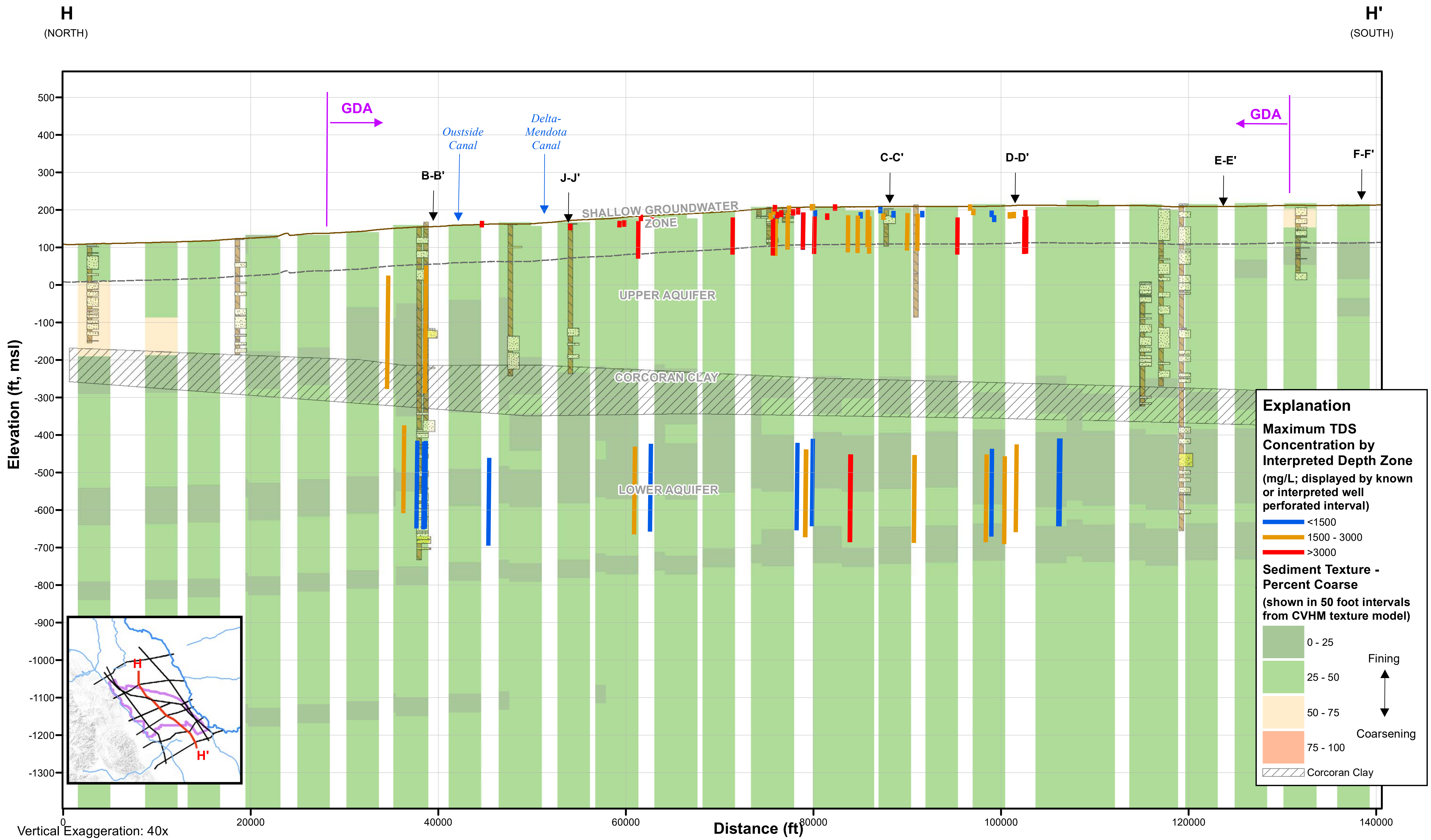

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FIGURE 6-12

TDS Concentrations by Depth Along Geologic Cross-Section H-H'

Grassland Drainage Area
Groundwater Quality Assessment Report

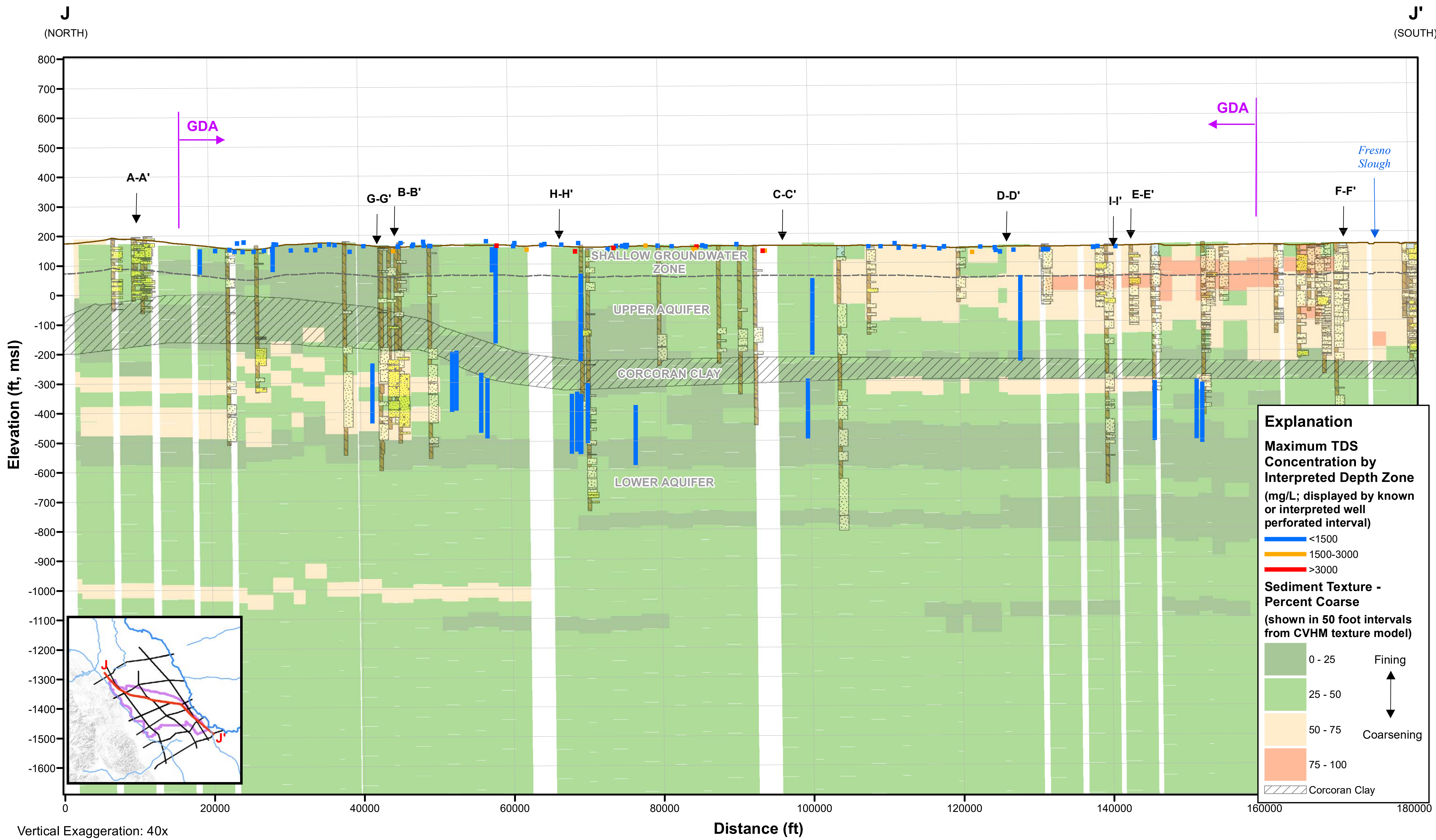

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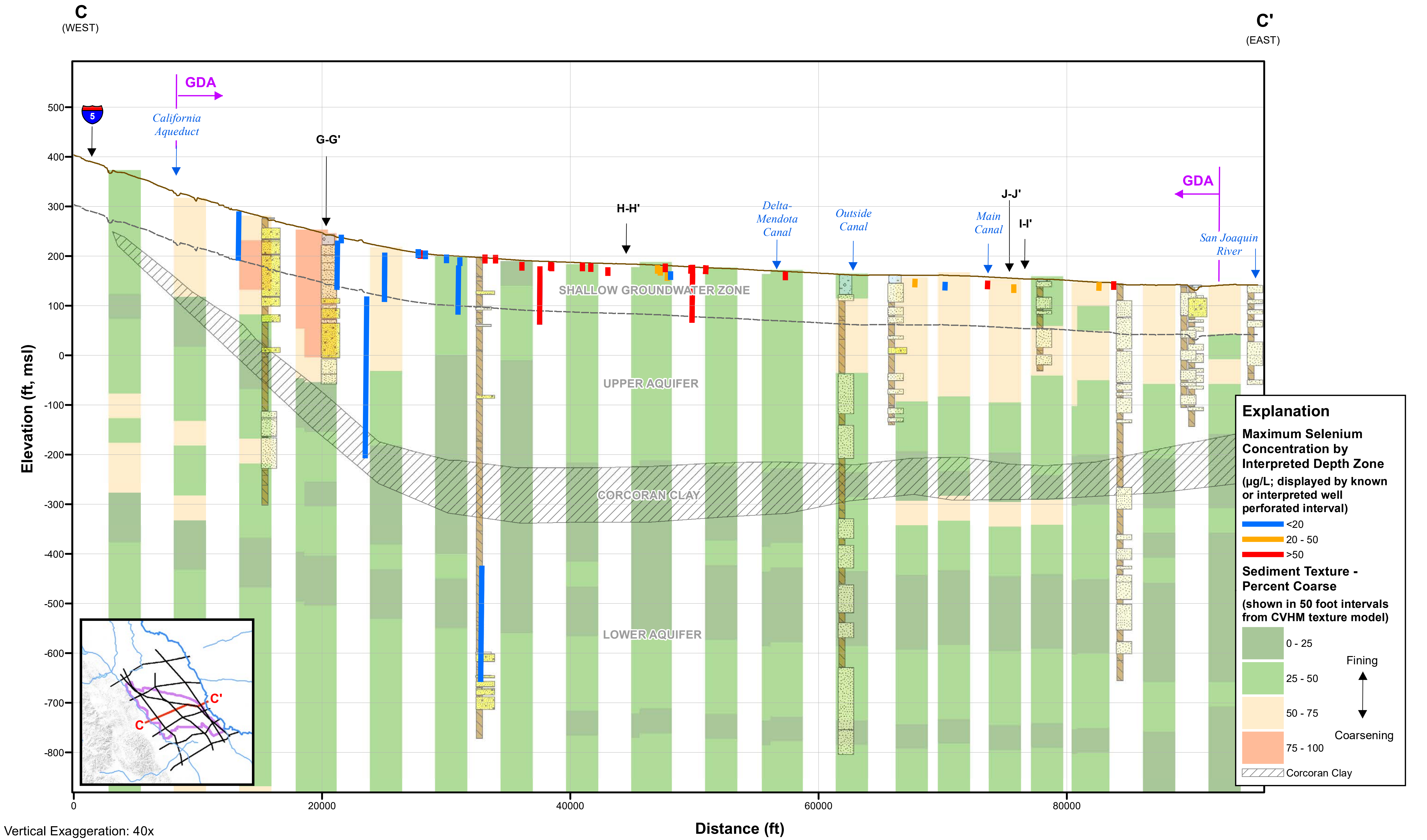
FIGURE 6-13

TDS Concentrations by Depth Along Cross Section J-J'

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-14 Selenium Concentrations by Depth Along Cross Section C.mxd

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FIGURE 6-14

Selenium Concentrations by Depth Along Geologic Cross-Section C-C'

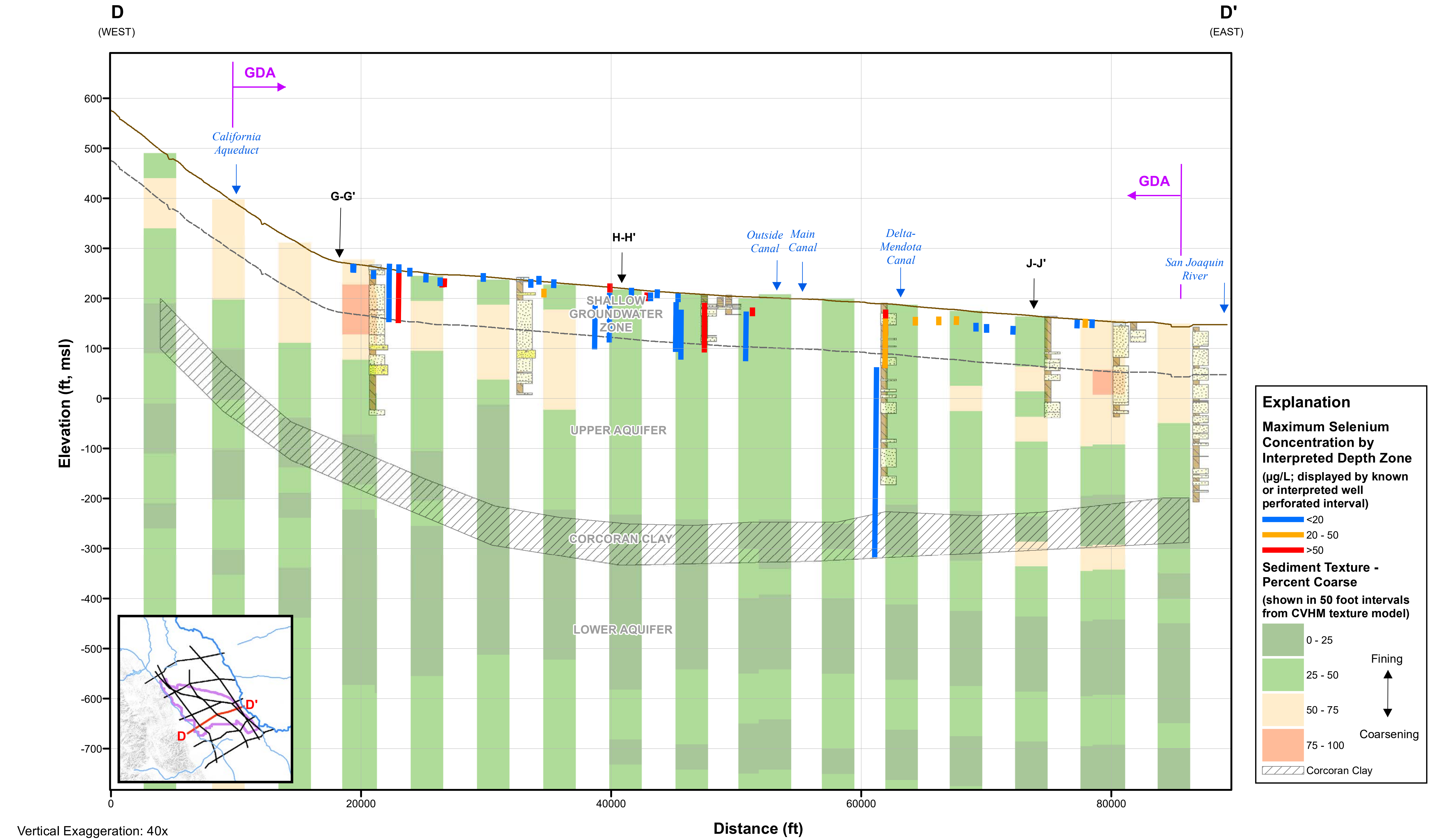

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FIGURE 6-15

Selenium Concentrations by Depth Along Geologic Cross-Section D-D'

Grassland Drainage Area
Groundwater Quality Assessment Report

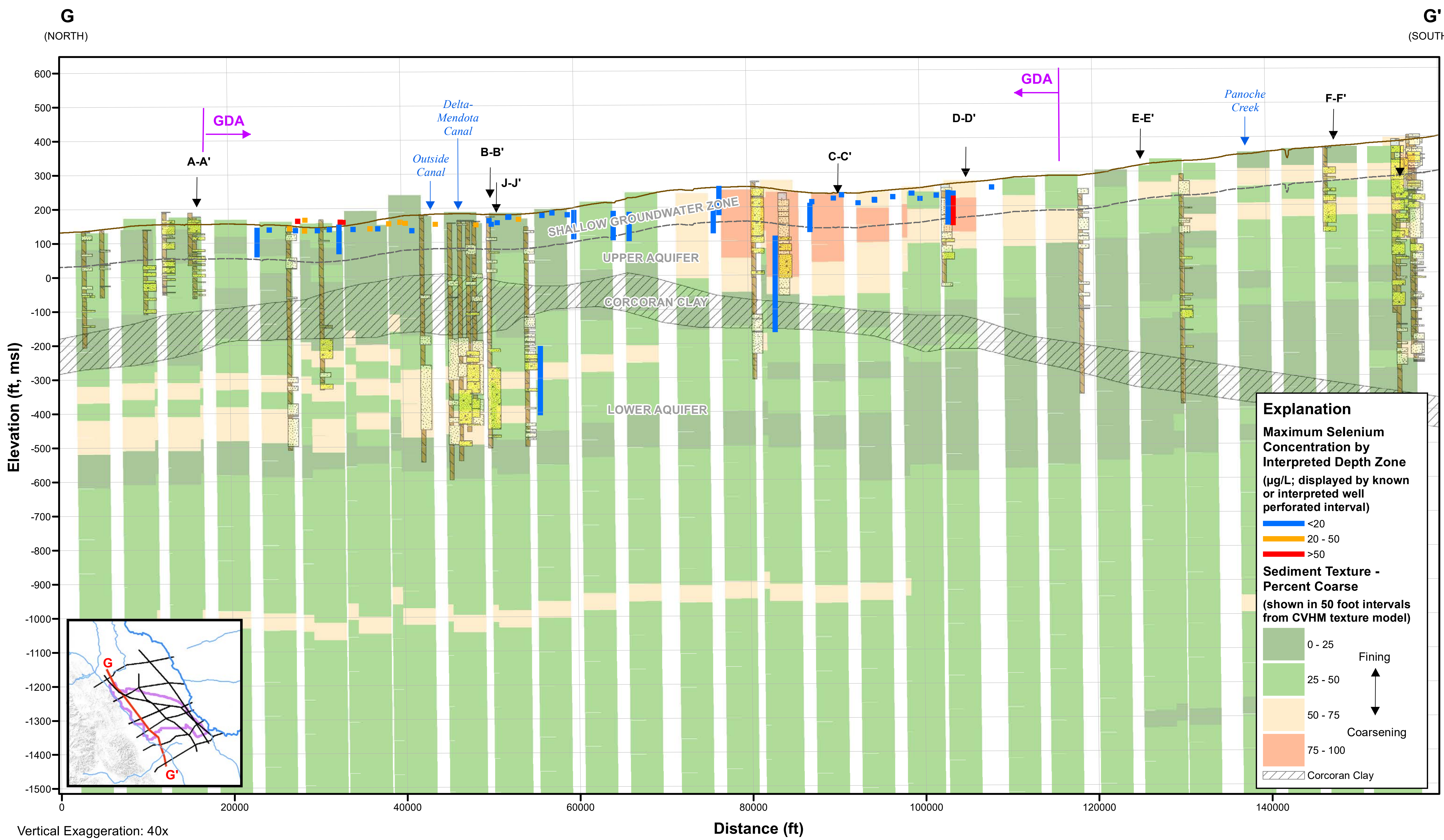

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FIGURE 6-16

Selinium Concentrations by Depth Along Geologic Cross-Section G-G'

Grassland Drainage Area
Groundwater Quality Assessment Report

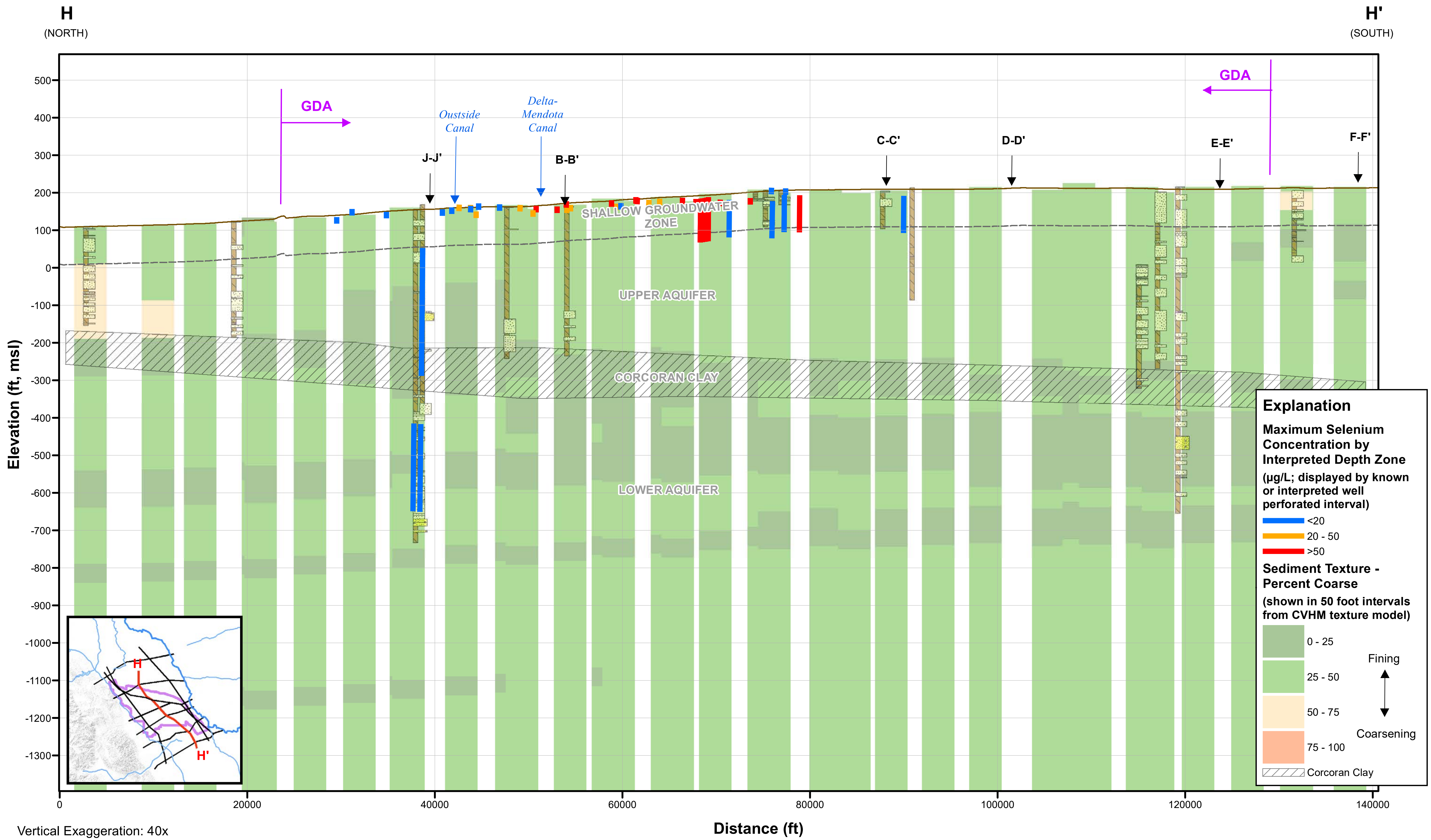

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FIGURE 6-17

Selenium Concentrations by Depth Along Cross Section H-H'

Grassland Drainage Area
Groundwater Quality Assessment Report

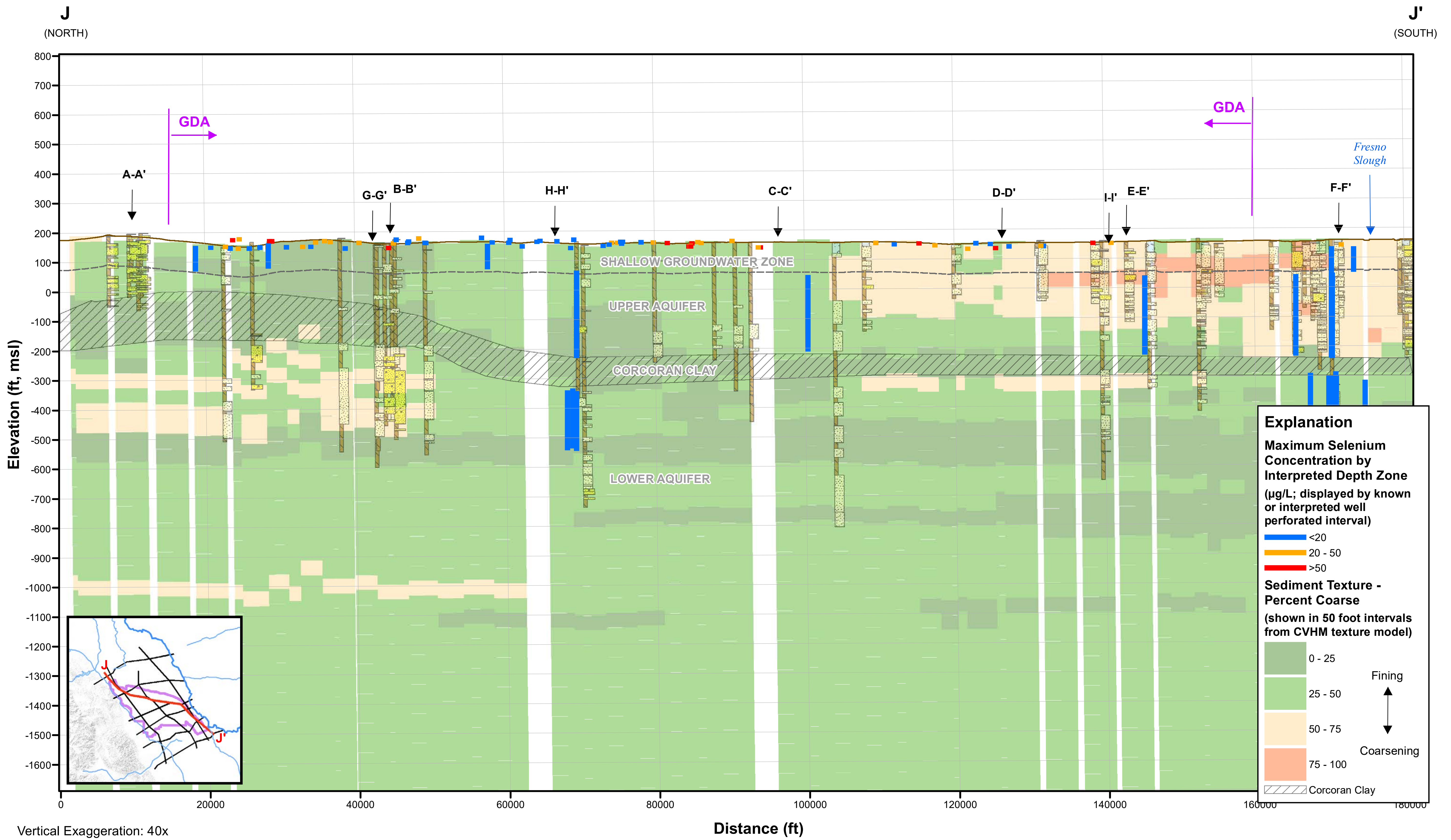

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FIGURE 6-18

Selenium Concentrations by Depth Along Cross Section J-J'

Grassland Drainage Area
Groundwater Quality Assessment Report

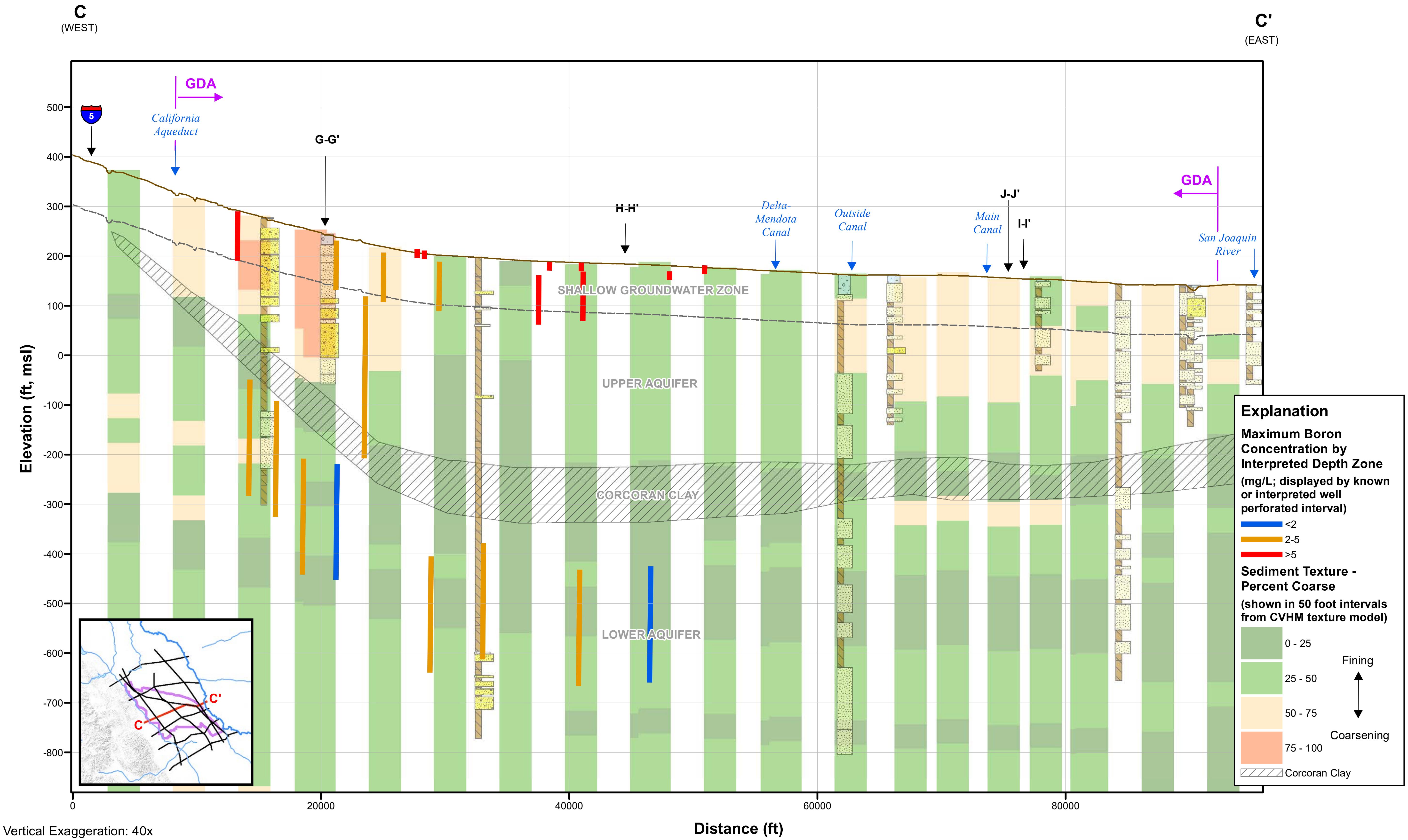

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FIGURE 6-19

Boron Concentrations by Depth Along Geologic Cross-Section C-C'

Grassland Drainage Area
Groundwater Quality Assessment Report

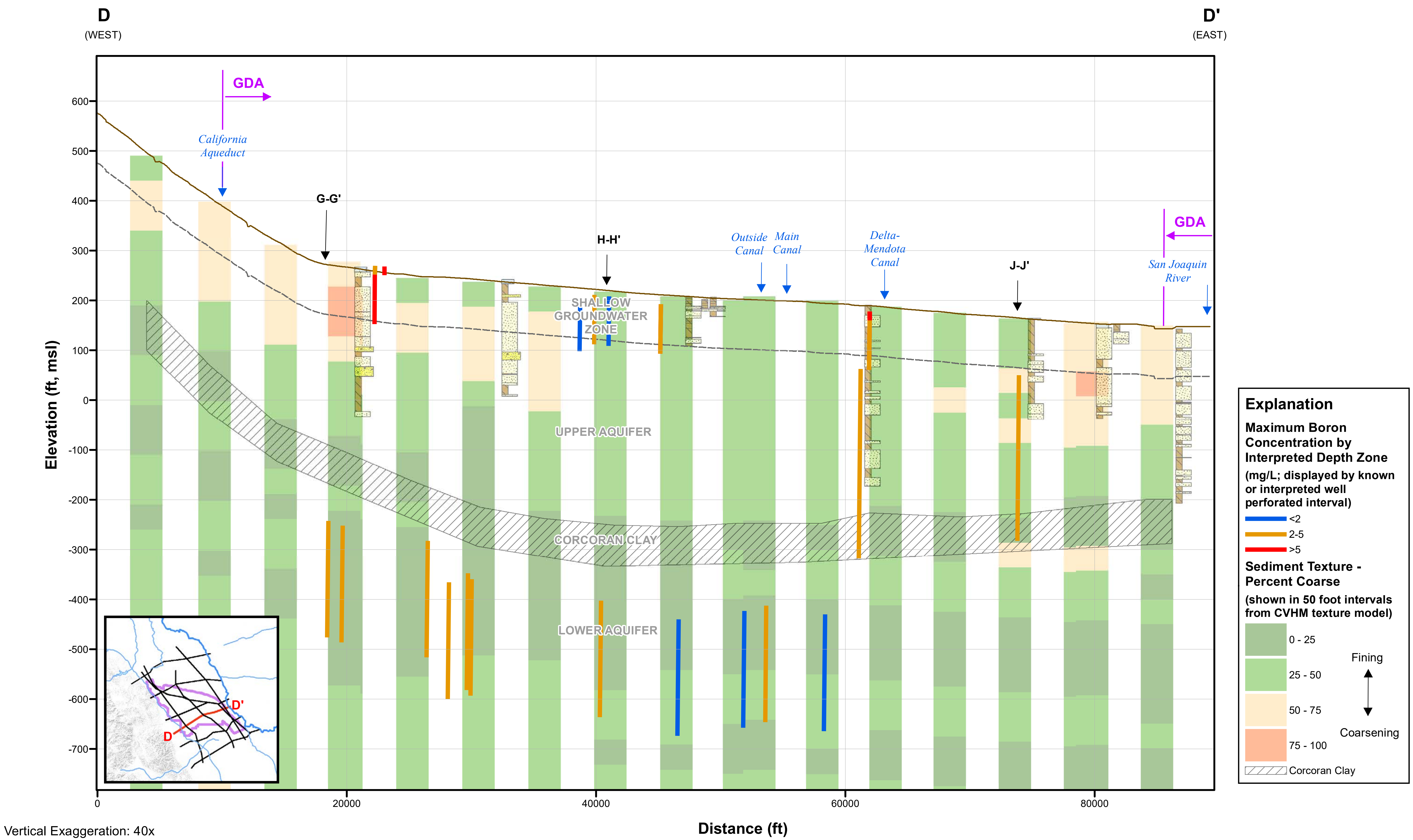

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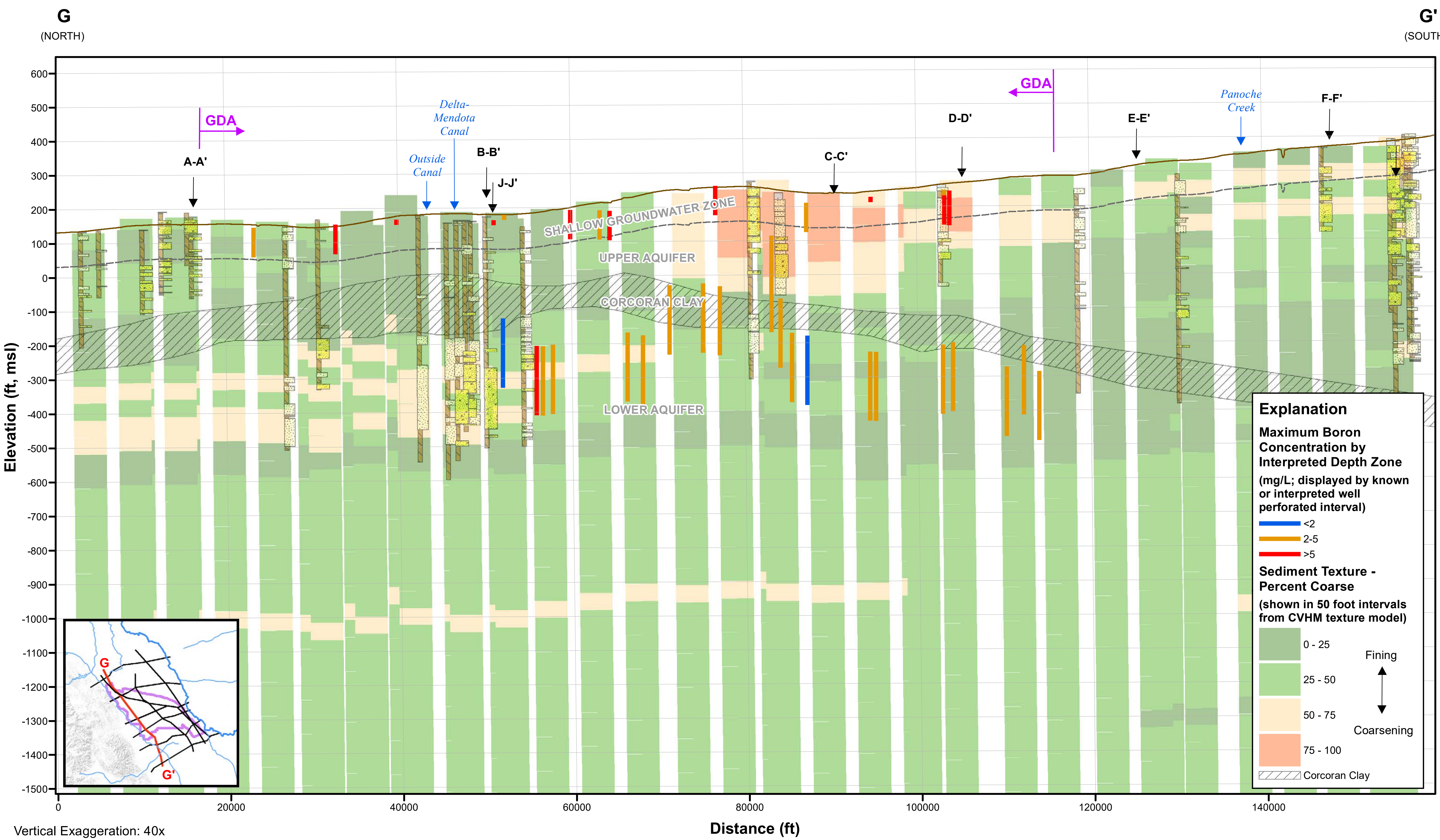
FIGURE 6-20

Boron Concentrations by Depth Along Geologic Cross-Section D-D'



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-21 Boron Concentrations by Depth Along Cross Section G.mxd

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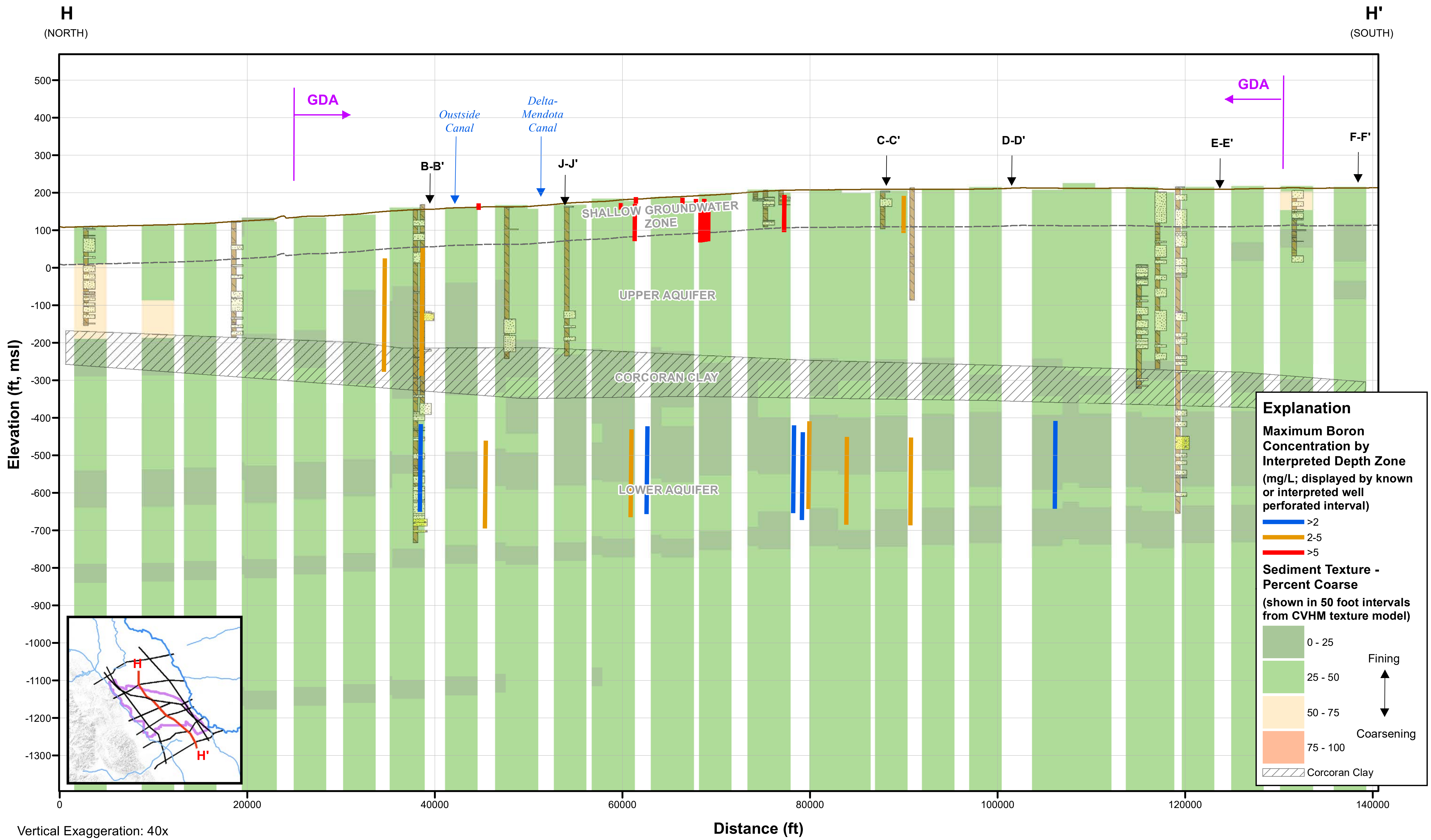
FIGURE 6-21

Boron Concentrations by Depth Along Geologic Cross-Section G-G'

Grassland Drainage Area
Groundwater Quality Assessment Report



Vertical Exaggeration: 40x

X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-22 Boron Concentrations by Depth Along Cross Section H.mxd

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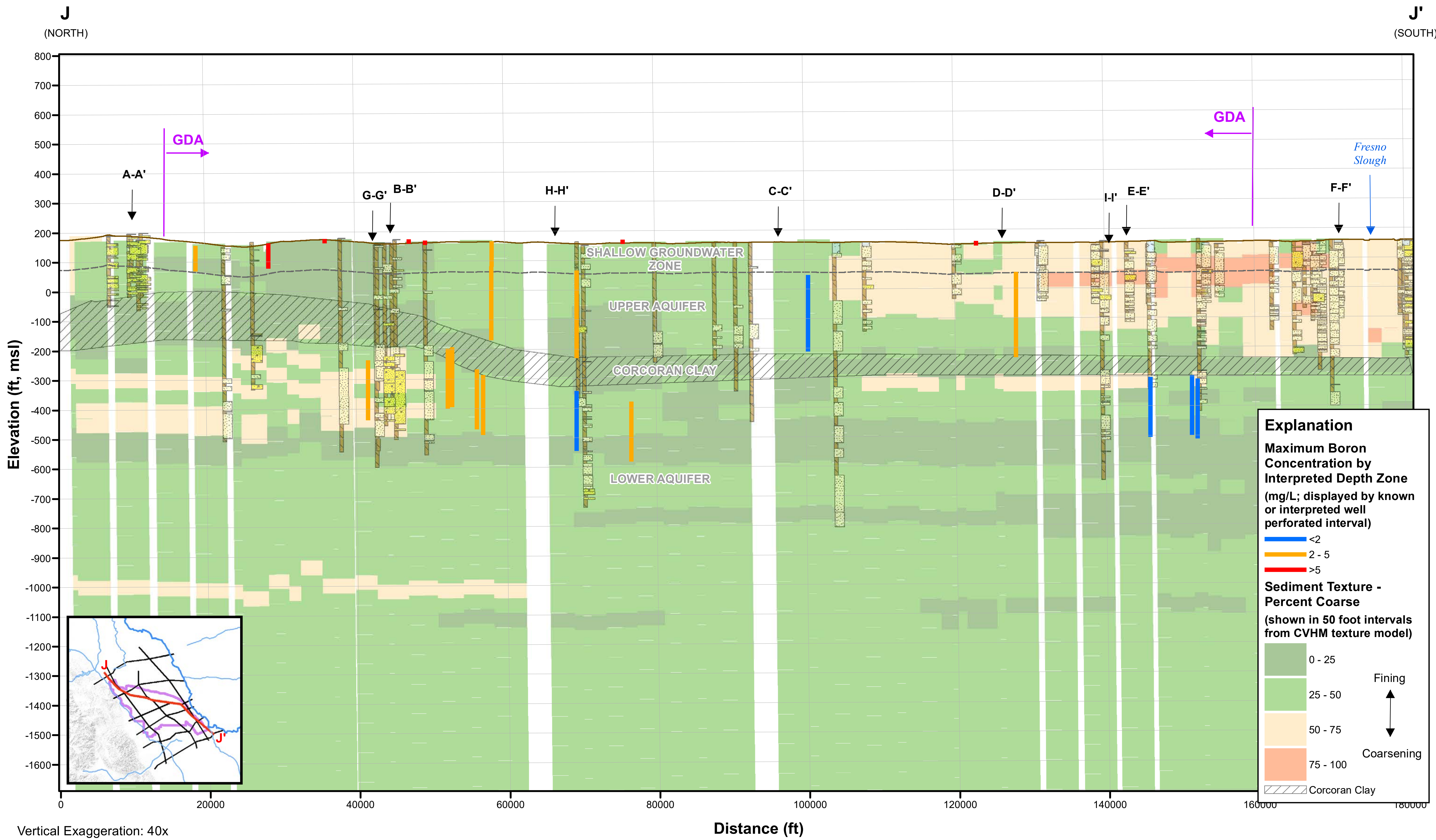
FIGURE 6-22

Boron Concentrations by Depth Along Geologic Cross-Section H-H'

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-23 Boron Concentrations by Depth Along Cross Section J.mxd

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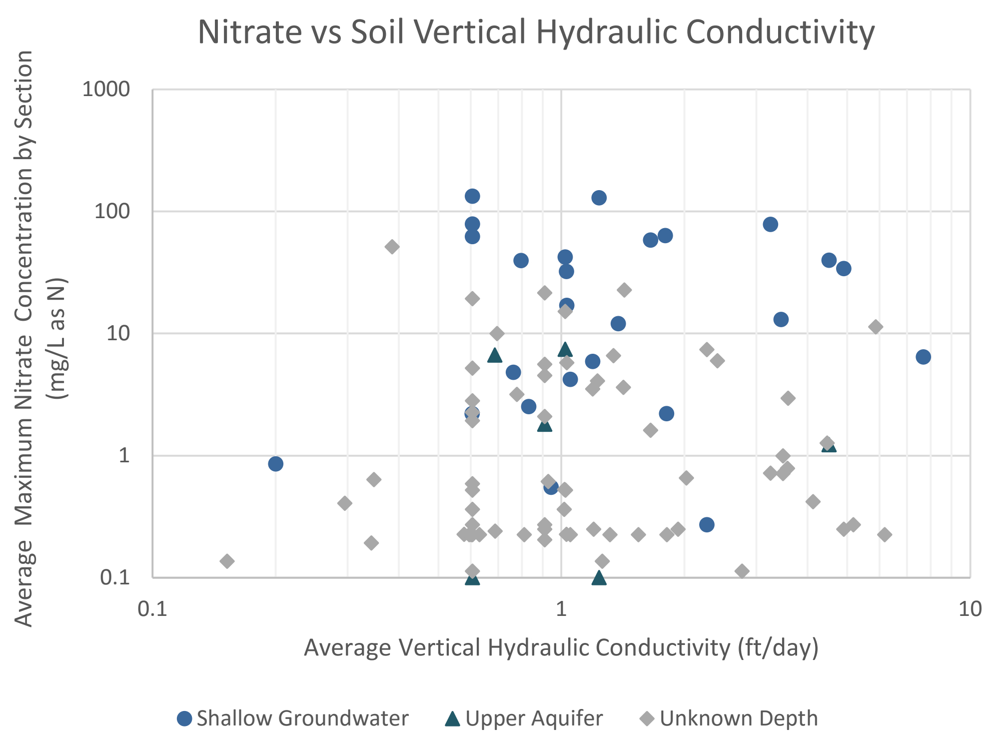
FIGURE 6-23

Boron Concentrations by Depth Along Geologic Cross-Section J-J'

Grassland Drainage Area
Groundwater Quality Assessment Report

a.



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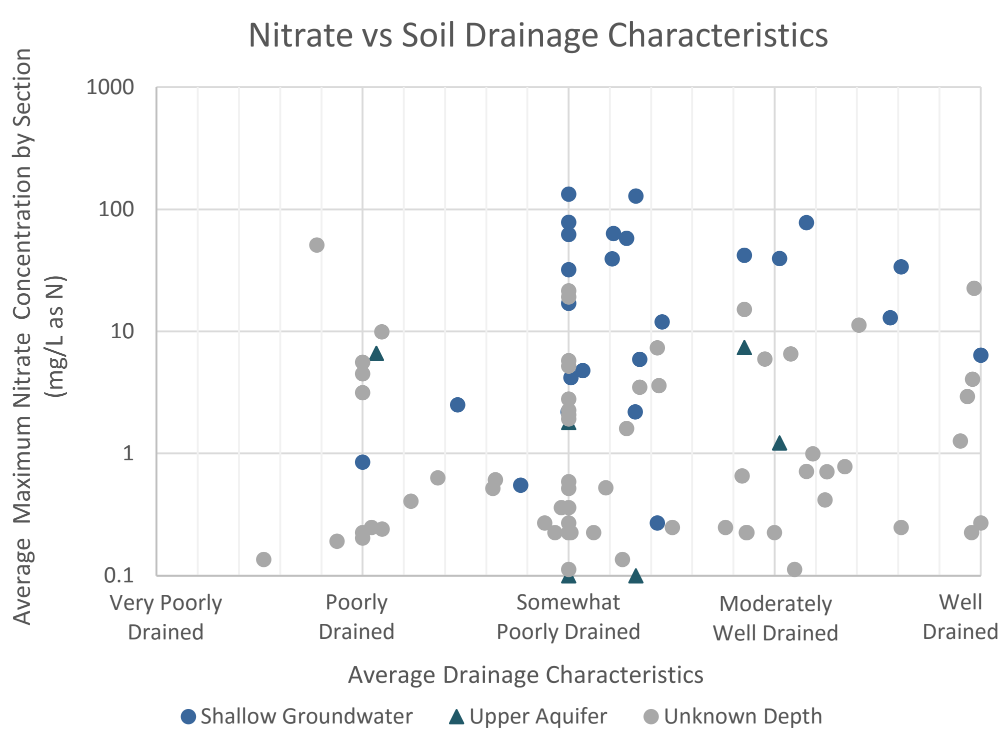

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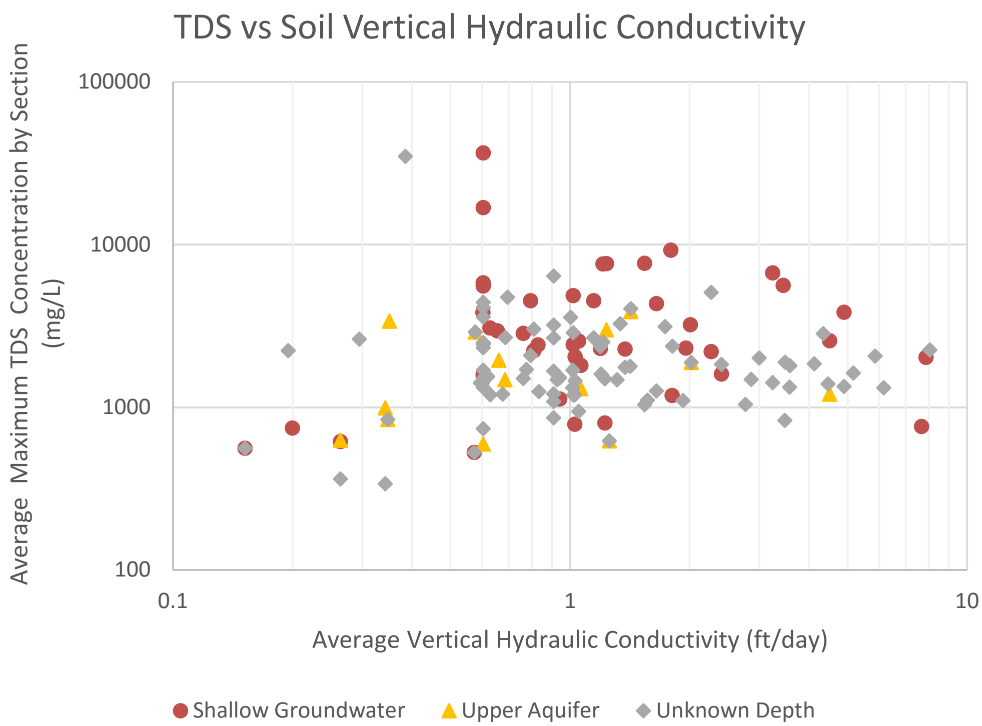
FIGURE 6-24
Comparisons of Nitrate Concentrations and Soil Characteristics

Grassland Drainage Area
Groundwater Quality Assessment Report

a.



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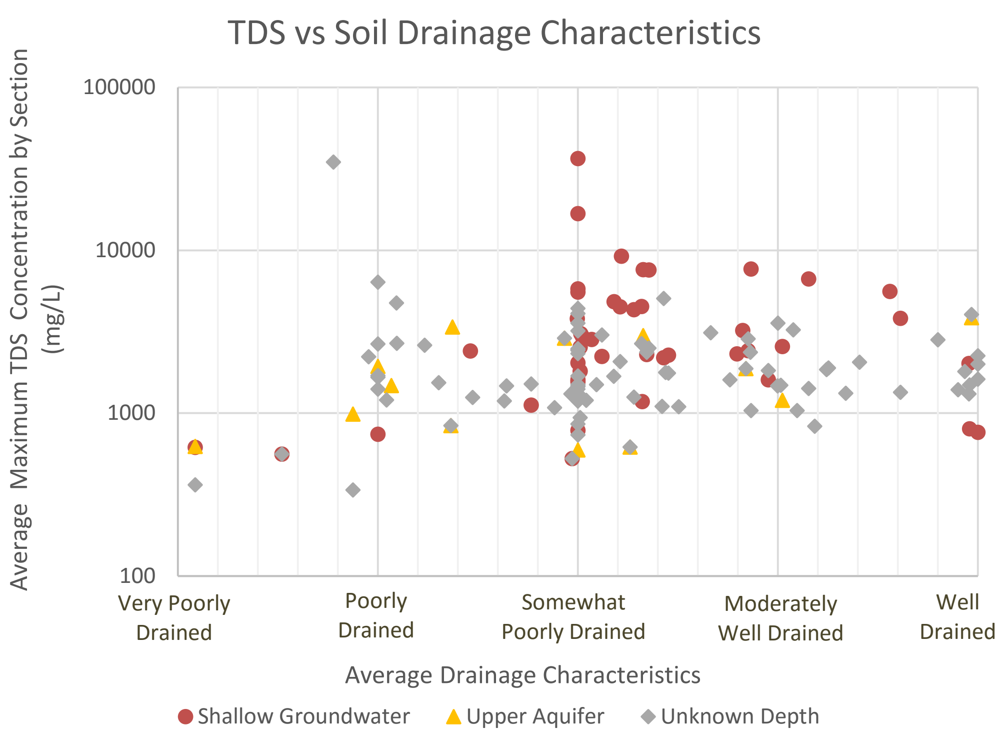

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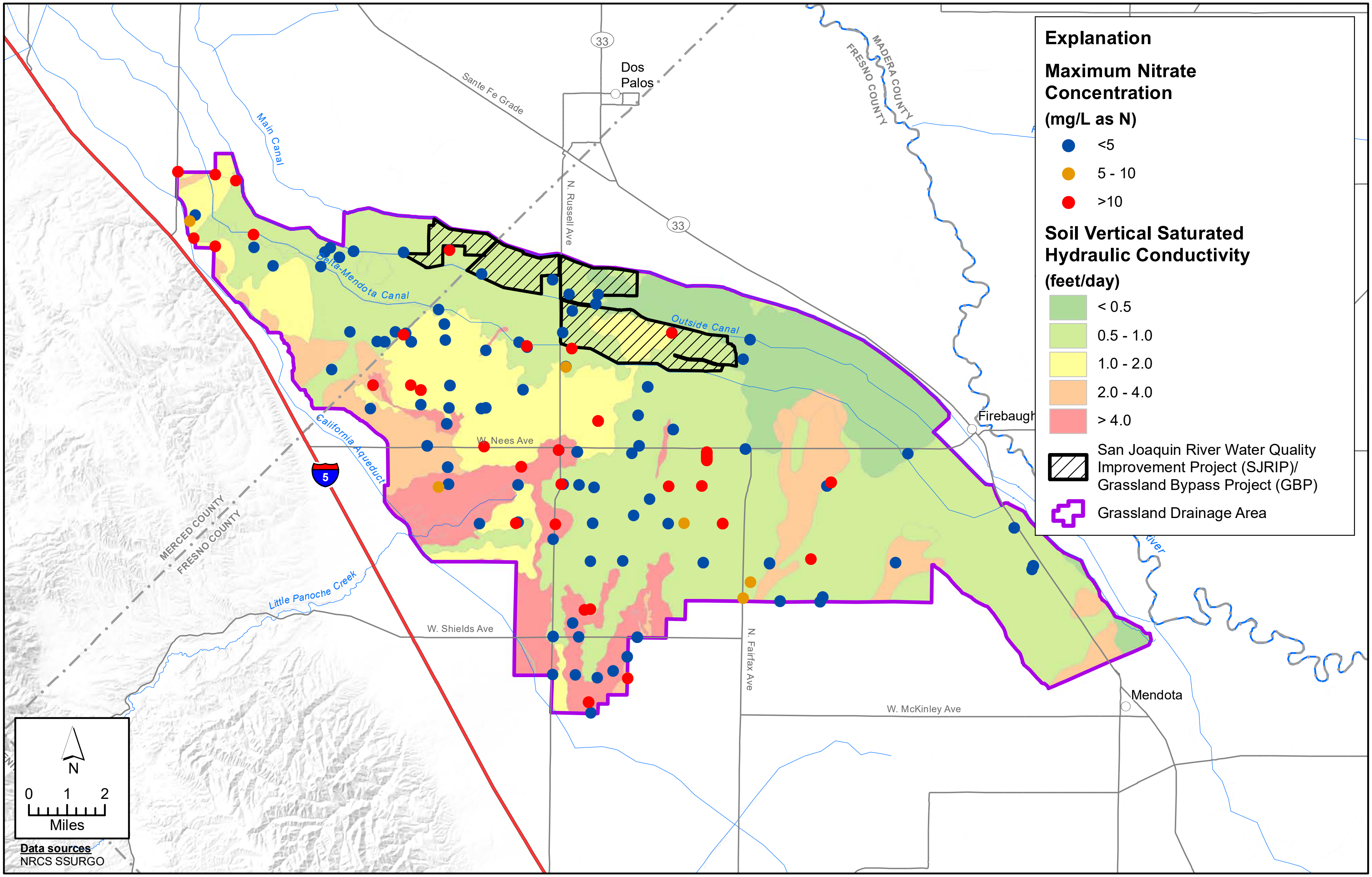
FIGURE 6-25
Comparisons of TDS Concentrations and Soil Characteristics

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-26 Map of Nitrate Concentrations with Soil Hydraulic Conductivity.mxd

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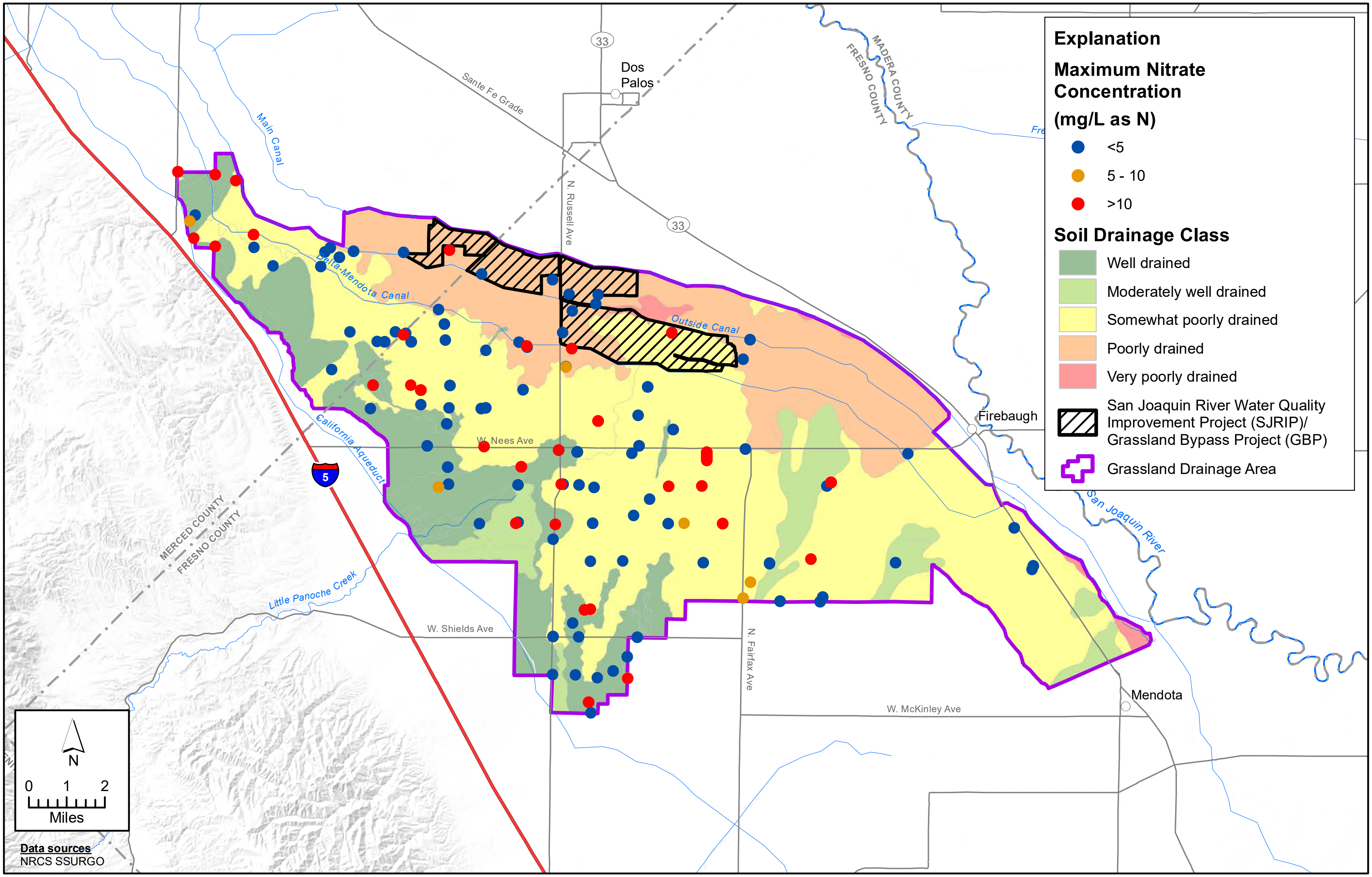
FIGURE 6-26
Map of Soil Hydraulic Conductivity With Nitrate Concentrations (Not Including Very Shallow Water Data)
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-27 Map of Nitrate Concentrations with Soil Drainage Characteristics.mxd

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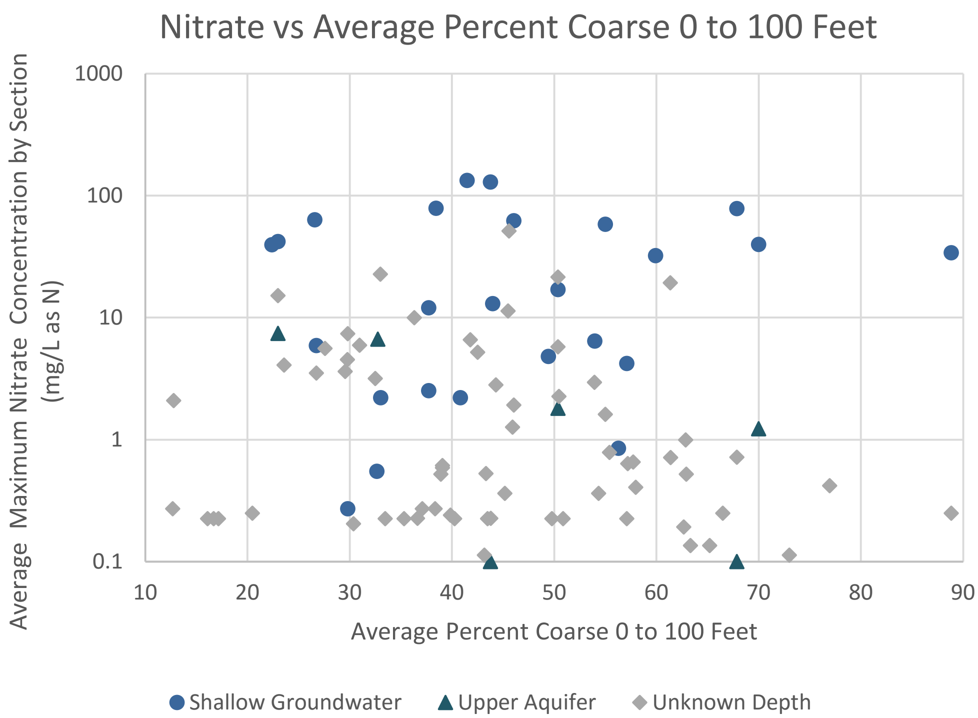
FIGURE 6-27
Map of Soil Drainage Characteristics With Nitrate Concentrations (Not Including Very Shallow Water Data)
Grassland Drainage Area
Groundwater Quality Assessment Report

a.



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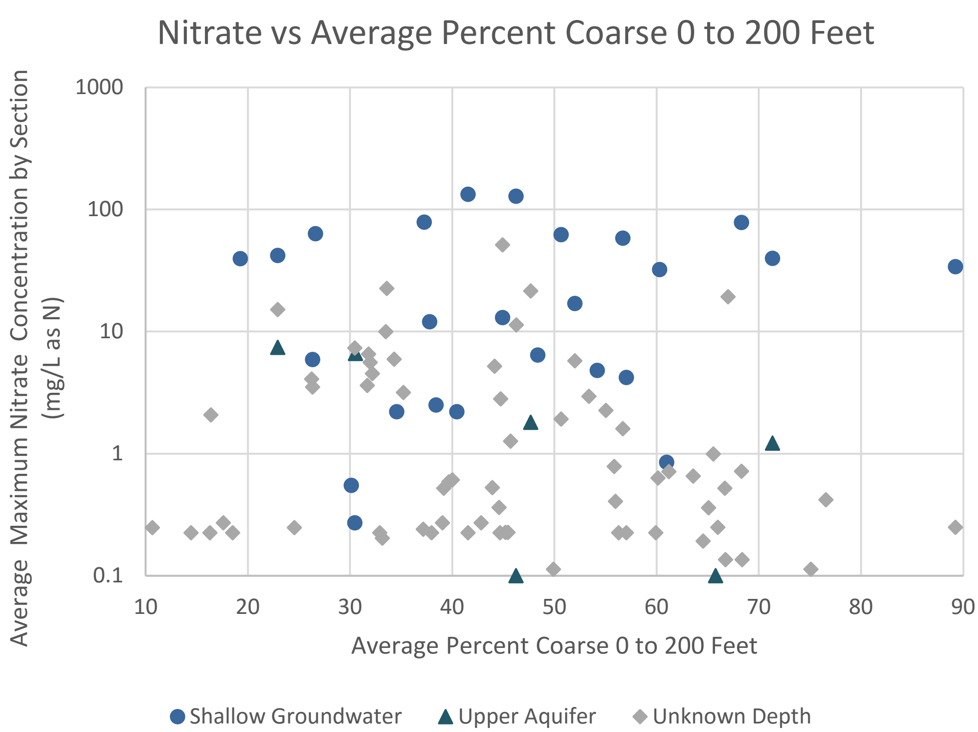

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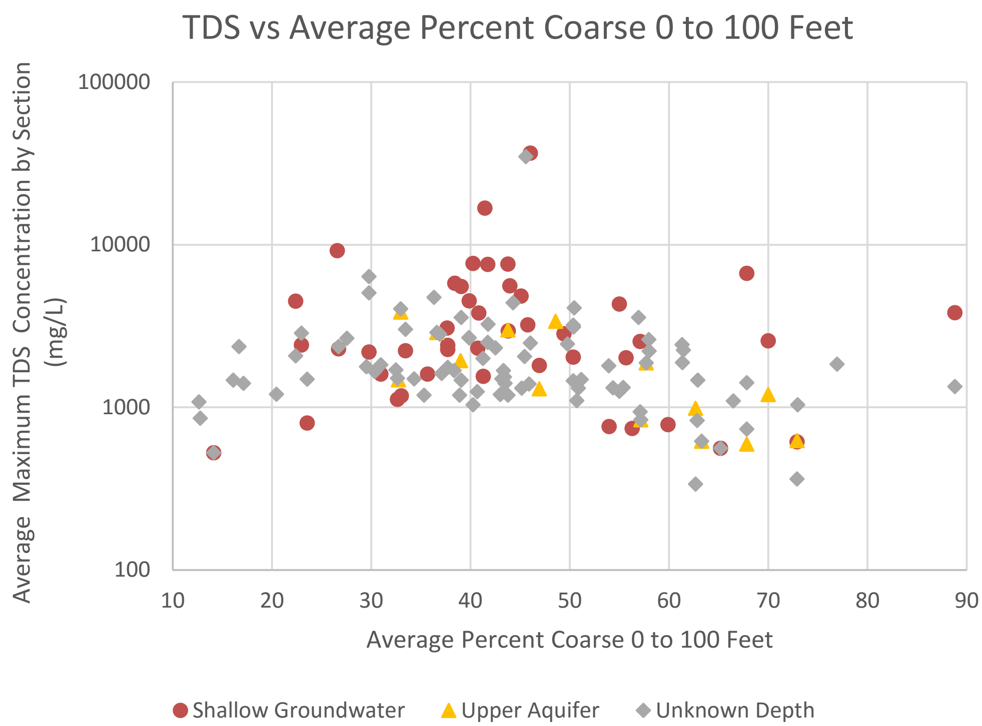
FIGURE 6-28
Comparisons of Nitrate Concentrations and Subsurface Sediment Texture

Grassland Drainage Area
Groundwater Quality Assessment Report

a.



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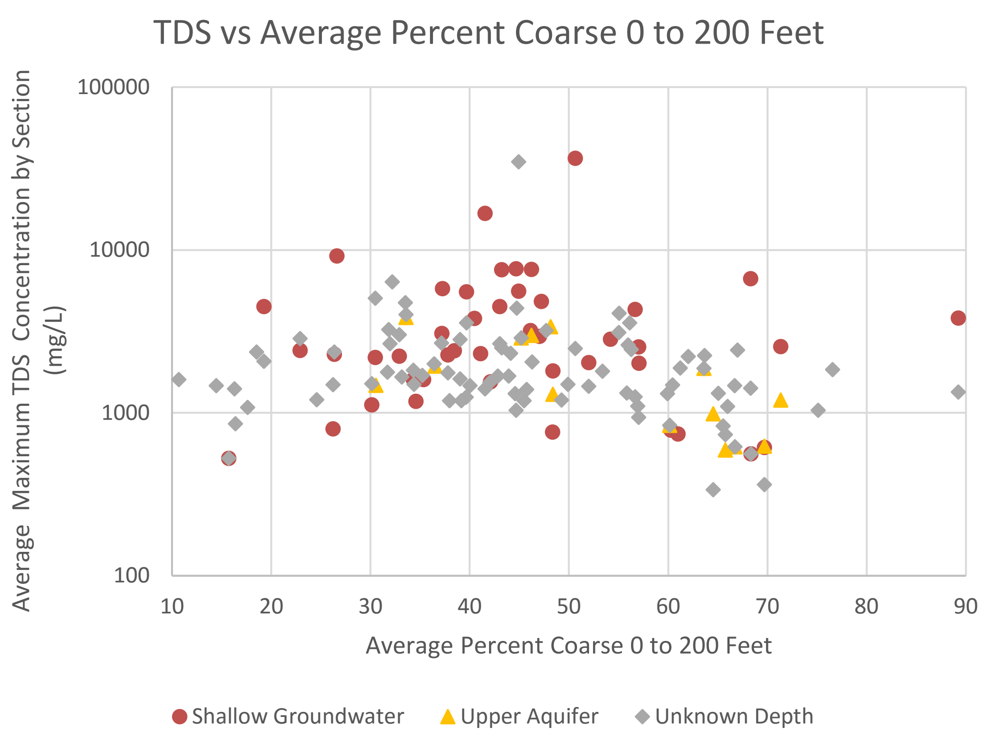

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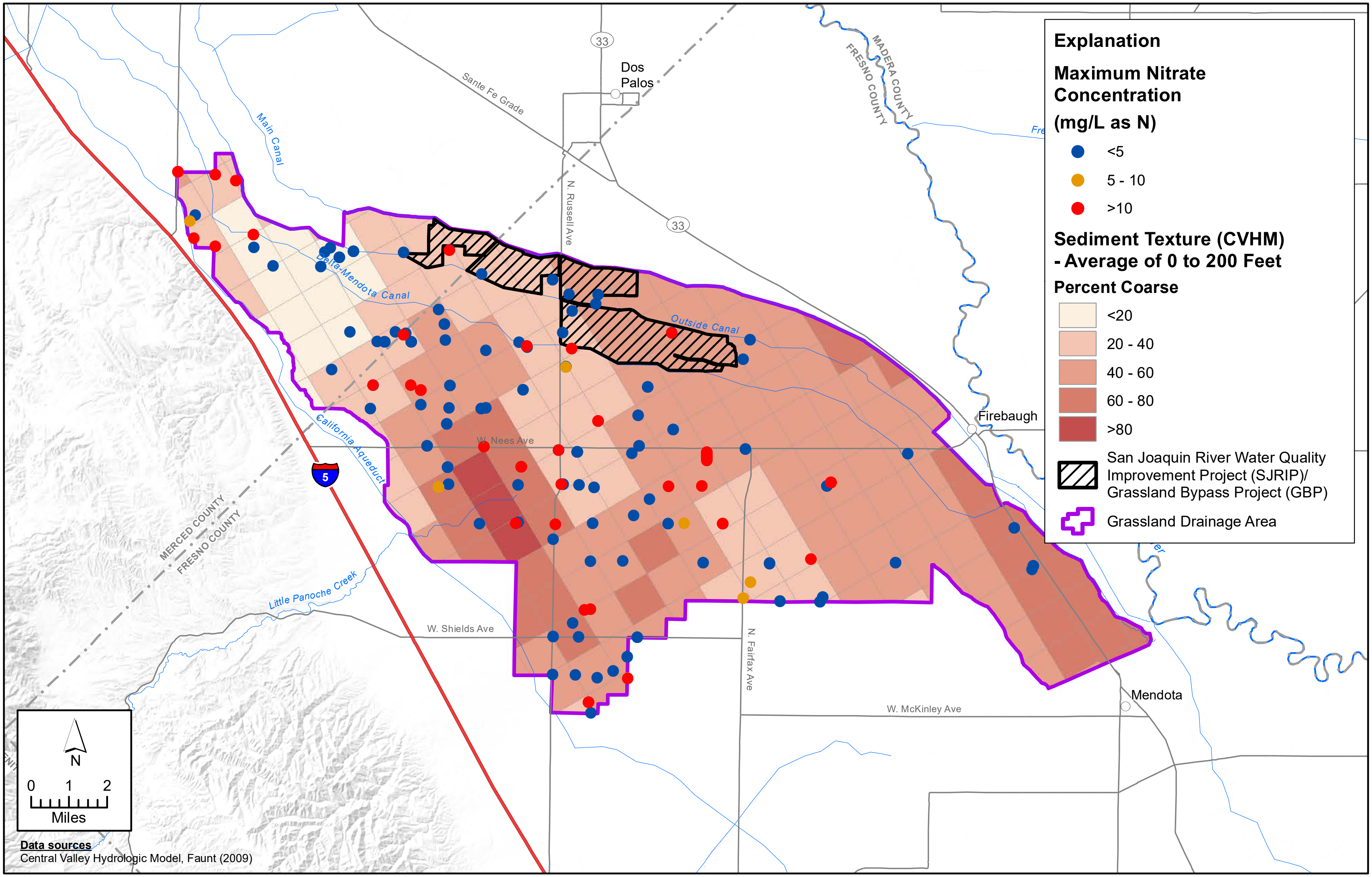
FIGURE 6-29
Comparisons of TDS Concentrations and CVHM Sediment Texture

Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-30 Map of Nitrate Concentrations with CVHM Sediment Texture.mxd

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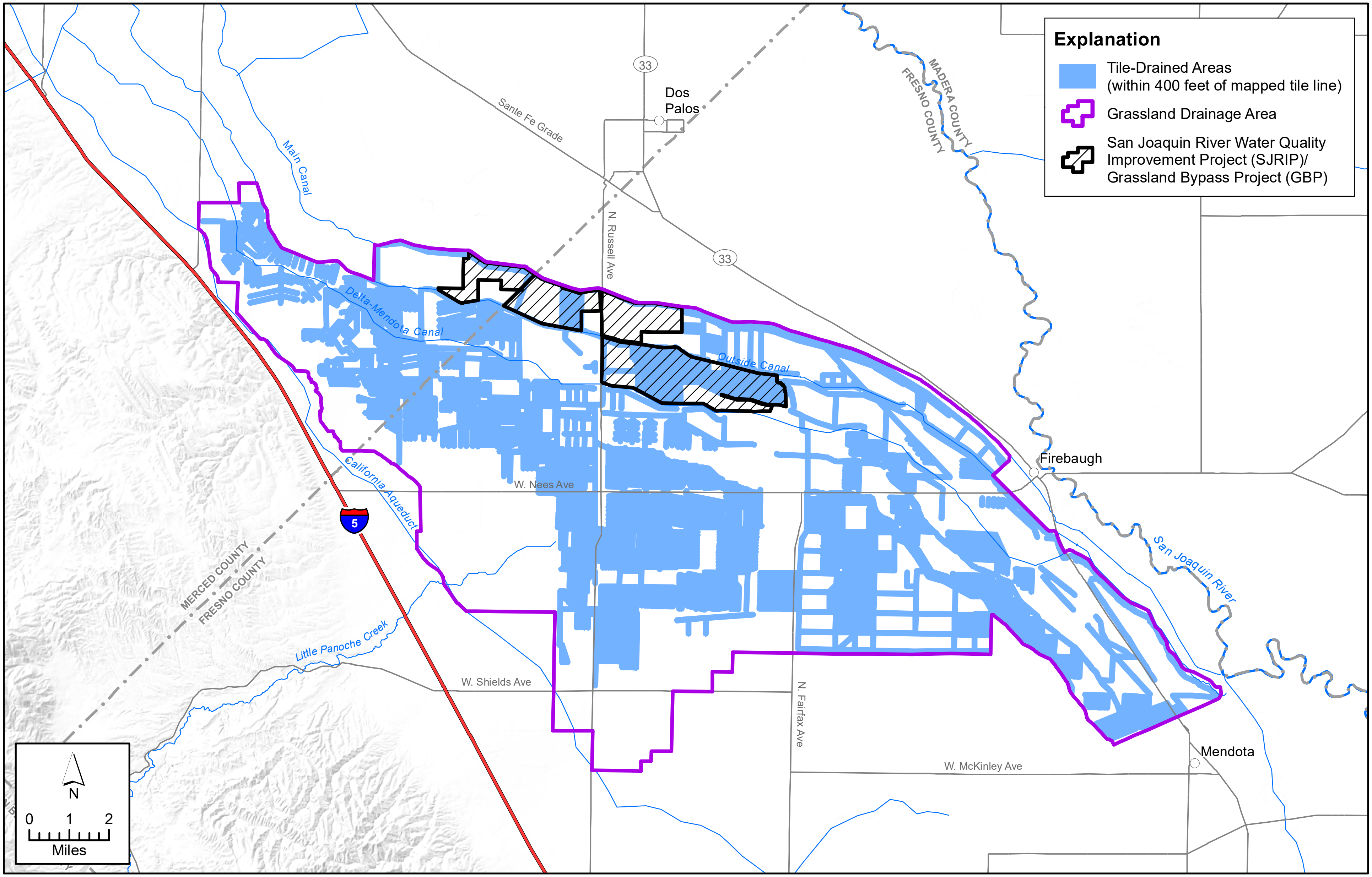
FIGURE 6-30
Map of Subsurface Sediment Texture With Nitrate Concentrations (Not Including Very Shallow Data)
Grassland Drainage Area
Groundwater Quality Assessment Report



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-31 Map of Tile Drained Areas.mxd

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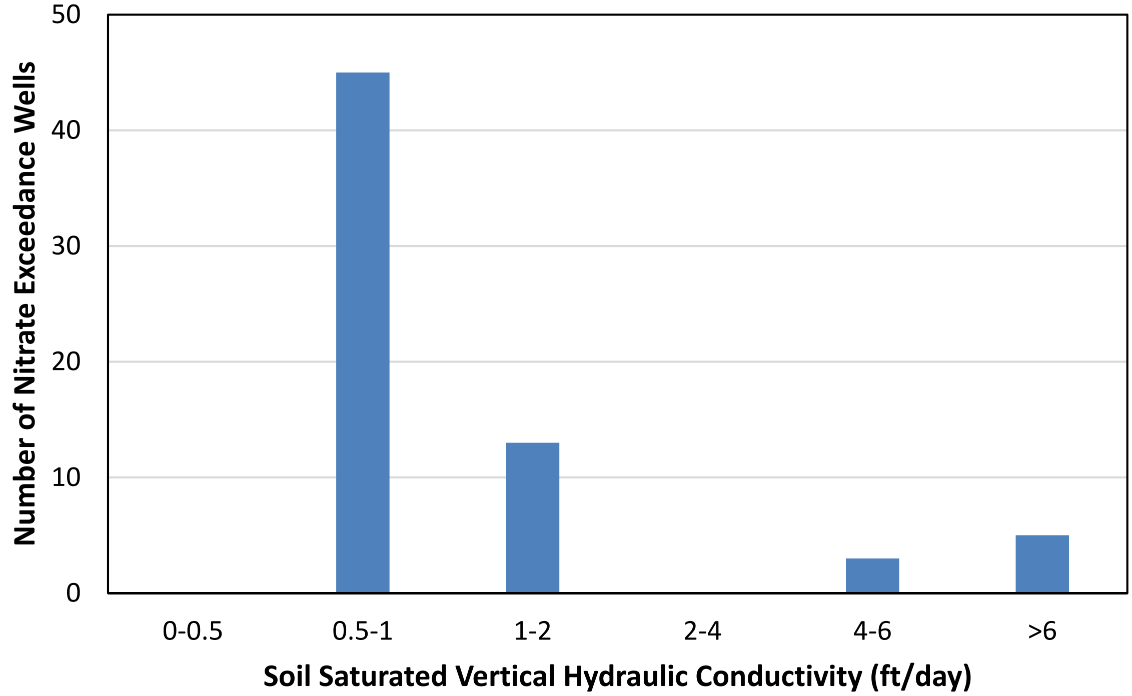
FIGURE 6-31

Map of Areas With Subsurface Tile Drains

Grassland Drainage Area
Groundwater Quality Assessment Report

a.



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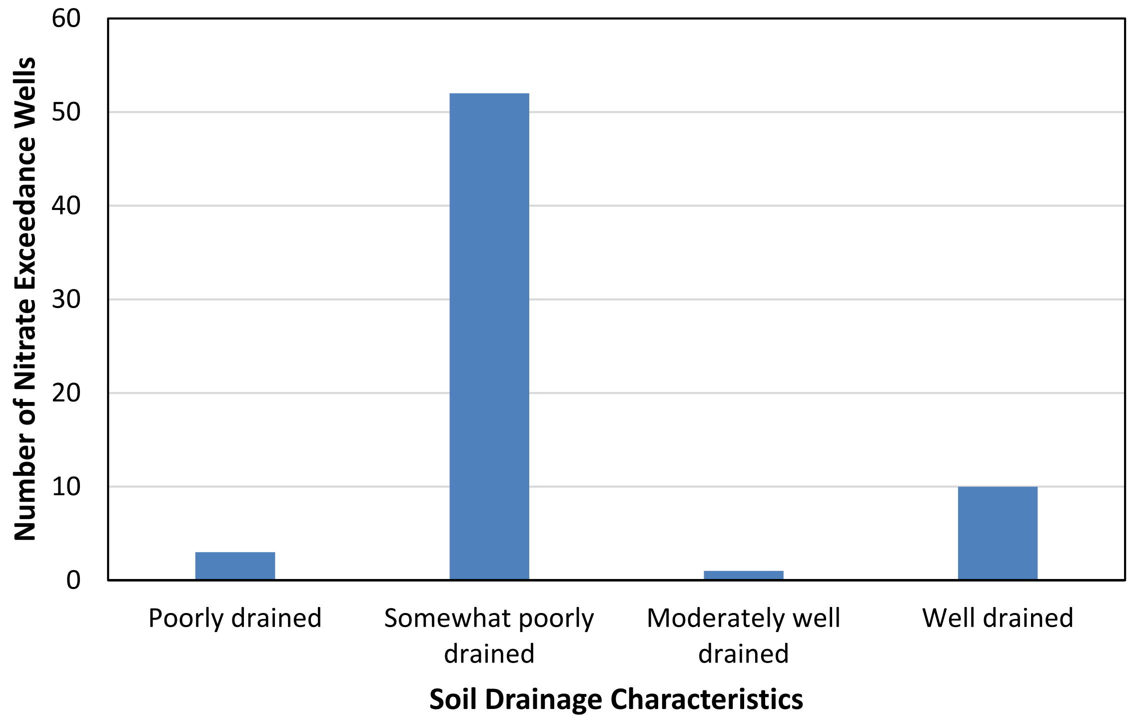

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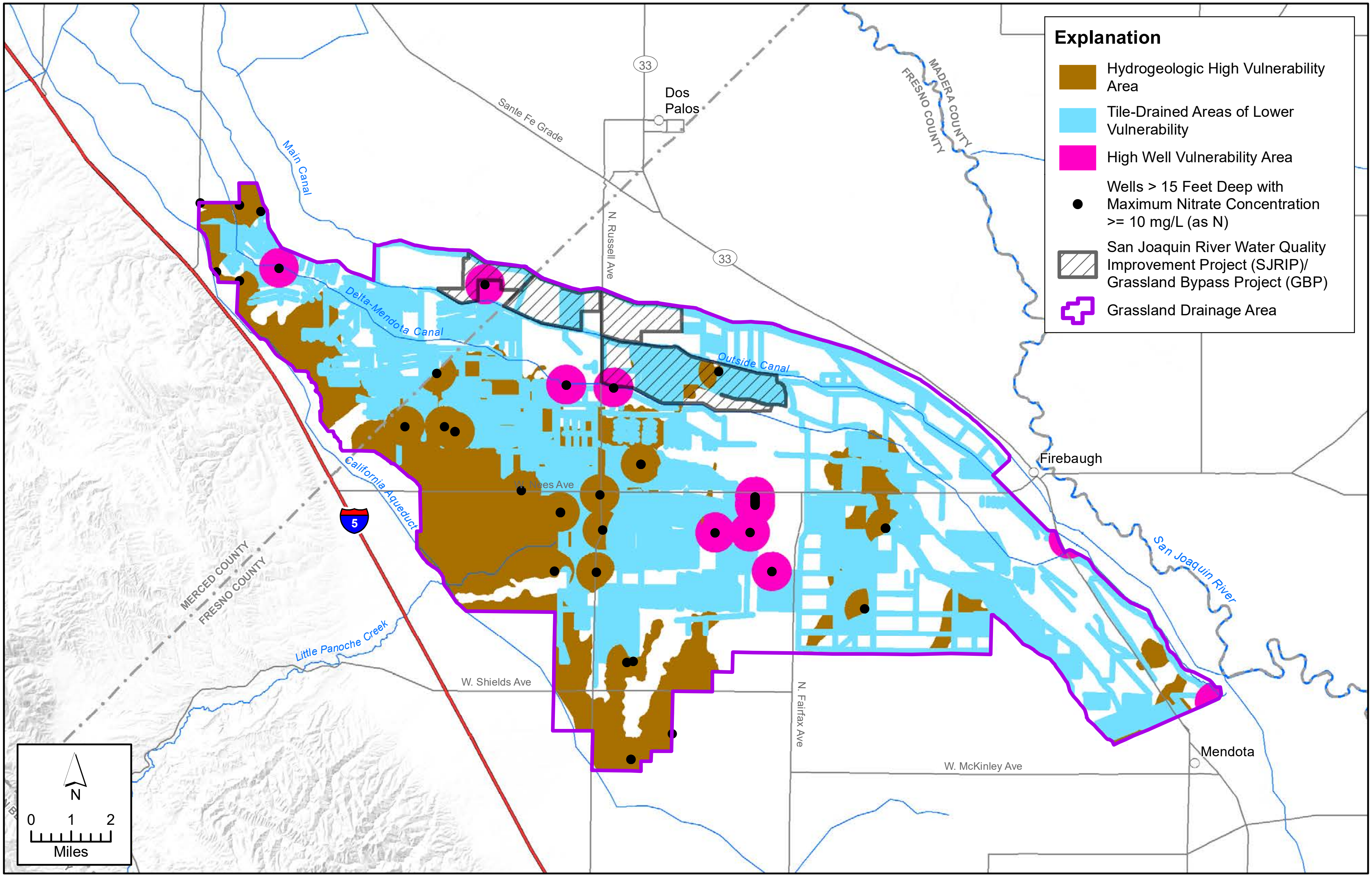
FIGURE 6-32
Nitrate Exceedance Wells in Relation to Soil Characteristics



X:\2015 Job Files\15-093 Grasslands - GAR\GIS_grasslands\Figures\Figure 6-33 High Vulnerability Area Components.mxd

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FIGURE 6-33

Map of High Vulnerability Area Components

Grassland Drainage Area
Groundwater Quality Assessment Report

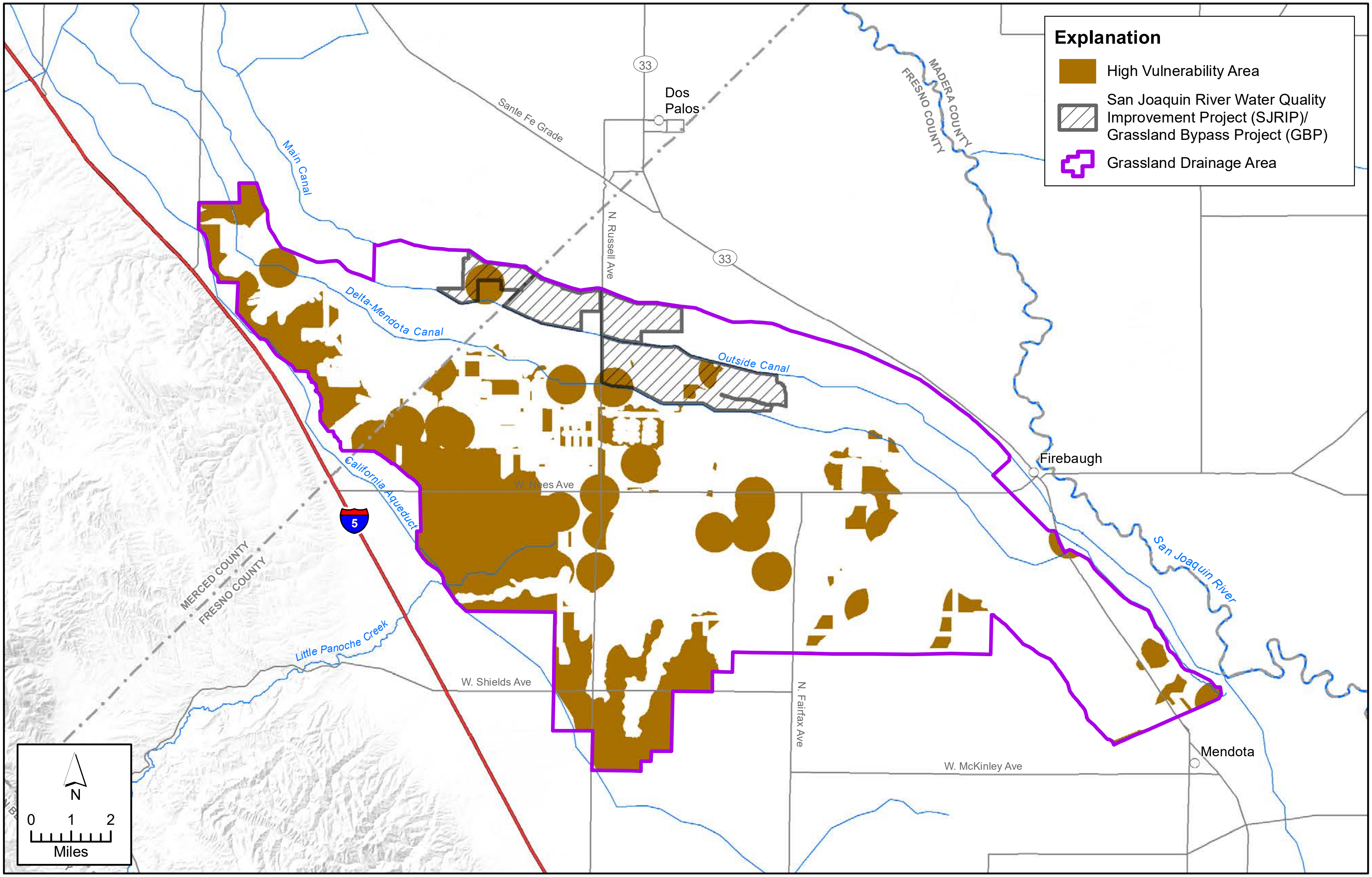

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FIGURE 6-34

Map of GDA High Vulnerability Area

Grassland Drainage Area
Groundwater Quality Assessment Report

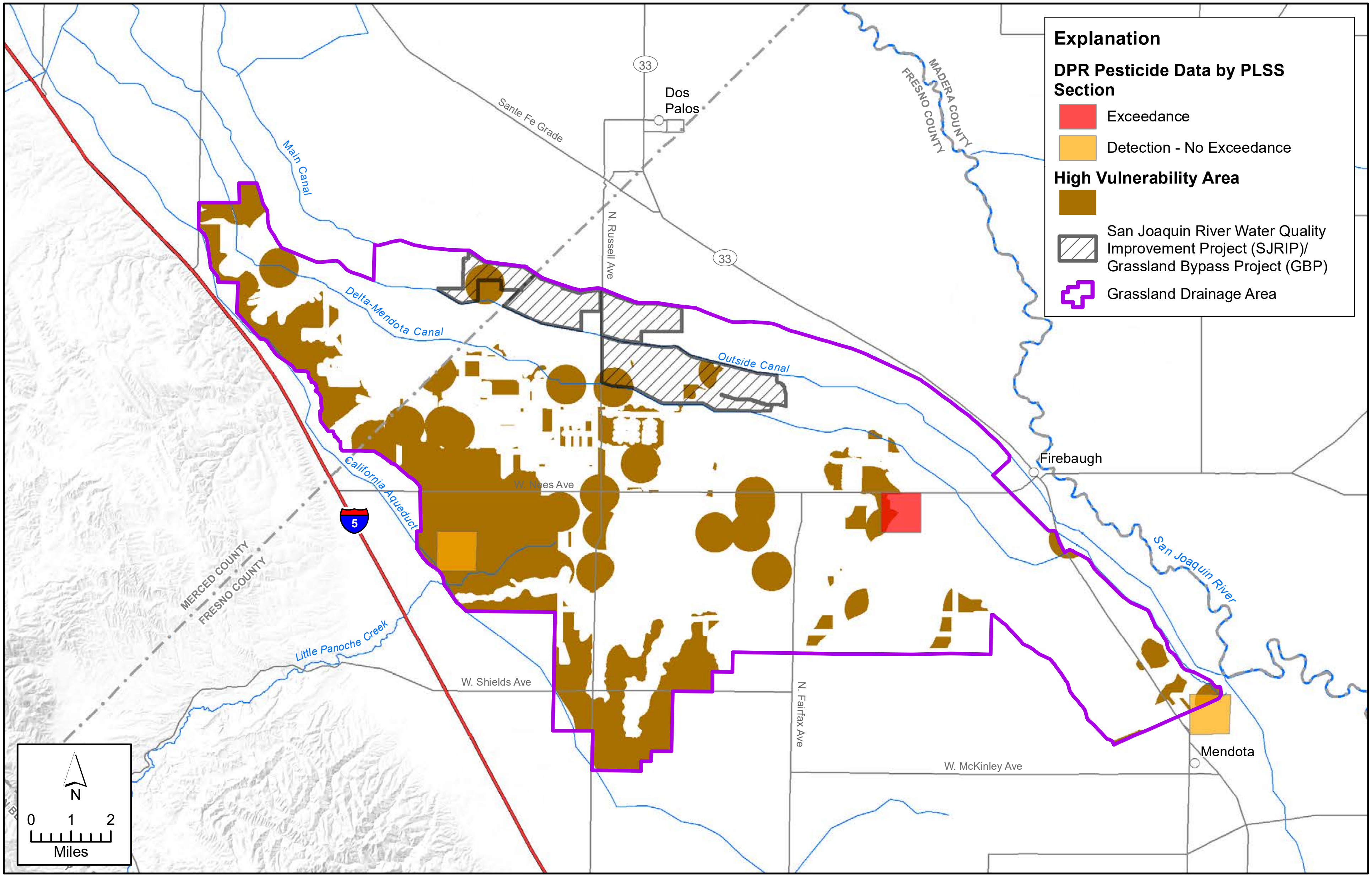

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FIGURE 6-35
Map of High Vulnerability Area With Pesticide Detections and Exceedances
Grassland Drainage Area
Groundwater Quality Assessment Report

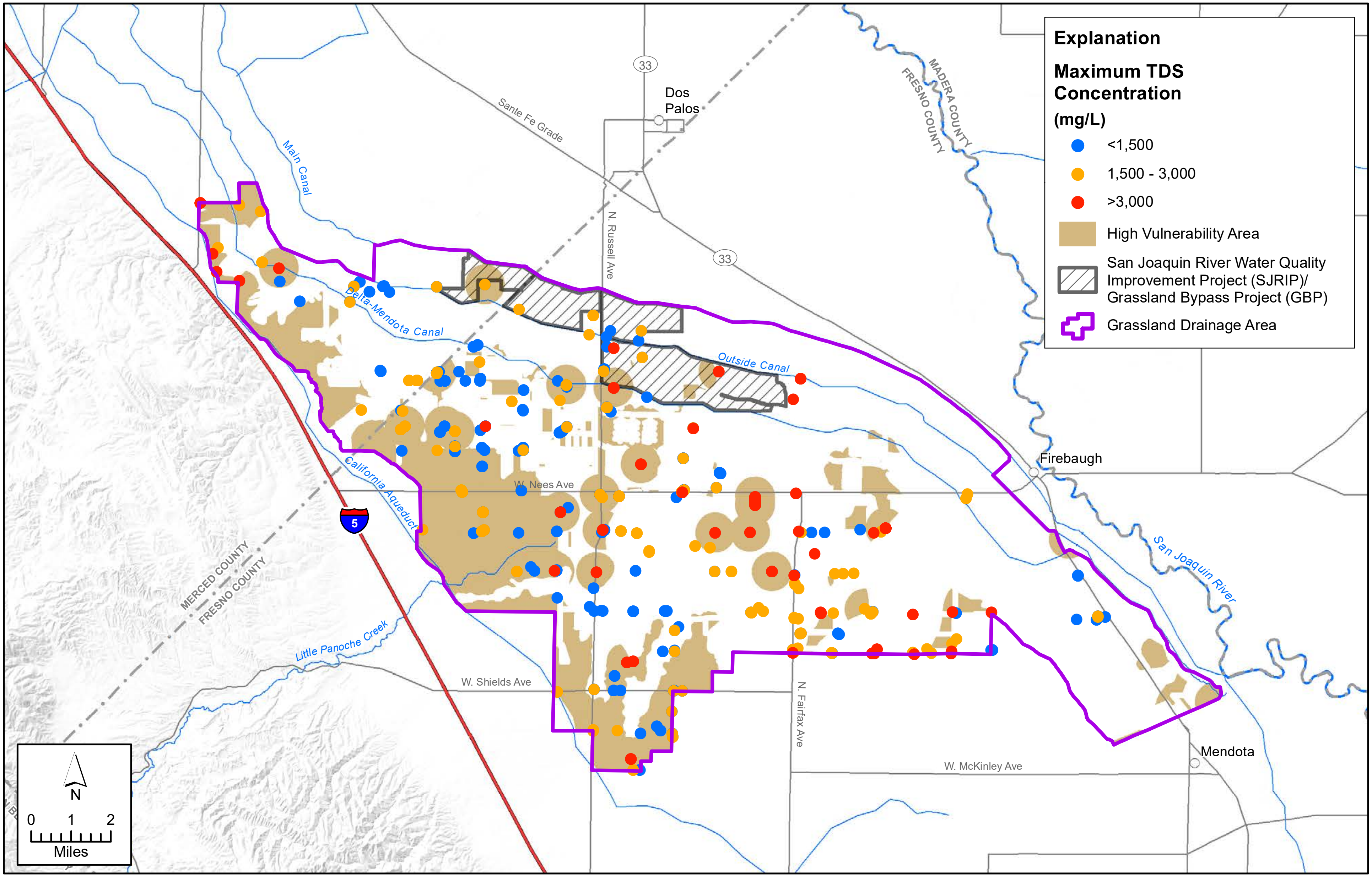

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FIGURE 6-36
Map of High Vulnerability Area With TDS Concentrations

Grassland Drainage Area
Groundwater Quality Assessment Report

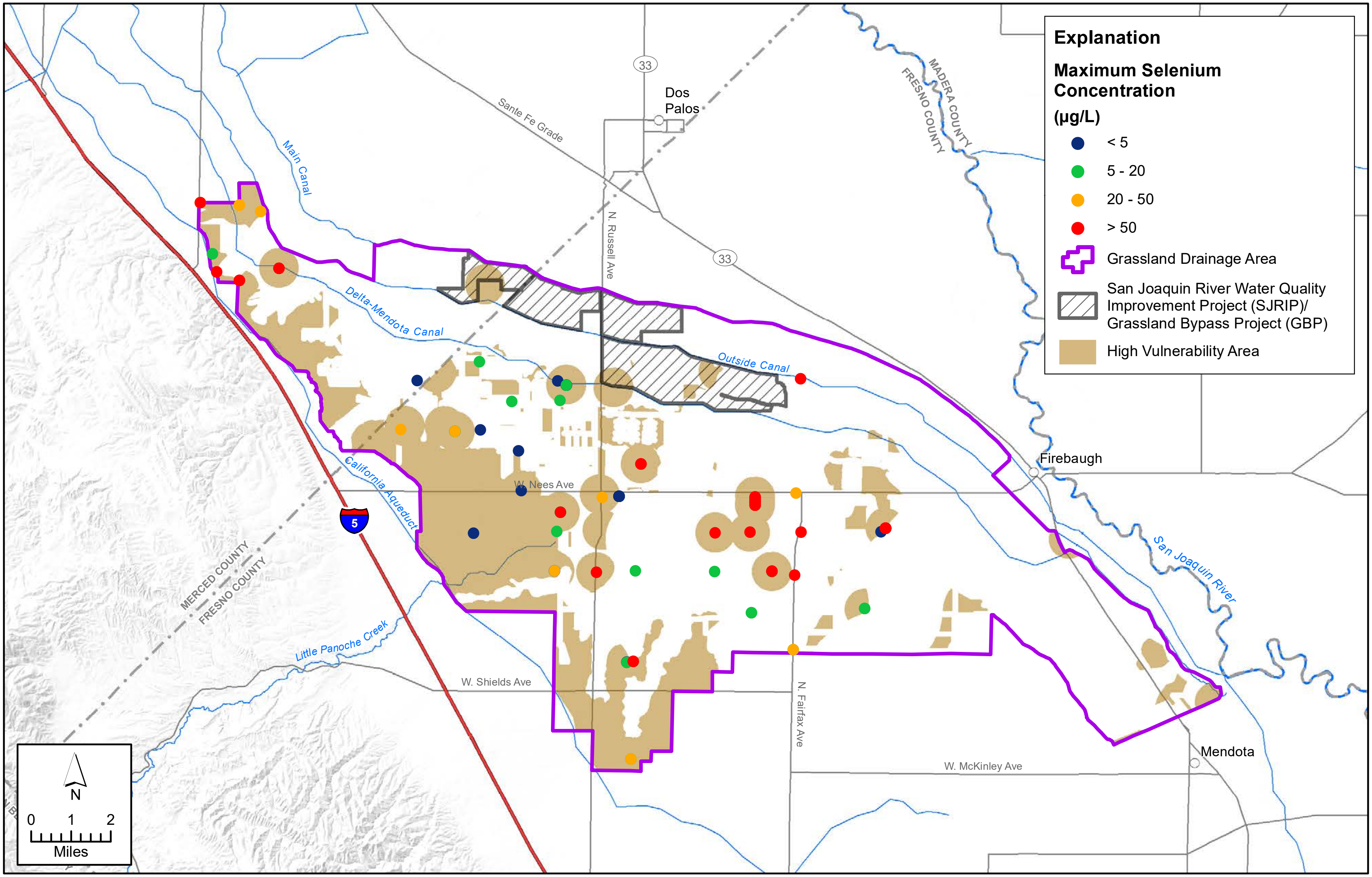

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FIGURE 6-37
Map of High Vulnerability Area With Selenium Concentrations
Grassland Drainage Area
Groundwater Quality Assessment Report

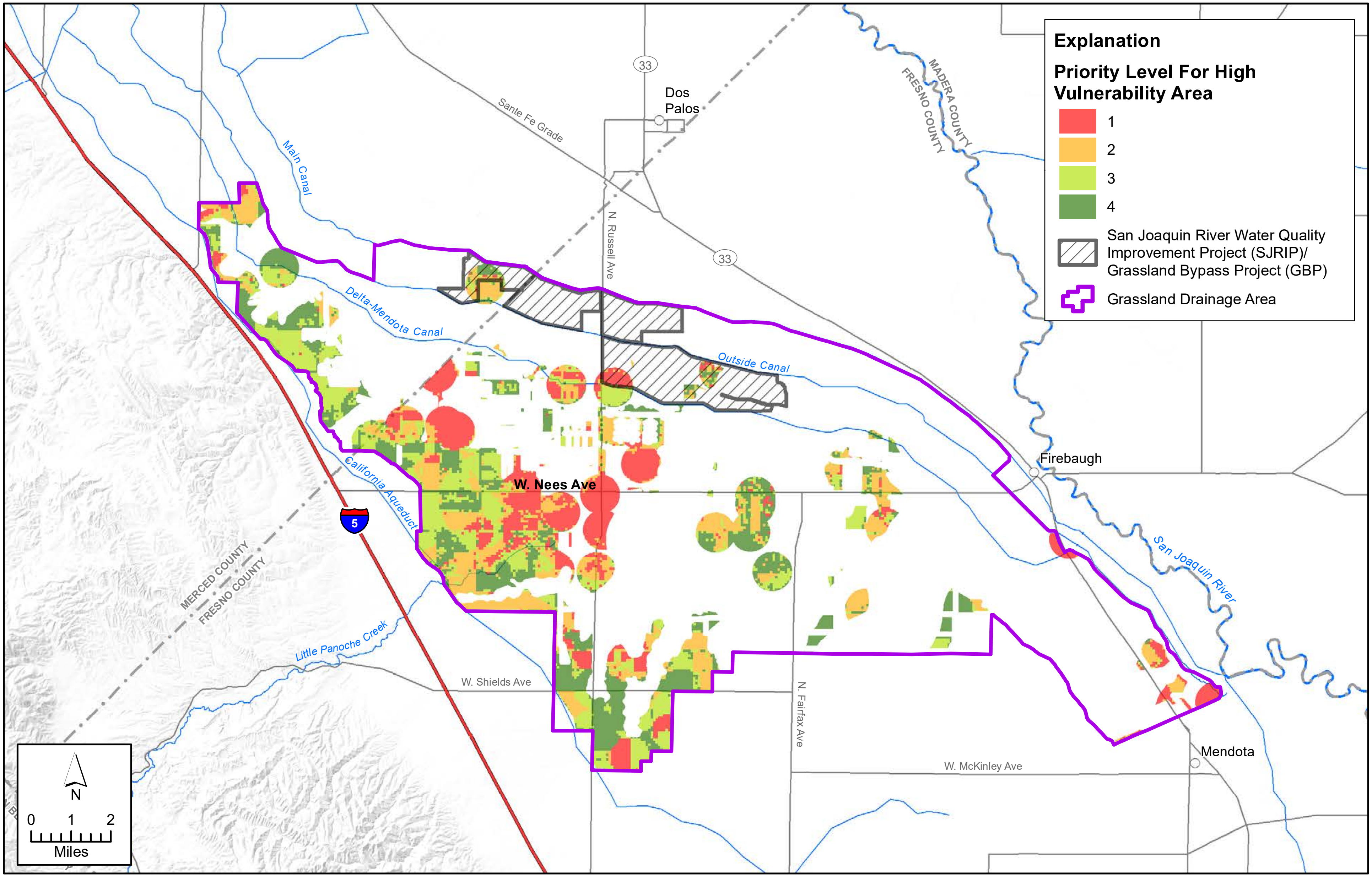

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FIGURE 6-38
Map of Prioritization of the GDA High Vulnerability Area
Grassland Drainage Area
Groundwater Quality Assessment Report

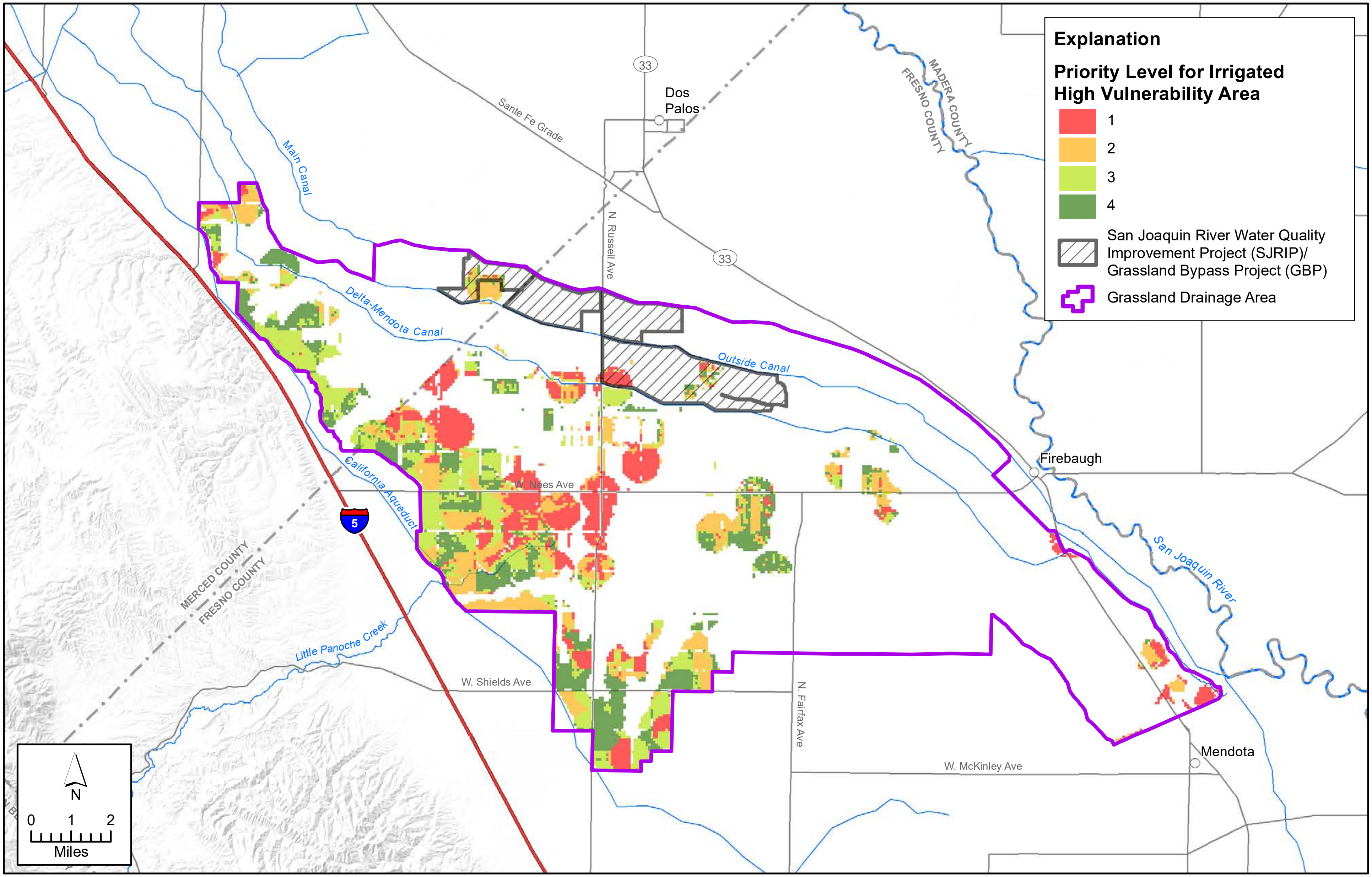

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FIGURE 6-39
Map of Priority Levels for the GDA High Vulnerability Area Within Irrigated Lands

Grassland Drainage Area
Groundwater Quality Assessment Report

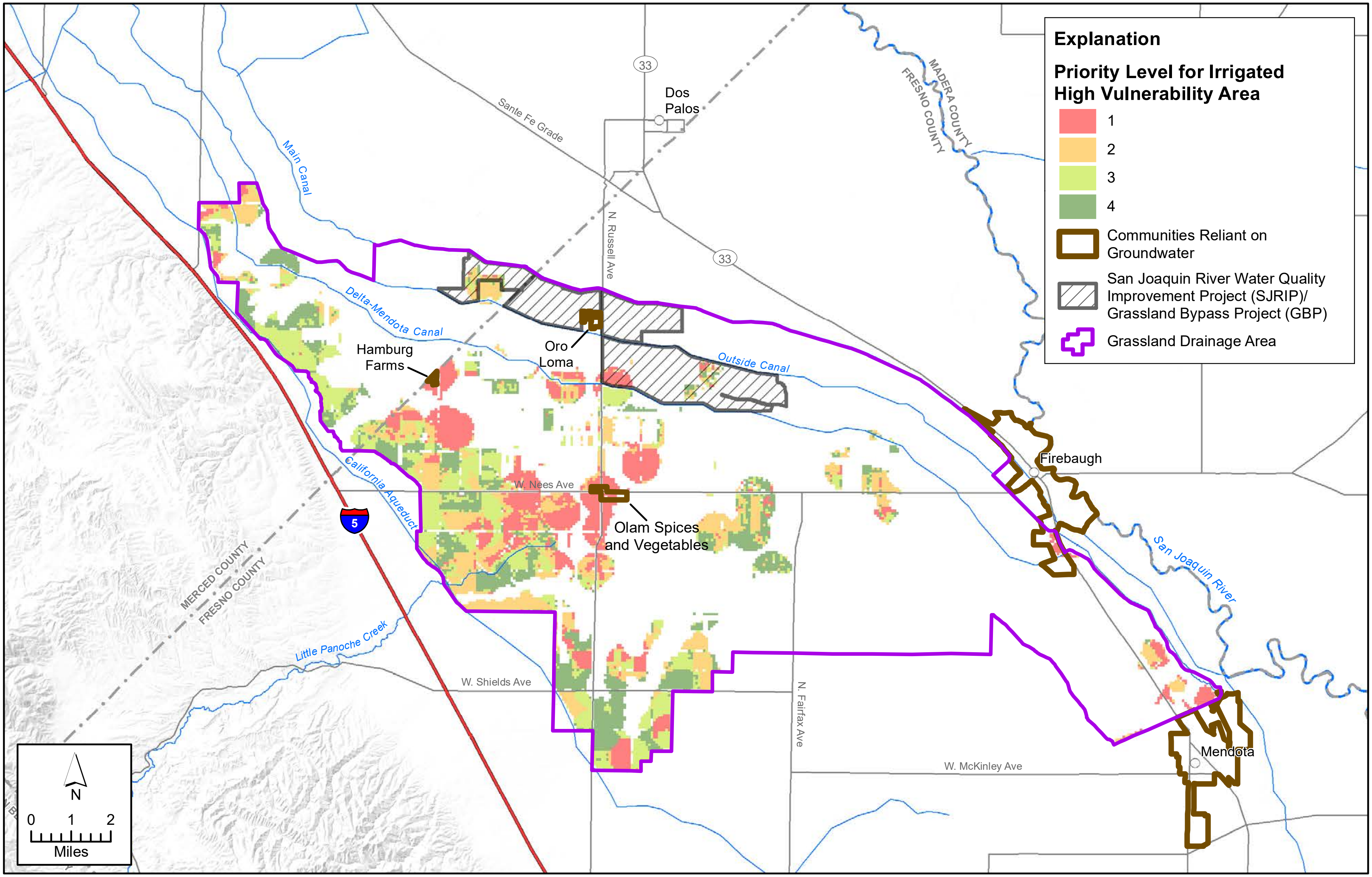

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FIGURE 6-40
Map of Communities Reliant on Groundwater Relative to Priority Areas
Grassland Drainage Area
Groundwater Quality Assessment Report

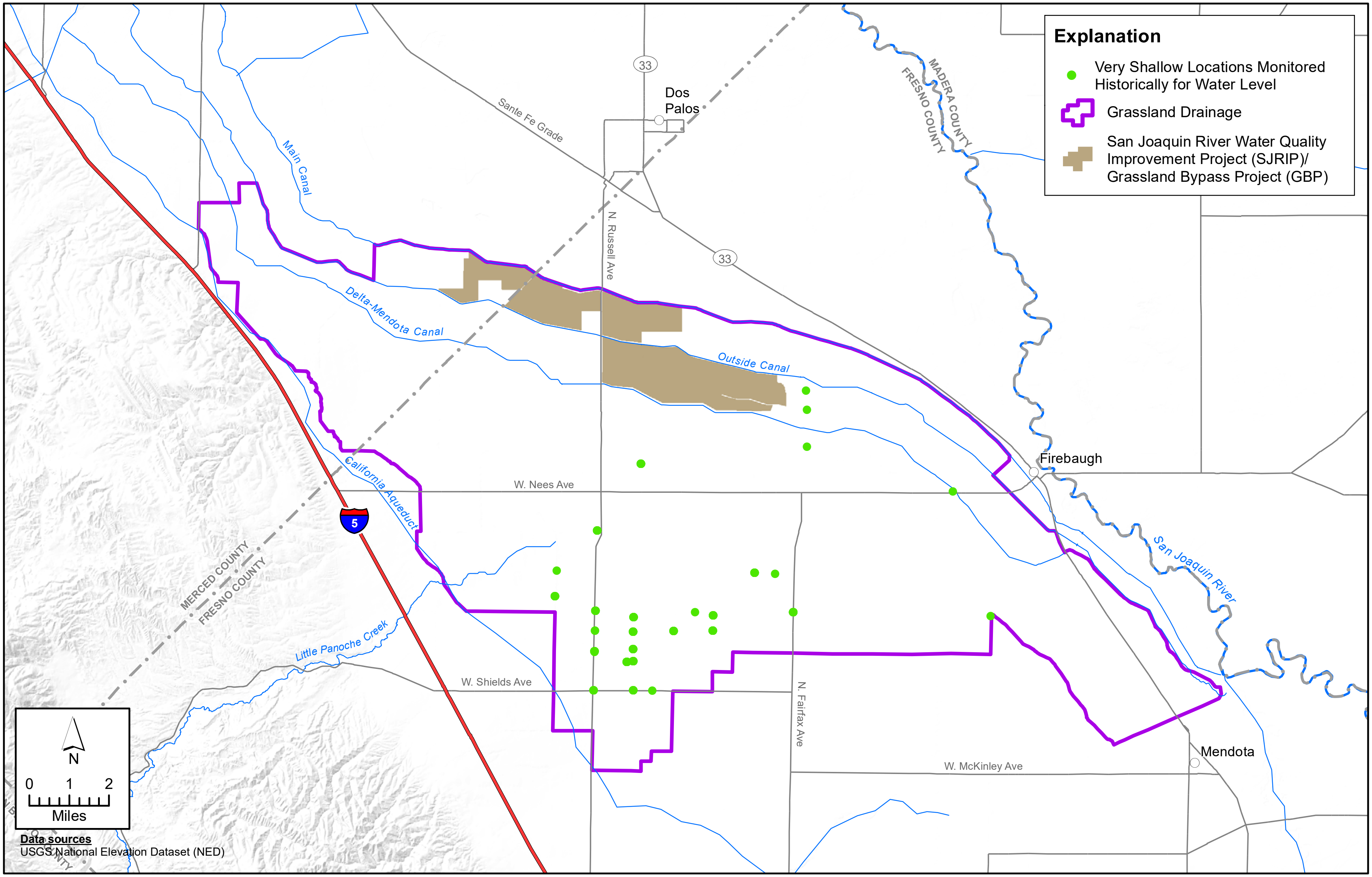

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FIGURE 7-1
Map of Locations Monitored Historically for Water Level: Very Shallow Water

Grassland Drainage Area
Groundwater Quality Assessment Report

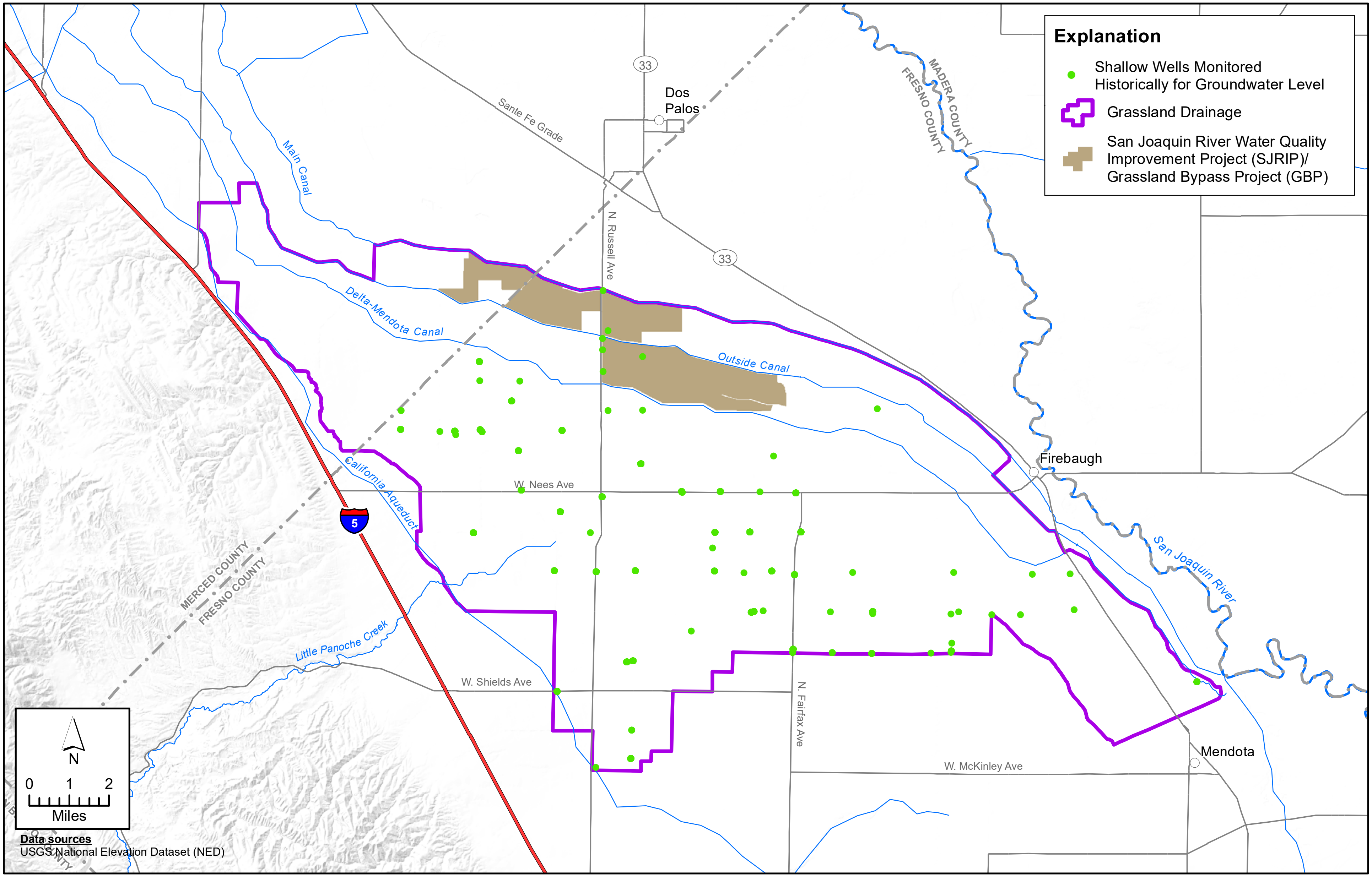

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FIGURE 7-2
Map of Wells Monitored Historically for Groundwater Level: Shallow Groundwater
Grassland Drainage Area
Groundwater Quality Assessment Report

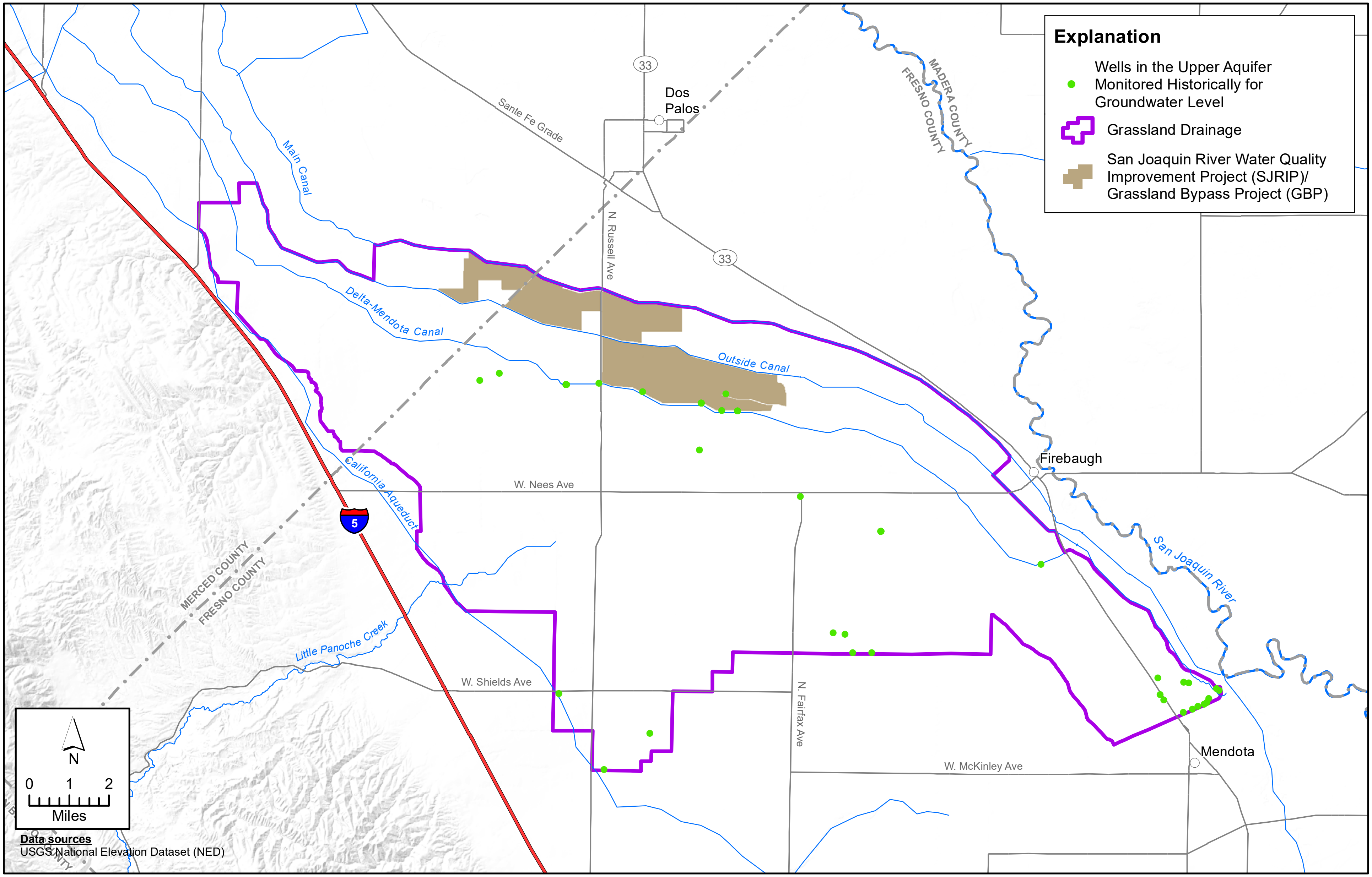

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FIGURE 7-3
Map of Wells Monitored Historically for Groundwater Level: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

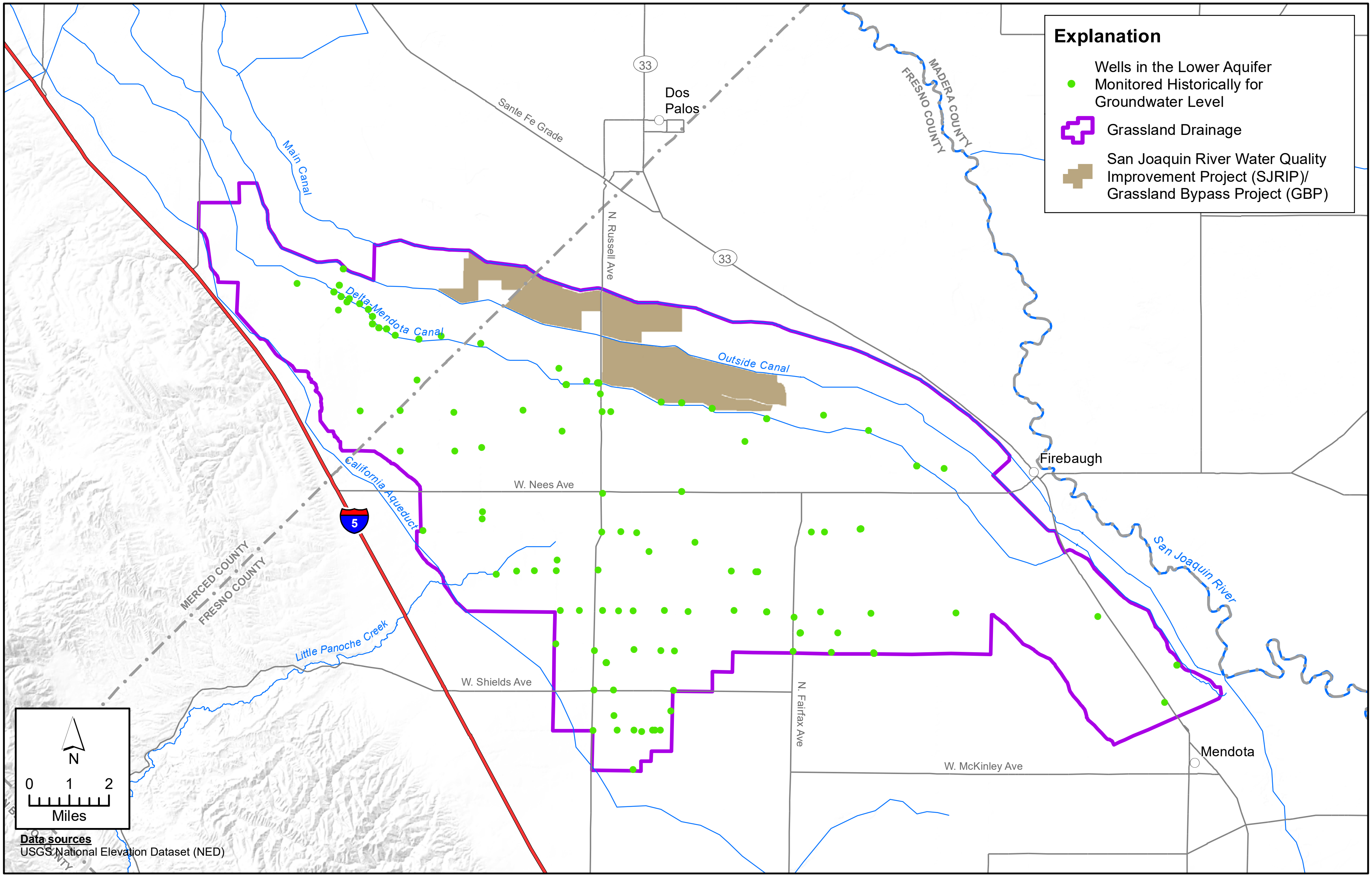

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FIGURE 7-4
Map of Wells Monitored Historically for Groundwater Level: Lower Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

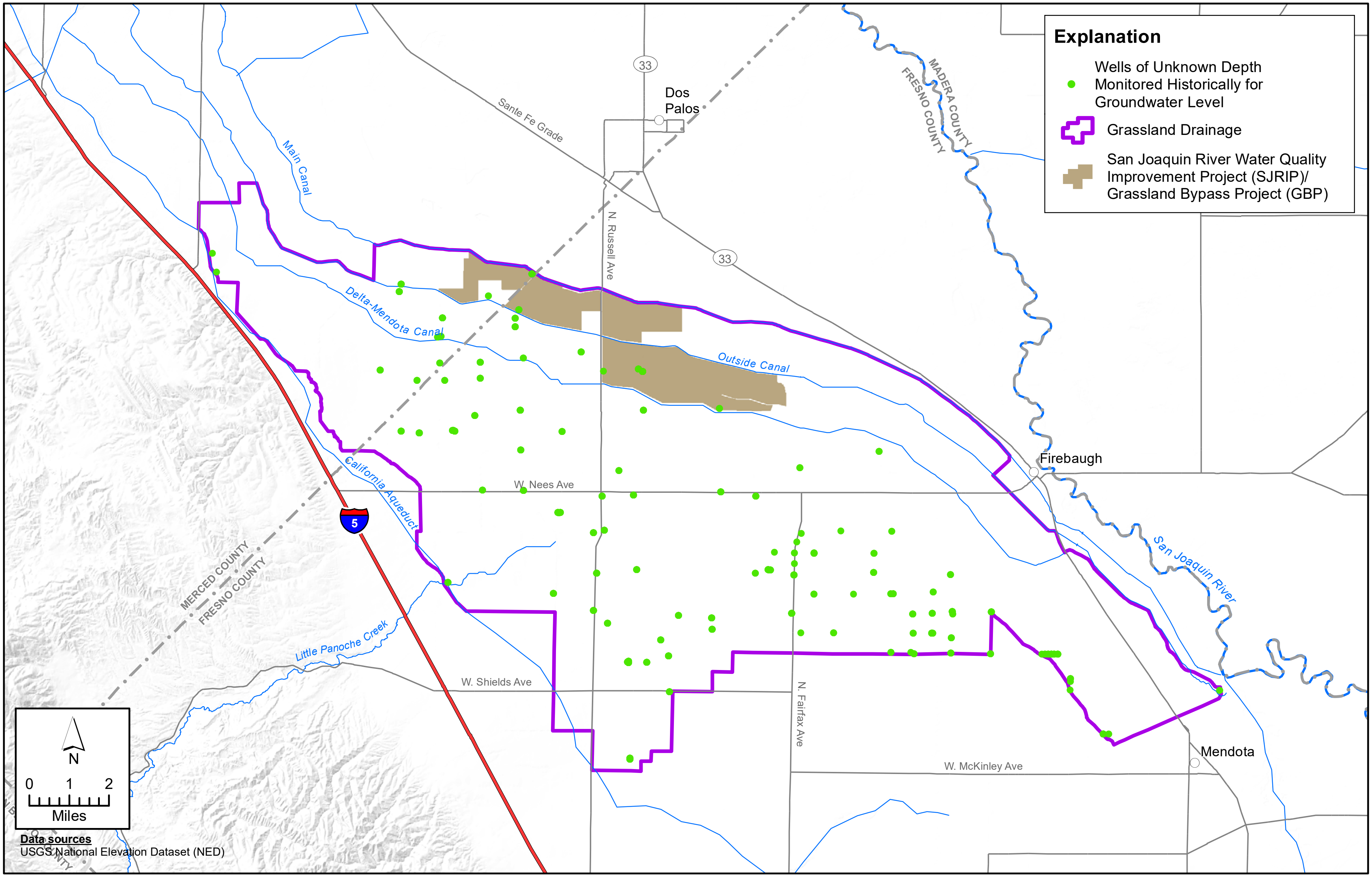

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FIGURE 7-5

Map of Wells Monitored Historically for Groundwater Level: Unknown Depth Zone

Grassland Drainage Area

Groundwater Quality Assessment Report

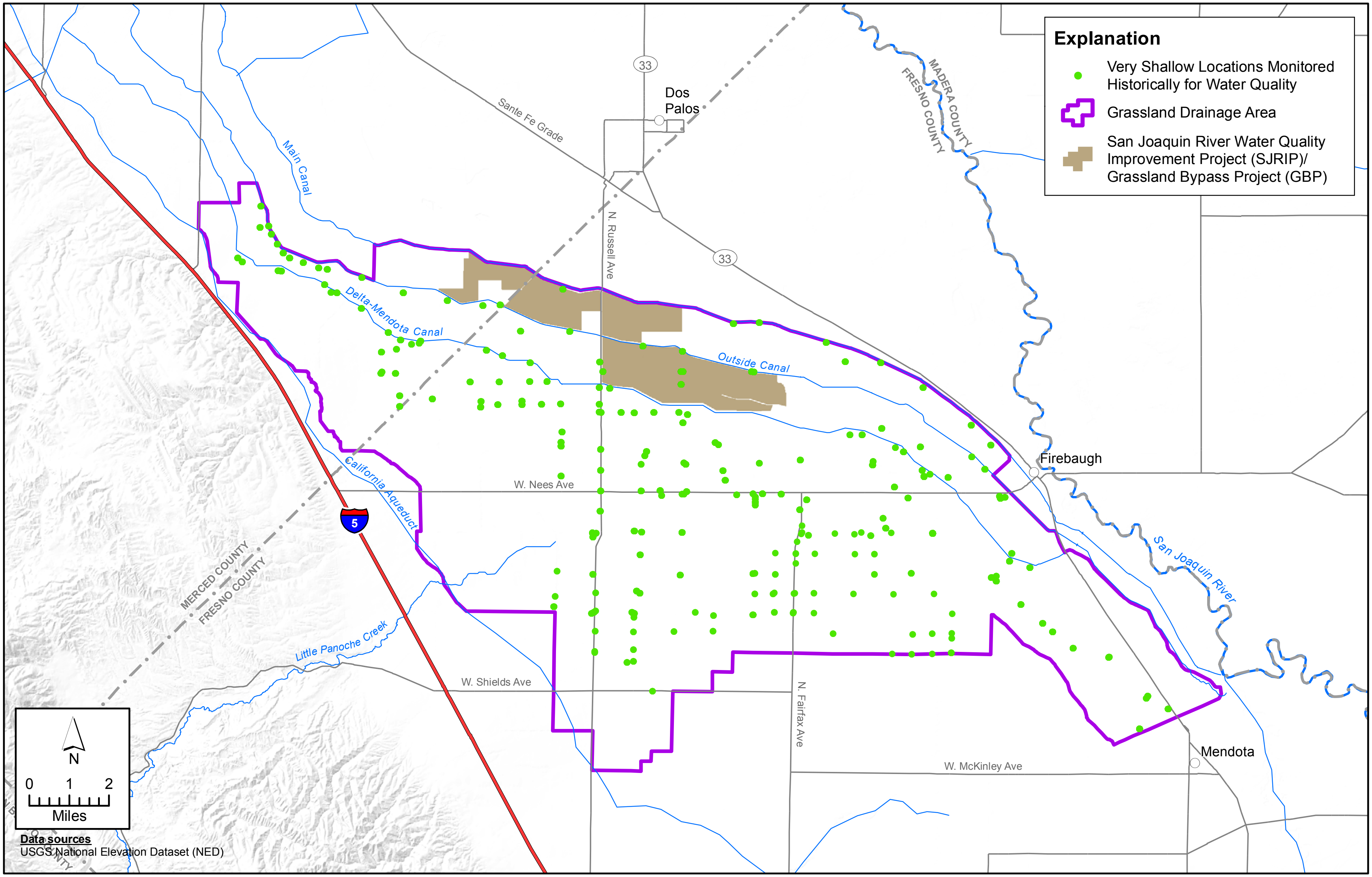

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FIGURE 7-6
Map of Locations Monitored Historically for Water Quality: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

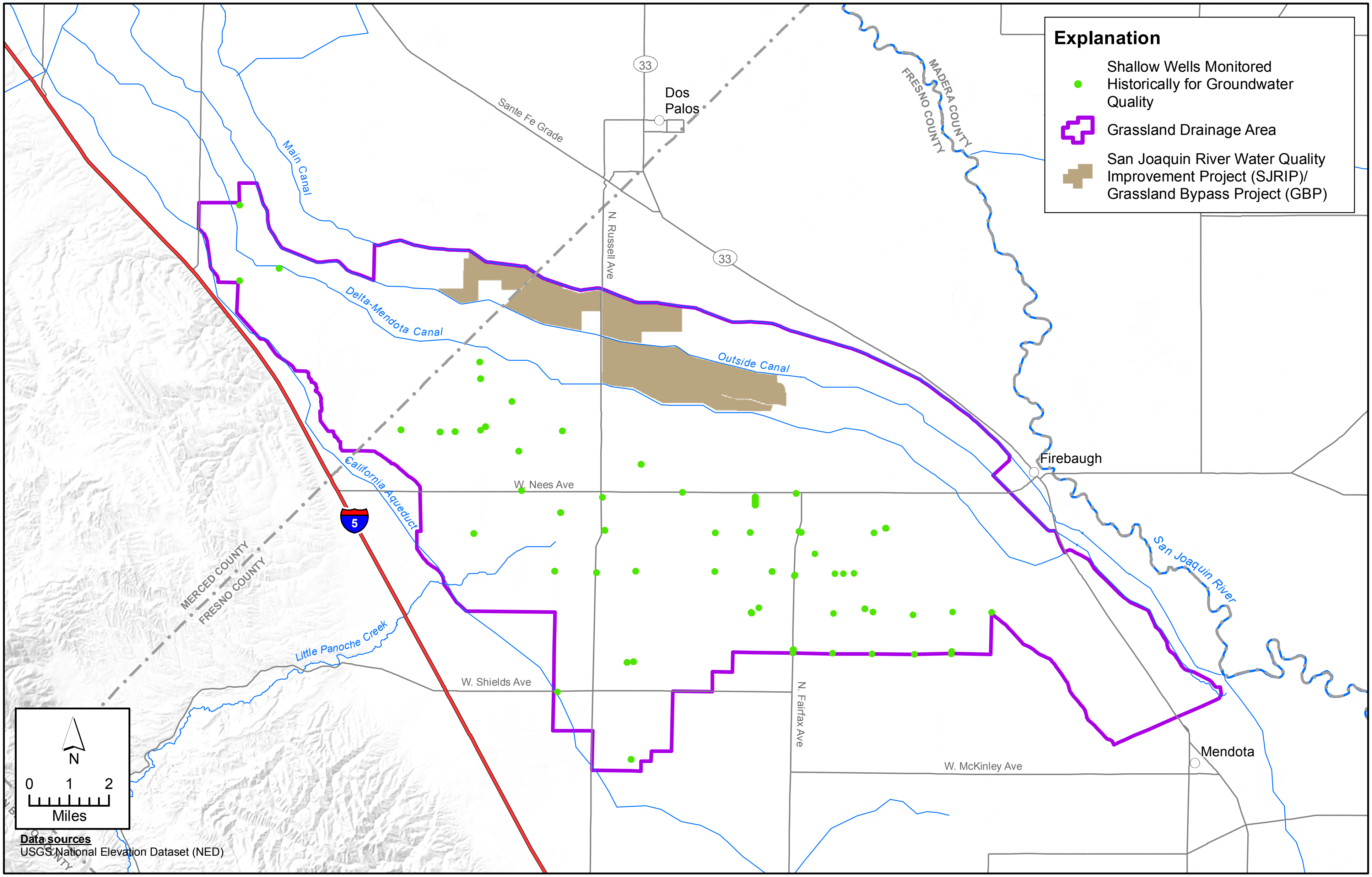

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FIGURE 7-7
Map of Wells Monitored Historically for Groundwater Quality: Shallow Groundwater

Grassland Drainage Area
Groundwater Quality Assessment Report

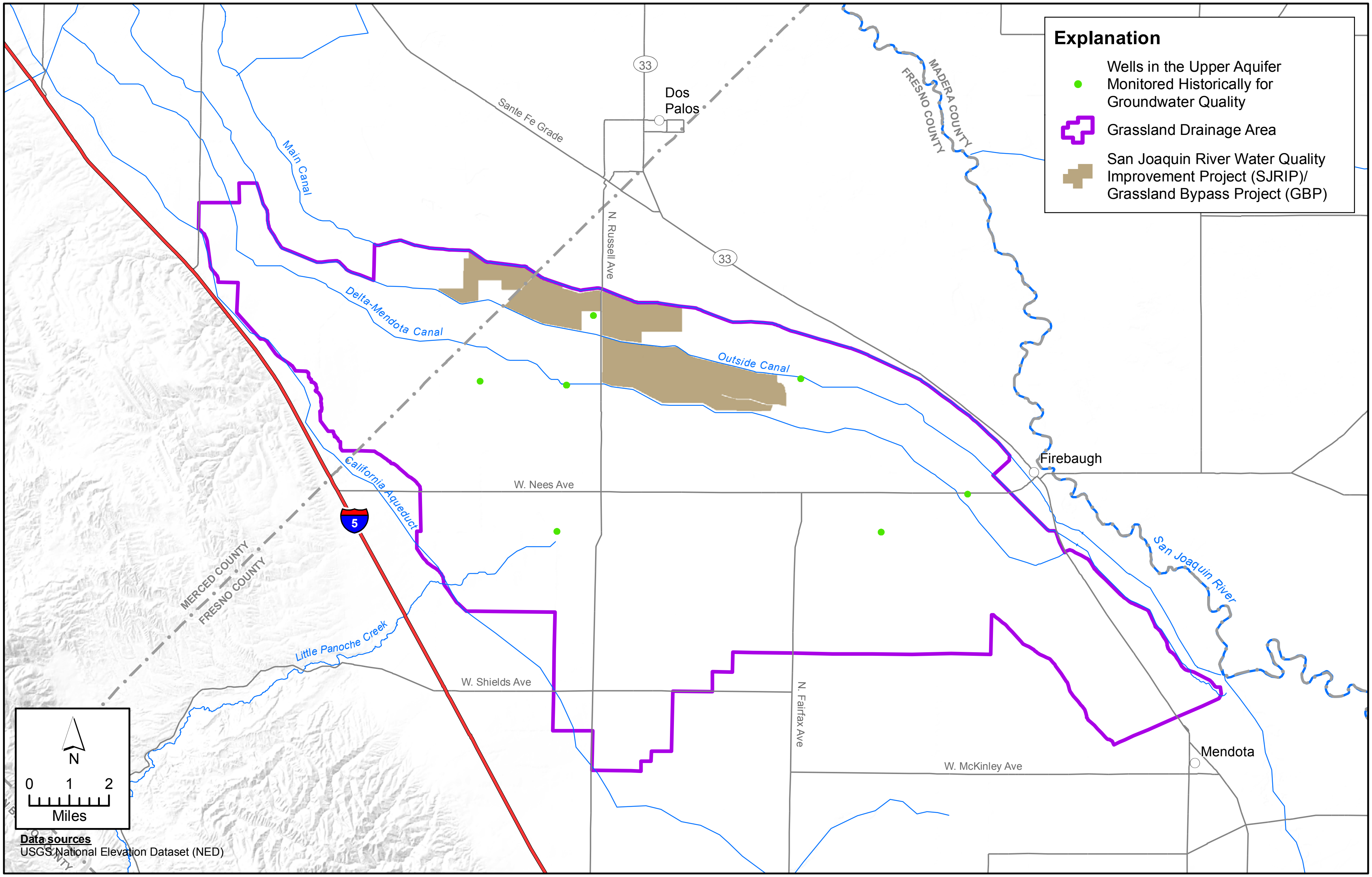

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FIGURE 7-8
Map of Wells Monitored Historically for Groundwater Quality: Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

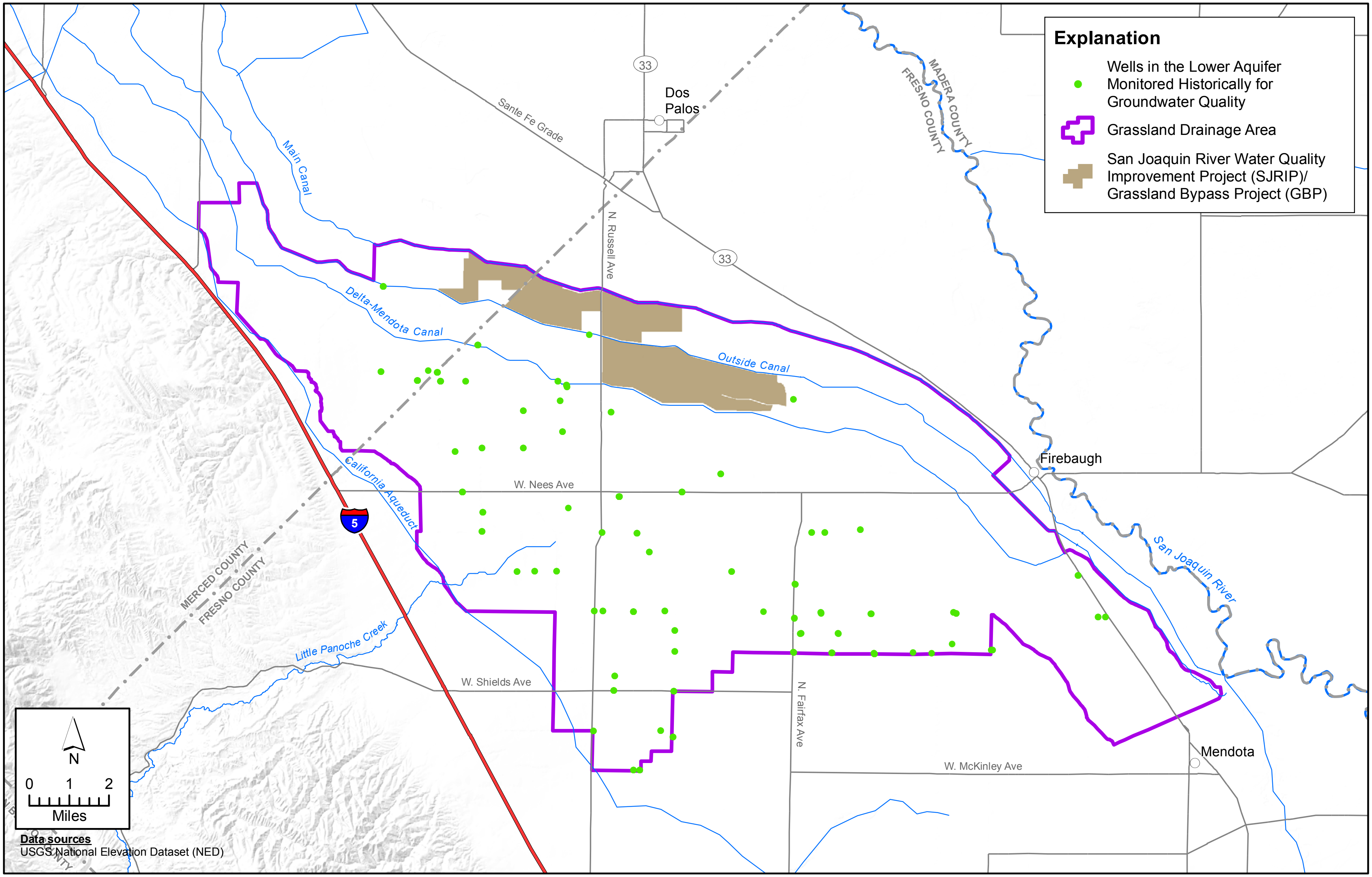

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FIGURE 7-9
Map of Wells Monitored Historically for Groundwater Quality: Lower Aquifer

Grassland Drainage Area
Groundwater Quality Assessment Report

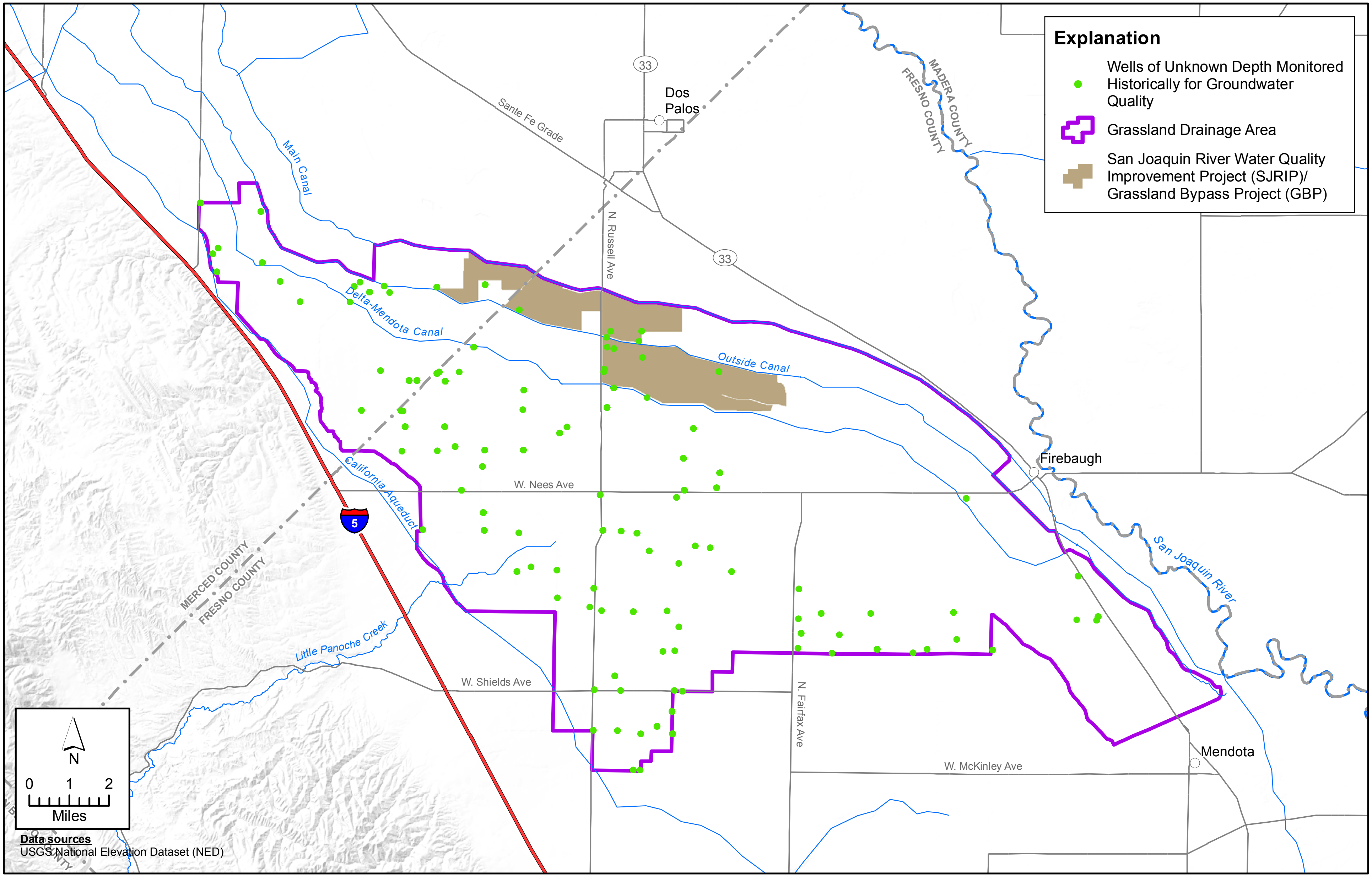

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FIGURE 7-10
Map of Wells Monitored Historically for Groundwater Quality: Unknown Depth Zone
Grassland Drainage Area
Groundwater Quality Assessment Report

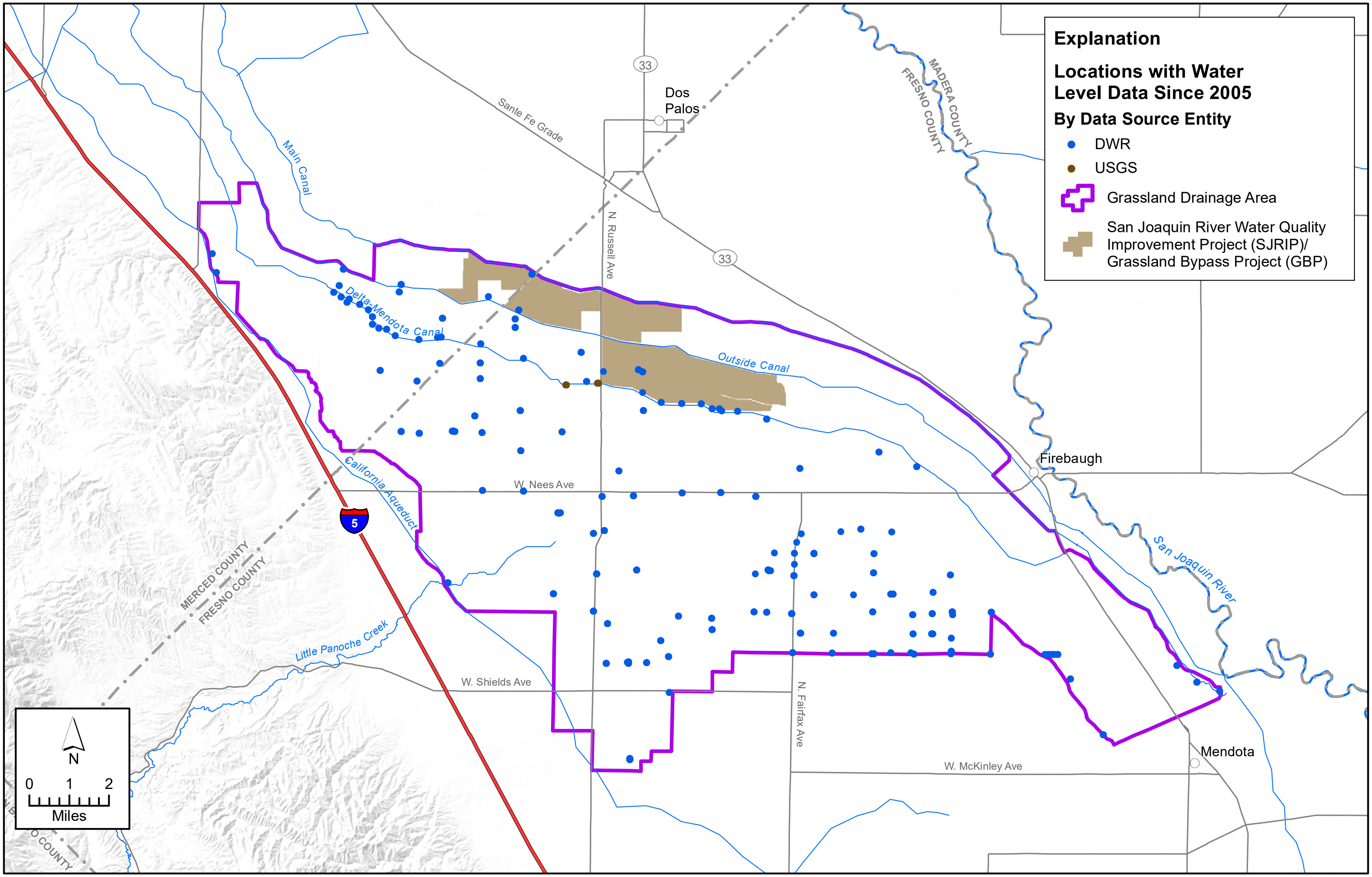

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FIGURE 7-11
Map of Locations Monitored Recently for Water Level by Entity
Grassland Drainage Area
Groundwater Quality Assessment Report

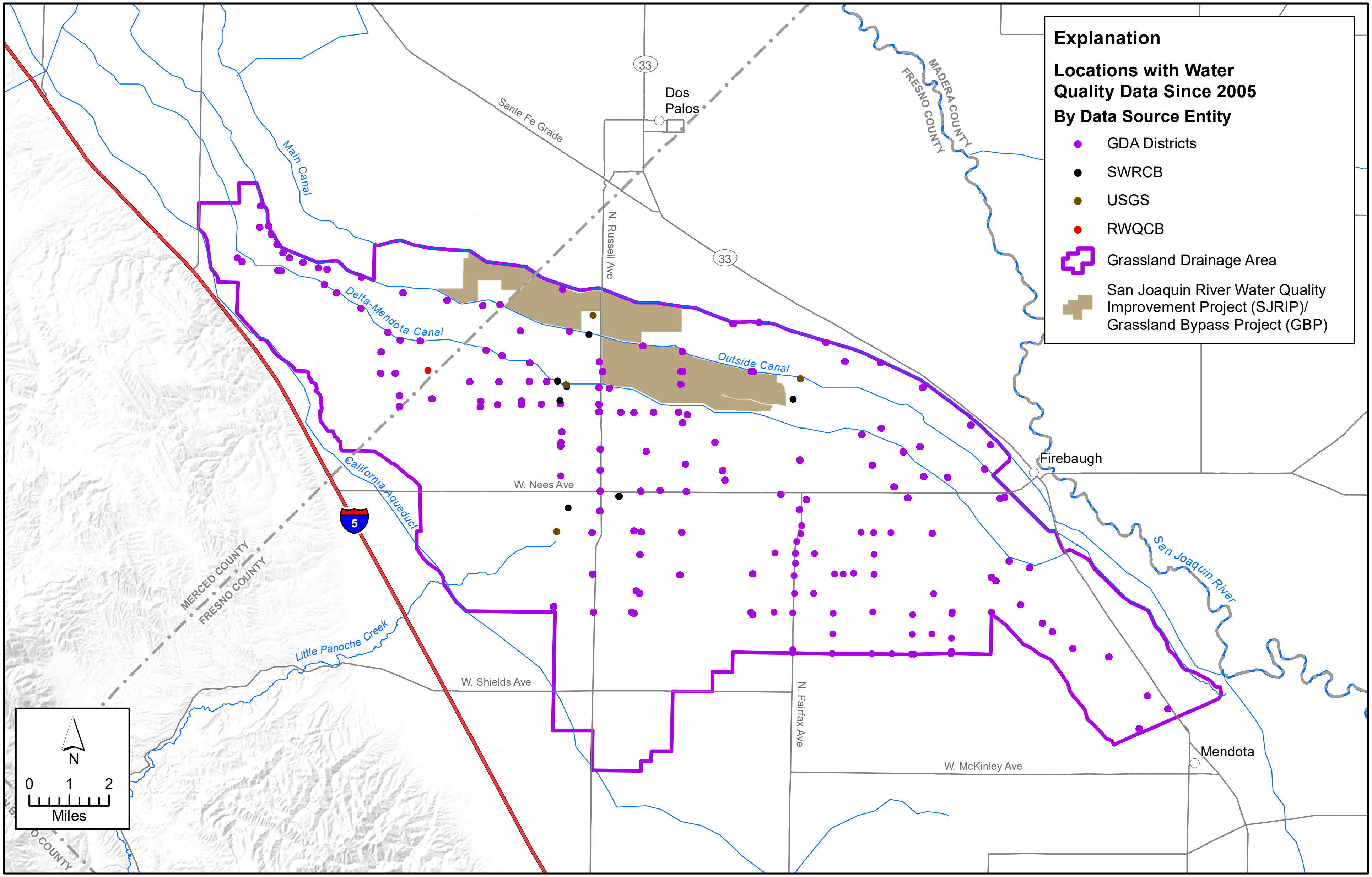

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FIGURE 7-12
Map of Locations Monitored Recently for Water Quality by Entity
Grassland Drainage Area
Groundwater Quality Assessment Report

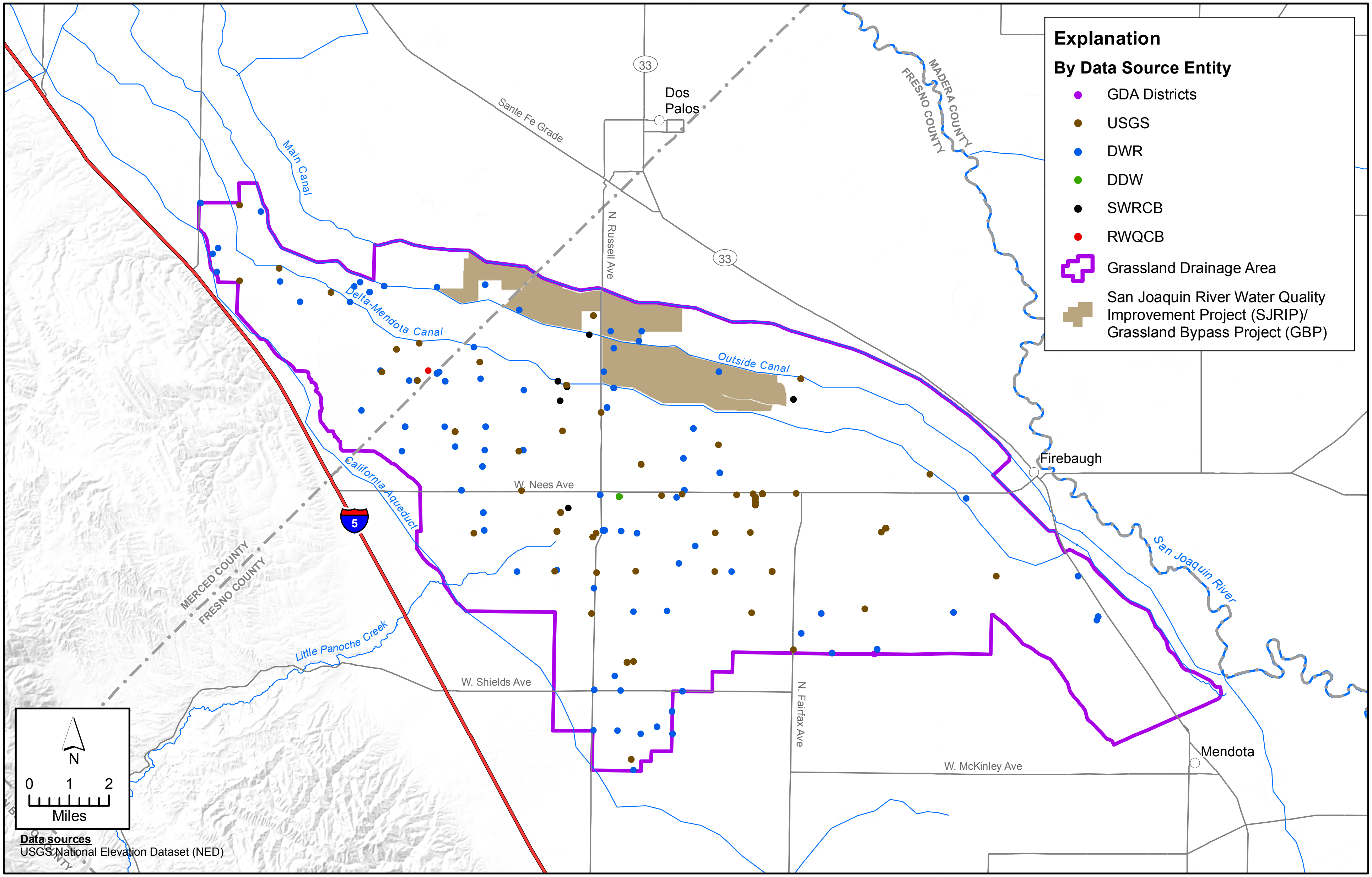

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FIGURE 7-12
Map of Wells Monitored Recently for Groundwater Quality by Entity
Grassland Drainage Area
Groundwater Quality Assessment Report

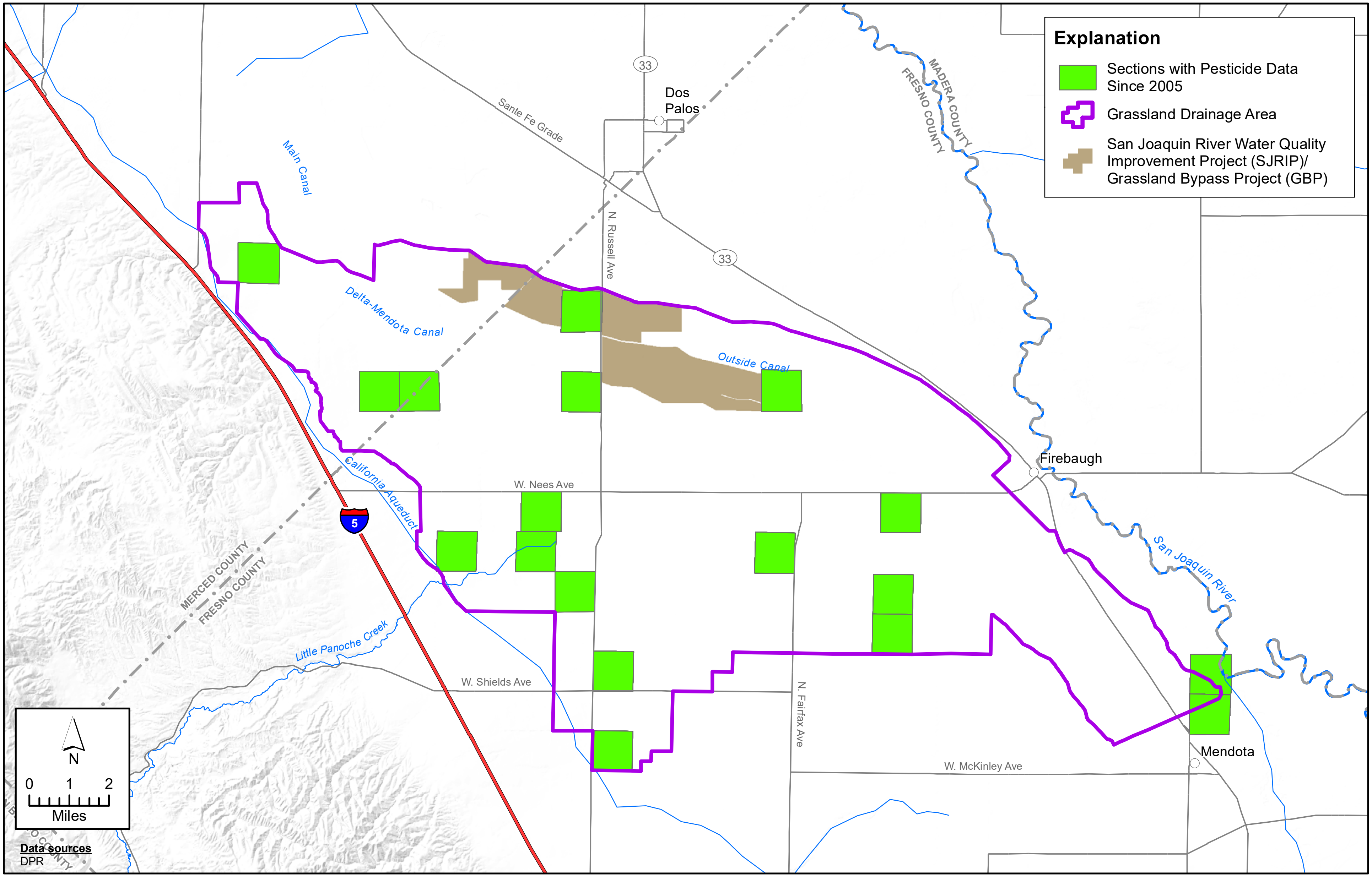

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FIGURE 7-13
Map of Sections Monitored Recently for Pesticides
Grassland Drainage Area
Groundwater Quality Assessment Report

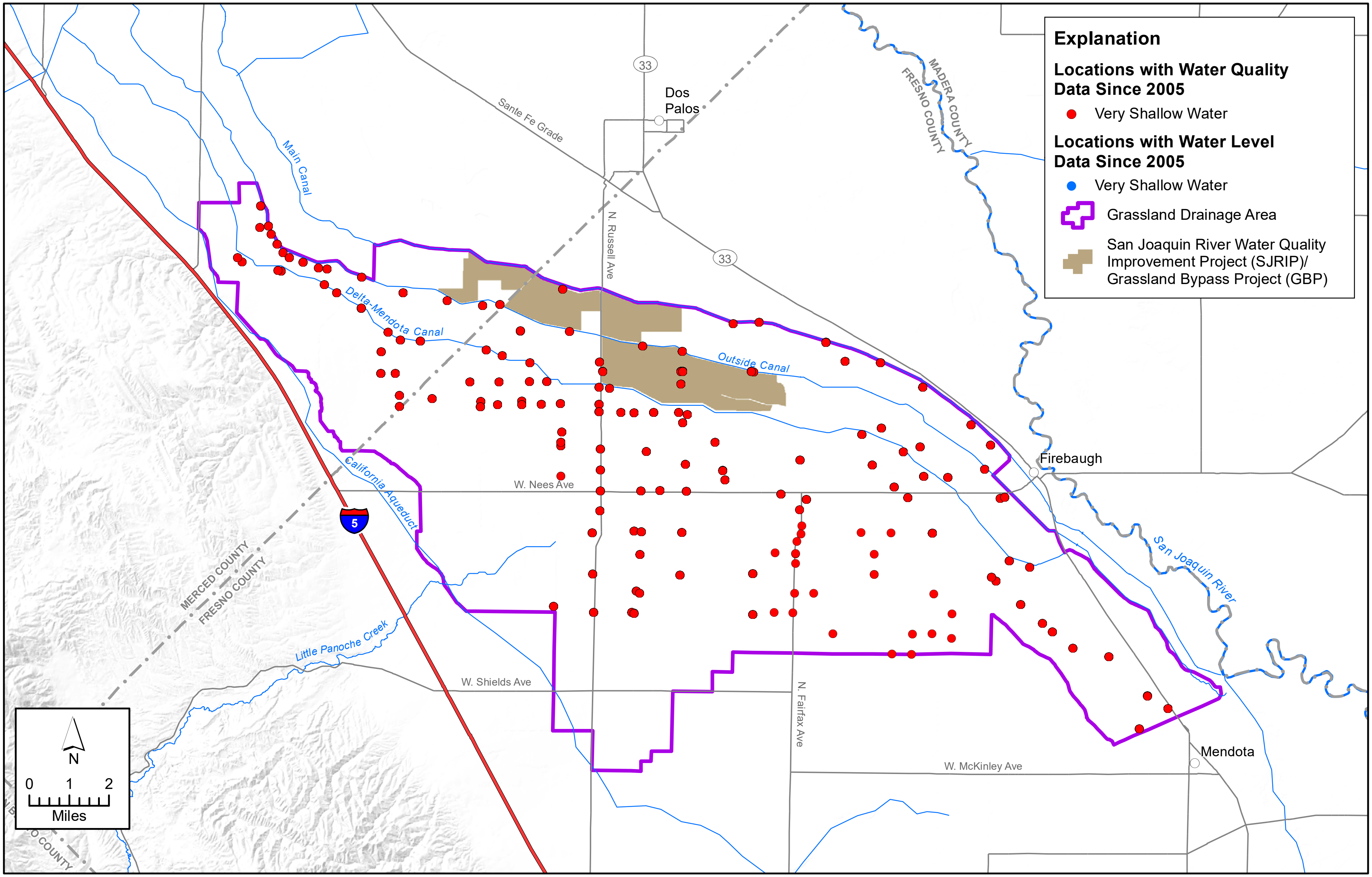

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FIGURE 7-14
Map of Locations Monitored Recently: Very Shallow Water
Grassland Drainage Area
Groundwater Quality Assessment Report

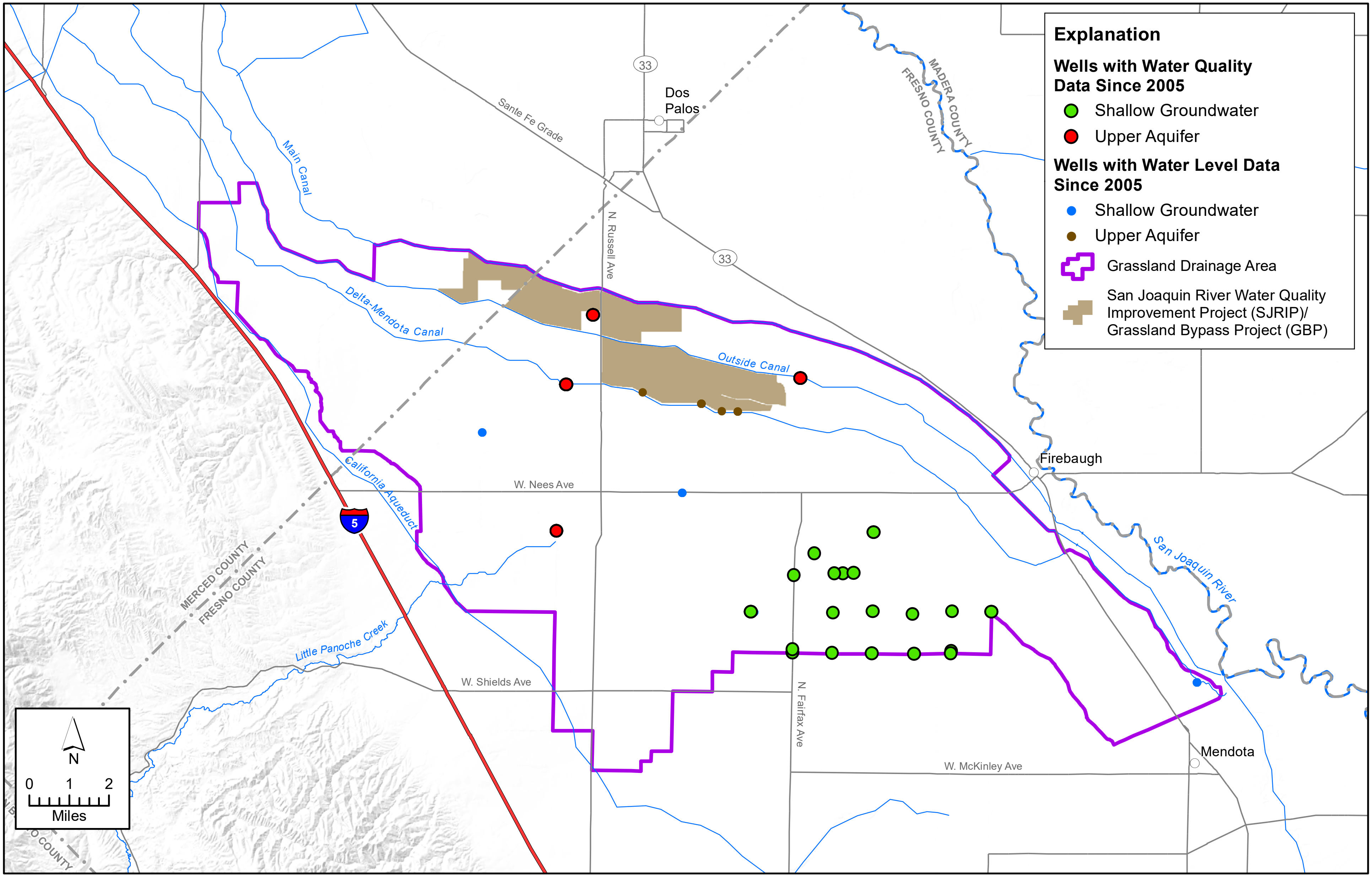

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FIGURE 7-15
Map of Wells Monitored Recently: Shallow Groundwater and Upper Aquifer
Grassland Drainage Area
Groundwater Quality Assessment Report

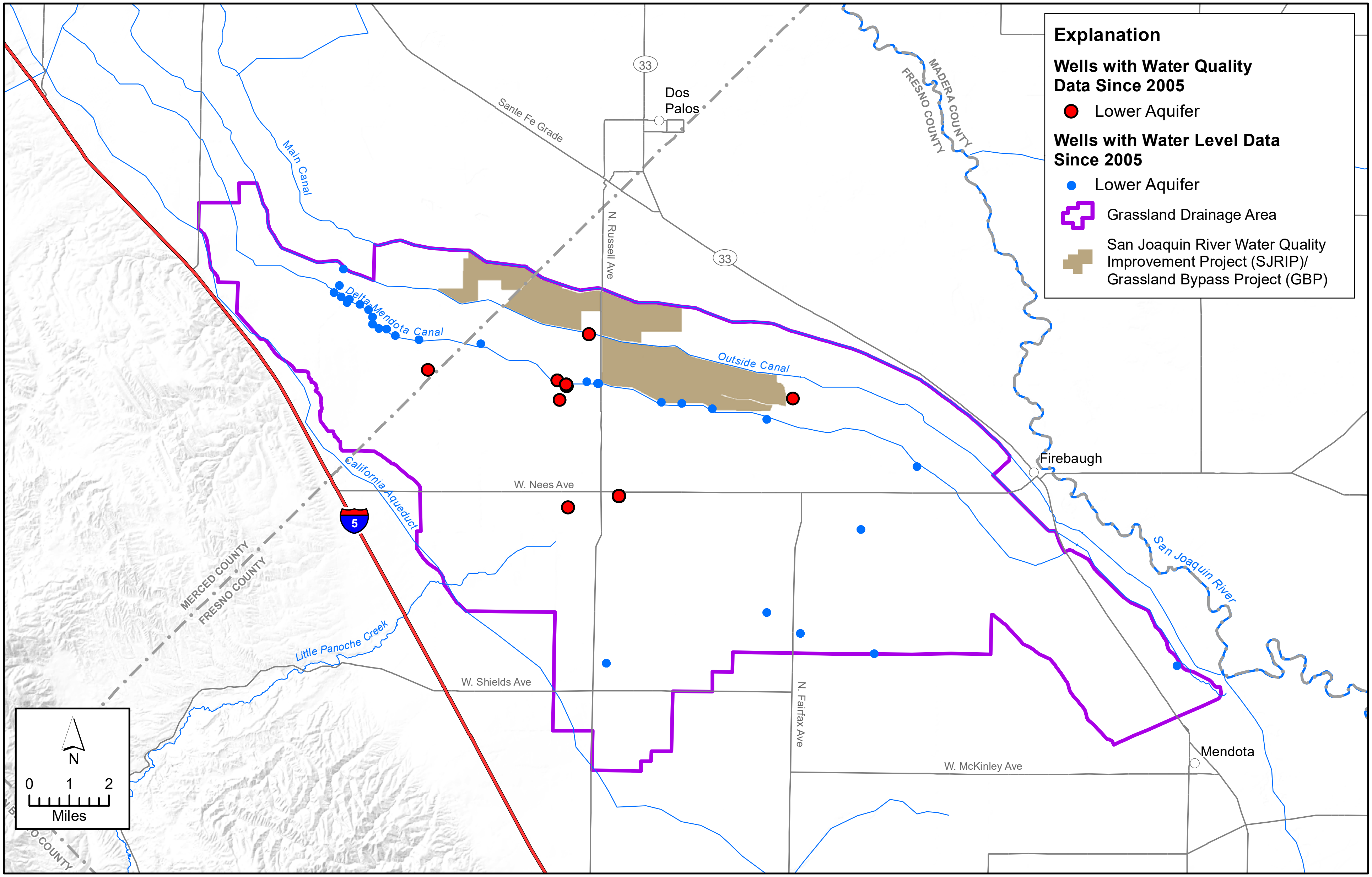

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FIGURE 7-16
Map of Wells Monitored Recently: Lower Aquifer

Grassland Drainage Area
Groundwater Quality Assessment Report

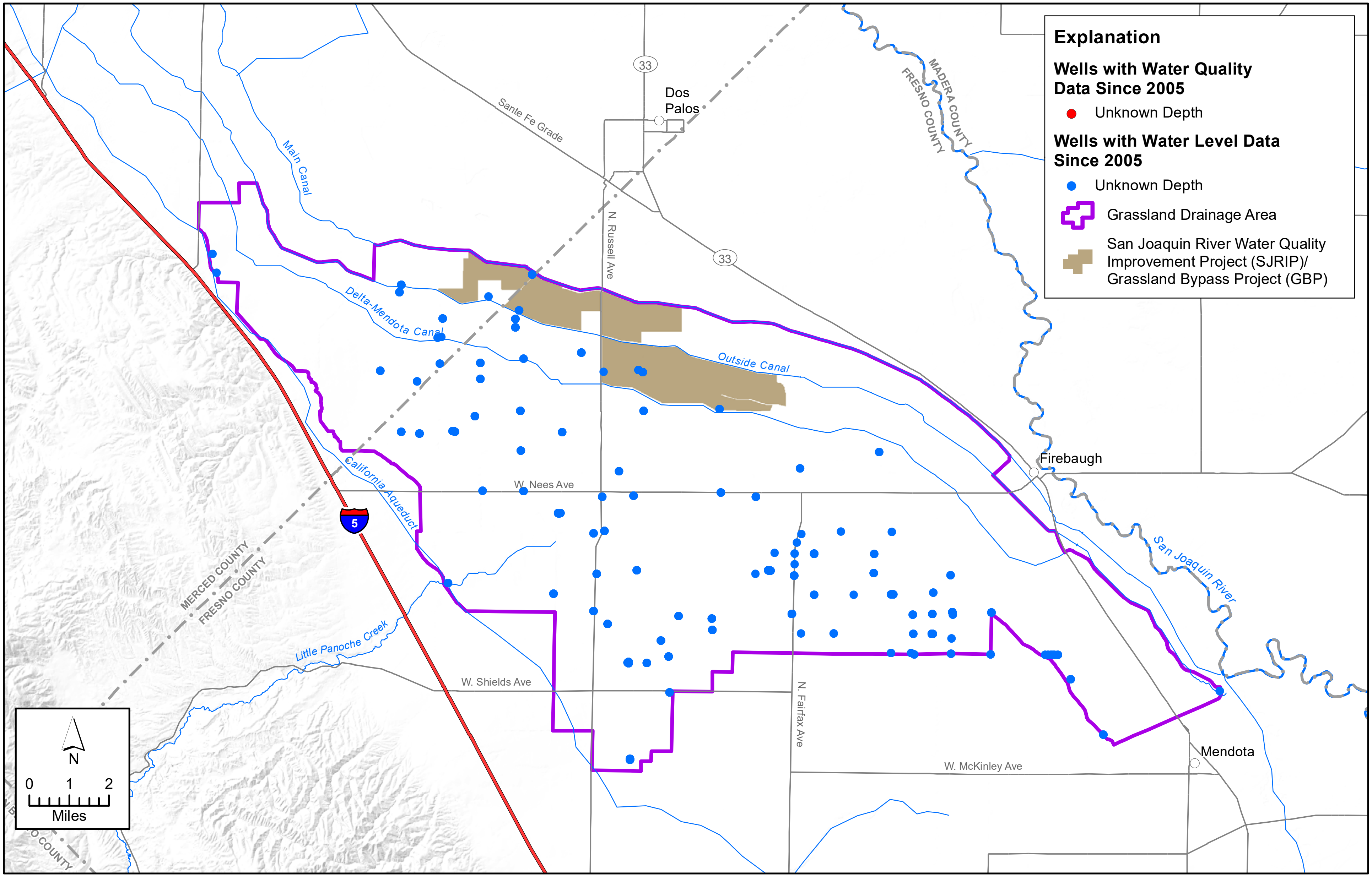

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FIGURE 7-17
Map of Wells Monitored Recently: Unknown Depth Zone
Grassland Drainage Area
Groundwater Quality Assessment Report