East San Joaquin
WATER QUALITY COALITION

East San Joaquin Water Quality Coalition Groundwater Quality Assessment Report

January 2014

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Prepared For
East San Joaquin Water Quality Coalition

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LIST OF ACRONYMS

af	acre-feet
bgs	below ground surface
CALVUL	California Vulnerability approach
CASGEM	California Statewide Groundwater Elevation Monitoring
CDPH	California Department of Public Health
CEHTP	California Environmental Health Tracking Program
cfs	cubic feet per second
CRCD	Coarsegold Resource Conservation District
CVHM	Central Valley Hydrologic Model
RWQCB	Central Valley Regional Water Quality Control Board
DBCP	1,2-dibromo-3-chloropropane
DEA	deethyl-atrazine
DEM	digital elevation model
DLPA	Division of Long Planning and Assistance
DPR	California Department of Pesticide Regulation
dS/m	decisiemens per meter
DWR	California Department of Water Resources
EC	electrical conductivity
EHAP	Environmental Hazards Assessment Program
EPA	U.S. Environmental Protection Agency
ESJHVA	East San Joaquin Water Quality Coalition High Vulnerability Area
ESJWQC	East San Joaquin Water Quality Coalition
FMMP	Farmland Mapping and Monitoring Program
GAMA	Groundwater Ambient Monitoring Assessment program
GAR	Groundwater Quality Assessment Report
GIS	Geographic Information Systems
GWPA	Groundwater Protection Area
HHVA	Hydrogeologic High Vulnerability Area
IAZ	Initial Analysis Zones
ILP	Irrigated Lands Program
ILRP	Irrigated Lands Regulatory Program
lbs/ac/year	pounds per acre per year
LWA	Larry Walker Associates
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
mg/L/yr	milligrams per liter per year
MID	Merced Irrigation District
MOU	Memorandum of Understanding
NED	National Elevation Dataset
NOA	Notice of Applicability
NRCS	Natural Resource Conservation Service
NWIS	National Water Information System
PLSS	Public Land Survey System
QA/QC	Quality Assurance/Quality Control
RWQCB	Central Valley Regional Water Quality Control Board

SSURGO	Soil Survey Geographic Database
SWRCB	California State Water Resources Control Board
TDS	total dissolved solids
TID	Turlock Irrigation District
µg/L	micrograms per liter
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WDL	Water Data Library

EXECUTIVE SUMMARY

This Groundwater Quality Assessment Report (GAR) has been prepared on behalf of the East San Joaquin Water Quality Coalition (ESJWQC or Coalition) in response to Waste Discharge Requirements (WDR), General Order R5-2012-0116 adopted by the Central Valley Regional Water Quality Control Board (RWQCB or Board) on December 4, 2012. This WDR is for the growers in the Eastern San Joaquin River Watershed that are members of the ESJWQC. The boundary of the Eastern San Joaquin River Watershed generally coincides with that of the ESJWQC region.

ES.1 East San Joaquin Water Quality Coalition

The ESJWQC serves as the third-party group for the growers within the Eastern San Joaquin River Watershed although some growers in the Watershed may elect to be regulated as individuals. The Eastern San Joaquin River Watershed has approximately one million acres of irrigated land and approximately 3,900 growers are in this region. Of this acreage, approximately 835,000 acres require regulatory coverage under this Order or other WDRs or conditional waivers of WDRs[1,2]. As of November 2013, 3,971 growers are ESJWQC members, and they occupy approximately 706,000 acres of irrigated lands (**Figure ES-1**).

ES.2 WDR Timelines Related to the GAR

Following the Board's adoption of the WDR on December 4, 2012, the Notice of Applicability (NOA) was approved on January 11, 2013. The approval date associated with the NOA starts the timeline for several requirements, including the requirement in the WDR Order (Section IV. A.) that, three months after receiving a NOA from the 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 April 11, 2013. Additionally, the due date for the GAR is set at one calendar year after approval of the NOA, which for the ESJWQC is January 13, 2014 (the first working day after January 11, 2014).

ES.3 Overview of the GAR

This GAR has been prepared in accordance with the outline submitted to the RWQCB in April 2013. The GAR content has been expanded to address the scientific quantification of vulnerable areas, particularly as related to the delineation between areas of relatively higher and lower

[1] WDR General Order R5-2012-0116; Findings Item 12.
[2] Approximately 165,000 acres are regulated under the Board's General Order of Existing Milk Cow Dairies (R5-2013-0122)

groundwater vulnerability. Additionally, to address the definition of high vulnerability in the WDRs (Attachment E), which specifies that wells with confirmed exceedances will also be considered especially if irrigated agriculture may cause or contribute to exceedances, six areas were designated as Tentative High Vulnerable Areas.

The relative vulnerability of groundwater to irrigated land agricultural impacts in the Coalition has been 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) has been assessed for areas located within the Central Valley Floor.

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] and California Department of Pesticide Regulation [DPR]), and presents the method developed for determining high vulnerability areas within the region encompassed by the Coalition boundary. To determine high vulnerability areas, a model for assessing groundwater vulnerability for the Eastern San Joaquin River Watershed was developed through statistical approaches and based on observed groundwater quality and hydrogeologic characteristics. 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 statistical method of determining groundwater vulnerability irrespective of land use also accounts 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 from the mid-1990s to 2012 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. Additionally, six areas have been identified as Tentative High Vulnerability Areas; further examination of these wells is recommended to determine whether it is appropriate to include these wells in the footprint identified as high groundwater vulnerability. Numerous existing wells, which were previously and/or are presently monitored, have been identified as a pool of potential wells to select from to 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

For the purposes of completing the GAR and the required groundwater vulnerability assessment component, available information and data on surface and subsurface sediments were acquired and assembled. The Coalition region includes parts of multiple DWR-designated groundwater basins and subbasins (**Figure ES-2**). Because of the hydrogeology of the surrounding mountains and generally low water-bearing nature of rocks outside the Central Valley Floor area and because of the lack of irrigated agriculture in these areas, the characterization of subsurface materials and the groundwater vulnerability assessment were generally limited to within the Central Valley Floor.

Within the Central Valley Floor, the primary water bearing units consist of Quaternary-aged unconsolidated continental deposits and older alluvium that are present across most of the western portion of the Coalition region. The continental and older alluvial deposits consist of layers of sand, gravel, silt, and clay that increase in thickness away from the margins of the valley. The continental deposits are generally mapped as the Turlock Lake Formation, North Merced Gravel, and Pleistocene non-marine sedimentary units, which occur along the eastern edge of the Central Valley Floor. Groundwater in the area generally occurs under confined, semi-confined, and unconfined conditions within primary water-yielding zones.

Soil survey data show the presence of numerous long and narrow coarser-textured deposits of higher conductivity resulting from modern and ancient stream channel depositional processes. Additionally, the historical lateral migration of alluvial channels has formed large fans of high conductivity soils. One area of particularly high conductivity soils is located north and west of Atwater and in association with the Merced River channel and alluvial fan network. Several other notable areas of high hydraulic conductivity soils exist in association with the Tuolumne River system in the general vicinity and to the east of Modesto and Ceres, as a result of stream channel deposition related to the Chowchilla River system, and near Madera in association with the river system of the current Fresno River. Many other sinuous stream channel deposits of coarse material are high conductivity areas across the Central Valley Floor area of the Coalition region.

The Corcoran Clay is a prominent stratigraphic layer that exists in parts of the Central Valley and is generally believed to divide deeper groundwater zones from shallow groundwater zones, where it exists. The Corcoran Clay is generally present only in the western portion of the Central Valley Floor area, approximately west of Highway 99. Depth to the top of the Corcoran Clay generally increases towards the center of the valley and ranges from less than 50 feet along parts of its eastern extent to more than 300 feet below ground in the southwest portion of the Central Valley Floor area. The thickness of the Corcoran Clay also increases towards the axis of the valley. Two areas where the Corcoran Clay is thickest are located generally to the west of Turlock and also to the south of Turlock where the thickness is generally greater than 60 feet with some thicker areas of 100 feet or more. Although the lateral extent of the Corcoran Clay is generally greater farther south, the unit tends to thin with many areas of less than 40 feet thickness, particularly across most of the eastern part of its southern extent.

ES.4.2 Groundwater Hydrology

An important aspect of characterizing the condition of groundwater resources within the Coalition region includes understanding groundwater levels. Data on groundwater levels provide foundational information with which to interpret and understand hydrogeologic conditions, including spatial and temporal patterns in flow direction, groundwater level trends, potential groundwater recharge and discharge areas, and other conditions.

Water level data consisting of more than 325,000 measurements from over 7,000 wells within the Coalition region were assembled into a database. Of these data, only a relatively small number of wells have available information on well construction such as depth or screened interval. However, for the purposes of differentiating and evaluating water level trends within the shallower part of the aquifer system from those within the relatively deeper part of the aquifer system, the depth category for all wells was interpreted from available information in the database. Wells were assigned into three general well depth categories: shallow, deep, and unknown. Shallow wells were defined to be wells with known depths less than 200 feet and also included well use categories of domestic wells, monitoring wells, and Turlock Irrigation District drainage wells. Deep wells included wells with depths greater than 200 feet and also municipal wells, irrigation wells, or other well uses indicating a greater likelihood of a well being deeper than 200 feet. Wells without any further information with which to assign them into either the shallow or deep category were designated unknown.

ES.4.2.1 Depth to Groundwater

Contours of the most recent spring depth to groundwater conditions were developed from available data and show extensive shallow groundwater levels (<20 feet below ground surface [bgs]) in the northwestern part of the Coalition region near Turlock and westwards toward the San Joaquin River. Another area with shallow groundwater exists in the general vicinity of Merced and along Owens Creek and its tributaries. Other more localized areas of shallow groundwater are evident along waterways, most notably along the Stanislaus River, Merced River, and San Joaquin River. Depth to groundwater tends to be deeper to the east and away and from San Joaquin River. Two notable pockets of deeper groundwater are apparent to the east of Turlock, in the vicinity of Chowchilla and between Merced and Madera in the more southerly portion of the area. The depth to groundwater is generally greater in the fall than in the spring indicating seasonal lowering of groundwater levels.

ES.4.2.2 Groundwater Flow Directions

Contours of the calculated recent spring and fall groundwater elevations within the Central Valley Floor area show a steeper groundwater surface with greater hydraulic gradients in the eastern part of the Central Valley Floor area with the presence of some notable local groundwater depressions, particularly in the vicinity of Chowchilla, between Merced and Madera, and east of Turlock. The hydraulic gradient of the groundwater surface generally flattens to the west, particularly in the northern and western part of the Coalition region. Both spring and fall groundwater elevation contours indicate that groundwater generally flows in a southwestern direction away from the hills and mountains to the northeast.

ES.4.2.3 Groundwater Trends

A relatively consistent pattern in declining groundwater levels is exhibited in many of the shallow wells with longer periods of record. The areas of greatest decline are on the eastern side of the Central Valley Floor and in the southern part of the Coalition region where some wells show declines in groundwater levels of greater than 100 feet since the 1960s and 1970s. Further north and where groundwater is generally shallower, historical water level declines are more moderate. Notable responses in shallow water levels to periods of wet (early to mid-1980s, mid- to late 1990s) and dry (late 1980s to early 1990s) climatic conditions are also evident in many well hydrographs.

As seen in the shallow wells, there are overall similar temporal and spatial patterns of generally declining groundwater levels in deeper wells. Wells in the northern part of the Central Valley Floor area have groundwater levels that fluctuate in response to seasonal and climatic conditions, including periods of decline and recovery, and show a relatively stable to slightly declining trend in water levels over the long term. To the south, and particularly along the eastern side of the Central Valley Floor area, conditions of consistent long-term decline in groundwater levels are more apparent since the 1960s with levels dropping as much as 100 feet during this time.

ES.4.2.4 Recharge Upgradient of Public Water Systems

For purposes of understanding and prioritizing impacted areas of groundwater, the groundwater elevation dataset developed for the Central Valley Floor area was used to identify areas of groundwater recharge located upgradient from public water systems that are reliant on groundwater. The spatial extent of public water systems reliant on groundwater from the California Department of Public Health's (CDPH's) California Environmental Health Tracking Program (CEHTP) Public Water Systems Boundary Tool was used as the basis for defining contributing groundwater areas to public water supply systems. The contributing areas were developed for all water systems within the CEHTP database with groundwater as a source, including active, inactive, and standby sources. Horizontal flow direction was determined for the recent spring groundwater elevation dataset. The flow direction calculation was generalized to 400 meter cells to achieve consistent and contiguous flow directions. ArcGIS hydrology tools were then used to estimate contributing (upgradient) groundwater areas to these identified public drinking water systems that are reliant on groundwater.

ES.4.3 Land Use

Characterizing changing land use conditions over time is important for understanding past, current, and future groundwater quality. To document and evaluate the spatial distribution of past and recent land use across the Coalition region , data from county land use surveys conducted periodically (every five to ten years) by the California Department of Water Resources (DWR) were used. The main surveyed counties with available data in the Coalition region include Alpine (2001), Calaveras (2000), Fresno (1986, 1994, 2000, 2009 East), Madera (1995, 2001, 2011), Mariposa (1998), Merced (1995, 2002), Stanislaus (1996, 2004), and Tuolumne (1997). Over 70 crop types and land uses are reported in the compiled land use survey snapshots. Sometimes irrigation methods are also recorded in the surveys. No irrigation method data were recorded for surveys from the mid-1990s, but some irrigation method information was available in the early 2000s survey data.

Because DWR land use surveys are only conducted on a periodic basis, land use data from 2012 US Department of Agriculture (USDA) California Cropland Data Layer were used to represent current land use conditions.

Because of the large number of unique land uses and crop types reported in the land use survey data from DWR and USDA, similar land uses were grouped into categories for purposes of evaluating spatial and temporal patterns and also for the groundwater vulnerability assessment. The list of over 70 crop types and land uses contained in the land use survey data were grouped into 12 main categories based on some general similarities in agricultural practices and estimated typical nitrogen application rates. Within the Central Valley Floor region, the largest land use category is non-agricultural followed by nut trees. Based on the DWR data, vegetables represented approximately nine to ten percent of the Central Valley Floor area between the mid-1990s and early 2000s. In the 2012 land use data from the USDA, many vegetable crops are mapped as "double crops". As a result, the percent of vegetable crops in the area as identified by USDA in 2012 is only three percent; however, the combined percent of vegetables and double crops in 2012 is a little over 7 percent and more consistent with the DWR land use data for the mid-1990s and early 2000s. The extent of dairies as mapped in the land use surveys by DWR generally represent the extent of the dairy waste management units (animal corrals, waste lagoons, etc.) and do not represent the full extent of dairy-owned land which may be under cultivation or used in other ways by a dairy.

Changes in land use occurred between the mid-1990s and 2012. Nut trees have shown the largest increase in acreage during this time and particularly since the early 2000s. As of 2012, there were nearly 400,000 acres of nut trees making up over 23 percent of the Central Valley Floor area within the Coalition region. Grasses were the second highest land use category in the mid-1990s at approximately 12 percent of the Central Valley Floor region, but have declined since that time, and in 2012 grasses only represented about eight percent of the area. Vegetables, when combined with double crops as identified by USDA, exhibit only a modest overall decline in acreage since the mid-1990s; although, there was an increase in vegetables between the mid-1990s and early 2000s.

The top agricultural crop categories within the Central Valley Floor of the Coalition region as derived from the USDA 2012 land use data and their cumulative percentages are nut trees, followed by grains/cotton, grasses, and grapes. These four categories represent the top 86 percent of agriculture by acres within the Central Valley Floor area of the Coalition region. As a result, these four categories were also used in the prioritization of high vulnerability areas as specifically mentioned in the WDR.

ES.4.3.1 Irrigation Practices

Available irrigation method data from the early 2000s DWR land use surveys were used to evaluate irrigation practices. As of the early 2000s, the predominant irrigation practice was basin/furrow irrigation representing the irrigation method used on approximately 65 percent of the irrigated lands area. Sprinkler irrigation and micro/drip represented the irrigation method used on 23 percent and 12 percent of the irrigated area, respectively. Although complete recent data on irrigation methods are not readily available, the data on land use and agricultural practices provided by the Coalition were also evaluated and used (ESJWQC, personal communication). These data included information assembled at various levels of detail from grower member reporting such as crop type grown, number of irrigated acres, Best Management Practices (BMP) being utilized (based on a 2007 survey), and irrigation methods from surveys between 2009 and 2012. The summary of irrigation method data maintained by the Coalition suggests a more recent shift in irrigation practices being used by the Coalition members.

Although the data represent a smaller sample size of irrigation practices (10 percent of the irrigated land within the Coalition), they suggest a potentially large shift in irrigation practices towards micro/drip.

ES.4.3.2 Fertilizer Use

Estimated nitrogen fertilizer use was compiled by the USGS from county fertilizer sales in the area (Gronberg and Spahr, 2012). These data show generally stable levels of fertilizer use in these counties between the late 1980s through late 1990s with a trend towards increasing use during the early 2000s and peaking in 2004. Nitrogen fertilizer use appears to have decreased after 2004.

Typical ranges of applied nitrogen by crop category in pounds per acre per year (lbs/ac/year) were considered based on data from the literature for 1973 and 2005 (Rosenstock et al., 2013; Viers et al., 2012). Vegetables generally have the highest typical nitrogen application rate based on 2005 estimates, particularly for corn (213 lbs/ac/year) and tomatoes (180 lbs/ac/year), which make up most of the vegetable crops. Grains/cotton and nut trees also tend to have higher applied nitrogen with typical rates of 174 to 177 lbs/ac/year for grains/cotton and between 138 and 179 lbs/ac/year for nut trees. Crop categories with the lowest nitrogen application rates include grasses (11 lbs/ac/year), grapes (27-44 lbs/ac/year), and seeds/beans (91 lbs/ac/year). The typical nitrogen application rate for crop categories of nut trees, vegetables, grains/cotton, and seeds/beans increased considerably between the 1970s and 2005. In contrast, grapes and grasses had notable decreases between 1973 and 2005 in the typical applied nitrogen.

Data from the California Department of Conservation Farmland Mapping and Monitoring Program (FMMP) were used to define the extent of the irrigated lands in the Coalition region.

ES.4.4 Groundwater Quality

ES.4.4.1 Nitrate and TDS – Spatial Distribution

High concentrations of nitrate are found in shallow groundwater throughout much of the western part of the Central Valley Floor. A large area where shallow groundwater is generally very high in nitrate is evident in the northwestern part of the Coalition region, particularly in the vicinity and to the west of Turlock. Numerous shallow wells in this area exhibit nitrate concentrations above the drinking water Maximum Contaminant Level (MCL) of 10 milligrams per liter (mg/L) (nitrate as nitrogen) with many wells having concentrations that are greater than two times the MCL. Groundwater is quite shallow in this area, and historical land use categories consist mainly of grasses, vegetables, and dairies. In the southwestern portion of the Coalition region, shallow nitrate concentrations appear to be generally lower, although much of the available data for this area date back to the 1970s and earlier.

Recent nitrate concentrations in deep wells show a somewhat similar spatial pattern as seen in shallow wells with higher nitrate concentrations occurring in the western part of the Central Valley Floor. An area of notably high nitrate concentrations is evident in deep wells in the vicinity of Turlock. Nitrate concentrations in deep wells in this area do not appear to be as high as in the shallow wells, and areas of high nitrate concentrations also do not appear to be as laterally extensive as in shallow wells. Although the areas of highest nitrate concentration in deeper wells are generally in the vicinity of Turlock, many other deep wells with nitrate concentrations above the MCL exist across the Central Valley Floor. Overall, nitrate concentrations in deep wells appear to be lower than those exhibited in the shallow wells.

Some areas of locally high total dissolved solids (TDS) concentrations exist in shallow wells, particularly in the vicinity of Modesto and also in some general locations west of Turlock. However, the most recent data indicate TDS concentrations in many shallow wells are below 500 mg/L, which represents the recommended MCL for Secondary Drinking Water Standards; upper and short term secondary MCLs for TDS are set at 1,000 mg/L and 1,500 mg/L, respectively. A number of wells with higher TDS concentrations are apparent in close proximity to the San Joaquin River along the western edge of the Coalition region where groundwater is generally very shallow. Elevated TDS concentrations can be a result of natural processes and the presence of high TDS concentrations does not necessarily indicate impacts from overlying land use activities. The available data from deep wells show most concentrations are below 500 mg/L although some deep wells with high concentrations are scattered throughout the Central Valley Floor area. Most the wells with the highest TDS concentrations (above 1,000 or 1,500 mg/L) are in the western part of the Coalition region.

ES.4.4.2 Pesticide Detections

Data assembled to evaluate the distribution of pesticide detections in the Coalition region were from DPR. These data are from wells, but the sampled locations are only provided at the spatial resolution of the Public Land Survey System (PLSS) section in which the well is located. Overall, out of 2,732 unique wells sampled for pesticides, 872 had detectable concentrations of a pesticide and 369 wells had pesticide concentration exceedances of a water quality objective. Of a total of 997 sections within which pesticide data archived by DPR are available, 375 sections have pesticide detections and 167 sections have exceedances. A total of 48 different pesticides have been detected within the Coalition region with exceedances reported for 8 different pesticides. The pesticides most often tested for were DBCP (1,2-dibromo-3-chloropropane), atrazine, simazine, and 1,2-dichloropropane and the most commonly detected pesticides were DBCP, simazine, DEA (deethly-atrazine), and atrazine. DBCP was detected in 632 unique wells within 250 different sections out of a total of 1,786 wells sampled; 331 wells in 154 different sections had concentrations above the primary MCL of 0.2 micrograms per liter (µg/L). Simazine was detected in 75 wells within 62 sections, but only one well had a concentration above the primary MCL of 4 µg/L. DBCP, aldicarb sulfone, and ethylene dibromide were the pesticides with the greatest number of exceedances, although DBCP accounted for 331 out of the 369 pesticide exceedances reported within the Coalition region.

ES.4.4.3 Nitrate and TDS Trends

Statistical analyses were conducted on available time-series data for wells to identify statistically significant trends in nitrate. The trend in nitrate concentrations is positive (increasing) for most shallow wells with a significant trend. Shallow wells in the area west of Turlock exhibit the greatest increasing trend with most wells having increasing trends of over 0.5 mg/L per year (mg/L/yr) and many with trends above 1 mg/L/yr. In the Modesto area and west of Modesto, a number of shallow wells also have significant increasing trends although the values for the rate of increase are slightly less, generally between 0.1 and 0.5 mg/L/yr.

The distribution of significant temporal trends in nitrate concentrations in deep wells and wells of unknown depth is much more variable. In general, the deep wells with significant trends exhibit a similar spatial pattern as is evident in trend data for shallow wells. Areas of increasing trends are apparent to the west of Turlock and between Turlock and Atwater and also in the general vicinity of Modesto. Although some areas have a relatively high number of wells with increasing trends, many of these same areas are interspersed with or have a similar number of wells with a flat or negative trend.

Although the spatial representation of shallow wells with significant temporal trends in TDS concentrations is somewhat sparse, a relatively large number of the shallow wells with significant trends exhibit positive trends of increasing TDS at a rate greater than 10 mg/L/year. Most of these wells are concentrated in the area generally west of Turlock where nitrate concentrations are high and also exhibiting a significantly positive temporal trend.

Significant temporal trends for deep wells in the Central Valley Floor suggest that TDS concentrations in most deep wells are relatively stable with generally flat trends. Numerous deep wells with positive trends exist throughout the Central Valley Floor, but their spatial distribution does not indicate any major patterns.

ES.4.4.4 Other Constituents

The focus of this GAR was on acquiring and summarizing general groundwater quality in the Coalition region 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. However, groundwater quality maps from the USGS Groundwater Ambient Monitoring and Assessment Program investigation reports for the area (Landon et al., 2010; Shelton et al., 2013) are included to illustrate the groundwater quality conditions with respect to some other constituents. Some of these constituents are naturally occurring and some of the constituents detected are related to irrigated agriculture.

ES.4.5 Groundwater Vulnerability

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. These methods are described in the GAR. Notably, two prior determinations of *Hydrogeologically Vulnerable Areas* by the State Water Resources Control Board (SWRCB) and *Groundwater Protection Areas* by DPR are recognized in the WDRs as potentially being considered (among other approaches) as the default designation of the high vulnerability area in the watershed in circumstances where no other scientific method is used and supported by data and analyses that ultimately meet the definition for groundwater vulnerability presented in the WDRs.

ES.4.5.1 SWRCB Hydrogeologically Vulnerable Areas

In 2000, the SWRCB created a map of *Hydrogeologically Vulnerable Areas* in response to Executive Order D-5-99 to identify areas where published literature suggest the presence of soil or rock conditions may make groundwater more vulnerable to contamination. The SWRCB map was updated in 2011. This determination was solely based on published literature and did not involve using a method that independently quantified hydrogeologic vulnerability.

ES.4.5.2 DPR Groundwater Protection Areas

The DPR developed the California Vulnerability (CALVUL) approach to delineation of *Groundwater Protection Areas* (GWPAs) to fulfill parts of a US Environmental Protection Agency (EPA) mandate for states to develop Pesticide Management Plans, including the development of a statewide vulnerability assessment. The CALVUL method 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 199b). From these associations, GWPAs are identified where soil and depth to water conditions suggest a greater potential for contamination. DPR's GWPAs are categorized as *leaching*, *runoff*, or *leaching or runoff* according to likely mechanism 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.

ES.4.5.3 Groundwater Vulnerability for Eastern San Joaquin River Watershed (Central Valley Floor)

ES.4.5.3.1 Approach

The approach for determining groundwater vulnerability in this GAR is modeled after the definition of *intrinsic vulnerability,* which 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 in detail in the GAR.

ES.4.5.3.2 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 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 flat topography, greater ability of soils or subsurface materials to transmit water, greater amount of groundwater recharge, and shallow groundwater are expected to increase 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 and 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 Eastern San Joaquin River Watershed. As an essential nutrient for plant growth, nitrogen is a component in many fertilizers that have 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; therefore, 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. This makes nitrate concentrations a more useful indicator of influence from irrigated agriculture than some other more commonly available groundwater quality measures such as TDS or electrical conductivity.

ES.4.5.3.3 Methods

To determine the groundwater vulnerability of the Eastern San Joaquin River Watershed for this GAR, statistical methods for assessing groundwater vulnerability were aimed at quantitatively describing relationships between physical characteristics of the study area and observed groundwater quality. This approach involved using multiple linear regression (*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. This approach is similar to index methods 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. However, snapshots of past land use conditions at different points in time were used to consider how land use has influenced water quality.

The methods used to determine groundwater vulnerability developed in this GAR are based on adaptations to index-based methods and incorporate “calibration” of the weighting for input variables based on the results from statistical analyses using observed nitrate concentrations. Multiple regression analyses were used to detect significant relationships between hydrogeologic characteristics and the observed nitrate concentration in groundwater across the study area, while controlling for different land use types. Land use categories as mapped for three time periods (mid-1990s, early 2000s, and 2012) were evaluated as controlling independent variables in the multiple regression analyses. Hydrogeologic variables investigated included soil hydraulic conductivity, deeper subsurface hydraulic conductivity, depth to groundwater, groundwater recharge, topographic slope, and Corcoran Clay characteristics. Square root transformation on the dependent variable of observed nitrate concentration created a more normal distribution of dependent variable values and yielded more normally distributed residuals in the multiple regression analyses.

Of the several models developed, the "Shallow Wells Model" performed best by capturing a greater percentage of the nitrate MCL exceedance wells at the 75^{th} percentile and a greater number of nitrate exceedance wells were within close distance from the 75^{th} percentile groundwater vulnerability area from the Shallow Wells Model. Additionally, the Shallow Wells Model fits the conceptual model for groundwater vulnerability better because it is based on nitrate observations in shallow wells only and the range of well depths included in that model is likely to be more limited. Because of the greater influence of soil hydraulic conductivity, results from the Shallow Wells Model indicate generally higher groundwater vulnerability in areas where coarse-textured soils exist from the deposition of sediment by shifting ancestral and modern waterways, which have created a network of alluvial channels and fans. These areas and depositional features typically exhibit a heterogeneous material composition in lateral and vertical dimensions. Such networks of sinuous alluvial channels of coarser material are particularly apparent in the vicinity south and west of Madera and west and south of Chowchilla, which is also evident in the Shallow Wells Model groundwater vulnerability map. This aspect of the Shallow Wells Model was an important consideration in the selection of the model.

ES.4.5.4 East San Joaquin Water Quality Coalition High Vulnerability Area (Central Valley Floor)

A Hydrogeologic High Vulnerability Area (HHVA) was identified for areas where groundwater vulnerability results from the Shallow Wells Model are of 75^{th} percentile or greater. This threshold was established because a natural break in the capture rate for nitrate exceedance wells exists at the 75^{th} percentile level with approximately 68% of exceedance wells fall within this area. The HHVA defines the area where groundwater is most likely to be vulnerable to contamination based on select hydrogeologic characteristics identified in the groundwater vulnerability model. Most nitrate exceedances occur within a short distance from the HHVA suggesting that the HHVA does well in capturing most areas where groundwater quality has been greatly impacted and that other areas of impacts tend to be near the HHVA. To account for some of the ambiguity associated with the vulnerability percentile cutoff for the HHVA and because of the gradational nature (transition from coarse to fine deposits) and intrinsic heterogeneity and discontinuity of the alluvial channel and fan deposits in the area, a 0.5-mile buffer around the HHVA was added in the vicinity of wells where an observed nitrate exceedance has occurred.

These exceedance locations represent areas where groundwater has already been impacted and the buffer takes into consideration the presence of exceedances in proximity to alluvial channels and fans where the vulnerability might not be as well characterized by mapped shallow and surficial geologic materials alone. Areas with alluvial deposits from migrating channels and fans are less likely to have major continuous layers that would prevent or greatly impede the vertical movement of a contaminant into the groundwater, even if the surficial soils and sediments suggest a lower vulnerability. Accordingly, professional judgment was also used in select circumstances to extend the buffer area to include other nearby exceedances.

The combined extents of the HHVA and buffer represent the East San Joaquin Water Quality Coalition High Vulnerability Area (ESJHVA)(**Figure ES-3**). **Table ES-1** compares the area of the ESJHVA to each of the areas designated by the SWRCB and DPR, and also to these areas combined. The table also summarizes the capture of wells with nitrate and pesticide exceedances that is achieved by each of the areas. Individually, approximately 71 percent of nitrate exceedances fall within the DPR area, however only 21 percent of nitrate exceedances fall within the SWRCB area. When combined, the DPR and SWRCB areas capture 82 percent of nitrate exceedances and cover approximately 791,000 acres. By contrast, 98 percent of nitrate exceedances fall within the ESJHVA (including the buffer area, but not including the Tentative High Vulnerability Areas). Within the irrigated lands area, 55 percent of the area is covered by the ESJHVA (plus the buffer area) representing a total of approximately 577,000 acres. Additionally, the ESJHVA captures a considerably larger number of wells with pesticide exceedances than either the DPR or SWRCB areas, and also captures more pesticide exceedance wells than the combined DPR and SWRCB areas.

ES.4.5.5 Prioritization of High Vulnerability Areas

For planning of future monitoring and management efforts focused on the high vulnerability areas and to fulfill requirements of the WDR, all high vulnerability areas were prioritized. These factors included those identified in the WDRs (listed here) as well as others:

- Identified exceedances of water quality objectives,
- 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 agriculture waste discharges that are 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
- 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 to calculate priority values across the high vulnerability area. From these priority calculations, areas were designated as high, moderate, and low priority to inform groundwater monitoring and management efforts (**Figure ES-4**).

ES.4.6 Sources of Information on Existing Groundwater Monitoring Programs

Many entities have conducted groundwater monitoring in the Coalition area, including monitoring on the Central Valley Floor and also in the Peripheral area. The WDR specifies that one year from the approval of the GAR the Coalition shall develop a workplan for conducting trend monitoring that meets the objectives and minimum requirements of the MRP. The objectives for the trend monitoring program include:

1. Determine current water quality conditions of groundwater relevant to irrigated agriculture; and
2. 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:

1. High and low groundwater vulnerability areas in the Coalition area;
2. Use of shallow wells "but not necessarily well completed in the uppermost zone of first encountered groundwater" (WDR R5-2012-0116, Attachment B, IV, C);
3. The potential suitability of existing monitoring networks such as those developed for purposes of AB 3030/SB 1938 groundwater management plans; and
4. The rationale for the distribution of the trend monitoring wells.

The GAR 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 future Groundwater Quality Trend Monitoring Program. As recognized in the GAR, 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.

X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure ES-1 Location Map.mxd

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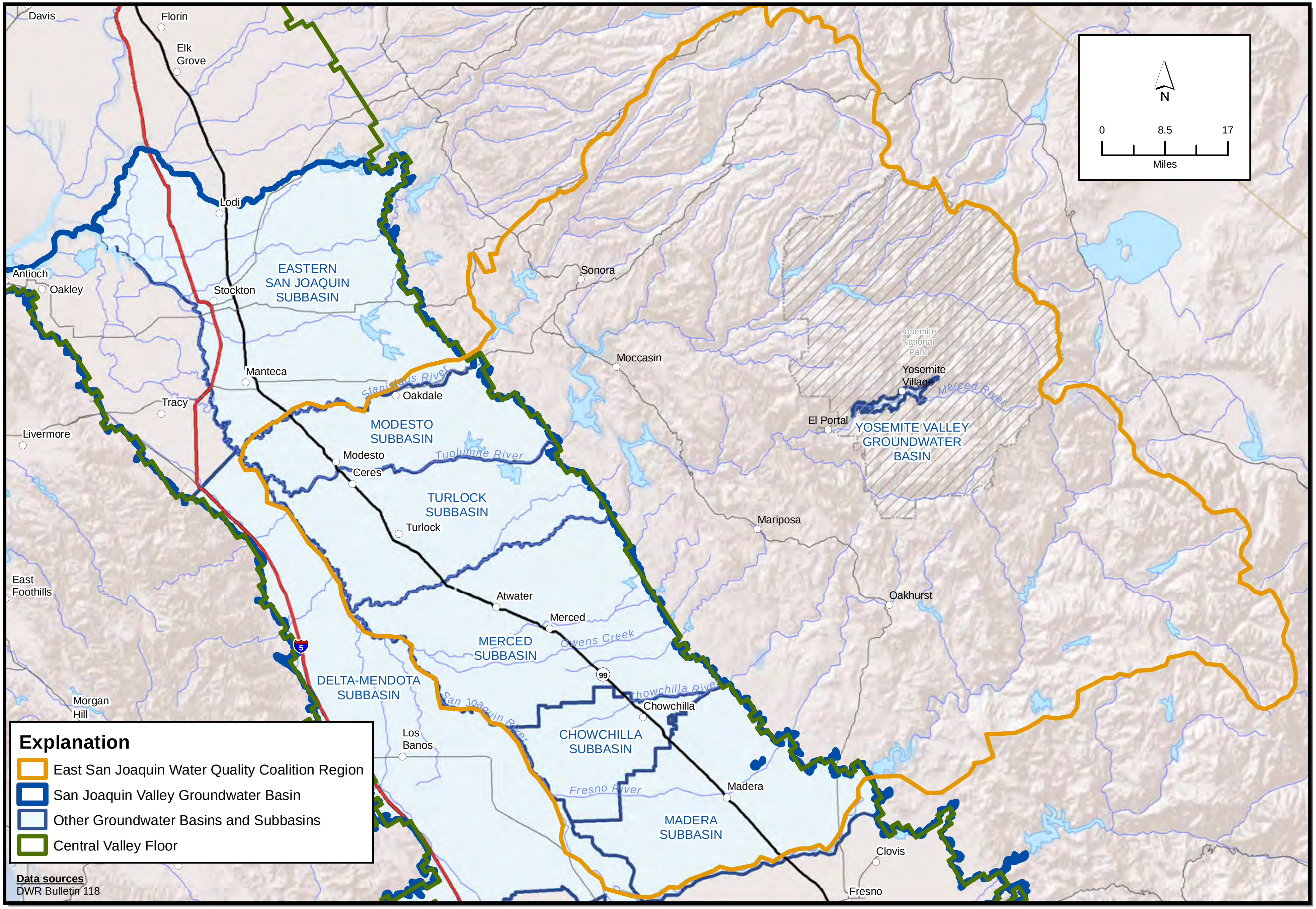
Figure ES-1
East San Joaquin Water Quality Coalition
Location Map



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure ES-2 DWR Designated Groundwater Basins and Subbasins.mxd

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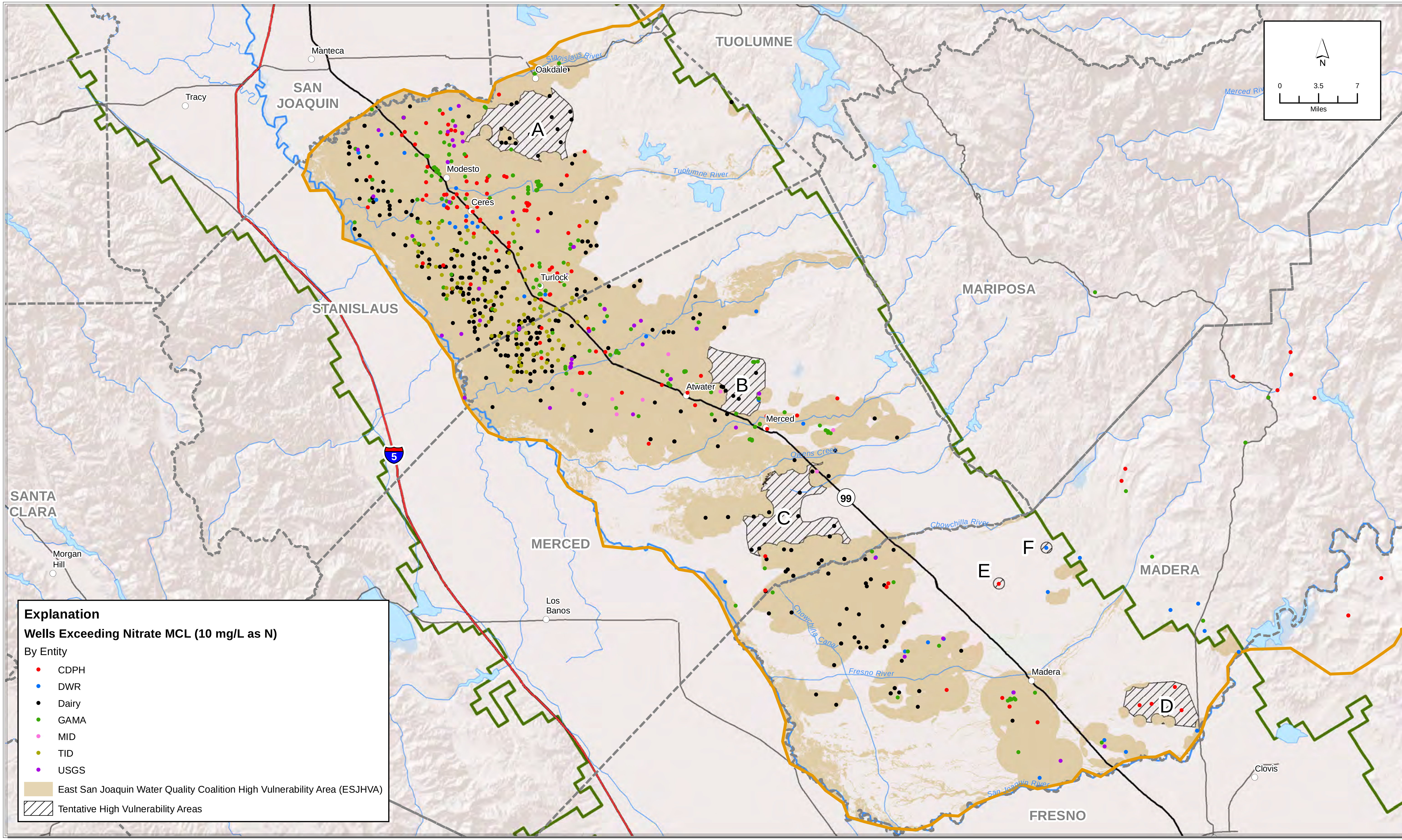
Figure ES-2
DWR Designated Groundwater Basins and Subbasins



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure ES-3 High Vulnerability Area for Eastern San Joaquin River Watershed GAR.mxd

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Figure ES-3
High Vulnerability Area for the East San Joaquin Water Quality Coalition

Table ES-1
Comparison of Vunerability Designations Within the Central Valley Floor

Area Description	Total Acres	Within Irrigated Lands (1,047,574 Acres)				Wells With Nitrate Exceedances Captured By Area Designation (1444 total exceedance wells within Central Valley Floor)	Wells With Pesticide Exceedances Captured By Area Designation (367 total exceedance wells within Central Valley Floor)	
		High Vulnerability (Acres)	Low Vulnerability (Acres)	High Vulnerability (%)	Low Vulnerability (%)		In Sections Where Designated Area Covers At Least 50% Of Section Area	In Sections Where Designated Area Covers Any Part Of Section Area
ESJ High Vulnerability Area (ESJHVA) (Hydrogeologic High Vulnerability Area Plus Buffer)	784,277	576,757	470,817	55%	45%	98% (1412 wells)	97% (357 wells)	100% (367 wells)
Additional Tentative High Vulnerability Areas	70,540	52,615	---	75%	---	2% (32 wells)	0% (0 wells)	0% (0 wells)
Total Tentative High Vulnerability Area (ESJHVA plus tentative areas; area to be considered as the high vulnerability area in this GAR)	854,817	629,372	418,202	60%	40%	100% (1444 wells)	97% (367 wells)	100% (367 wells)
Combined DPR and SWRCB Areas	791,311	568,212	479,362	54%	46%	82% (1182 wells)	89% (327 wells)	92% (339 wells)
SWRCB Hydrogeologically Vulnerable Areas	416,790	295,898	751,676	28%	72%	21% (305 wells)	62% (226 wells)	69% (253 wells)
DPR Groundwater Protection Areas	487,667	354,254	693,320	34%	66%	71% (1030 wells)	66% (244 wells)	66% (244 wells)

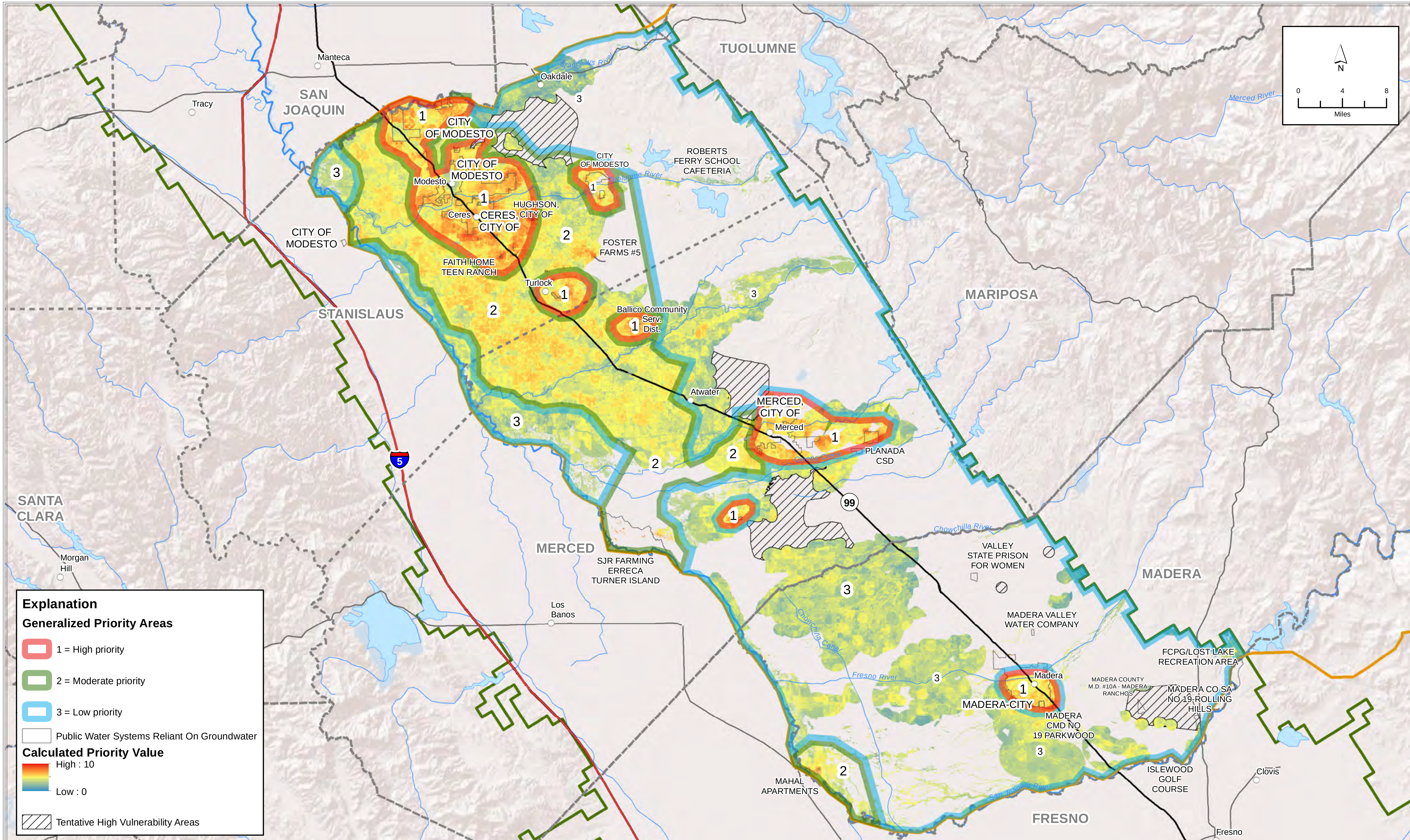

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Figure ES-4
Generalized High Vulnerability Priority Areas

1 INTRODUCTION

This Groundwater Quality Assessment Report (GAR) has been prepared on behalf of the East San Joaquin Water Quality Coalition (ESJWQC or Coalition) in response to Waste Discharge Requirements (WDR), General Order R5-2012-0116 adopted by the Central Valley Regional Water Quality Control Board (RWQCB or Board) on December 4, 2012. This WDR is for the growers in the Eastern San Joaquin River Watershed that are members of the Coalition. The boundary of the Eastern San Joaquin River Watershed generally coincides with that of the Coalition region.

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 Board has coordinated with growers to encourage them to combine resources by forming water quality coalitions. There are 13 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 who are part of one of these 13 coalition groups. The ESJWQC is one of the 13 coalition groups.

1.1.1 Eastern San Joaquin Water Quality Coalition

The Coalition serves as the third-party group for the growers within the Eastern San Joaquin River Watershed although some growers in the Watershed may elect to be regulated as individuals. The Eastern San Joaquin River Watershed has approximately one million acres of irrigated land and approximately 3,900 growers are in this region. Of this acreage, approximately 835,000 acres require regulatory coverage under this Order or other WDRs or conditional waivers of WDRs[3,4]. As of November 2013, 3,971 growers are ESJWQC members, and they occupy approximately 706,000 acres of irrigated lands (**Figure 1-1**).

[3] WDR General Order R5-2012-0116; Findings Item 12.
[4] Approximately 165,000 acres are regulated under the Board's General Order of Existing Milk Cow Dairies (R5-2013-0122)

1.1.2 Waste Discharge Requirements and Other Timelines

Following the Board's adoption of the WDR on December 4, 2012, the Notice of Applicability (NOA) was approved on January 11, 2013. The approval date associated with the NOA starts the timeline for several requirements, including the requirement in the WDR Order (Section IV. A.) that, three months after receiving a NOA from the 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 Groundwater Quality Assessment Report (GAR) outline was April 11, 2013. Additionally, the due date for the GAR is set at one calendar year after approval of the NOA, which for the ESJWQC is January 13, 2014 (the first working day after January 11, 2014).

The GAR outline was submitted by the ESJWQC to the Board on April 11, 2013, and the Board sent a letter on May 6, 2013 approving the GAR outline. The GAR development process is new to both the Board and to the agricultural community. As such, meetings have occurred throughout the process to ensure understanding by the ESJWQC of the requirements and anticipated GAR content, and to maintain an open dialogue with the Board and stakeholders during the GAR development process. Meetings and other coordinated efforts during the process have included:

- Meeting with Board staff to discuss a preliminary GAR outline (March 20, 2013)
- Meeting with the Stakeholder Advisory group to discuss the GAR outline and implementation (April 17, 2013)
- Presentation of an informational item at a Board Meeting, agenda item: *Update on Implementation of the Waste Discharge Requirements for Growers within the Eastern San Joaquin River Watershed* (May 31, 2013)
- Meeting with Board staff and the United States Geological Survey (USGS) to have an open dialogue about opportunities to coordinate monitoring programs, including USGS investigations as part of the Groundwater Ambient Monitoring and Assessment Program and ESJWQC future groundwater monitoring (July 1, 2013)
- Meeting with Board staff to present information on the vulnerability assessment methodology and preliminary vulnerability results (September 17, 2013)
- Coordination with RWQCB regarding data needs from the California Department of Public Health (letter prepared by Board on October 15, 2013 to CDPH explaining data needs for ESJWQC GAR)
- Coordination with RWQCB regarding data needs from Merced County (Board facilitates conference call among Board staff, the County, and ESJWQC and its consultants on October 23, 2013)
- Meeting with Board staff as a follow up to September 17, 2013 meeting to present updated vulnerability results (December 3, 2013)

1.2 Purpose of Groundwater Quality Assessment Report (GAR)

The water resources of the Eastern San Joaquin River Watershed (Watershed) are essential to the livelihood and prosperity of the area, including growers and associated businesses. The ESJWQC GAR is a key piece of its LTILRP, with the focus of this assessment on groundwater conditions and long-term protection of regional groundwater quality. The GAR documents current groundwater quality in the Eastern San Joaquin River Watershed area (with an emphasis on nitrate 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), especially for the area of the ESJWQC within the Central Valley Floor. **Table 1-1** summarizes major requirements of the GAR as identified in the WDR and where they are addressed within this GAR document.

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 for areas located within the Central Valley Floor.

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] and California Department of Pesticide Regulation [DPR]), and presents the method developed for determining high vulnerability areas within the region encompassed by the Coalition boundary. To determine high vulnerability areas, a model for assessing groundwater vulnerability for the Eastern San Joaquin River Watershed was developed through statistical approaches and based on observed groundwater quality and hydrogeologic characteristics. 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 statistical method of determining groundwater vulnerability irrespective of land use also accounts 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 from the mid-1990s to 2012 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.

1.3 Eastern San Joaquin River Watershed

1.3.1 Focus: Central Valley Floor (extent of DWR Bulletin 118 groundwater basins/subbasins)

The study area for the GAR includes the entire Eastern San Joaquin River Watershed region (**Figure 1-1**). **Figure 1-2** also illustrates a key distinction between what is hydrogeologically referred to as the Central Valley Floor (see Central Valley boundary) and areas peripheral to the Central Valley Floor in the Eastern San Joaquin River Watershed. Greater than 99 percent of the DWR-designated groundwater basins and subbasins within the Watershed are located within the Central Valley Floor, and these basins represent the area that is the focus of most of the work for the GAR.

1.3.2 Reconnaissance Discussion in GAR: Peripheral Area to Central Valley Floor

The Peripheral Area to the Central Valley Floor that is within the Coalition boundary will be addressed through a reconnaissance assessment of existing groundwater data. The assessment for this area evaluates groundwater quality data (to the extent available), especially nitrate and salt results for wells on or in the vicinity of irrigated lands.

2 PHYSICAL SETTING

2.1 Location

The East San Joaquin Water Quality Coalition region encompasses an area of approximately 5.7 million acres (8,900 square miles), including approximately 1 million acres of irrigated land within the Eastern San Joaquin River Watershed. The Watershed extends eastward from the San Joaquin River in the Central Valley to the Sierra Nevada crest and is bounded to the north by the Stanislaus River. As shown in **Figure 1-1**, major population centers within the Coalition region are generally located within the Central Valley Floor area and include Modesto, Turlock, Merced, and Madera. The Coalition region also includes smaller communities located within the Central Valley Floor and in the foothills and mountains and encompasses Yosemite National Park.

Elevations in the watershed range from less than 100 feet above mean sea level to over 10,000 feet along the Sierra crest as shown in **Figure 2-1**. The topography in the Coalition region ranges from flat to rolling land within the Central Valley Floor area to steep alpine terrain at higher elevations. Within the Central Valley Floor area, the topography flattens to the west with much of the area having a slope of less than 0.5 degrees (1 percent). Topographic slope within the Central Valley Floor area of the Coalition region is shown in **Figure 2-2**.

2.2 Climate

The climate of the Coalition region ranges greatly from the Central Valley Floor to the higher elevations. Annual precipitation ranges from less than 10 inches in areas of the Central Valley Floor to more than 60 inches at high elevations. A map showing the spatial distribution of average annual precipitation in the area is included as **Figure 2-3**. As seen in **Figure 2-3**, most of the Central Valley Floor area receives less than 14 inches of annual precipitation with many areas having less than 12 inches of annual precipitation. **Figure 2-4** shows average monthly precipitation at Modesto, Merced, and Madera within the Central Valley Floor. Precipitation in the Central Valley Floor occurs mainly during winter months with almost 90 percent of precipitation occurring between November and April.

2.3 Surface water

Major rivers in the Coalition region include the San Joaquin River and its main tributaries the Chowchilla River, Merced River, Tuolumne River, and Stanislaus River, which are shown on **Figure 2-5**. Historical annual streamflows at several stream gage locations within the Coalition region are shown in **Figure 2-5**. Historical average annual flows in the San Joaquin River (based on the available period of record) range from 850-900 cubic feet per second (cfs) below Friant and near Mendota and increase to nearly 4,500 cfs near Vernalis along the northwestern edge of the Coalition region. Merced River average annual streamflow is about 560 cfs above its confluence with the San Joaquin River and Tuolumne River has an average annual flow of more than 1,340 cfs at Modesto. Average annual streamflows in the Stanislaus River at Ripon are 956 cfs.

3 HYDROGEOLOGY

3.1 Geologic setting

The San Joaquin Valley sits near 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 3-1** shows the geology within the Coalition region as generalized from Jennings (1977). **Figure 3-2** shows more detailed geologic mapping focusing on the Central Valley Floor area of the Coalition region. 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 with generally fining in texture towards the axis of the valley (Faunt et al., 2010). Lacustrine and flood plain deposits also exist closer to the valley axis as thick silt and clay layers. Lakes present during the Pleistocene in parts of the San Joaquin Valley deposited great thicknesses of clay sediments that have been commonly referred to as the Corcoran Clay. Resistant sedimentary, metamorphic, volcanic, and crystalline rocks define the foothills and mountains that border the eastern edge of the Central Valley Floor. The regional dip of strata is generally to the southwest.

3.1.1 General Hydrogeologic Setting

The Central Valley Floor and San Joaquin Valley Groundwater Basin are generally defined by the extent of unconsolidated and semi-consolidated continental sedimentary deposits. These deposits are mapped and described as alluvium, sandstone, and conglomerate by Jennings (1977) and are shown in **Figures 3-1** and **3-2**. Groundwater subbasins within the area, as designated by DWR in Bulletin 118, include all of the Modesto, Turlock, Merced, Chowchilla, and Madera subbasin and portions of the Eastern San Joaquin and Delta-Mendota subbasins (**Figure 1-2**). The more consolidated and competent sedimentary, metamorphic, and crystalline rocks define the extent of the groundwater basin and Central Valley Floor area to the east. These rocks occurring outside of the Central Valley Floor have generally low primary porosity and water-yielding characteristics; although the Yosemite Valley Groundwater Basin located outside the Central Valley Floor consists of water-bearing glacial and fluvial deposits of sand, gravel, boulders, silt, and clay that extend over 1,000 feet below the Yosemite Valley floor and can yield considerable water (DWR, 2003). For the purposes of this GAR, areas outside the Central Valley Floor are referred to as the Peripheral Area because they have a very different hydrogeologic environment and considerably different land uses and water demands. Of approximately 1,048,097 total irrigated acres within the Coalition region, all but 523 irrigated acres (1,047,574 acres or 99.95 percent) are located within the Central Valley Floor.

Within the Central Valley Floor, the primary water bearing units consist of Quaternary-aged unconsolidated continental deposits and older alluvium that are present across most of the western portion of the Coalition region. The continental and older alluvial deposits consist of layers of sand, gravel, silt, and clay that increase in thickness away from the margins of the valley. The continental deposits are generally mapped as the Turlock Lake Formation, North Merced Gravel, and Pleistocene non-marine sedimentary units which occur along the eastern edge of the Central Valley Floor as shown on **Figure 3-2**. The extent of the older alluvium is generally represented by geologic units mapped as alluvium, Riverbank Formation, Modesto Formation, and Great Valley deposits shown in **Figures 3-1** and **3-2**. The Corcoran Clay is an extensive clay unit and is believed to separate shallow and deep groundwater systems where it is present. Groundwater in the area generally occurs under confined, semi-confined, and unconfined conditions within primary water-yielding zones. Consolidated sedimentary rocks of lower water-bearing capacity include the Mehrten Formation, Valley Springs Formation, and Ione Formation which occur along the eastern edge of the Central Valley Floor and have lesser importance as a groundwater resource, although the Mehrten Formation, which consists primarily of sandstone, breccia, and conglomerate, is an important aquifer in the area (DWR, 2003).

3.2 Surface and Shallow Subsurface Sediments Characterization

For the purposes of completing the GAR and the required groundwater vulnerability assessment component, available information and data on surface and subsurface sediments were acquired and assembled. Because of the hydrogeology of the surrounding mountains, generally low water-bearing nature of rocks outside the Central Valley Floor area, and lack of irrigated agriculture in these areas, the characterization of subsurface materials and groundwater vulnerability assessment were limited to within the Central Valley Floor. Sources of data used to characterize the surface and subsurface sediments in the area consisted primarily of county soil surveys completed by the Natural Resource Conservation Service (NRCS), subsurface sediment texture model data from the USGS Central Valley Hydrologic Model (CVHM), and thickness and depth characteristics of the Corcoran Clay as represented in the CVHM (Faunt et al., 2009).

3.2.1 <u>Soils</u>

3.2.1.1 Soil Hydraulic Conductivity

Figure 3-3 shows the hydraulic conductivity of soils as derived from NRCS soil surveys within the Central Valley Floor area of the Coalition region. Hydraulic conductivity is a measure of the ability of a material to transmit water; the greater a material’s hydraulic conductivity, the faster water moves through the matrix of the material. Notably, the NRCS soil survey data presented in

Figure 3-3 show the presence of numerous long and narrow coarser-textured deposits of higher conductivity resulting from modern and ancient stream channel depositional processes. Additionally, the historic lateral migration of alluvial channels has formed large fans of high conductivity soils. One area of particularly high conductivity soils is located north and west of Atwater and in association with the Merced River channel and alluvial fan network. Several other notable areas of high hydraulic conductivity soils exist in association with the Tuolumne River system in the general vicinity and to the east of Modesto and Ceres, as a result of stream channel deposition related to the Chowchilla River system, and near Madera in association with the river system of the current Fresno River. Many other sinuous stream channel deposits of coarse material are shown as high conductivity areas across the Central Valley Floor area of the Coalition region in **Figure 3-3**.

3.2.1.2 Soil Chemistry

Figure 3-4 shows the spatial distribution of soil salinity within the Central Valley Floor area of the Coalition region, as derived from NRCS soil surveys. Salinity is a measurement of the amount of salt present in soil, and is estimated by measuring the electrical conductivity (EC) of the soil. From an agricultural standpoint, salinity of the soil is important because it can greatly impact the ability of the soil to support crops. While crops vary in their tolerance for elevated soil salinity, the productivity of most crops becomes impacted when EC levels are above 4 decisiemens per meter (dS/m), although some more sensitive crops may have declining yields at lower salinity levels (Waskom et al., 2012).

Areas of higher soil salinity are largely limited to the western portion of the Central Valley Floor area of the Coalition region, and particularly in the southwest. Large areas of high salinity soils are also located south of Atwater and Merced, and to the west of Madera. A smaller area of soils with high salinity is present west of Turlock.

The spatial distribution of soil pH, as derived from NRCS soil surveys, is shown in **Figure 3-5** for the Central Valley Floor area of the Coalition region. Soil pH is a measurement of the concentration of hydrogen ions present in soil. A pH in the range of 7 is considered neutral with increasing pH levels indicating more alkaline soil conditions and decreasing pH values indicating more acidic soil conditions. Crops vary in their ability to tolerate levels of soil pH; however, most crops grow best when the soil pH is slightly acidic at a value between 6 and 7 and highly alkaline soils (pH > 7.8) can affect plant health.

Soils are mainly in the neutral pH range from 6.6 to 7.5 throughout a large part of the Central Valley Floor of the Coalition region. However, considerable areas of alkaline soils are present. The most alkaline soils (higher pH) are generally located in the western portion of the Central Valley Floor area of the Coalition region, particularly to the south of Atwater and Merced and to the west of Madera. Other areas of alkaline soils are present to the west and southwest of

Turlock. More acidic soils (lower pH) are generally located in the northern and eastern portions of the Central Valley Floor area of the Coalition region. Areas of greatest soil acidity exist to the northeast of Merced and along the eastern margins of the Central Valley Floor within the Coalition region.

3.2.2 Subsurface Sediments

3.2.2.1 CVHM Hydraulic Conductivity

The characteristics of subsurface sediments below the soil layers are more difficult to describe and map in a spatially continuous manner because it must be inferred and interpolated from available boring information. As part of the development of the CVHM, Faunt et al. (2009) created a three-dimensional sediment texture model to characterize the valley-fill deposits within the Central Valley Floor area. This model incorporated interpretation and interpolation of lithologic data from numerous well drillers' logs and other available data to develop a layered spatial representation of subsurface hydraulic conductivity at a horizontal grid scale of one-square mile and approximately 50-foot thickness intervals. Data from the texture model were compiled into layers for use in the CVHM. For the purposes of understanding the relationship between irrigated agriculture and groundwater quality, particularly the hydrogeologic vulnerability, the characteristics of the uppermost layer of the CVHM are of greatest interest in this GAR. In the Coalition region, Layer 1 of the CVHM generally extends to a depth of 50 feet, and **Figure 3-6** shows the vertical hydraulic conductivity as represented in Layer 1 of the CVHM.

3.2.2.2 Corcoran Clay

The Corcoran Clay is a prominent stratigraphic layer that exists in parts of the Central Valley and is generally believed to divide deeper groundwater zones from shallow groundwater zones, where it exists. The spatial extent, thickness, and depth to the top of the Corcoran Clay in the Coalition region, as depicted in the CVHM, are shown in **Figures 3-7a** and **3-7b**. The Corcoran Clay is generally present only in the western portion of the Central Valley Floor area, approximately west of Highway 99 as shown on **Figure 3-7a** and **3-7b**. Depth to the top of the Corcoran Clay generally increases towards the center of the valley and ranges from less than 50 feet along parts of its eastern extent to more than 300 feet below ground in the southwest portion of the Central Valley Floor area as illustrated in **Figure 3-7a**. The thickness of the Corcoran Clay also increases towards the axis of the valley as shown in **Figure 3-7b**. Two areas where the Corcoran Clay is thickest are located generally to the west of Turlock and also to the south of Turlock where the thickness is generally greater than 60 feet with some thicker areas of 100 feet or more. Although the lateral extent of the Corcoran Clay is generally greater farther south, the unit tends to thin with many areas of less than 40 feet thickness, particularly across most of the eastern part of its southern extent.

3.2.3 Known Tile Drains

The presence of shallow or perched groundwater in parts of the San Joaquin Valley has led to the installation of tile drains in some areas. Readily available data sources were researched in an attempt to identify locations of known tile drains within the Coalition region. **Figure 3-8** shows the locations of identified tile drains based on DWR water quality sampling points. This map shows the presence of tile drains throughout much of the Sacramento Delta area and in areas west of the San Joaquin River. However, these data do not show the existence of any tile drains within the Coalition region, although the presence of shallow groundwater conditions and shallow wells used by irrigation districts to drain the shallow groundwater is discussed below as it relates to groundwater level data. Tile drains apparently exist along the western edge of the Coalition region, although specific locations for these features are not known.

3.3 Groundwater Hydrology

3.3.1 Groundwater Levels

An important aspect of characterizing the condition of groundwater resources within the Coalition region includes understanding groundwater levels. Data on groundwater levels provide foundational information with which to interpret and understand hydrogeologic conditions, including spatial and temporal patterns in flow direction, groundwater level trends, potential groundwater recharge and discharge areas, and other conditions. In order to characterize historical and present groundwater conditions for the GAR, groundwater level data for the Coalition region were gathered from available data sources.

3.3.1.1 Groundwater Level Dataset

Groundwater level data from all readily available sources were acquired. Available public data sources include DWR's Water Data Library (WDL) and California Statewide Groundwater Elevation Monitoring (CASGEM) database, USGS's National Water Information System (NWIS), and SWRCB's Geotracker database (GAMA). Local entities such as county public health and environmental departments and irrigation districts were also contacted about available data not included in the public databases. Through this process, additional water level data were acquired from Merced Irrigation District (MID) and Turlock Irrigation District (TID). Data requests to local entities were limited to data readily available in electronic format such as databases and spreadsheets with a focus on acquiring groundwater level data previously not reported to or available through public databases. During this process, TID provided considerable water level data, including measurements of groundwater levels from drainage wells and from a network of shallow (15-foot deep) groundwater monitoring wells located on section corners. Although no well depth information was provided with the drainage well data from TID, the drainage wells measured by TID were said to be generally less than 200 feet deep. Additional water level data were also provided by MID for use in preparation of the GAR. No additional data were acquired from local county agencies, although the Merced County Health Department maintains an extensive database of water level measurements, especially for domestic wells. Because of confidentiality agreements with well owners, Merced County could not provide data with any specific location or construction information for the wells. Because of this major limitation, these data from Merced County were not useful for this GAR. Oakdale Irrigation District (OID) also conducts groundwater level monitoring in wells and reports data to CASGEM; many of these water level data from OID were acquired through the CASGEM database.

In addition to water level measurement data, spatial datasets representing groundwater levels as developed by the California Department of Pesticide Regulation (DPR) and DWR were also reviewed and evaluated. These included interpolated groundwater level data from the DPR Environmental Hazards Assessment Program, Depth to Groundwater Database (DPR, 2000) and from DWR contour maps for select areas of available data, primarily in the western part of the Central Valley Floor area within the Coalition region.

Water level data consisting of more than 325,000 measurements from over 7,000 wells within the Coalition region were assembled into a database. **Table 3-1** summarizes the number of wells and water level measurements acquired from each source. The spatial distribution of these data is shown in **Figure 3-9**. Of these data, only a relatively small number of wells have available information on well construction such as depth or screened interval. However, for the purposes of differentiating and evaluating water level trends within the shallower part of the aquifer system from those within the relatively deeper part of the aquifer system, the depth category for all wells was interpreted from available information in the database. Wells were assigned into three general well depth categories: shallow, deep, and unknown. Shallow wells were defined to be wells with known depths less than 200 feet and also included well use categories of domestic wells, monitoring wells, and TID drainage wells (because of anecdotally provided information about general well depth) when well depth was not provided. Deep wells included wells with depths greater than 200 feet and also municipal wells, irrigation wells, or other well uses indicating a greater likelihood of a well being deeper than 200 feet. Wells without any further information with which to assign them into either the shallow or deep category were designated unknown. A summary of these data by source, well use, and depth category is presented in **Table 3-1**.

The greatest number of wells in the water level dataset are from DWR's WDL, and these data also represent the oldest water level data available, extending back into the early 1900s. The number of monitored wells and the total number of measurements peaked in the 1970s and has subsequently declined. TID also has extensive shallow groundwater level data beginning in the 1950s which represents approximately half of the total number of water level measurements in the dataset (**Table 3-1**). In contrast to the decline in DWR groundwater level monitoring since the 1970s, TID has maintained a relatively consistent groundwater level monitoring network with approximately 300 wells monitored and an average of about 2,500 measurements per year through all decades as summarized in **Table 3-1**. The groundwater level data from MID also begin in the 1950s with between 200 and 400 wells monitored during this time.

The spatial distribution of groundwater level data by data source is presented in **Figure 3-9**. This map shows the localized areas where TID and MID monitor groundwater levels in comparison with the more spatially distributed nature of the groundwater level data from DWR (including CASGEM), USGS, and GAMA. The distribution of groundwater level data by year is displayed in **Figure 3-10**. These figures illustrate the great spatial and temporal variability in the available groundwater level data.

3.3.1.2 Development of Groundwater Level Contours

As a foundational element of the GAR, a spatially complete representation of current groundwater levels across the Coalition region 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 depletion/recharge. All of these factors can contribute to groundwater levels changing on short- and long-term temporal scales. An attempt was made to capture the spatial trends in current groundwater levels under spring and fall seasonal conditions in the form of interpolated groundwater levels across the Central Valley Floor area of the Coalition region. The development of these spatial datasets was limited to the Central Valley Floor since this is where the majority of irrigated agriculture exists and also because the hydrogeologic environment within the Central Valley Floor area is different from the Peripheral Area of the Coalition region.

A spatially continuous depth to groundwater surface was developed from the assembled water level data using Geographic Information Systems (GIS) spatial analysis tools and capabilities provided within the ArcGIS (ESRI, ArcGIS 10.1) software program. Variability in the spatial and temporal distribution of the groundwater level data is considerable as discussed above and shown in **Figures 3-9** and **3-10**. Because of this, a hierarchical approach to interpreting the recent groundwater level surface was used. Furthermore, for the purposes of this GAR and the groundwater vulnerability assessment, a specific focus and priority on recent shallow groundwater levels was followed. Data from wells classified as shallow with groundwater level measurements collected between 2000 and 2013 were selected first. The average recent spring and fall season water levels were calculated separately for each well over this time period. Because these data did not provide complete spatial and temporal coverage, incorporation of data from deeper wells or wells of unknown depth was required in order to develop a complete spatial representation of groundwater levels across the Central Valley Floor area. Data from wells with deep or unknown construction and also older water level measurements were included in a stepwise manner. A 2-mile buffer was created around the shallow wells with recent measurements. Outside of this buffer, deep wells or wells with unknown depth that had measurements in the 2010s were selected and the average water level was determined for each well. This process was continued with water level data in the 1990s, 1980s, and 1970s. Wells that had only measurements from prior to 1970 were not included. For areas that lacked data, particularly near the study area boundary, nearby well data outside of the study area were used to estimate water levels. From these point data, a continuous depth to groundwater surface was interpolated using the Natural Neighbor point interpolation method (ESRI, ArcGIS 10.1, Spatial Analyst) and contoured.

3.3.1.3 Spatial Patterns in Depth to Groundwater

3.3.1.3.1 Central Valley Floor

Contours of the most recent spring depth to groundwater conditions developed from available data, as described above are shown in **Figure 3-11**. The spring depth to groundwater contours in **Figure 3-11** show extensive shallow groundwater levels (<20 feet below ground surface [bgs]) in the northwestern part of the Coalition region near Turlock and westwards toward the San Joaquin River. Another area of considerable shallow groundwater exists in the general vicinity of Merced and along Owens Creek and its tributaries. **Figure 3-11** also highlights other more localized areas of shallow groundwater evident along waterways, most notably along the Stanislaus River, Merced River, and San Joaquin River. Depth to groundwater tends to be deeper to the east and away from San Joaquin River. Two notable pockets of deeper groundwater are apparent to the east of Turlock, in the vicinity of Chowchilla, and between Merced and Madera in the more southerly portion of the area. Similar spatial patterns are evident in the contours of fall depth to groundwater as shown in **Figure 3-12**. However, as expected, the depth to groundwater is generally greater in the fall than in the spring indicating seasonal lowering of groundwater levels.

In 2000, DPR developed a depth to groundwater map for California's Central Valley (DPR, 2000). The well data used were from DPR's Environmental Hazards Assessment Program (EHAP), which included approximately 260,000 spring season water level measurements collected since 1987. The major source of the data in EHAP's database comes from DWR's Division of Long Planning and Assistance (DLPA). **Figure 3-13** shows a contour map of depth to groundwater, based on the analysis by DPR. These contours show similar spatial patterns in groundwater levels as those developed for this GAR and illustrated in **Figure 3-11**. DPR depth to groundwater contours also show extensive shallow groundwater levels in the northwest towards the San Joaquin River, deeper groundwater levels to the east, and subregional groundwater level depressions to the east of Turlock, and southeast of Merced. These spatial patterns in groundwater levels are also generally consistent with contour maps of groundwater levels in the area published by DWR for 2008 through 2010 (DWR, 2012a and 2012b; DWR, 2011; DWR, 2008).

Figure 3-14 shows areas of potential groundwater discharge where the current depth to groundwater contours indicate shallow groundwater conditions (<10 feet bgs). Particularly notable areas where groundwater is within 10 feet of the ground surface are evident from **Figure 3-14** in the vicinity of Turlock and along lower reach sections of many tributary rivers to the San Joaquin River, including the Stanislaus, Tuolumne, Merced, and Fresno Rivers. As a result, some of these tributary reaches may experience gaining conditions during some times. A number of sections of the San Joaquin River also have shallow groundwater conditions which may result in groundwater discharge areas along or near the river. These general patterns are similar to those depicted by DWR groundwater level contour maps (2010a; 2010b).

3.3.1.3.2 Peripheral Area

Because of the relatively sparse spatial distribution of available water level data, and the different hydrogeologic environment of the Peripheral Area in which groundwater commonly occurs in and moves through networks of fractures, interpreting spatial patterns can be challenging and misleading since groundwater conditions can be highly localized. Therefore, groundwater levels outside of the Central Valley Floor were not contoured. However, available recent water level data points in the Peripheral Area are shown in **Figure 3-15** to illustrate some of the general groundwater level conditions in the area. Because of the hydrogeologic environment of the Peripheral Area, differentiation of groundwater resources into shallow and deep zones is also not as meaningful. **Figure 3-15** shows the average depth to groundwater value within the Peripheral Area for wells of all depth, regardless of time of year. This map shows a wide range of average depth to groundwater values ranging from shallow to greater than 700 feet below ground surface. The shallowest groundwater levels generally occur in valleys and deeper water levels are generally in upland areas away from waterways.

3.3.1.4 Groundwater Flow Directions

The continuous depth to groundwater spatial dataset and associated contours generated for recent spring and fall time periods as described above were used to calculate groundwater elevations across the Central Valley Floor area and for estimating groundwater flow direction. The depth to groundwater level GIS raster surface was subtracted from the USGS National Elevation Dataset (NED) 10-meter resolution digital elevation model (DEM) to calculate the groundwater elevation. In an effort to represent more regional flow paths rather than more localized anomalies, the depth to groundwater raster and DEM raster were both smoothed prior to performing this calculation. The smoothing operation involved resampling each dataset at a 1-mile spatial resolution using cubic interpolation. Then the depth to groundwater raster dataset was subtracted from the DEM. Finally, the calculated groundwater elevation raster dataset was resampled at a spatial resolution of 400-meter cells using cubic interpolation in order to represent the dataset at a higher resolution for mapping and interpretation of groundwater flow directions.

Figures 3-16 and **3-17** show contours of the calculated recent spring and fall groundwater elevations within the Central Valley Floor area. These figures show a steeper groundwater surface with greater hydraulic gradients in the eastern part of the Central Valley Floor area with the presence of some notable local groundwater depressions, particularly in the vicinity of Chowchilla, between Merced and Madera, and east of Turlock. The hydraulic gradient of the groundwater surface generally flattens to the west, particularly in the northern and western part of the Coalition region. Arrows on **Figures 3-16** and **3-17** show the interpreted directions of groundwater flow under spring and fall conditions based off of the contour maps. Both spring and fall groundwater elevation contours indicate that groundwater generally flows in a southwestern direction away from the hills and mountains to the northeast.

3.3.1.5 Temporal Groundwater Level Trends

3.3.1.5.1 Shallow Wells

Select hydrographs illustrating temporal groundwater level trends in shallow wells across the Central Valley Floor area are shown in **Figure 3-18**. Hydrographs shown on **Figure 3-18** are displayed with different ranges of vertical axis values. A relatively consistent pattern in declining groundwater levels are exhibited in many of the shallow wells with longer periods of record. The areas of greatest decline are on the eastern side of the Central Valley Floor and in the southern part of the Coalition region where some wells show declines in groundwater levels of greater than 100 feet since the 1960s and 1970s. Further north and where groundwater is generally shallower, historical water level declines are more moderate. Notable responses in shallow water levels to periods of wet (early to mid-1980s, mid- to late 1990s) and dry (late 1980s to early 1990s) climatic conditions are also evident in many well hydrographs. Additionally, considerable shorter-term fluctuations in water levels over seasonal timeframes are evident in most wells.

3.3.1.5.2 Deep Wells

Figure 3-19 presents select hydrographs illustrating temporal groundwater level trends in deep wells. Again, hydrographs shown on **Figure 3-19** are displayed with different ranges of vertical axis values. However, as seen in shallow wells, there is an overall similar temporal and spatial pattern of generally declining groundwater levels in deep wells evident from many of the hydrographs in **Figure 3-19**. Wells in the northern part of the Central Valley Floor area have groundwater levels that fluctuate in response to seasonal and climatic conditions, including periods of water level decline and recovery, and show a relatively stable to slightly declining trend in water levels over the long term. To the south, and particularly along the eastern side of the Central Valley Floor area, conditions of consistent long-term decline in groundwater levels are more apparent since the 1960s with levels dropping as much as 100 feet during this time. But overall, groundwater level declines in deep wells appear to be less extreme than the water levels declines evident in shallow wells. Response to long-term periods of wet (early to mid-1980s, mid- to late 1990s) and dry (late 1980s to early 1990s) climatic conditions and shorter-term fluctuations on a seasonal time scale are also apparent in deep well hydrographs.

3.3.2 Recharge to Groundwater

The primary process for groundwater recharge within the Central Valley Floor area is from percolation of applied irrigation water. Groundwater recharge estimates made by DWR (2003) for each of the five main groundwater subbasins within the Coalition region indicate that natural groundwater recharge represents a relatively small fraction of total recharge when compared with estimates of recharge from applied water. Annual natural recharge estimates made by DWR for the five main groundwater subbasins within the Coalition region total 274,000 acre-feet (af) (Modesto: 86,000 af, Turlock: 33,000 af, Merced: 47,000 af, Chowchilla: 87,000 af, Madera: 21,000 af). In contrast, estimates of average annual recharge from applied water for these subbasins totals 1,231,000 af (Modesto: 92,000 af, Turlock: 313,000 af, Merced: 243,000 af, Chowchilla: 179,000 af, Madera: 404,000 af).

The modeled net recharge within the Central Valley Floor area from the CVHM output is shown in **Figure 3-20**. This map depicts model-simulated annual net recharge in units of inches at a one square mile grid scale with values ranging from below negative 20 inches per year to greater than 20 inches per year. The areas of highest net recharge correspond with areas of high vertical hydraulic conductivity in CVHM model layers (as shown for CVHM Layer 1 on **Figure 3-6**) and also areas where depth to groundwater is generally deeper (as shown in **Figures 3-11** and **3-12**). Conversely, negative net recharge values are generally in areas where groundwater is shallow resulting in greater evapotranspiration of water within the root zone and potential discharging of groundwater.

Areas with high potential for groundwater recharge within the Central Valley Floor area of the Coalition region are shown in **Figure 3-21**. The areas of potential groundwater recharge are based on mapped areas of high soil hydraulic conductivity (harmonic mean of saturated soil vertical hydraulic conductivity >2 feet/day) which overlie mapped unconsolidated geologic units, mainly alluvium. High conductivity soils are shown in blue in **Figure 3-21** and occur along many of the main tributary river channels and as the result of distributary channel and fan deposition. The areas where the greatest potential for groundwater recharge exists are areas where these high conductivity soils overlie unconsolidated alluvium which functions as the primary aquifer system in the area. Where the Corcoran Clay exists (**Figure 3-21)**, groundwater recharge is more likely to be limited to shallow groundwater zones. As a result, the areas with potential for deep groundwater recharge are more likely to be located in the eastern part of the Central Valley Floor where the Corcoran Clay is not present.

3.3.2.1 Recharge Areas Upgradient of Public Water Systems Reliant on Groundwater

In addition to the utilization of groundwater for agricultural irrigation, another important beneficial use for groundwater within the Coalition region includes use for public and domestic drinking water supply. For the purpose of understanding and prioritizing impacted areas of groundwater, the groundwater elevation raster dataset developed for the Central Valley Floor area was used to identify areas of groundwater recharge located upgradient from public water systems that are reliant on groundwater. The spatial extent of public water systems reliant on groundwater from CDPH's California Environmental Health Tracking Program (CEHTP) Public Water Systems Boundary Tool (CDPH, 2013a) was used as the basis for defining contributing groundwater areas to public water supply systems. The contributing areas were developed for all water systems within the CEHTP database with groundwater as a source, including active, inactive, and standby sources (**Table 3-2**). Contributing areas to all public drinking water systems in the CEHTP database that rely on groundwater were defined using hydrology tools within ArcGIS based on the recent spring groundwater elevation raster dataset developed for the Central Valley Floor area, as described above. Horizontal flow direction was determined for the recent spring groundwater elevation raster dataset at a grid cell level based on the steepest downslope neighbor using ArcGIS hydrology tools. The flow direction calculation was generalized to 400 meter cells in order to achieve consistent and contiguous flow directions. The watershed function within the ArcGIS hydrology tools was then used to estimate contributing groundwater areas to these identified public drinking water systems that are reliant on groundwater. The watershed tool estimates the contributing upgradient areas for a set of user defined points; vertices of the water system polygons were used for this analysis, and the contributing areas for all points were combined. Through this process the contributing area to each public water system reliant on groundwater area was defined as shown on **Figure 3-22**.

4 LAND USE

Characterizing changing land use conditions over time is important for understanding past, current, and future groundwater quality. Land use activities can have a range of effects on groundwater quality; documenting the spatial distribution of land use and assessing the intensity of effects from different land uses on the groundwater quality are important for development of effective groundwater quality monitoring and management strategies. Additionally, documenting past and present land use is critical in assessing groundwater vulnerability, which is discussed in detail in **Section 6**.

4.1 Agriculture Within the Coalition Region

Agriculture is a dominant source of industry within the Coalition region, and the agricultural crop value produced within the Coalition region in 2011 was estimated by the California Department of Food and Agriculture (CDFA) to be more than 2.1 billion dollars (A. Gunesakara, personal communication). The top crops within the Coalition region in 2011 by value included almonds ($289 million), table and raisin grapes ($282 million), wine grapes ($202 million), corn ($137 million), and alfalfa ($115 million) and numerous other crops with values less than $100 million. In 2011, almonds were also the top crop by acreage with over 213,000 acres estimated in the Central Valley Floor, nearly twice the next highest commodity. Corn, alfalfa, cotton, and wine grapes are the next most common crops by acreage. **Figure 4-1** summarizes the top ten commodities within the Coalition region by value and by acreage.

4.2 Land Use Data

4.2.1 DWR Land Use Data

To document and evaluate the spatial distribution of past and recent land use across the Coalition region, data from county land use surveys conducted periodically (every five to ten years) by DWR were used. DWR land use surveys are conducted through on-ground visual identification. The main surveyed counties with available data in the Coalition region include Alpine (2001), Calaveras (2000), Fresno (1986, 1994, 2000, 2009 East), Madera (1995, 2001, 2011), Mariposa (1998), Merced (1995, 2002), Stanislaus (1996, 2004), and Tuolumne (1997). The three counties making up the Central Valley Floor include Madera, Merced, and Stanislaus counties; each of these counties has two or more surveys conducted between the mid-1990s and early 2000s. Past land use condition was compiled for two land use time snapshots for Madera, Merced, and Stanislaus Counties: the mid-1990s, which includes 1995 and 1996 surveys and for the early 2000s, which includes 2001, 2002, and 2004 surveys. Over 70 crop types and land uses are reported in the compiled land use survey snapshots. Sometimes irrigation methods are also recorded in the surveys. No irrigation method data were recorded for surveys from the mid-1990s, but some irrigation method information was available in the early 2000s survey data.

4.2.2 USDA Land Use Data

Because DWR land use surveys are only conducted on a periodic basis, land use data from the 2012 US Department of Agriculture (USDA) California Cropland Data Layer were used to represent current land use conditions. The USDA land use data are produced in a different way from the DWR land use surveys. These data are developed using satellite imagery and sensor data from which unique aspects or signatures for crop types are identified. Through this process, crop type or land use type can be identified to a spatial resolution of 56 meters, or 0.77 acres. The digital analysis and results process are verified through ground-truthing and the accuracy for the 2012 dataset is reported to be approximately 84 percent.

4.2.3 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 12 main categories based on some general similarities in agricultural practices and estimated typical nitrogen application rates. **Table 4-1** 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. Within the Central Valley Floor area, the largest land use category is non-agricultural followed by nut trees. Vegetables represented approximately nine to ten percent of the Central Valley Floor area between the mid-1990s and early 2000s based on DWR data. In the 2012 land use data from the USDA, many vegetable crops are mapped as “double crops”. As a result, the percent of vegetable crops in the area as identified by USDA in 2012 is only three percent; however, the combined percent of vegetables and double crops in 2012 is a little over 7 percent and more consistent with the DWR land use data for the mid-1990s and early 2000s. It should be noted that the extent of dairies as mapped in the land use surveys by DWR generally represents the extent of the dairy waste management units (animal corrals, waste lagoons, etc.) and does not represent the full extent of dairy-owned land which may be under cultivation or used in other ways by a dairy.

4.3 Land Use Change

Changes in land use between the mid-1990s and 2012 are most clearly illustrated in **Figures 4-2** through **4-5**. **Figure 4-2** shows the changing acreage by land use category within the Central Valley Floor area. Nut trees have shown the largest increase in acreage during this time and particularly since the early 2000s. As of 2012, there were nearly 400,000 acres of nut trees making up over 23 percent of the Central Valley Floor area within the Coalition region. Grasses were the second highest land use category in the mid-1990s at approximately 12 percent of the Central Valley Floor area but have declined since that time, and in 2012 grasses only represented about eight percent of the area. Vegetables, when combined with double crops as identified by USDA, exhibit only a modest overall decline in acreage since the mid-1990s, although there was an increase in vegetables between the mid-1990s and early 2000s.

The spatial distribution of land use at each of the three land use snapshots (mid-1990s, early 2000s, and 2012) are shown in **Figures 4-3** through **4-5**. As discussed above, there are differences in methodology and land use identification systems between the DWR and USDA land use surveys shown in these figures. However, as highlighted in the graph of land use change discussed above, (**Figure 4-2)**, some major differences in the spatial distribution of land use in 2012 are apparent in **Figure 4-5**, especially the presence of many areas identified as double crops in 2012 that were mapped as vegetables in the mid-1990s and early 2000s. Also notable are the increased areas of nut trees in 2012 throughout the Central Valley Floor and particularly in the southern part of the Coalition region.

4.4 Predominant Commodities

Table 4-2 shows the top agricultural crop categories within the Central Valley Floor portion of the Coalition region as derived from the USDA 2012 land use data and their cumulative percentages by land area. As mentioned above and also shown in **Table 4-2**, nut trees are the top category by land area, followed by grains/cotton, grasses, and grapes. These four categories represent the top 86 percent of agriculture by acres within the Central Valley Floor area of the Coalition region. As a result, these four categories were also used in the prioritization of high vulnerability areas as specifically mentioned in the WDR and discussed below in **Section 6**.

4.5 Irrigation Practices

Available irrigation method data from the early 2000s DWR land use surveys were used to evaluate irrigation practices. The spatial distribution of irrigation practices in the Central Valley Floor portion of the Coalition region is shown in **Figure 4-6**. **Table 4-3** and **Figure 4-7** summarize the irrigation method by agricultural crop category based on the early 2000s DWR data. As of the early 2000s, the predominant irrigation practice was basin/furrow irrigation, representing the irrigation method used on approximately 65 percent of the irrigated lands area. Sprinkler irrigation and micro/drip represented the irrigation method used on 23 percent and 12 percent of the irrigated area, respectively. By crop category, grasses, grains/cotton, and vegetables all relied heavily on basin/furrow irrigation as of the early 2000s. Nut trees and citrus/subtropics used mostly sprinkler irrigation, while grapes and fruit trees used mainly micro/drip and sprinkler. Although complete recent data on irrigation methods are not readily available, the data on land use and agricultural practices provided by the Coalition were also evaluated and used (ESJWQC, personal communication). These data included information assembled at various levels of detail from grower member reporting such as crop type grown, number of irrigated acres, Best Management Practices (BMPs) being utilized (based on a 2007 survey), and irrigation methods from surveys between 2009 and 2012. The summary of irrigation method data maintained by the Coalition suggests a more recent shift in irrigation practices being used by the Coalition members. Although the data represent a smaller sample size of irrigation practices (10 percent of the irrigated land within the Coalition region), they suggest a potentially large shift in irrigation practices towards micro/drip as shown in **Table 4-3**.

4.6 Fertilization Practices

The estimated nitrogen fertilizer use from the late 1980s to mid-2000s for the three counties of Merced, Madera, and Stanislaus that make up the Central Valley Floor portion of the Coalition region is illustrated in **Figure 4-8**. The data presented in **Figure 4-8** represent estimated nitrogen fertilizer use and were compiled by the USGS from county fertilizer sales in the area (Gronberg and Spahr, 2012). These data show generally stable levels of fertilizer use in these counties between the late 1980s through late 1990s with a trend towards increasing use during the early 2000s and peaking in 2004. Nitrogen fertilizer use appears to have decreased after 2004.

Table 4-1 shows typical ranges of applied nitrogen by crop category in pounds per acre per year (lbs/ac/year) based on data from the literature for 1973 and 2005 (Rosenstock et al., 2013; Viers et al., 2012). The typical applied nitrogen by crop category for 1973 is also included in **Table 4-1**. These data indicate that vegetables generally have the highest typical nitrogen application rate based on 2005 estimates, particularly for corn (213 lbs/ac/year) and tomatoes (180 lbs/ac/year) which make up most of the vegetable crops within the Coalition region. Grains/cotton and nut trees also tend to have higher applied nitrogen with typical rates of 174 to 177 lbs/ac/year for grains/cotton and between 138 and 179 lbs/ac/year for nut trees. Crop categories with the lowest nitrogen application rates include grasses (11 lbs/ac/year), grapes (27-44 lbs/ac/year), and seeds/beans (91 lbs/ac/year). The typical nitrogen application rate for crop categories of nut trees, vegetables, grains/cotton, and seeds/beans increased considerably between the 1970s and 2005. In contrast, grapes and grasses had notable decreases between 1973 and 2005 in the typical applied nitrogen.

4.7 Definition of Extent of Irrigation Lands Area for GAR

Data from the California Department of Conservation Farmland Mapping and Monitoring Program (FMMP) were used to define the extent of the irrigated lands in the Coalition region (**Figure 4-9**). The FMMP provides maps of farmland in agricultural counties throughout

California in which soil quality and irrigation status are used to rank land in terms of its ability to be cultivated. The FMMP data were used to determine the extent of the irrigated lands within the Coalition region because these data are used by the Regional Board staff to define irrigated lands (L. Wilson, personal communication). Based on guidance from the Regional Board, and consistent with the Regional Board definition of irrigated lands, the following FMMP categories were considered irrigated lands for this study: prime farmland, farmland of statewide importance, unique farmland, and farmland of local importance. All other FMMP land use categories were defined as non –irrigated and include grazing land, urban and built-up land, other land, rural residential, semi-agricultural and rural commercial land, vacant or disturbed land, confined animal agriculture, and nonagricultural or natural vegetation.

5 GROUNDWATER QUALITY

The emphasis of the GAR requirements is on characterizing past and present groundwater quality and impacts to groundwater quality from irrigated agricultural practices within the Coalition region. The goal is to develop focused management plans and procedures based on the best understanding of the hydrogeology and groundwater resources in the area. In order to provide a characterization of groundwater quality conditions in the area, an extensive effort to assemble readily available groundwater quality data was conducted. The data collection effort focused on nitrate, total dissolved solids (TDS), electrical conductivity (EC), and pesticides. Nitrate is one of the most common groundwater contaminants and is generally the water quality constituent of greatest concern in areas of irrigated agriculture where application of fertilizers containing nitrogen can lead to groundwater contamination. Natural concentrations of nitrate in groundwater are generally low, and elevated levels usually indicate impacts from land use activities. Nitrate presents health concerns at high concentrations and is regulated in public drinking water systems. The US Environmental Protection Agency (EPA) has established a Maximum Contaminant Level (MCL) for nitrate (as nitrogen) of 10 milligrams per liter (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. TDS concentrations in groundwater are a general measure of salinity and overall water quality. Although agricultural practices can increase salinity in groundwater, natural TDS concentrations can also be high because of the hydrogeologic and environmental conditions. EC is directly related to the TDS concentration and, therefore, also provides a measure of general salinity of the water. Like nitrate, pesticides are an indicator of groundwater impacts resulting from land use activities. Groundwater quality data for other constituents as presented in published reports, particularly the USGS reports on results from the Groundwater Ambient Monitoring and Assessment Program investigations conducted for the area, are also summarized.

5.1 Groundwater Quality Dataset

Groundwater quality data from all readily available sources were acquired. Available public data sources include California Department of Public Health's (CDPH) Water Quality Analyses Database Files, DWR's Water Data Library (WDL), USGS's National Water Information System (NWIS), SWRCB's Geotracker database (GAMA), data from wells on dairy permitted lands acquired from the RWQCB, and DPR pesticide sampling database. Because of confidentiality and security reasons, locational coordinates for wells and associated data from CDPH are only approximate. Locations provided by CDPH are up to one mile from the true well location. Data from DPR were provided only at the Public Land Survey System (PLSS) township/range/section level.

Local entities such as county public health and environmental departments and irrigation districts were also contacted concerning available groundwater quality data not included in public databases. Data requests to local entities were constrained to data readily available in electronic format such as databases and spreadsheets with a focus on acquiring groundwater level and quality data previously not reported to or available through public databases. Limited additional groundwater quality data were provided by Merced Irrigation District (MID) and Turlock Irrigation District (TID). No additional data were acquired from local county agencies, although the Merced County Health Department maintains an extensive database of groundwater quality data, especially for domestic wells. Because of confidentiality agreements with well owners, Merced County could not provide data with any specific well locational information. Because of this major limitation, these data from Merced County were not useful for this GAR.

Initial steps of processing these data involved QA/QC procedures including numerous steps of filtering to identify duplicate well and sample records, when possible, and detecting and evaluating erroneous data. Where water quality results were reported as less than the laboratory detection level, values of one half the indicated laboratory detection limit were used. In such cases where the laboratory detection limit was not reported, values of 0.1 mg/L and 10 mg/L were assigned for nitrate (as nitrogen) and TDS, respectively, based on a review of the common laboratory detection limits provided in the data. **Table 5-1** summarizes the groundwater quality data assembled for this GAR. Because of the numerous sources drawn from for constructing this database, the data range widely in spatial accuracy and the amount of well and sample attribute information provided varies. As shown in **Table 5-1**, over 50,000 nitrate concentration records were assembled from more than 6,500 individual wells; nearly 20,000 TDS concentration records from more than 4,500 unique wells were assembled. These data range in time, but most data are from the 2000s and 2010s. Data from CDPH and GAMA consisted of the largest fraction of the data.

Figures 5-1a and **5-2b** show the spatial distribution of assembled groundwater quality data for nitrate and TDS by constituent, data source, and most recent year. Particularly notable in these figures is the relative higher density of available groundwater quality data in the northwestern portion of the Coalition region when compared to other areas. Additionally, the decade of the most recent data, as shown in Figures **5-2a** and **5-2b** highlight the limited availability of recent groundwater quality data in the more southern areas of the Coalition region. **Figure 5-3** shows the distribution of the assembled groundwater quality data by decade and by constituent. Nitrate groundwater quality data represent a large fraction of the total assembled dataset with most water quality observations occurring in the 2000s.

Nitrate data were acquired as reported values for nitrate as nitrate and also for nitrate as nitrogen. All nitrate concentration values reported as nitrate were converted to nitrate as nitrogen by dividing values by 4.427, which represents a conversion based on atomic weight. All values for nitrate concentrations reported in this report reference the units of nitrate in mg/L as nitrogen. Similarly, because of the direct relationship between TDS concentration and measured EC, all EC values were converted to TDS using a multiplier of 0.64 and are referenced as TDS concentrations throughout this report. The TDS concentrations referenced in this report are in units of mg/L.

As was done with groundwater level data, groundwater quality data were differentiated by interpreted depth category. This was performed following the same guidelines and procedures used for groundwater level data. Groundwater quality observations were assigned to three general well depth categories: shallow, deep, and unknown. Shallow wells were defined to be wells with known depths less than 200 feet and also included well use categories of domestic wells, monitoring wells, and TID wells (because of anecdotally provided information about general well depth) when well depth was not provided. Deep wells included wells with depths greater than 200 feet and also municipal wells, irrigation wells, or other well uses indicating a greater likelihood of a well deeper than 200 feet. Wells without any further information with which to assign them into either the shallow or deep category were designated unknown. Of the nitrate data, 2,245 wells were considered to be shallow, 3,472 wells were considered deep, and 855 were unknown (**Table 5-1**). Only 521 wells had reported depth information out of the 6,572 wells within the Coalition region with nitrate data; 696 of the wells with TDS data had reported well depth information. The only data source with reported well depth information was USGS.

A detailed breakdown of the assembled groundwater quality data is presented in **Table 5-1**. From the 6,572 wells for which nitrate data were assembled, 1,479 wells (23 percent) had reported concentrations above the MCL of 10 mg/L for nitrate as nitrogen; 711 wells had concentrations of two or more times the MCL. Of the 4,516 wells with TDS concentration data, 1,108 wells (25 percent) had concentrations above the Secondary Drinking Water Standard of 500 mg/L and 381 (8 percent) had concentrations above 1,000 mg/L.

Because the GAR is focused on managing groundwater quality as it relates to irrigated agriculture, an emphasis was placed on characterizing and evaluating nitrate concentrations in groundwater for this report. Additional attention was given to documenting pesticide detections and TDS concentrations in groundwater. However, data on concentrations of other chemical constituents were not assembled or evaluated in any detail as part of this report. A general overview of groundwater quality conditions for other constituents as investigated and summarized by the USGS as part of the SWRCB and USGS collaborative Groundwater Ambient Monitoring and Assessment Program is included in **Section 5.4**.

5.2 Spatial Patterns in Groundwater Quality

5.2.1 Nitrate Concentrations

5.2.1.1 Central Valley Floor

The spatial distribution of recent nitrate concentrations in shallow groundwater within the Central Valley Floor is shown in **Figure 5-4**. **Figure 5-4** displays the most recent nitrate observation for each well. This map shows high concentrations of nitrate in shallow groundwater throughout much of the western part of the Central Valley Floor. From **Figure 5-4**, a large area where shallow groundwater is generally very high in nitrate is evident in the northwestern part of the Coalition region, particularly in the vicinity and to the west of Turlock. Numerous shallow wells in this area exhibit nitrate concentrations above the drinking water MCL of 10 mg/L (as nitrogen) with many wells having concentrations that are greater than two times the MCL. Groundwater is quite shallow (see **Figures 3-11** and **3-12**) in this area and historical land use categories consist mainly of grasses, vegetables, and dairies. In the southwestern portion of the Coalition region, shallow nitrate concentrations shown on **Figure 5-4** appear to be lower, although much of the available data for this area date back to the 1970s and earlier as shown in **Figure 5-2a**.

Recent nitrate concentrations in deep wells presented in **Figure 5-5** show a somewhat similar spatial pattern as seen in shallow wells with higher nitrate concentrations occurring in the western part of the Central Valley Floor. An area of notably high nitrate concentrations is evident in deep wells in the vicinity of Turlock. Nitrate concentrations in deep wells in this area do not appear to be as high as in the shallow wells and areas of high nitrate concentrations also do not appear to be as laterally extensive as in shallow wells. Although the areas of highest nitrate concentration in deeper wells are generally in the vicinity of Turlock, many other deep wells with nitrate concentrations above the MCL exist across the Central Valley Floor. However, nitrate concentrations in deep wells appear to be lower than concentrations in the shallow wells. It is noteworthy that some of the spatial trends in nitrate concentration in deep wells that are evident in **Figure 5-5** may also be a result of the date of testing. Particularly in the southern and southwestern part of the Coalition region, recent groundwater quality data are relatively sparse as shown on **Figure 5-2a**.

5.2.1.2 Peripheral Area

Available groundwater quality data are more limited in the Peripheral Area. For this reason, and also because of the different hydrogeologic setting in which groundwater commonly occurs in and moves through networks of fractures, interpreting spatial patterns is challenging and groundwater conditions can exhibit highly localized trends. As displayed in **Figure 5-6**, the nitrate data for the Peripheral Area indicate that concentrations are generally below the MCL with a few exceptions. No major irrigated agriculture exists in the Peripheral Area (as mapped by DWR and FMMP), and the few areas where high nitrate concentrations are observed are most likely a result of some localized impact such as a septic system or some other point source contamination.

5.2.2 TDS Concentrations

5.2.2.1 Central Valley Floor

The spatial distribution of TDS data are relatively sparse and detecting spatial patterns in TDS concentrations is difficult. However, **Figure 5-7** presents the most recent TDS concentrations in shallow wells within the Central Valley Floor and indicates the general salinity of shallow groundwater. The most recent data indicate TDS concentrations in many shallow wells are below 500 mg/L, which represents the recommended MCL for Secondary Drinking Water Standards; upper and short term secondary MCLs for TDS are set at 1,000 mg/L and 1,500 mg/L, respectively. Secondary Drinking Water Standards are established for aesthetic reasons such as taste, odor, and color and are not based on public health concerns. Some areas of locally high TDS concentrations exist in shallow wells in the vicinity of Modesto and also in some locations west of Turlock as shown in **Figure 5-7**. A number of wells with higher TDS concentrations are apparent in close proximity to the San Joaquin River along the western edge of the Coalition region where groundwater is generally very shallow. Elevated TDS concentrations can be a result of natural processes and the presence of high TDS concentrations does not necessarily indicate impacts from overlying land use activities.

As shown in **Figure 5-8**, available TDS data for deep wells within the Coalition region are also sparse. The available data from deep wells show most concentrations are below 500 mg/L although some deep wells with high concentrations are scattered throughout the Central Valley Floor area. Most of the wells with the highest TDS concentrations (above 1,000 or 1,500 mg/L) are in the western part of the Coalition region.

5.2.2.2 Peripheral Area

As with nitrate, the available groundwater quality data for TDS are limited in the Peripheral Area. As displayed in **Figure 5-9**, the TDS data for the Peripheral Area indicate that concentrations are below 250 mg/L in most areas with a few areas of slightly higher concentrations. Few locations with TDS concentrations above 500 mg/L are shown on **Figure 5-9** and these areas appear to be concentrated around small communities in the Peripheral Area, particularly in the vicinity of Sonora and Oakhurst. No major irrigated agriculture exists in the Peripheral Area (as mapped by DWR and FMMP), and the few areas where high TDS concentrations are observed are most likely a result of localized natural conditions or anthropogenic influences from land uses in these areas. Interpreting spatial patterns is challenging and groundwater conditions can exhibit highly localized trends in this area because of the hydrogeologic setting in which groundwater commonly occurs in networks of fractures.

5.2.3 Pesticides

Data assembled for pesticide concentrations were limited to data available from DPR in this GAR. Pesticide data available from DPR are from wells, but locations are only provided at the spatial resolution of the PLSS section in which the well is located. **Figures 5-10a** through **5-10c** show 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 Coalition region. Because well locations are not provided with these pesticide data, it is possible that wells in sections that are only partly within the Coalition region actually fall outside of the Coalition area. The sections where pesticide detections have occurred are symbolized in **Figure 5-10a** according to the percent of samples with detections. **Figure 5-10b** shows sections where pesticide detections have occurred by the number of wells with detections within each section. The locations of sections where pesticides have been detected at concentrations exceeding levels provided in the SWRCB Water Quality Goals Online Database (SWRCB, 2013a) are shown in **Figure 5-10c**. **Table 5-2** summarizes pesticides and ranges of concentrations that have been detected in wells that are in sections that overlap with the Coalition region to some degree. 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, where applicable, and otherwise using the US Environmental Protection Agency (EPA) Primary MCL or California notification level, as available. No exceedance threshold value was used if no available values existed for the chemical in the SWRCB online database, or if the chemical could not be located in the database. In such cases where no exceedance value could be found in the SWRCB database, the CDPH list of MCLs (CDPH, 2013b) was consulted to verify that no applicable exceedance value was available.

Three main areas of notably higher rates of pesticide detections and exceedances are evident within the Coalition region. These areas include in the vicinity of Modesto, to the north and west of Atwater, and south of Madera, as shown on **Figures 5-10a** through **5-10c**. Although a relatively large fraction of pesticide detections and exceedances are concentrated in a few main areas, detections and exceedances have also been reported in other areas that are distributed throughout the Coalition region. All but 18 of the wells with pesticide detections are located within the Central Valley Floor area of the Coalition region, and no major spatial patterns in pesticide detections are obvious in the Peripheral Area. Only two pesticide exceedances have been reported in the Peripheral Area. None of the sections with pesticide detections in the Peripheral Area are in locations mapped as irrigated lands.

Overall, out of 2,732 unique wells sampled for pesticides, 872 had detectable concentrations of a pesticide and 369 wells had a pesticide concentration exceedance (**Table 5-2**). Of a total of 997 sections within which pesticide data are available, 375 sections have pesticide detections and 167 sections have exceedances. A total of 48 different pesticides have been detected within the Coalition region with exceedances reported for 8 different pesticides. The pesticides most often tested for were DBCP (1,2-dibromo-3-chloropropane), atrazine, simazine, and 1,2-dichloropropane and the most commonly detected pesticides were DBCP, simazine, DEA (deethyl-atrazine), and atrazine. As shown on **Table 5-2**, DBCP was detected in 632 unique wells within 250 different sections out of a total of 1,786 wells sampled; 331 wells in 154 different sections had concentrations above the primary MCL of 0.2 micrograms per liter (µg/L). Simazine was detected in 75 wells within 62 sections, but only one well had a concentration above the primary MCL of 4 µg/L. DBCP, aldicarb sulfone, and ethylene dibromide were the pesticides with the greatest number of exceedances, although DBCP accounted for 331 out of the 369 pesticide exceedances reported within the Coalition region.

5.3 Temporal Trends in Groundwater Quality

5.3.1 Time-Series Nitrate Concentrations

Select graphs of available time-series nitrate concentration data for wells within the Coalition region are shown in **Figures 5-11** through **5-13**. The graphs of nitrate concentrations displayed in these figures are presented at different scale ranges of mg/L of nitrate as nitrogen on the vertical axis.

5.3.1.1 Central Valley Floor

Graphs of time-series data for nitrate concentrations since 1980 in select shallow wells in the Coalition region are shown in **Figure 5-11**. A limited number of shallow wells exist with long and continuous periods of record for time-series display of temporal trends in nitrate concentrations. Of the wells shown on **Figure 5-11**, only a few have a period of record that includes data from before 2005, and none of the wells shown have data from before 2000. Because of the limited time-series shallow well data, it is difficult to detect any consistent temporal trends in groundwater quality in shallow wells. **Figure 5-12** illustrates graphs of time-series nitrate concentration in select deep wells. Although each of the wells on **Figure 5-12** exhibit unique time-series nitrate concentration characteristics with localized influences, a general pattern of stable nitrate concentrations is seen up until the early to mid-2000s, followed by increasing concentrations through 2010. Perhaps the most notable characteristic of the nitrate concentration graphs in **Figures 5-11** and **5-12** is the variability in nitrate concentration at different time scales.

5.3.1.2 Peripheral Area

No detectable and consistent time-series patterns are apparent in select graphs of nitrate concentrations in the Peripheral Area shown in **Figure 5-13**. As expected, water quality trends in wells in the Peripheral Area appear to be more localized with primary influences on groundwater quality coming from point source contamination from leaching septic systems or other sources, where present. However, overall nitrate concentrations in most wells within the Peripheral Area are generally very low.

5.3.2 Significant Temporal Trends in Nitrate and TDS Concentrations

Basic statistical analyses were conducted on available time-series data for wells to identify significant trends in nitrate and TDS concentrations through time. Separate statistical tests were performed on nitrate and TDS data to determine if there was a significant *linear* relationship between time and concentration for nitrate and TDS concentrations detected in well samples. This was done to assist in identifying notable patterns and trends in groundwater quality based on data from numerous wells throughout the Coalition region. The correlation coefficients (using date and concentration pairs) were calculated for each well 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 well). 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 0.05 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 well using least squares regression. The significance of trends can only be evaluated for wells with three or more samples.

5.3.2.1 Central Valley Floor

Based on statistical analyses of time-series nitrate concentrations for shallow wells, significant temporal trends were identified and are shown in **Figure 5-14**. **Figure 5-14** shows significant trends in nitrate concentrations over the time period of record for each well. The trend in nitrate concentrations is positive (increasing) for most shallow wells with a significant trend. Shallow wells in the area west of Turlock exhibit the greatest increasing trend with most wells having increasing trends of over 0.5 mg/L per year (mg/L/yr) and many with trends above 1 mg/L/yr. In the Modesto area and west of Modesto, a number of shallow wells also have significant increasing trends although the values for the rate of increase are slightly less, generally between 0.1 and 0.5 mg/L/yr.

The distribution of significant temporal trends in nitrate concentrations in deep wells and wells of unknown depth is much more variable, as shown in **Figure 5-15**. Many of the wells in **Figure 5-15** have relatively flat trends between -0.1 and 0.1 mg/L/yr, although there are more wells with positive trends above 0.1 and 0.5 mg/L/yr than there are wells with negative trends of less than -0.1 and -0.5 mg/L/yr. In general, the deep wells with significant trends in **Figure 5-15** exhibit a similar spatial pattern as is evident in the trend analysis for shallow wells. Areas of increasing trends are apparent to the west of Turlock and between Turlock and Atwater and also in the general vicinity of Modesto. However, the variability in trend data is also very apparent in **Figure 5-15.** Although some areas have a relatively high number of wells with increasing trends, many of these same areas are interspersed with or have a similar number of wells with a flat or negative trend.

5.3.2.2 Peripheral Area

Significant temporal trends in nitrate concentrations in wells of all depths in the Peripheral Area are shown in **Figure 5-16**. Although the spatial distribution of the data limits the ability to discern any major patterns, most wells with significant temporal trends exhibit generally stable nitrate concentrations or trends around zero. However, some areas on **Figure 5-16** show increasing trends, especially in the vicinity of the town of Oakhurst where several wells have significant temporal trends in nitrate concentrations greater than 0.5 mg/L/yr. A number of other wells throughout the Peripheral Area and particularly near the town of Sonora also show increasing nitrate concentration trends. Overall, temporal trends in nitrate concentrations in most wells in the Peripheral Area appear to be stable. However, localized influences on groundwater quality may occur from point sources, potentially through leaching septic systems or other localized sources of nitrogen. None of the wells are in locations mapped as irrigated lands.

5.3.3 Time-Series TDS Concentrations

Select graphs of available time-series TDS concentration data for wells within the Coalition region are shown in **Figures 5-17** through **5-19**. The graphs of TDS concentrations displayed in these figures are presented at different scale ranges on the vertical axis.

5.3.3.1 Central Valley Floor

Few wells within the Coalition region have long periods of record of TDS concentrations. Some select shallow wells located in the Central Valley Floor with longer records are shown in **Figure 5-17**. Major limitations in the available time-series TDS data are apparent in **Figure 5-17** with only a few wells having periods of record of more than 10 years. From these data there are no consistent patterns in the time-series data, although it is notable the degree to which concentrations in some of these wells have changed and fluctuated over relatively short periods of time.

Time-series data for TDS concentrations in deep wells are even more limited as illustrated in **Figure 5-18**. Although it is not possible to discern any major trends from these data, several wells on **Figure 5-18** appear to exhibit fluctuations in TDS concentrations on both short (seasonal) and longer (multi-year) time frames. A few wells in the vicinity west and north of Atwater show notable decreasing TDS concentrations during the late 1980s. Few deep wells have continuous periods of record into and through the 2000s.

5.3.3.2 Peripheral Area

Select graphs of time-series TDS concentration data for wells of all depths in the Peripheral Area are presented on **Figure 5-19**. Graphs of TDS concentrations in **Figure 5-19** show a number of wells with relatively lengthy periods of record extending from the 1980s and 1990s through present. Although each graph of time-series TDS concentrations in **Figure 5-19** is unique, a notable pattern is evident in quite a few wells in which TDS concentrations are generally increasing during the period from the mid-1990s and mid-2000s followed by a period of decreasing concentrations after the mid-2000s.

5.3.4 <u>Significant Trends in TDS Concentrations</u>

5.3.4.1 Central Valley Floor

Shallow wells located within the Central Valley Floor with significant temporal trends in TDS concentrations are displayed in **Figure 5-20**. Although the spatial representation of shallow wells with significant temporal trends in TDS concentrations is somewhat sparse, a relatively large number of the shallow wells with significant trends exhibit positive trends of increasing TDS at a rate greater than 10 mg/L/year. Most of these wells are concentrated in the area generally west of Turlock where nitrate concentrations are high and also exhibiting a significantly positive temporal trend (see **Figure 5-17**).

Significant temporal trends for deep wells in the Central Valley Floor are displayed on **Figure 5-21** and suggest that TDS concentrations in most deep wells are relatively stable with generally flat trends. Numerous deep wells with positive trends exist throughout the Central Valley Floor, but their spatial distribution does not indicate any major patterns.

5.3.4.2 Peripheral Area

Wells of all depths in the Peripheral Area with significant temporal trends in TDS concentration are displayed on **Figure 5-22**. Temporal trends in TDS concentration are flat for all but a few wells shown on **Figure 5-22**. Several wells with positive trends greater than 50 mg/L/yr are clustered in a valley north of the town of Oakhurst and a few sporadic locations with positive trends between 10 and 50 mg/L/yr are located throughout other parts of the Peripheral Area.

5.4 Additional Groundwater Quality Data

As discussed above, the focus of this GAR was on acquiring and summarizing general groundwater quality in the Coalition region 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. However, groundwater quality maps from the USGS Groundwater Ambient Monitoring and Assessment Program investigation reports for the area (Landon et al., 2010; Shelton et al., 2013) are included as tiles in **Figures 5-23a** through **5-23g** to illustrate the groundwater quality conditions with respect to some other constituents. Some of these constituents are naturally occurring and some of the constituents detected are related to irrigated agriculture. Maps of concentrations of arsenic, vanadium, uranium, fumigants (including DBCP), herbicides, solvents (e.g., tetrachloroethylene, trichloroethylene), and perchlorate from Landon et al. (2010) and Shelton et al. (2013) are shown in **Figures 5-23a** through **5-23g**.

Figure 5-23a displays maps of arsenic concentration measured in wells. Arsenic is a chemical that occurs naturally in groundwater and has a Primary Drinking Water MCL of 10 µg/L. It is not uncommon in the Central Valley for measured concentrations of naturally occurring arsenic in groundwater to exceed the MCL. **Figure 5-23a** shows that most arsenic concentrations in groundwater are low to moderate although concentrations above the MCL have been detected in a number of wells throughout the Coalition region. The greatest density of wells with elevated arsenic concentrations occurs in the area between Turlock and Modesto, but there are also high arsenic concentrations in wells spread out across much of the Central Valley Floor area.

Figure 5-23b presents maps of vanadium concentrations measured in the groundwater. Vanadium is generally released into groundwater from natural processes of erosion and weathering of rocks containing minerals with vanadium. Most wells within the Coalition region with vanadium measurements have low to moderate concentrations although a few wells with higher concentrations do exist, mainly in the vicinity of Turlock. Vanadium has a “notification level”, which is a health-based advisory level, of 50 µg/L.

Figure 5-23c displays maps of uranium concentrations measured in wells. Uranium is a naturally occurring chemical that generally is mobilized in groundwater through erosion and weathering of uranium bearing rocks. The Primary Drinking Water MCL for uranium is 30 µg/L. The concentrations of uranium in most wells with data are low to moderate although a number of wells have uranium concentrations above the MCL. Five samples collected as part of the USGS Groundwater Ambient Monitoring and Assessment Program study in the area west of Madera exhibit high uranium concentrations. Data from CDPH for several wells in the Modesto area also indicate high uranium concentrations.

In **Figure 5-23d** the concentrations of DBCP are shown for the northern part of the Central Valley Floor and general categorical measures for the presence of fumigants are shown for the southern part. In both areas, most wells have undetectable concentrations or low concentrations of DBCP or other fumigants. However, a considerable number of wells have concentrations of DBCP considered to be moderate to high according to the USGS studies; these wells are mainly around the population centers of Modesto, Atwater, Chowchilla, and Madera. Only low or undetectable concentrations of herbicides exist in measured wells as shown in **Figure 5-23e**. The wells with detectable, but low, concentrations of herbicides are scattered across the Central Valley Floor area, including in more upland areas on the eastern margins of the valley.

Figure 23f displays wells with measured solvent concentrations. Most wells in the Central Valley Floor have low or undetectable concentrations of solvents although a handful of wells have moderate or high concentrations, which are generally located in urban areas such as Modesto, Turlock, and Madera. **Figure 23g** presents measured concentrations of perchlorate in wells in the Central Valley Floor. Perchlorate has a Primary Drinking Water MCL of 6 µg/L. Most wells have low concentrations of perchlorate or concentrations below the detection limit; however, wells considered in the USGS reports to have moderate concentrations of perchlorate occur in some of the population centers like Modesto, Atwater, and Merced and also are scattered across other areas of the Central Valley Floor, with several notable moderate concentrations in areas west and east of Madera. The concentrations of perchlorate considered moderate in these studies is in the range of 0.6 to 1.5 µg/L, which is well below the MCL.

6 DETERMINING GROUNDWATER VULNERABILITY

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.)." and 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 through statistical approaches and based on observed groundwater quality and hydrogeologic characteristics. 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

[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.

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 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 EPA 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 EPA. 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.

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). 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 Eastern San Joaquin River Watershed

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 Protections 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 the SWRCB *Hydrogeologically Vulnerable Areas* and DPR *Groundwater Protection Areas* (or other approaches), together with areas of exceedances of groundwater quality objectives for which irrigated agricultural waste discharges are a contributing factor. The referenced SWRCB and DPR assessments were performed using different methods with varying factors of consideration and degrees of complexity. The methods used in each of these approaches are described below.

6.1.1.1 Hydrogeologically Vulnerability Areas (SWRCB)

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 that fall within the Coalition region as provided by RWQCB staff (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). *Hydrogeologically Vulnerable Areas* constitute approximately 417,000 acres within the Eastern San Joaquin River Watershed representing approximately seven percent of the entire Coalition region and approximately 25 percent of the Central Valley Floor area within the Coalition region.

6.1.1.2 Groundwater Protection Areas (DPR)

The DPR developed the California Vulnerability (CALVUL) approach to delineate of *Groundwater Protection Areas* (GWPAs) to fulfill parts of an EPA 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 6-2** shows the extent of the areas designated by DPR as GWPAs (DPR, 2013). GWPAs constitute approximately 188,000 acres within the Coalition region representing approximately nine percent of the watershed and 29 percent of the Central Valley Floor area.

6.2 Eastern San Joaquin River Watershed Groundwater Vulnerability 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 as discussed in detail later in the section.

To determine the groundwater vulnerability of the Eastern San Joaquin River Watershed for this GAR, statistical methods for assessing groundwater vulnerability were aimed at quantitatively describing relationships between physical characteristics of the study area and observed groundwater quality. This 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. This approach is similar to index methods 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.

Multiple regression was chosen over logistic regression because the dependent variable in the analysis is water quality concentration with values reported on a continuous scale. Therefore, a statistical method capable of considering the full range of values in the dependent variable (nitrate concentrations) was desired. Logistic regression can be particularly useful in predicting the probability of exceeding a specified water quality concentration threshold; however, the dependent variable must be binary (in two categories). It is possible that important information would be lost in an analysis using logistic regression by converting the dependent variable from continuous concentration values into two categories based on a specified threshold.

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 flat topography, greater ability of soils or subsurface materials to transmit water, greater amount of groundwater recharge, and shallow groundwater are expected to increase the vulnerability of a location to groundwater contamination.

6.2.2 Multiple Regression Analysis Approach

Multiple regression is a statistical analysis that models the relationship between two or more independent (explanatory) variables and an observed dependent (response) variable with a linear equation. In determining groundwater vulnerability, 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 contamination in all areas of the watershed based on the hydrogeologic conditions present. Accordingly, groundwater quality observations were used as the dependent variable, and physical hydrogeologic characteristics were used as independent variables to understand the relationship between hydrogeologic characteristics and observed water quality. All multiple regression statistical analyses were conducted using the statistical software program STATISTICA, Version 7.1 (StatSoft, Inc., 2005)

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 Eastern San Joaquin River Watershed. As an essential nutrient for plant growth, nitrogen is a component in many fertilizers that have 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; therefore, 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. This makes nitrate concentrations a more useful indicator of influence from irrigated agriculture than some other more commonly available groundwater quality measures such as TDS or EC.

Additionally, data on nitrate concentrations in groundwater are more broadly available than most other contaminants associated with irrigated agricultural practices such as pesticides. For these reasons, nitrate was used as the primary measure for groundwater quality impacts from irrigated agriculture for the purposes of assessing the intrinsic groundwater vulnerability of areas within the Coalition region. Results from the multiple regression analysis were compared to locations of wells with observed nitrate concentrations of 5 mg/L and above and 10 mg/L and above as discussed later in this section.

As discussed above, available data for observations of nitrate concentrations in groundwater in the Eastern San Joaquin River Watershed area were compiled from various sources. Using this dataset representing locations of wells with observed nitrate concentrations, spatial datasets representing hydrogeologic characteristics across the entire study area were used to designate the properties for each of the independent hydrogeologic variables of interest at each nitrate observation location. The hydrogeologic properties selected for investigation through multiple regression were chosen based on several factors: 1) professional judgment and conceptual interpretation of important physical characteristics and mechanisms for transport of contamination into the groundwater, 2) approaches and results from other groundwater vulnerability studies, and 3) availability of data at compatible spatial scales. Land use conditions in the vicinity of each nitrate observation point were determined for three different time periods between 1995 and 2012 based on land use surveys conducted by DWR and USDA. The resultant dataset was used to perform multiple regression analyses to identify relationships between the independent hydrogeologic variables and the dependent variable (nitrate concentration) in order to calculate a measure of groundwater vulnerability across the entire study area, including areas where groundwater quality data are limited or non-existent. This was done separately for each land use time period. The relationships among hydrogeologic variables and observed nitrate concentration were investigated through multiple regression analysis as part of this groundwater vulnerability assessment, although the statistical relationships between the hydrogeologic variables and the observed nitrate concentration do not necessarily indicate a cause-and-effect relationship. Land use was incorporated into the analysis by including land use conditions at different time periods to recognize past land uses across the study area.

The following hydrogeologic variables were used in this analysis: shallow (soil) hydraulic conductivity, deeper subsurface hydraulic conductivity, depth to groundwater, recharge rate, topographic slope, and characteristics of the Corcoran Clay. Year of observation and well depth were also investigated as independent variables. Land use characteristics were investigated and controlled for based on several mapped land use time snapshots and data sources. This analysis assumes 1) the amount of nitrogen applied is similar within each land use category across the analysis area, 2) the length of time over which applications have occurred is similar across the analysis area, and 3) subsurface microbial degradation rates are similar across the analysis area.

The Eastern San Joaquin River Watershed is partly within the San Joaquin Valley Groundwater Basin as defined by DWR (DWR, 2003) and greater than 99.9 percent of the irrigated acreage present in the Coalition region (based on 2010 FMMP data) lie within the extent of the San Joaquin Valley Groundwater Basin. This area within both the San Joaquin Valley Groundwater Basin and Eastern San Joaquin River Watershed is referred to as the "Central Valley Floor" in discussions within this section. The groundwater vulnerability assessment for the Eastern San Joaquin River Watershed focusses on the irrigated lands within the Central Valley Floor. The Central Valley Floor area represents the extent of valley fill sediments and is where the greatest impacts from irrigated agriculture have occurred in the past and are most likely to occur in the future. The Central Valley Floor extent is also coincident with the domain of the CVHM model in the area, which is a source of spatial data on several hydrogeologic variables investigated through the multiple regression analysis. All multiple regression analyses were limited to the extent of the Central Valley Floor area within the Coalition region.

6.2.2.1 Multiple Regression Variables

6.2.2.1.1 Dependent (Response) Variable

The observed concentration of nitrate (as nitrogen) from samples of wells at specified locations within the Central Valley Floor was used as the dependent variable in the multiple regression analysis. Available data on nitrate observations were compiled for the study area as discussed above. These data span the timeframe from the 1940s to 2013 as shown in **Figures 5-2a** and **5-3**. The spatial distribution of available nitrate data cover much of the Central Valley Floor, however, the date of observations are unique and are highly variable. Because groundwater quality changes with time, the relative point in time at which the nitrate concentration was measured is important. Controlling for differences in timing between water quality observations is especially critical when using these observations as a means of assessing the groundwater vulnerability or likelihood for groundwater to be contaminated based on hydrogeologic conditions. Investigation of the temporal and spatial distribution of the data showed that the spatial richness of the dataset would be greatly diminished through implementation of filtering on the data based on limited time periods. Instead, to account for the consideration of time without loss of valuable data, **only the most recent nitrate observation in a given well was used in the multiple regression analysis** and the year of the observation was included as an independent variable to control for time-dependency in the analysis. This approach enabled the use of a greater amount of data, with a greater spatial distribution, while also accounting for differences in timing between observations.

6.2.2.1.2 Hydrogeologic Independent (Explanatory) Variables

Soil Hydraulic Conductivity

Conceptually, the hydraulic conductivity of soils is expected to influence the observed nitrate concentration at a location because higher conductivity soils are likely to enable more rapid infiltration. To investigate any relationship between the hydraulic properties of shallow surficial geologic materials and potential to transmit contaminants vertically, soil characteristics around each nitrate observation were included in the multiple regression as an independent variable. Natural Resource Conservation Service (NRCS) Soils Survey Geographic database (SSURGO) of soil mapping was used as the basis for developing shallow soil hydraulic conductivity data for analysis. 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 Central Valley Floor area. 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). **Figure 3-3** shows the spatial distribution of soil saturated hydraulic conductivity throughout the Valley Floor within the Coalition region. From these data, an area-weighted average value for soil saturated hydraulic conductivity within a radius of one-quarter mile around each nitrate observation location was then calculated.

Deeper Subsurface Hydraulic Conductivity

Hydraulic properties of deeper subsurface geologic materials at each nitrate observation location were also included in the multiple regression. As with shallow hydraulic conductivity measured in soils, the conceptual model for groundwater vulnerability holds that the conductivity of deeper subsurface materials is likely to influence the observed nitrate concentration and the ability of chemicals to move vertically into the groundwater; the vertical transport of chemicals is expected to occur more readily in sediments that are hydraulically conductive. Vertical hydraulic conductivity data from the uppermost model layer (Layer 1) of the CVHM were used to extract deeper subsurface hydraulic conductivity values at each observation location. Layer 1 of the CVHM represents the subsurface to a depth of 50 feet below ground surface. The CVHM vertical hydraulic conductivity data were originally derived from sediment textural data developed from approximately 8,500 well drillers' logs in the Central Valley. Vertical hydraulic conductivity values in CVHM were calculated from sediment texture data using a weighted power mean, similar to the harmonic mean (Faunt et al., 2009). CVHM vertical hydraulic conductivity data are available for the study area at a model cell size of one-square mile as shown on **Figure 3-4**.

Depth to Groundwater

From a conceptual standpoint, depth to the groundwater surface is expected to be negatively correlated with observed nitrate concentration, provided the assumptions mentioned above are valid. This relationship is expected because in the conceptual model for groundwater vulnerability, the depth to groundwater is considered to be representative of the distance that a chemical must travel before it reaches the groundwater. As a result, because of factors relating to the attenuation of the chemical in time and concentration, the observed nitrate concentration is expected to be less with greater depth to groundwater. Spatial datasets representing spring and fall depth to groundwater throughout the Valley Floor area within the watershed were developed from the best available water level data as part of this GAR and for use in the groundwater vulnerability assessment, as discussed earlier. These depth to groundwater datasets were generated in an effort to represent the best and most current shallow groundwater conditions available. A hierarchical approach was employed by considering recent shallow groundwater level measurements first and incorporating gradually older water levels and water levels from deep wells or wells of unknown depth only as necessary to fill gaps in available shallow groundwater level data. **Figures 3-9** and **3-10** show the most recent shallow depth to groundwater datasets for spring and fall that were generated as part of this GAR. Values from each of these depth to groundwater datasets developed as part of this GAR were attributed to all nitrate observation locations for the multiple regression analysis to investigate relationships between both spring and fall depth to groundwater and the observed nitrate concentrations in groundwater. Depth to groundwater as derived from a spatial dataset developed by DPR for the time period 1987 to 1999 was also evaluated as an independent variable through multiple regression analysis. The DPR depth to groundwater dataset is generally similar to depth to groundwater datasets developed for this GAR and is shown on **Figure 3-11**; however, the DPR dataset presents limitations because it does not have complete spatial coverage of the Valley Floor area, especially towards the eastern margins.

Recharge Rate

Conceptually, groundwater recharge is expected to be related to observed nitrate concentrations; the greater the amount of recharge, the more likely a chemical is to be leached or mobilized for vertical transport into or through the subsurface towards the groundwater. Groundwater recharge is a difficult variable to accurately measure or characterize, and spatial representations of recharge are typically not readily available. Average net annual recharge rate (using years 1983-2003) output from CVHM was evaluated as an independent variable in the multiple regression analysis. As with other CVHM spatial datasets, net recharge output data from CVHM are available at a cellular resolution of one-square mile. The spatial distribution of net recharge values from CVHM are shown on **Figure 3-18**. All nitrate observations in the analysis dataset were attributed with the net recharge value at the location from the CVHM spatial dataset.

Topographic Slope

The topographic slope is expected to be inversely related to groundwater vulnerability because of its relationship with groundwater recharge. Slope is an important physical consideration in groundwater vulnerability because precipitation runoff is expected to be higher in areas of higher slope. Conversely, infiltration of precipitation, hence natural groundwater recharge, is expected to be higher in low topographic slope areas. Topographic slope throughout the study area was calculated from the USGS National Elevation Dataset (NED) 10 meter resolution digital elevation model (DEM). **Figure 2-2** illustrates the slope characteristics throughout the Valley Floor area. From this spatial dataset, slope values were extracted at each nitrate observation location for use as an independent variable in the multiple regression analysis.

Corcoran Clay

The presence of the Corcoran Clay geologic unit in the Eastern San Joaquin River Watershed is one unique aspect of the area. The Corcoran Clay is a low-permeability stratigraphic unit throughout much of the study area. However, the occurrence, depth, and thickness of the unit in the area are spatially variable. Several properties of the Corcoran Clay, as derived from CVHM datasets, were investigated as independent variables in the analysis. Variables representing the occurrence (presence/absence), depth, and thickness of the Corcoran Clay were considered in the multiple regression analysis. The spatial datasets from CVHM representing these properties of the Corcoran Clay are shown in **Figures 3-5a** and **3-5b**. All nitrate observations in the analysis dataset were attributed with the associated Corcoran Clay properties at the location for investigation through multiple regression analysis.

Well Depth

In a groundwater vulnerability conceptual model in which separate aquifers exist at different depths and possibly under confined conditions, depth to groundwater does not capture the true vertical distance that a contaminant must travel vertically to reach a groundwater aquifer from which a well draws its water. Under such circumstances, well depth would be expected to provide a more representative measure of the vertical travel distance for a contaminant to reach the aquifer in which water quality is being measured. Nitrate observation data assembled from the USGS groundwater quality database contained information on the depth of the well from which the groundwater quality samples were obtained. However, most nitrate observations did not contain any specific well depth information. Well depth was included as an independent variable in analyses conducted only on a USGS data subset of 488 observations. All nitrate observations were categorized into three general depth groups, based on depth information, if available, or as inferred from the type of well or based on the source of the data. The general depth categories include shallow wells (assumed to be less than 200 feet), deep wells (assumed to be wells greater than 200 feet), and wells of unknown depth and the methods for categorizing wells by depth are described in greater detail above in **Section 5 Groundwater Quality**. Subsets of the data based on well depth category were analyzed separately with multiple regression.

6.2.2.1.3 Observation Time and Land Use Control Variables

Year of Nitrate Observation

The dataset of nitrate observations used in this analysis includes observations spanning multiple decades. The year of each nitrate observation was included as an independent variable in the multiple regression analysis in order to control for differences between the timing of observations and evaluate temporal trends in the regression. Square-root and natural logarithm transformations of the year of observation were also investigated through different multiple regression analyses, This was done to evaluate possible non-linearity to temporal trends in nitrate concentrations. Additionally, differences in temporal trends between the pre- and post-2000 time periods were evaluated using categorical indicator variables (true/false). Filtering of the data by decadal time periods was also explored, although subsets of data resulting from such filtering were greatly diminished in terms of spatial distribution.

Land Use Conditions

The objective of the groundwater vulnerability assessment for this GAR was to develop a statistical relationship to describe the intrinsic groundwater vulnerability independent of land use conditions. However, the observed groundwater quality is a function of past land use practices and hydrogeologic conditions. In the context of determining intrinsic groundwater vulnerability, land use is a confounding factor on the observed groundwater quality. Therefore, a statistical method of determining groundwater vulnerability irrespective of land use must 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 conditions mapped at three different snapshots in time from the mid-1990s to 2012 were utilized in the analyses to account for different land use conditions. Three different land use snapshots were evaluated, as it was not known if the observed groundwater quality is most representative of land use during any specific time period.

Mapped land use for the Central Valley Floor for the mid-1990s (Madera County [1995], Merced County [1995], Stanislaus County [1996]), early 2000s (Madera County [2001], Merced County [2002], Stanislaus County [2004]), and for 2012 were included and evaluated in the multiple regression analysis as independent variables to control for different land uses and practices that potentially affect the groundwater quality outcome. These land use variables were also evaluated as independent explanatory variables of secondary interest since they are not intrinsic physical characteristics of the hydrogeologic system.

Mapped land use crop types and descriptions were grouped into categories based largely on published typical nitrogen application rates for crops and in accordance with criteria described above in **Section 4 Land Use**. Each nitrate observation was attributed with values representing the percent of each land use category mapped within radiuses of one-quarter mile and one-half mile of the observation. In some cases, data on land use conditions were not available for the entire radius of interest around a point. Points were excluded from analyses where land use was unknown for greater than 25 percent of the area within the radius; for all other points, land use percentages were calculated according to the fractions of known land uses within the radius. This process was done separately for mapped land use conditions in the mid-1990s, early 2000s, and 2012 for evaluation through multiple regression.

6.2.2.2 Description of Multiple Regression Analyses

6.2.2.2.1 Assumptions

Multiple linear regression models using standard estimation techniques make several primary assumptions that should be recognized:

1. Linearity: the relationship between dependent and independent variables is linear.
2. Constant variance (homoscedasticity): the spread of dependent variable values around the mean (variance in error) is the same regardless of values of the independent variables.
3. Normality: residuals (errors) are normally distributed.
4. Independence: errors of the dependent variables are not correlated with each other; the location of any dependent variable in relation to its mean cannot be predicted.

6.2.2.2.2 Preliminary Data Investigation

The data were explored in many ways prior to and during the multiple regression analysis process in order to characterize and determine a reasonable and robust approach to analyzing the data and determining groundwater vulnerability. Transformations of both the dependent variable and independent hydrogeologic variables were investigated during the process of conducting multiple regression analyses as part of evaluating how well the data meet the main assumptions of multiple regression analysis. The frequency distribution of untransformed values for the dependent variable (observed nitrate concentration) is shown in **Figure 6-3**. These data exhibit a positively skewed distribution with a greater frequency of observations at low nitrate concentrations than at higher concentrations; this is a common pattern in water quality datasets.

Transformations of the dependent variable values using natural logarithm and square root transformations were performed on the dependent variable in an attempt to make the distribution of the dependent variable more symmetrical prior to conducting the multiple regression analysis. Square root transformation of the dependent variable greatly reduced the amount of positive skew of the data as illustrated in **Figure 6-3**. The effects of conducting transformations of the independent variables on the model results were investigated as part of the analysis. A model that does not fully meet all of the assumptions of linearity could lead to error in predicted values; however, in this assessment the primary objective is to determine a relative prediction of groundwater vulnerability.

Some degree of spatial clustering (spatial autocorrelation) of the dependent variable is present in the data (Global Moran's I ranging from 0.3 to 0.6 for the analysis data subsets) suggesting that nitrate concentrations are spatially autocorrelated and may not fully meet the assumption of independence in the model. This spatial clustering is not surprising because land use and hydrogeologic characteristics, which are expected to influence nitrate concentrations, are also spatially clustered. Although the assumption of independence in the model may not be fully met, it is important to consider the context of this analysis recognizing that the multiple regression analysis is intended to provide an objective evaluation of the relationships between hydrogeologic factors and observed nitrate concentrations that can be used to assign weights to different hydrogeologic variables. Throughout the analysis, results were evaluated for reasonableness using professional judgment and with respect to the conceptual model for groundwater vulnerability. Additionally, qualitative and quantitative evaluations of the results were conducted based on groundwater quality observations to identify a model that performs best and produces the most reasonable assessment of groundwater vulnerability. Diagnostic plots of residuals and predicted values from the model results were also inspected to evaluate how well the models met the assumptions of independence and constant variance of errors (residuals), as discussed later in this report.

Data outliers and their influence on the analyses were investigated and addressed through multiple methods. Outliers have the potential to greatly affect the multiple regression results. Obvious outliers resulting from erroneous data entry or other factors related to the collecting and assembling of the data were discarded early in the data preparation and quality control process. Additional outliers in the data were evaluated based on comparison of model residuals (predicted minus observed value) to the standard errors from the multiple regression analyses. Residual outliers, where the residual is two or three times greater than the standard error for the multiple regression, were identified and represent locations where the predicted value for the dependent variable differs greatly from the observed value. Data points with notably high observed values of nitrate were consistently identified as residual outliers. In the context of this analysis, extreme observed values in the dependent variable are more likely to be a result of localized impacts from unique factors associated with land use in the vicinity, well construction or use (lack of sanitary seal, etc.), or other localized factors than they are to be a function of a given set of hydrogeologic characteristics. This is a particularly important issue because the objective of the multiple regression analysis is to identify and quantify hydrogeologic factors that are significantly related to nitrate concentration (i.e., a determination of intrinsic vulnerability of an area rather than well vulnerability). In this analysis, agricultural or other practices occurring on the land are assumed to be similar across all areas of a given land use category.

Initial exclusion of outliers from the analyses improved the normality of the residuals, better satisfying the multiple regression model assumption of normal distribution of the error in predicted values. The exclusion of data points identified as residual outliers (residuals greater than two or three times the standard error) was initially evaluated through separate analyses. Thresholds for designating outliers based on absolute dependent variable values (instead of residuals) were also explored in order to better understand the context (and extreme nature) of outliers within the conceptual model for nitrate contamination. The main objective in treatment of outliers was to address extreme observed dependent variable values that are most likely a function of anomalous land use or well conditions instead of hydrogeologic characteristics. **Table 6-2** summarizes the independent variable values in the multiple regression dataset. The dependent variable values (untransformed) range from non-detect to 340 mg/L, and the mean and median values of the untransformed dependent variable in the complete dataset are 8.81 and 4.07 mg/L, respectively. For the square root transformed data, the mean is 2.41 and the median value is 2.02 in the full dataset. For the dataset of only shallow wells, the mean and median untransformed values are 13.73 and 7.4 mg/L, whereas the square root transformed mean and median are 3.06 and 2.72, respectively. Through exploration and based on professional judgment, a threshold for identification and exclusion of dependent variable outliers was established at 60 (untransformed, mg/L of nitrate as N). This threshold represents a concentration of six times the MCL for drinking water and addresses those data points also identified as residual outliers while yielding more normal distributions in the residuals across all analyses. Excluding untransformed outliers above 60 mg/L, the mean and median values of the untransformed dependent variable for wells of all depths are 8.03 and 4.07 mg/L, respectively. For the square root transformed data (excluding outliers) the mean is 2.34 and the median value is 2.02. For the dataset of only shallow wells, and excluding outliers, the mean and median untransformed values are 12.14 and 7.2 mg/L, whereas the square root transformed mean and median are 2.93 and 2.68, respectively.

At a threshold of 60 mg/L (untransformed) for dependent variable outliers, 46 observations (from unique wells) out of a total of 5,001 datapoints in the complete dataset are excluded from analyses. All regression results exhibit much more normally distributed residuals after exclusion of dependent variable outliers. By excluding these outliers, the results from the multiple regression analyses evaluate statistical relationships between the independent variables and the dependent variable through a range of values from zero to 60 mg/L for the dependent variable.

The exclusion of outliers did not result in any major changes in the significant variables or their coefficients.

Relationships between the variables were also evaluated through transformations of the independent variables. Multiple regression analyses were performed using untransformed values for hydrogeologic independent variables and also natural logarithm transformations of the hydreogeologic independent variables. Results and diagnostics from multiple regression analyses on transformed and untransformed values were evaluated and compared. Non-linearity in the relationship between time and observed nitrate was evaluated by comparing results from multiple regression analyses conducted using the observation year, a squared value of observation year, and a natural logarithm of observation year. Potential differences in temporal trends by recent time period were also evaluated by differentiating pre-2000 observations from post-2000 observations using a categorical variable.

Individual relationships between independent variables and the dependent variable were explored to understand the data. The presence of multicollinearity between independent hydrogeologic variables was evaluated to inform the analyses. **Table 6-3** presents a matrix of the correlations between independent variables in the dataset. Correlation values presented in **Table 6-3** are relative to a possible range of values indicating no correlation (zero) between independent variables to perfect positive correlation (one) or perfect negative correlation (minus one) between independent variables. Preliminary analyses on the multiple regression dataset showed a strong correlation between the independent variables of Corcoran Clay characteristics (depth and thickness) and depth to water and relatively strong correlations between net recharge and depth to water (0.46 and 0.50), as shown in **Table 6-3**. The presence of multicollinearity between independent variables was taken into consideration during performance of the multiple regression analyses, and using professional judgment, some independent variables were excluded from analyses because they exhibited high correlation with another independent variable, as discussed below.

6.2.2.2.3 Accounting for Land Use Conditions

Multiple regression analyses were performed separately using variables for land use conditions under the three different time snapshots (mid-1990s, early 2000s, and 2012) shown in **Figures 4-3** through **4-5**. The percent of land use categories within a radius of each data point location were included as independent variables in the multiple regression. Separate models were developed based on each land use time snapshot. During the statistical analysis process it became evident that multiple regression analysis results from the mid- and early 2000s land use conditions data were similar and generally explained considerably more of the variation than did models using the 2012 land use conditions. This finding is not surprising, and it might be expected that observed groundwater quality is more likely a result of past or legacy practices and conditions of the past two decades than those of the current time. Furthermore, the methodology for field surveys used by DWR to develop the mid-1990s and early 2000s land use data was different from the USDA's technique, which utilizes remote sensing data. For these reasons, multiple regression analyses focused on evaluating the relationships among variables based on the mid-1990s and early 2000s land use conditions. Separate multiple regression analyses were conducted on subsets of the data based on well depth category designation and specified well depth. Evaluations by well depth included separate multiple regressions performed using data for wells of all depths, for shallow wells only, and for USGS wells where well depth is known and specified as a continuous variable.

6.2.2.2.4 Performing the Multiple Regression Analyses

Several multiple regression models for groundwater vulnerability were developed for evaluation and comparison. Multiple regression analyses were performed using stepwise backward elimination of the independent hydrogeologic variable having the highest p value, until all remaining independent hydrogeologic variables have p values of less than 0.1. A p value level of 0.1 was used in this study to define statistical significance. P values provide a measure of assessing the probability that the result is to have occurred by chance, assuming the null hypothesis is true. A p value below 0.1 indicates that the result is unlikely to be a product of random chance alone and is considered statistically significant in this evaluation. During the multiple regression analyses, colinearity between independent variables was also considered to inform the variable elimination process. Professional judgment was also exercised to evaluate whether variables with a high degree of colinearity should be retained based on results from the multiple regression analyses and consistency with the conceptual model for groundwater vulnerability.

The correlation between net recharge and depth to water is reasonably high (0.46-0.5) (**Table 6-3**) in the dataset. Some early results from multiple regression analyses conducted using net recharge and depth to water together as independent variables yielded negative correlations between net recharge and the dependent variable, which were inconsistent with the conceptual model for groundwater vulnerability. The values for net recharge are derived from model-simulated output from the CVHM, and the spatial resolution of the data are at a one-square mile cell size as compared to depth to water data that are measured and are available at a finer spatial resolution. For these reasons, consideration of net recharge as an independent variable in multiple regression analyses, particularly while also including the variable depth to water, was done while exercising professional judgment and generally giving priority to depth to water instead of net recharge as an independent variable for inclusion in the multiple regression model.

Characteristics of the Corcoran Clay were difficult to incorporate into the conceptual model for groundwater vulnerability because the depth of the Corcoran Clay relative to the depth of the well in which observations were made is generally not known because of constraints on available well information. This fact also was evident through multiple regression analyses using Corcoran Clay thickness and depth, which resulted in counterintuitive and confusing relationships with the dependent variable (i.e., the sign of the coefficient was opposite of what is expected based on the conceptual model). Furthermore, thickness of the Corcoran Clay was highly positively correlated with depth to water. Largely due to the limitation on the availability of specific well depth and construction information in conjunction with nitrate observations, characteristics of the Corcoran Clay were excluded in the development of all multiple regression models.

6.2.3 Multiple Regression Results

Following the stepwise backward elimination process outlined above, multiple regression analyses using different land use snapshots, variable transformations, and subsets of the data were performed to construct models for assessing groundwater vulnerability. Through these analyses, several candidate models were identified for evaluation and comparison based on a combination of conceptual groundwater vulnerability considerations and output from the multiple regression analyses. The top candidate models evaluated and compared include the following:

1. Shallow Wells Model
2. All Wells Model
3. All Wells Untransformed Model
4. USGS Wells Model
5. Groundwater Subbasin Models

These candidate models illustrate and capture various aspects of the conceptual model for groundwater vulnerability. The Shallow Wells Model is based only on data from shallow wells; whereas the All Wells Models are from analysis using data from all wells, regardless of depth. The USGS Wells Model incorporates well depth as an independent variable and only uses data from the USGS database where a well depth is provided. The Groundwater Subbasin Models are results of analyses conducted on spatially constrained subsets of the data based on location relative to DWR-designated groundwater subbasin boundaries.

The results from multiple regression analyses used in development of the candidate models are summarized in **Table 6-4**. Each of the candidate models was developed using separate multiple regressions on mid-1990s land use conditions and early-2000s land use conditions. Accordingly, the results from analyses using the two different land use snapshots are reported separately as two values in **Table 6-4**. The results of the multiple regression analyses show overall statistical significance (defined at a value of less than 0.1 in this assessment) to all of the model regression equations, with all models having an overall p value of less than 0.0005. Furthermore, **Table 6-4** illustrates patterns in statistical significance of independent variables with several hydrogeologic variables consistently retained in the final model equations. Soil hydraulic conductivity, depth to water, and topographic slope were most commonly found to have statistically significant relationships in the models. Additionally, p values for the hydraulic conductivity of deeper subsurface materials in the All Wells models, most notably, were also low and considered statistically significant. Although the multiple regression analyses indicate statistical significance to some relationships between independent variables and the dependent variable, it is important to note that these results do not necessarily suggest a cause-and-effect relationship between the variables.

The R-squared values for the regression models, which provide a measure of the amount of variance in the dependent variable that is explained by independent variables, range from 0.14 to 0.23. In output from a regression analysis, R-squared values have a possible range from zero to one. The somewhat low R-squared values for all of the multiple regression models suggest that there is a considerable amount of variance in the dependent variable that is not explained by the independent variables included in the multiple regression analyses. More importantly though,, the results of the analyses suggest that there is significance to the relationship between several hydrogeologic independent variables and observed nitrate concentrations in groundwater. The relatively low R-squared values exhibited by the multiple regression models are not particularly surprising because there are numerous potential sources of variability inherent in the data used in the multiple regression data that are unable to be accurately characterized. **Table 6-5** lists some likely sources of variability present in the data used in multiple regression analyses. This groundwater vulnerability assessment has attempted to consider some of the hydrogeologic characteristics that are most likely to affect groundwater quality and for which data are available. There are many complex hydrogeologic characteristics and interactions that influence groundwater quality and not all of these factors are known or measured in the study area, nor included in the multiple regression analyses.

Among the candidate models, there is general similarity in multiple regression results from analyses using data for only shallow wells and those using data for all wells. Similar independent variables exhibit statistically significant relationships with the dependent variable and the R-squared values for the overall regressions are generally similar among the different models. Additionally, results from analyses using mid-1990s land use conditions show similar relationships as analyses using early 2000s land use conditions, although most models have a slightly higher R-squared value for the regression using mid-1990s land use.

6.2.3.1 Hydrogeologic Independent Variables

Significant relationships between hydrogeologic variables and the observed nitrate concentration detected in the multiple regression models are discussed below as shown in **Table 6-4**. The sign (positive or negative) of the coefficient for an independent variable indicates the direction of the relationship between that variable and the dependent variable. A positive coefficient means that for any given increase in the value for the independent variable, the predicted value for the dependent variable will increase, holding all other variables constant. Conversely, a negative coefficient means that for a given increase in the value for the independent variable, the predicted value for the dependent variable will decrease (holding all other variables constant). The results from multiple regression analyses were used to develop model equations to assess the relative vulnerability of groundwater. As discussed below, the consistency between results from different multiple regression analyses and the consistency of multiple regression results with the conceptual model for groundwater vulnerability were considered in development of the final model equations.

6.2.3.1.1 Soil Hydraulic Conductivity

Following the conceptual model for groundwater vulnerability, any apparent relationship between the ability of soils to transmit water and the observed nitrate concentration in groundwater is expected to be positive. Through the stepwise backward elimination of hydrogeologic independent variables and candidate model development, shallow soil hydraulic conductivity was statistically significant in the Shallow Wells Model, the All Wells Models, and in the Turlock/Modesto and Merced Subbasin models. In these models, the relationship between soil saturated hydraulic conductivity and the dependent variable was positive in all cases, which is consistent with the conceptual model for groundwater vulnerability.

6.2.3.1.2 Deeper Subsurface Hydraulic Conductivity

The relationship between the hydraulic conductivity of deeper subsurface materials (the first 50 feet of subsurface materials as represented by CVHM Layer 1 and the observed nitrate concentration in groundwater is expected to be positive. In the candidate models, vertical hydraulic conductivity of CVHM Layer 1 was statistically significant in the All Wells Models and positively correlated with the dependent variable. However, in the Chowchilla/Madera Subbasins Model, multiple regression results indicate vertical hydraulic conductivity of CVHM Layer 1 is negatively correlated with the dependent variable; a negative correlation between vertical hydraulic conductivity and the observed nitrate concentration is not consistent with the conceptual model for groundwater vulnerability. It is believed that some of the conflicting results between these models may be partially attributable to differences in the spatial and temporal distribution of data across the Central Valley Floor area. As discussed above and illustrated in **Figures 5-1a** and **5-1b**, available nitrate concentration data, particularly recent data, are considerably more sparse in the Chowchilla/Madera Subbasins Model area than in other areas of the Central Valley Floor.

6.2.3.1.3 Depth to Groundwater

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; because of factors related to nitrate attenuation, as depth to groundwater increases the concentration of nitrate in groundwater is expected to decrease. In fact, depth to water was significantly related with the dependent variable in many of the candidate models. Exceptions include the USGS Wells Model, the only model in which well depth is included, and the Merced Subbasin Model. The correlation in the Shallow Wells Model, All Wells Models, and the Turlock/Modesto Subbasins Model is negative and consistent with the conceptual model for groundwater vulnerability. But in the Chowchilla/Madera Subbasins Model, multiple regression results indicate depth to water is positively related with the dependent variable, meaning that as depth to water increases the predicted nitrate concentration increases. Again, this result is not consistent with the conceptual model for groundwater vulnerability and may be partially a result of limitations on data availability in the Chowchilla/Madera Subbasins Model area.

6.2.3.1.4 Topographic Slope

From the standpoint of the conceptual model for groundwater vulnerability, any potential relationship between topographic slope and observed nitrate concentration is expected to be primarily a function of effects of slope on recharge, with a greater amount of natural recharge occurring in low-slope areas than in high-slope areas. In the multiple regression models, the relationship between slope and the dependent variable was statistically significant in most models. In the Shallow Wells Model, the All Wells Models, the USGS Wells Model, and the Modesto/Turlock Subbasins Model, the coefficient of the relationship was negative, indicating that topographic slope increases the predicted nitrate concentration decreases. However, slope was not statistically significant in the Chowchilla/Madera Subbasins Model; in the Merced Subbasin Model, slope was not significant using mid-1990s land use and the p value for topographic slope using the early-2000s land use was only slightly below the significance level of 0.1. Although results from the Merced Subbasin Model for early-2000s land use indicate that the coefficient for the relationship between topographic slope and nitrate concentration was positive in this area, this result is contrary to the conceptual model for groundwater vulnerability and the p values for the results under two different land use snapshots indicate no or only a marginally statistically significant relationship.

6.2.3.1.5 Well Depth

Well depth information was only available for a subset of data, these data came from the USGS database. The USGS Wells Model is the only model that included well depth as an independent variable. In a groundwater vulnerability conceptual model in which confined aquifers exist at depth, well depth would be expected to provide a measure of the distance that a contaminant must travel vertically to reach a deeper confined aquifer. As such, a negative correlation between well depth and observed nitrate would be expected. Consistent with the conceptual model, well depth was statistically significant and negatively correlated with the dependent variable in the USGS Wells Model, meaning the deeper the well the lower the predicted nitrate concentration.

6.2.3.1.6 Groundwater Recharge

Based on the conceptual model, groundwater recharge is expected to be positively correlated with observed nitrate concentration. This is because, when holding all other variables constant, increasing recharge rates would be expected to increase transport, mobilization, or leaching of chemicals into the groundwater. As discussed earlier, values for net recharge available for this analysis were model-simulated output from CVHM. The results from multiple regression analyses conducted using net recharge as a variable yielded confounding relationships between variables. Although net recharge was statistically significant in the USGS Wells Model and the Groundwater Subbasin Models, the results from these analyses exhibited conflicting relationships between depth to water and net recharge that were not consistent with the conceptual model for groundwater vulnerability. The nature of the CVHM-generated net recharge data and the results exhibited in multiple regression analyses were considered using professional judgment during the multiple regression analyses and model development. Net recharge was eliminated from the Shallow Wells Model and All Wells Models because it was not statistically significant.

6.2.3.2 Other Independent Variables

Not surprisingly, across all multiple regression analyses and models, year of observation was positively correlated with the dependent variable and highly statistically significant. Additionally, analyses performed using squared year of observation indicate statistical significance to the relationship between squared year and the dependent variable in the All Wells Model, suggesting that the relationship between observation year and the dependent variable may not be linear. Results from using squared year in the All Wells Model suggest that there is a convex relationship (declining rate of increase with time) between year and observed nitrate concentration. However, the coefficients of hydrogeologic independent variables change little when the squared year is included in the model indicating that the relative groundwater vulnerability is unlikely to change considerably from the model based on year.

Although land use independent variables were used primarily to control for influences of variations in land use treatments on the observed concentration of nitrate in groundwater, notable statistically significant relationships for different land uses were observed in the models. Not surprisingly, this suggests that land use practices likely influence the groundwater quality, in addition to hydrogeologic characteristics that make certain locations intrinsically more vulnerable to groundwater contamination. More discussion about land use practices in relationship to the results of the groundwater vulnerability assessment is included later in this section.

6.2.3.3 Multiple Regression Equation Development

From the results of each of the multiple regression analyses, unique linear equations were developed to represent the different models for relative groundwater vulnerability based on intrinsic hydrogeologic characteristics. The complete linear equation for calculation of the predicted nitrate concentration in a well takes the form of:

$$\hat{Y} = a + b_{YEAR}Year + (b_{HG1}HG1 + b_{HG2}HG2 + \ldots + b_{HGX}HGX) + (b_{LU1}LU1 + b_{LU2}LU2 + \ldots + b_{LUX}LUX)$$

where,

$\hat{Y}$	predicted nitrate concentration
a	is a constant (intercept) from the multiple regression analysis
b	is a coefficient from the multiple regression (multiplier of a statistically significant independent variable)
Year	is observation year
HG	is a known statistically significant hydrogeologic independent variable
LU	is a known land use independent variable

Observation year and land use were included as independent variables in the multiple regression analyses, but their function was first and foremost to account for effects of time and land use practices on the dependent variable so that the relationship between hydrogeologic variables and the observed nitrate concentration could be discerned. The groundwater vulnerability approach in this GAR was aimed at assessing intrinsic groundwater vulnerability across the entire study area based only on measured hydrogeologic characteristics. Therefore, predicated nitrate concentrations were calculated holding land use and time constant across the entire study area and the vulnerability scores were generated as relative values scaled between the lowest predicted result and the highest predicted result. In this way, groundwater vulnerability results were calculated for the entire Central Valley Floor area of the Coalition region.

6.2.3.4 Multiple Regression Results Diagnostics

Figure 6-4 illustrates the normal probability plots of residuals (normal probability plots) for the Shallow Wells Model and All Wells Model. These graphs show the distribution of residuals (model-predicted value minus observed value) for models compared to a line illustrating how a normal distribution of residuals would appear. A normal distribution of error (residuals) is a central assumption of multiple regression analysis. As is evident in **Figure 6-4**, the patterns in the distributions of residuals for these two models are similar and are highly consistent between mid-1990s land use and early 2000s land use equations for both models. Residuals from the

Shallow Wells Model exhibit a relatively normal distribution as displayed on the normal probability plots (**Figure 6-4)**. In the Shallow Wells Model, the residuals plot along the line of expected normal residual value between a wide range of residual values from approximately negative 3 to positive 4. In the normal probability plots for the All Wells Model (**Figure 6-4**), the distribution of residuals deviates more from a normal pattern, particularly for higher residuals. The other candidate models exhibit residuals that deviate considerably from a normal distribution throughout much of their range.

Global Moran's I values were calculated for the residuals in the Shallow Wells Model and All Wells Models to evaluate the degree of spatial clustering of residuals in the models. The range of possible Global Moran's I values is from negative one to positive one where a value of zero indicates random spatial distribution in the data with increasing spatial clustering (positive spatial autocorrelation) as values increase to one. Values less than zero indicate negative spatial autocorrelation (dispersed) with more negative values indicating more dispersed data. The calculated Global Moran's I values for both the Shallow Wells Model and the All Wells Model suggest that the residuals in these models are clustered to some degree. Global Moran's I values for the model residuals range from 0.34 to 0.37 for the Shallow Wells Model and from 0.4 to 0.43 for the All Wells Model. As discussed above, this may indicate that the assumption of spatial independence of data in the models is not fully met. Although this is noteworthy, it is also important to consider the overall objective of the analysis and context for the use of this analysis in assessing relative groundwater vulnerability. Although a multiple regression model that does not fully meet all of the assumptions could potentially have a greater error in predicted values, the results from the models developed in this assessment were compared and evaluated in qualitative and quantitative ways to confirm that the results from the model are reasonable and consistent with observed groundwater quality data and hydrogeologic and land use conditions.

6.2.4 Groundwater Vulnerability Model Evaluation and Characterization

As described above, multiple regression equations were developed for several candidate groundwater vulnerability models using significant hydrogeologic independent variables. These models were compared and evaluated based on quantitative and qualitative (conceptual) performance measures. Two separate vulnerability equations were developed for each model based on the results from multiple regression analyses conducted using the mid-1990s land use and early 2000s land use conditions. The results from each model equation were compared using graphical presentations of residuals and calculated relative groundwater vulnerability values. Using the spatial datasets for the hydrogeologic variables, in a GIS grid format at a cell size of 30 meters by 30 meters, model equations were applied to the entire Central Valley Floor area within the Coalition region to calculate the relative groundwater vulnerability for each model equation. For each model, two separate groundwater vulnerability results were calculated for each cell based on the multiple regression equations developed from analyses using mid-1990s and early 2000s land use conditions. The maximum groundwater vulnerability value calculated from these two equations (mid-1990s and early 2000s) for each model was selected for each cell in the Central Valley Floor area of the Coalition region. The groundwater vulnerability value for a given model represents the maximum value selected from the results of two separate calculations using the mid-1990s and early 2000s regression equations for each model. Eventually, the maximum groundwater vulnerability values for each model were converted to percentiles for evaluation and comparison through various performance measures.

Based on preliminary evaluations of the models, results from the Groundwater Subbasin Models were inconsistent with other multiple regression models and the conceptual model. Additionally, model diagnostics on the All Wells Untransformed Model show residuals that are not very normally distributed, although the relationship of hydrogeologic variable coefficients was very similar to the All Wells Model. The USGS Wells Model includes well depth as an independent variable and illustrates the significance of well depth in nitrate concentrations. This model is likely more suitable for evaluating well vulnerability where well depth is known. However, the groundwater vulnerability assessment for the GAR is intended to evaluate all areas of the Coalition region so applying the USGS Wells model to determine groundwater vulnerability throughout the entire study area is problematic. Because of these reasons, the Shallow Wells Model and the All Wells Model were considered the top candidate models for further evaluation and application. Both models represented statistical relationships between hydrogeologic characteristics that were consistent with the conceptual model. The comparison below summarizes the results and performance of the Shallow Wells Model and the All Wells Model.

6.2.4.1 Shallow Wells Model

The significant hydrogeologic independent variables in the Shallow Wells Model are *soil hydraulic conductivity*, *depth to water*, and *slope*. **Table 6-4** shows the coefficients and p values for these variables in the mid-1990s and early 2000s model equations. From a closer evaluation of residuals from the Shallow Wells Model, the frequency distribution of residuals for the mid-1990s and early 2000s Shallow Wells Model equations show a relatively normal distribution as displayed in **Figure 6-5.**

Figures 6-6 and **6-7** show plots of the observed versus predicted values and observed versus residual value for each of the Shallow Wells Model equations. These figures illustrate general trends and patterns in the model performance. Overall, these plots show general similarity between results from the two Shallow Wells Model equations. Although there is considerable scatter in the data, the plots of predicted versus observed values (**Figure 6-6**) show a generally positive trending relationship between observed and predicted values. Interestingly, observed and predicted values are most similar, and the residuals are therefore lowest, for locations where observed values are near the average square-root transformed value of 2.93 for the dataset. Also, these plots show that the model tends to overpredict for many locations where observed values are relatively low and underpredict for many locations where observed values are high. Notably, there is a distinct pattern showing the model predicting the highest values (with smaller variability in predicted values) at locations where observed values are high. Similarly, there are relatively few locations where the model predicts a very low value when the observed value is high. Conversely, the variability in predicted values is greater for locations with lower observed values. This suggests that the model is able to identify the highest vulnerability areas in a relative sense, although the predicted values are generally below the observed values. Conceptually, this may indicate that observed values can be low in higher vulnerability areas if the land use conditions have not greatly impacted the groundwater quality; likewise, this pattern appears to suggest that the highest observed concentrations tend to be primarily where there are intrinsically more vulnerable conditions. For comparison, **Figure 6-8** displays the spatial distribution of model residuals across the study area. This map shows spatial trends in residuals and illustrates how well the model performs by observation location. **Figure 6-8** displays some of the clustering of residuals indicated based on the Global Moran's I values, particularly for positive residuals, although some clustering of negative residuals is also apparent.

Additional methods of model assessment were performed to evaluate the model performance with respect to assessing groundwater vulnerability across the entire study area. The performance of each model was evaluated with regard to the relationship between relative groundwater vulnerability and the observed groundwater quality. **Figure 6-9** shows the maximum calculated groundwater vulnerability from the mid-1990s and early 2000s Shallow Wells Model equations. For purposes of evaluating model results, the calculated relative groundwater vulnerability was converted to percentile values. Percentile is used to indicate the percentage of observations in a group that fall below a given level. In other words the 75th percentile is the level below which 75 percent of values will fall. Converting relative groundwater vulnerability values to percentiles proved to be useful for qualitatively and quantitatively evaluating the performance of the model. The spatial distribution of calculated groundwater vulnerability was compared with the locations of observed nitrate concentration above the Maximum Contaminant Level (MCL) standard ("exceedances") as shown in **Figure 6-9**. Additional comparisons of the predicted groundwater vulnerability relative to well locations with concentrations above 5 mg/L were also conducted and are discussed later in this section. Qualitatively, the groundwater vulnerability for the Shallow Wells Model appears to be reasonable and shows quite similar spatial trends in vulnerability as indicated by the observed exceedances. Most of the nitrate exceedances are located within areas of higher predicted groundwater vulnerability. Visually, results from the Shallow Wells Model indicate the higher vulnerability areas are in locations of generally high soil hydraulic conductivity, low depth to groundwater, and low slope. The influence of soil characteristics and depth to water conditions on the groundwater vulnerability results is particularly apparent in **Figure 6-9**. The largest areas of higher vulnerability values within the Coalition region are concentrated in the northwestern portion of the Valley Floor area where groundwater is relatively shallow. Additionally, higher vulnerability areas tend to follow river and alluvial fan systems where soils are generally coarser in texture and have higher hydraulic conductivity characteristics.

Figure 6-10 shows the overall good model performance more quantitatively using measures based on "capturing" of nitrate exceedances by vulnerability percentile. Nitrate exceedances shown and discussed are for all wells (i.e., shallow, deep, and unknown depth) in which any past measurement of nitrate concentration has exceeded the MCL of 10 mg/L. As shown in **Figure 6-10**, approximately 56 percent of exceedances are captured at the 80th percentile groundwater vulnerability level and 68 percent of exceedances are captured at the 75th percentile level; this means that 68 percent of exceedances fall within the top 25 percent of calculated groundwater vulnerability values. The generally good model performance is also confirmed by a plot of distance of exceedances to the highest vulnerability areas in **Figure 6-11**, as represented at the 75th percentile groundwater vulnerability level. This figure shows that exceedances are generally within or in close proximity to areas of highest vulnerability (75th percentile) with a high percentage (86 percent) of exceedances within one-quarter mile and a total of 92 percent of exceedances within one-half mile of a 75th percentile area.

Overall, the Shallow Well Model results show a clear pattern between groundwater vulnerability percentile and the observed nitrate at locations as shown in **Figure 6-12.** This figure shows that groundwater vulnerability is generally higher in areas where observed nitrate is higher; however, as described above, there are areas where the groundwater vulnerability is high even though the nitrate concentrations in groundwater are still relatively low. Although it is many of these areas of low observed nitrate that have the largest residuals in the model, this pattern is expected and these areas likely represent areas where past land use practices have resulted in less contamination of groundwater despite the hydrogeologic conditions that make the areas more vulnerable.

6.2.4.2 All Wells Model

The significant hydrogeologic independent variables in the All Wells Model are *soil hydraulic conductivity*, *deeper subsurface conductivity*, *depth to water*, and *slope*. **Table 6-4** shows the coefficients and p values for these variables in the mid-1990s and early 2000s model equations. In contrast to the Shallow Wells Model, the All Wells Model includes deeper subsurface conductivity as an independent variable and also has lower coefficients for soil hydraulic conductivity. The coefficient for the depth to water is also more highly negative in the All Wells Model than it is in the Shallow Wells Model and the coefficient for slope is less negative in the All Wells Model than in the Shallow Wells Model. When compared with the Shallow Wells Model, the normal probability plot of residuals displayed in **Figure 6-4** suggests that residuals for the All Wells Model are relatively normally distributed, but the distribution is not as normal as the Shallow Wells Model, particularly for higher residuals. The frequency distribution plot of residuals in **Figure 6-5** also illustrates differences in residual trends between the two models.

Figures 6-13 and **6-14** show plots of the observed versus predicted values and observed versus residual values for both of the All Wells Model equations using mid-1990s and early 2000s land use. Again, these figures show general similarity between results from the two All Wells Model equations and also illustrate highly similar prediction trends to those exhibited by the Shallow Wells Model, although the overall density of data is much greater for the All Wells Model. As with the Shallow Wells Model, there is considerable scatter in the plots showing observed versus predicted and residual values for the All Wells Model. However, the plots show a generally positive trending relationship between observed and predicted values with the smallest model residuals occurring where observed nitrate concentrations are near the mean (square-root transformed value of 2.34). Overall, the model tends to predict the highest values (with smaller variability in predictions) at locations where observed values are high, although predicted values tend to be lower than observed. The existence of unique land use factors at locations where the highest nitrate concentrations are observed may potentially explain the general underprediction of results for the highest observed values. For locations with lower observed values, the variability in predicted values is greater. From a conceptual standpoint, this may again suggest that observed values can be low in higher vulnerability areas (areas of higher predicted nitrate) if the land use conditions have not greatly impacted the groundwater quality. For comparison, **Figure 6-15** displays the spatial distribution of residuals for the All Wells Model across the study area. The spatial trends in residuals shown in this map are similar to those for the Shallow Wells Model.

Figure 6-16 shows the maximum calculated groundwater vulnerability from the two All Wells Model equations. The calculated relative groundwater vulnerability was converted to percentile values for analysis and display as in **Figure 6-16**. The spatial distribution of groundwater vulnerability results for the All Wells Model is remarkably similar to those from the Shallow Wells Models although there are subtle differences. These differences are most evident in areas of deeper groundwater such as areas southwest of Merced and in the vicinity of the Chowchilla River alluvial fan. Like the Shallow Wells Model, most nitrate exceedances are located within areas of higher predicted groundwater vulnerability. The influences of soil characteristics and depth to water conditions on the All Wells Model groundwater vulnerability results are most apparent in the spatial distribution of results and the diminished influence of the slope variable can also be seen in **Figure 6-16** with generally lower vulnerability values in eastern portion of the Valley Floor area. As with the Shallow Wells Model, the largest areas of higher vulnerability values within the Coalition region are concentrated in the northwestern portion of the Valley Floor area where groundwater is relatively shallow and higher vulnerability areas tend to also follow river and alluvial fan systems where soils generally have higher hydraulic conductivity characteristics.

More quantitative performance measures, such as the number of exceedances captured by groundwater vulnerability percentile from the All Wells Model presented in **Figure 6-17,** better illustrate subtle differences between performance of the Shallow Wells and All Wells Models.

Again, **Figure 6-17** shows an overall good model performance for the All Wells Model with similar capture rates for exceedances by vulnerability percentile as the Shallow Wells Model. Approximately 62 percent of exceedances are captured at the 80th percentile groundwater vulnerability level and 68 percent of exceedances are captured at the 75th percentile level; this means that 68 percent of exceedances fall within the top 25 percent of calculated groundwater vulnerability values, which is slightly below the percentage of exceedances captured by the Shallow Wells Model at the 75th percentile. Although the All Wells Model captures a higher percentage of exceedances within the highest vulnerability percentiles, with respect to capturing of nitrate exceedances, the model performance falls off slightly at vulnerability percentiles of 75th and below. At vulnerability percentiles of 75th and below, the Shallow Wells Model outperforms the All Wells Model in the capturing of exceedances. Additionally, although the generally good model performance is confirmed by a plot of distance of exceedances to the 75th percentile groundwater vulnerability level in **Figure 6-18**, the number of exceedances within distances of one-quarter mile and one-half mile of these areas of highest vulnerability is less than for the Shallow Wells Model.

6.2.4.3 USGS Wells Model

Although the R-squared values for the USGS Wells Model regressions were slightly higher than those for some of the other models, the application of the model equations for predicting groundwater vulnerability is problematic and questionable. There are many potential reasons for why the fit of the USGS Wells Model regressions is slightly better (higher R-squared values). Firstly, the dataset incorporates well depth as an independent variable, which is also found to be statistically significant in the regressions. Additionally, greater consistency in water quality sample collection and analysis, well selection criteria, and timing for sampling performed by the USGS may also reduce the amount of variance that the model is unable to account for. **Figure 6-19** shows the calculated groundwater vulnerability for the USGS Wells Model. This figure highlights the difficulty associated with applying this model to assess groundwater vulnerability across the study area. The spatial relationship between calculated groundwater vulnerability using the USGS Wells Model and exceedances clearly indicates the relatively poor performance of the model when compared with known impacted groundwater conditions. Since the model includes the well depth variable, but does not include depth to groundwater as an independent variable (because it was not significant in the multiple regression), the calculated groundwater vulnerability fails to capture areas where groundwater is shallow.

6.2.5 Defining the High Vulnerability Area Using the Shallow Wells Model

Both the Shallow Wells Model and All Wells Model showed generally very strong agreement and similarity in groundwater vulnerability results; however, by quantitative measures the Shallow Wells Model performs better by capturing a slightly greater percentage of the MCL exceedance wells at the 75th percentile and also at lower groundwater vulnerability percentiles. As shown in **Figure 6-10**, a high percentage of exceedance wells are captured within the highest groundwater vulnerability percentile areas based on the Shallow Wells Model and the number of exceedance wells drops off considerably below the 75th percentile level. Additionally, a greater number of exceedance wells are within close distance from the 75th percentile groundwater vulnerability area from the Shallow Wells Model. **Figure 6-20** shows that a natural break also occurs at the 75th percentile groundwater vulnerability level for capturing wells with nitrate concentrations above 5 mg/L (as N). Additionally, the Shallow Wells Model fits the conceptual model for groundwater vulnerability better because it is based on nitrate observations in shallow wells only and the range of well depths included in the Shallow Wells Model is more constrained than for the All Wells Model. Because of the greater influence of soil hydraulic conductivity, results from the Shallow Wells Model indicate generally higher groundwater vulnerability in areas where coarse-textured soils exist from the sediment deposition of shifting ancestral and modern waterways creating a network of alluvial channels and fans. These areas and depositional features typically exhibit a heterogeneous material composition in lateral and vertical dimensions. Such networks of sinuous alluvial channels of coarser material are particularly apparent in the vicinity south and west of Madera and west and south of Chowchilla as shown on the map of soil hydraulic conductivity (**Figure 3-3**) and as evident in the Shallow Wells Model groundwater vulnerability map (**Figure 6-9**). This aspect of the Shallow Wells Model was an important consideration in the selection of this model.

A **Hydrogeologic High Vulnerability Area (HHVA)** was identified for areas where groundwater vulnerability results from the Shallow Wells Model are of 75th percentile or greater. This threshold was established because a natural break in the capture rate for exceedance wells (including shallow, deep, and unknown depth designations) exists at the 75th percentile level with approximately 68 percent of exceedance wells falling within this area. The HHVA is shown in **Figure 6-21** and defines the area where groundwater is most likely to be vulnerable to contamination based on select hydrogeologic characteristics identified in the groundwater vulnerability model. **Figure 6-11** shows that most exceedances occur within a short distance from the HHVA suggesting that the HHVA does well in capturing most areas where groundwater quality has been greatly impacted and that other areas of impacts tend to be near the HHVA. To account for some of the ambiguity associated with the vulnerability percentile cutoff for the HHVA and because of the gradational nature (transition from coarse to fine deposits) and intrinsic heterogeneity and discontinuity of the alluvial channel and fan deposits in the area, a 0.5-mile buffer around the HHVA was added in the vicinity of wells where an observed exceedance has occurred. These exceedance locations represent areas where groundwater has already been impacted and the buffer takes into consideration the presence of exceedances in proximity to alluvial channels and fans where the vulnerability might not be as well characterized by mapped shallow and surficial geologic materials alone. Areas with alluvial deposits from migrating channels and fans are less likely to have major continuous layers that would prevent or greatly impede the vertical movement of a contaminant into the groundwater, even if the surficial soils and sediments suggest a lower vulnerability. Accordingly, professional judgment was also used in select circumstances to extend the buffer area to include other nearby exceedances. As shown in **Figure 6-22**, the half-mile buffer is generally only included around the HHVA within two miles of an observed exceedance; HHVAs that are greater than two miles from an observed exceedance are not buffered, although some professional judgment was used to extend the buffer in select areas.

The combined extents of the HHVA and buffer area represent the **East San Joaquin Water Quality Coalition High Vulnerability Area (ESJHVA)**(**Figure 6-23)**. A total of 98 percent of all exceedances within the Central Valley Floor portion of the Coalition region fall within the ESJHVA and any exceedances falling outside these areas are addressed below. **Figure 6-24** illustrates the characterization of all exceedance wells that do <u>not</u> fall within the high vulnerability area. Only 32 wells with observed exceedances do not fall within the ESJHVA. Of these 32 wells, only 10 are within the irrigated lands area with five of these ten exceedance wells being dairy-related wells. Dairy wells may have factors beyond the hydrogeologic characteristics that contribute to the exceedances. Of the five exceedance wells that are not dairy wells, only one has a "confirmed exceedance" (2 or more observations at or above the MCL). The fact that so few "vulnerability outlier" wells exist suggests that the ESJHVA is a reasonable representation of high vulnerability areas based on a combination of hydrogeologic conditions and known exceedances. The breakdown of characteristics for all exceedances is shown in **Table 6-6**.

Several additional areas where exceedances have occurred but which fall well outside the ESJJVA were designated as Tentative High Vulnerability Areas (labeled A through F) because they have been added to capture wells with nitrate exceedances that do not fall within the ESJHVA. These areas are identified on **Figure 6-23** and each of these Tentative High Vulnerability Areas is shown in detail on **Figure 6-25** illustrating the locations of exceedance wells and other wells within each area with groundwater quality data. **Table 6-7** displays information about the exceedance wells located within each Tentative High Vulnerability Area that can be related to wells identified on **Figure 6-25**. A total of 32 exceedance wells are located within the Tentative High Vulnerability Areas. Tentative High Vulnerability Areas are included as part of the high vulnerability area designated in this GAR, but are distinct from the ESJHVA because they are not in areas of predicted high vulnerability based on hydrogeologic conditions and quantitative analyses. In the future, the Coalition may seek to obtain additional information to address whether these Tentative High Vulnerability Areas are appropriately designated as high vulnerability. There may be unique characteristics of the vulnerability outlier wells within the Tentative High Vulnerability Areas 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.

Table 6-8 summarizes and compares the vulnerability areas as developed in this GAR. Within the Coalition region, the total number of acres in the ESJHVA is approximately 784,000 acres out of almost 1,690,000 acres located within the Central Valley Floor. This represents about 47 percent of the Central Valley Floor area within the Coalition region. Approximately 577,000 acres of the ESJHVA occur within the irrigated lands portion of the Coalition region representing approximately 55 percent of the nearly 1,048,000 irrigated acres. The addition of the six Tentative High Vulnerability Areas increases the high vulnerability area by alomost 71,000 acres to a total of approximately 855,000 acres within the Coalition region. Of these 855,000 acres of the Total Tentative High Vulnerability Area, approximately 629,000 acres are irrigated lands.

6.2.6 Comparison of the East San Joaquin Water Quality Coalition High Vulnerability Area (ESJHVA)

A visual comparison of the ESJHVA developed in this GAR with DPR's designated GWPAs and SWRCB *Hydrogeologically Vulnerable Areas* is presented in **Figure 6-26**. As discussed above in **Section 6.1.1**, the SWRCB *Hydrogeologically Vulnerable Areas* are based on the mapped extent of geologic units that are interpreted to enable the vertical movement of contaminants. The DPR GWPAs represent areas where soil and depth to groundwater conditions within a section are similar to conditions in sections in which pesticides have been detected. In **Figure 6-26**, general similarities between the ESJHVA and the DPR GWPAs and the SWRCB *Hydrogeologically Vulnerable Areas* are apparent, particularly in the northern portion of the Central Valley Floor within the Coalition region. Further south, the ESJHVA differs considerably in extent from both the DPR and SWRCB areas. In the southern portion, the DPR GWPAs are generally located along the western part of the Central Valley Floor, whereas the SWRCB *Hydrogeologically Vulnerable Areas* are further east. For the most part, the main areas where DPR GWPAs are not covered by the ESJHVA occur in the southwestern portion of the Central Valley Floor in areas designated by DPR as having high runoff potential because of hardpan soils. These are areas of low soil hydraulic conductivity as shown on **Figure 3-3;** consequently, the groundwater vulnerability model in this GAR suggests low groundwater vulnerability in these areas. The main areas where SWRCB *Hydrogeologically Vulnerable Areas* fall outside of the extent of the ESJHVA occur in the southern and more eastern parts of the Central Valley Floor. Many of these areas are located where the hydraulic conductivity of soils is low and where depth to groundwater is high (**Figures 3-11** and **3-12**). Partly for these reasons, the groundwater vulnerability model in this GAR does not indicate high groundwater vulnerability in these areas.

6.2.6.1 Nitrate

Table 6-9 provides a comparison of the DPR GWPAs, SWRCB *Hydrogeologically Vulnerable Areas,* and the ESJHVA with respect to how well these areas capture locations of wells with elevated nitrate concentrations. Approximately 71 percent of nitrate MCL exceedance wells fall within the extent of DPR's designated GWPAs. GWPAs with leaching potential capture 64 percent of nitrate exceedances and GWPAs with runoff potential capture 7 percent of nitrate exceedances. By contrast, only 28 percent of nitrate exceedances fall within the SWRCB Hydrogeologically Vulnerable Area. When combined, the DPR and SWRCB designated areas capture 82 percent of nitrate exceedances and cover approximately 791,000 acres. For comparison, 98 percent of nitrate exceedances fall within the ESJHVA, although the area of the ESJHVA is approximately 7,000 acres less than the combined area of the DPR and SWRCB designated areas. Within the irrigated lands area, 55 percent of the area is covered by the ESJHVA representing a total of approximately 577,000 acres.

Further comparisons of the different vulnerability area designations with respect to locations of wells with nitrate concentrations of 5 mg/L or above are also presented in **Table 6-9**. Although 5 mg/L represents a concentration that is half of the MCL, such results may indicate concentrations above naturally occurring levels. In a comparison of wells with a concentration equal to or greater than 5 m/L, 64 percent of wells fall within the DPR GWPAs and 30 percent of wells are within the extent of the SWRCB *Hydrogeologically Vulnerable Areas*. Together, the combined DPR and SWRCB designated areas capture 80 percent of wells with a nitrate concentration of 5 mg/L or greater. This is in contrast to the ESJHVA, which captures 93 percent of wells with observed nitrate concentration of 5 mg/L or above.

6.2.6.2 Pesticides

The spatial relationship between locations with pesticide concentrations exceeding groundwater quality goals (as defined above in **Section 5.2.3**) and the extent of the ESJHVA is illustrated in **Figure 6-27**. Similar to elevated nitrate concentrations, pesticides in groundwater generally indicate impacts from agricultural land uses. **Figure 6-27** shows the PLSS sections in which pesticide exceedances have occurred within the Central Valley Floor overlain on the ESJHVA. Although pesticide concentrations from DPR are only reported by section (approximately one-square mile area), there are clearly strong indications that the ESJHVA reasonably captures the highest vulnerability areas as indicated by pesticide exceedances. As seen on **Figures 5-10a** through **5-10c**, pesticides have also been detected in wells in the Peripheral Area, although land use mapping indicates no irrigated lands are in these areas.

Table 6-10 summarizes the locations of pesticide exceedances with respect to the ESJHVA, the SWRCB *Hydrogeologically Vulnerable Areas*, and DPR GWPAs. Because data from DPR on pesticide concentrations measured in wells is only referenced to the section in which the sample was collected, evaluating the locations of wells with exceedances relative to the ESJHVA and other designated areas of groundwater vulnerability is challenging. For that reason, the data on pesticide exceedances within the Central Valley Floor are presented in **Table 6-10** in several ways: 1) percent of the total area of sections with an exceedance covered by high/low vulnerability categories, 2) percent and number of exceedance wells that are within sections assigned as high/low vulnerability based on the dominant (>50 percent) category for the section, and 3) percent and number of exceedance wells that are within sections where any part of the section is covered by the high vulnerability designation.

Of the total area of sections in which a pesticide exceedance has been reported, 96 percent of the total area of these sections falls within the ESJHVA. Of these same sections, 60 percent of the total area is within the SWRCB *Hydrogeologically Vulnerable Areas* and 65 percent is within areas designated by DPR as GWPAs. DPR GWPAs designated as having runoff potential capture only 3 percent of the total area of sections with an exceedance. The combined area of the DPR and SWRCB areas cover 90 percent of the total area of sections in which a pesticide exceedance has been reported.

A total of 357 out of 367 exceedance wells (97 percent) are in sections that are more than 50 percent within the ESJHVA. Only 226 exceedance wells (62 percent) are in sections that are mostly within the extent of SWRCB *Hydrogeologically Vulnerable Areas*; 244 exceedance wells (66 percent) are in sections that are mostly within areas designated by DPR as GWPAs. Of the 244 exceedance wells captured by DPR's GWPAs, only 8 (2 percent) were located in sections designated as having runoff potential. All pesticide exceedance wells within the Central Valley Floor are in sections that have some amount of coverage by the ESJHVA; 92 percent of wells are in sections that are at least partly covered by the combined area of the DPR and SWRCB areas.

6.2.6.2 TDS

Figure 6-28 compares the extent of the ESJHVA with observed TDS concentrations in groundwater. While TDS concentration in groundwater is not as good a measure of impacts from irrigated agriculture as nitrate concentration, it provides an interesting comparison and illustrates some similar spatial trends as are exhibited by nitrate, although there are notable differences. Major areas of difference in the spatial patterns exhibited by nitrate and TDS concentrations occur along the San Joaquin River. Nevertheless, most areas where TDS is consistently high are also located within the ESJHVA.

6.2.7 Summary of Vulnerability Designation

The approach to determining groundwater vulnerability developed in this GAR is based on adaptations to index-based methods and incorporates "calibration" of the weighting for input variables based on the results from statistical analyses using observed nitrate concentrations. Multiple regression analyses were used to detect significant relationships between hydrogeologic characteristics and the observed nitrate concentration in groundwater across the study area, while controlling for different land use types. Land use categories as mapped for three time periods (mid-1990s, early 2000s, and 2012) were evaluated as controlling independent variables in the multiple regression analyses. Hydrogeologic variables investigated included soil hydraulic conductivity, deeper subsurface hydraulic conductivity, depth to groundwater, groundwater recharge, topographic slope, and Corcoran Clay characteristics. Square root transformation of observed nitrate concentration created a more normal distribution of dependent variable values and, together with exclusion of outliers of greater than 60 mg/L, yielded more normally distributed residuals in the multiple regression analyses.

Using stepwise backward elimination of insignificant (p value > 0.1) independent variables, several candidate groundwater vulnerability models were developed from the multiple regression results and selected for further comparison and evaluation from quantitative and qualitative performance standpoints. The two primary model candidates were:

1. **Shallow Wells Model –**based on data from shallow wells only and dependent variable of square root transformed nitrate concentration; included significant hydrogeologic independent variables of *soil hydraulic conductivity*, *depth to groundwater*, and *slope*

2. **All Wells Model –** based on data from wells of all depths and dependent variable of square root transformed nitrate concentration; included significant hydrogeologic independent variables of *soil hydraulic conductivity, deeper subsurface conductivity, depth to groundwater*, and *slope*

The performance of these two models was compared and evaluated. The **Shallow Wells Model** performs better in quantitative and qualitative measures based on capturing and proximity of nitrate MCL exceedances and also considering conceptual aspects of the hydrogeologic conditions. Using groundwater vulnerability results from the Shallow Wells Model a Hydrogeologic High Vulnerability Area (HHVA) was defined based on the natural break in the capture rate for exceedances at the 75^{th} percentile groundwater vulnerability level. Buffer areas and some professional judgment were applied to extend the high vulnerability area generally by 0.5 miles around the HHVAs in the vicinity (< 2 miles) of known groundwater degradation as defined by exceedances. Therefore, the extent of the ESJHVA for this GAR includes the HHVAs and buffer areas in the vicinity of known exceedances. Tentative High Vulnerability Areas were assigned to areas where vulnerability outlier wells exist (wells with exceedances far from the ESJHVA). These Tentative High Vulnerability Areas are included as part of the high vulnerability area designated in this GAR but are distinct from areas denoted as ESJHVA because they have been added to capture wells with nitrate exceedances that do not fall within the area of predicted high vulnerability. In the future, these areas may warrant further attention to determine if they should appropriately be designated as high vulnerability. However, until such an investigation can be completed, and for the purposes of this GAR, the Tentative High Vulnerability Areas are included as part of the high vulnerability area.

6.3 Prioritization of High Vulnerability Area

For planning of future monitoring and management efforts focused on the high vulnerability areas and to fulfill requirements of the WDR, all high vulnerability areas were prioritized. In Attachment E 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,
- 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
- 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 areas of high, moderate, and low priority were generalized 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 high vulnerability area. **Table 6-11** 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 6-11** 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 the calculated groundwater vulnerability percentile 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 high vulnerability area. For each component considered in the priority calculation, all locations within the high vulnerability area 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 6-11**). 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 high vulnerability area from which generalized high priority areas could be defined. The components and groupings included in the prioritization matrix are detailed in **Table 6-11** 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.

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*. The hydrogeologic groundwater vulnerability component was used as a way of incorporating a measure of intrinsic vulnerability at locations based on results from the groundwater vulnerability analysis described above. The hydrogeologic groundwater vulnerability component was ranked according to groundwater vulnerability percentile at locations (**Figure 6-9**) and weighted at 15 percent.

Legacy or ambient conditions of groundwater quality were incorporated through measures of the observed groundwater quality and from temporal trends in groundwater quality. These measures were ranked from zero to ten based on average nitrate concentration and average temporal trend in nitrate within one half mile. The data used in ranking these measures are shown in **Figures 5-4** and **5-5** and **Figures 5-14** and **5-15**. 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 6-11**. The data shown in **Figures 5-4** and **5-5** 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 percent of wells with a detection 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 5-10a**.

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 high vulnerability area, 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 high vulnerability area 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 4-1**. Land use was determined from the USDA 2012 data for ranking applied nitrogen and it was weighted at 7.5 percent. Typical irrigation method by land use category was based on data from DWR early 2000s land use surveys and as shown in **Table 4-3** and was ranked by location using 2012 USDA land use data. Land use categories were ranked zero to ten based on percentage of different types of irrigation methods used in early 2000s. Irrigation method was weighted at 12.5 percent in the priority calculation. Whether a commodity represented the top 80 percent of the high vulnerability area was also incorporated as a yes/no factor based on land use category and as weighted at 2.5 percent. The top land use categories are shown in **Table 4-2**.

Other prioritization factors identified in the WDR such as proximity to recharge areas for public water systems reliant on groundwater and groundwater basins currently under review by CV-SALTS were also incorporated. Proximity to recharge areas for public water systems reliant on groundwater was included based on the calculated contributing groundwater to located public water systems from CDPH's CEHTP spatial data as shown on **Figure 3-20** and listed in **Table 3-2**. The ranking system was based on distance from the system boundary with a greater weighting on locations within a contributing area to a public water system. This factor was weighted high at 30 percent because these public water systems rely on groundwater as a significant source of supply of drinking water for communities. 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, 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 as 2.5 percent.

From applying this prioritization matrix, priority values ranging from zero to ten (low to high priority) were calculated for the entire high vulnerability area. The calculated priority values are shown on **Figure 6-29**.

6.3.2 Final Generalized Priority Areas

Using the calculated priority values described above as guidance, generalized areas of high, moderate, and low priority were drawn to inform groundwater monitoring and management efforts within the high vulnerability area. The generalized prioritization of high vulnerability areas that was developed from the calculated priority values is shown on **Figure 6-30**. Because the proximity to public water systems reliant on groundwater has a high weighting in the prioritization matrix, high priority areas tend to be focused around public water systems in particular in the vicinity of Modesto, Merced, and Madera. Other areas where groundwater quality factors rank high (i.e., high nitrate, pesticide detections) also have high calculated priority values, although they are not as high as in the vicinity of the public water systems.

Table 6-12 summarizes the land within the different priority areas. Approximately 144,000 acres of the ESJHVA are located within the highest priority area (Priority 1) and of those acres over 50 percent (more than 79,000 acres, based on FMMP 2010 data) are irrigated lands. Over 267,000 acres of the ESJHVA are located in the moderate priority area (Priority 2) of which about 225,000 acres are irrigated lands (based on FMMP 2010 data). The remaining nearly 373,000 acres of the ESJHVA are in the relatively lower priority area (Priority 3) and include approximately 270,000 acres of irrigated lands (based on FMMP 2010 data).

As shown in **Table 6-12**, based on USDA 2012 cropland data, nut trees currently represent the largest agricultural land use category by area across each of the three priority area types. Within the Priority 1 area, non agricultural land uses make up the largest fraction of the area totaling 71,344 acres. Nut trees cover 44,121 acres within the Priority 1 area, which is more than half of the irrigated lands within the Priority 1 area. Grains/cotton and grasses represent the next largest land use categories within the Priority 1 area with total acreages of 9,440 and 7,257 acres, respectively. Within the Priority 2 area, nut trees represent the largest land use category encompassing 85,397 acres. A total of 60,949 acres of the Priority 2 area are non agricultural lands. Grains/cotton represents the next largest land use category within the Priority 2 area at 35,215 acres followed by land use categories of double crops (31,617 acres) and grasses (23,733 acres). The dominant land use category in the Priority 3 area is non agricultural (111,388 acres). Nut trees (95,804 acres), grasses (43,739 acres), and grapes (43,944 acres) are the most common agricultural land use categories within the Priority 3 area.

7 GROUNDWATER MONITORING PROGRAMS

7.1 Sources of Information on Existing Groundwater Monitoring Programs

As indicated in earlier report sections, many entities have conducted groundwater monitoring in the Coalition region, including monitoring on the Central Valley Floor and also in the Peripheral area. The WDR specifies that within one year from the approval of the GAR, the Coalition shall develop a workplan for conducting trend monitoring that meets the objectives and minimum requirements of the MRP. The objectives for the trend monitoring program include:

3. Determine current water quality conditions of groundwater relevant to irrigated agriculture; and
4. 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:

5. High and low groundwater vulnerability areas in the Coalition region;
6. Use of shallow wells "but not necessarily well completed in the uppermost zone of first encountered groundwater" (WDR R5-2012-0116, Attachment B, IV, C);
7. The potential suitability of existing monitoring networks such as those developed for purposes of AB 3030/SB 1938 groundwater management plans; and
8. 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.

7.1.1 <u>DWR</u>

In the Coalition region, historically, groundwater levels have been measured in over 7,100 wells. DWR has monitored 3,372 wells for groundwater levels, including 1,300 shallow wells (**Table 7-1**).

Groundwater quality measurements have been made in over 6,500 wells for nitrate and over 4,500 for TDS. DWR has monitored 836 of these for water quality, including 29 in the deep zone and 807 that have unknown depths or cannot be classified qualitatively (**Table 7-1**). Due to the lack of readily available well construction information, it is not known whether there are shallow wells monitored by DWR for water quality in the Coalition region. Groundwater quality samples have been collected by DWR since before 1970 at 607 wells for nitrate and 847 wells for TDS (**Table 7-1**). In the 1980s, there were 127 wells sampled by DWR for nitrate and 130 for TDS. Since the 1990s, there do not appear to be wells sampled by DWR for water quality in the Coalition region.

7.1.2 GAMA

As part of the GAMA program (including wells that were sampled historically that later were included in the GAMA program), 1,932 wells have been monitored for groundwater levels, including 750 shallow wells (**Table 7-1**).

As part of the GAMA program, more than 2,000 wells have been monitored for nitrate and over 1,600 for TDS. In the shallow zone, 483 wells have been monitored for nitrate and 254 for TDS (**Table 7-1**). Groundwater quality samples have been collected since before 1970 at 296 wells for nitrate and 371 wells for TDS (**Table 7-1**). In the 1980s, there were 159 wells sampled for nitrate and 169 wells for TDS. In the 2000s, there were 1,057 GAMA wells sampled for nitrate and 881 wells for TDS. Recently, since 2010, there have been 989 wells sampled for nitrate and 415 for TDS.

7.1.3 USGS

As part of special studies or longer-term investigations, the USGS has monitored 1,250 wells for groundwater levels, including 646 shallow wells (**Table 7-1**).

The USGS has monitored 540 wells for nitrate and 722 for TDS. In the shallow zone, 320 wells have been monitored for nitrate and 429 for TDS (**Table 7-1**). Groundwater quality samples have been collected since before 1970 at 306 wells for nitrate and 371 wells for TDS (**Table** 7-1). In the 1980s, there were 85 wells sampled for nitrate and 149 wells for TDS. In the 2000s, there were 147 USGS wells sampled for nitrate and 161 wells for TDS. Since 2010 there have been 7 wells sampled for nitrate and 9 for TDS.

7.1.4 MID

The Merced Irrigation District has monitored 239 wells for groundwater levels, with no wells classified as shallow wells (**Table 7-1**).

MID has monitored 29 wells for nitrate and 29 for TDS; the depths of these wells are unknown. (**Table 7-1**). The only time period during which MID sampled wells was during the 2000s and they sampled 29 wells for nitrate and TDS. No additional groundwater quality sampling has been completed since the 2000s.

7.1.5 TID

The Turlock Irrigation District has monitored 363 wells for groundwater levels all of which are shallow wells (**Table 7-1**).

TID has monitored 108 wells for nitrate and 108 for TDS; these wells are indicated by TID to be in the shallow zone (**Table 7-1**). The first groundwater quality sampling was completed in the 1990s when TID sampled 54 wells for nitrate and TDS. In the 2000s, there were 105 wells sampled for nitrate and TDS. No water quality sampling has been performed by TID since 2010.

7.1.6 OID

The Oakdale Irrigation District currently monitors groundwater levels in at least 20 wells that are reported to CASGEM.

7.1.7 DPR

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. A large number of agencies report groundwater testing data to DPR, however, recent data since 2005 for the Coalition region have been from CDPH (92%), SWRCB (4%), and DPR (3%). Other contributors of data before 2005 include the USGS, Rhone-Poulenc Agricultural Company, DWR, U.S. Forest Service, Madera County, and Fresno County. Under the Safe Drinking Water Act, CDPH provides regulatory oversight of public water systems, from which results are reported to DPR. 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 legal use of the chemicals.

When DPR receives a result indicating a pesticide detection, DPR investigates the detection to determine if it was the result of legal agricultural practices, and if 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.

7.1.8 CDPH

Community water systems are required to report water quality parameters on a triennial or more frequent schedule, pending location of the system and specific circumstances that may require more frequent testing and reporting. CDPH data for the Coalition region include 1,235 wells for nitrate and 915 for TDS. Due to lack of access to well construction information, these wells are categorized as completed in the deep zone (**Table 7-1**). No record of groundwater quality samples before the 1980s exist for CDPH. In the 1980s, there were 216 wells sampled for nitrate and 213 wells for TDS. In the 1990s there were 344 CDPH wells sampled for nitrate and 332 wells sampled for TDS. In the 2000s, there were 1,160 CDPH wells sampled for nitrate and 829 wells sampled for TDS. More recently, since 2010, there have been 991 CDPH wells sampled for nitrate and 598 wells sampled for TDS (**Table 7-1**).

7.1.9 RWQCB – Dairy Monitoring Programs

As part of the overall RWQCB dairy monitoring program, existing wells located on dairy properties regulated under the Dairy General Order are required to be monitored. In addition, some dairies have individual WDRs. The available data for the GAR included these two datasets, which are available from the RWQCB. Under the dairy source, 1,775 wells have been monitored for nitrate and 34 for TDS. Of these wells, 1,334 wells monitored for nitrate and 34 for TDS are indicated to be in the shallow zone (**Table 7-1**). Groundwater quality samples were only collected during the 2000s, a period during which 1,775 wells were sampled for nitrate and 34 wells were sampled for TDS (**Table 7-1**).

7.1.10 Groundwater Management Plans in Watershed Area

Groundwater Management Plans in the Coalition region were reviewed to assess the existence of monitoring being conducted by other local entities. The monitoring described in these plans is summarized below. It is likely that groundwater monitoring described in these plans overlaps to some extent with the online groundwater data available from the sources described above. For purposes of this section, this overlap is not addressed.

Modesto Subbasin: The Integrated Regional Groundwater Management Plan for the Modesto Subbasin (Bookman Edmonston, 2005) includes a table of “Current Level of Monitoring Efforts”. This table lists a number of member agencies, including Modesto Irrigation District, Oakdale Irrigation District, a number of small communities and also DWR and CDPH. Altogether, the table shows a total of 113 wells monitored for water levels and 104 wells monitored annually for water quality.

Turlock Subbasin: The 2008 Turlock Groundwater Subbasin Groundwater Management Plan (Turlock Groundwater Basin Association, 2008) includes a table of “Current Level of Monitoring Efforts”. The local agencies listed on this table overlap to some extent with the table described above for the Modesto Subbasin. The table shows a total of 68 wells monitored monthly for water levels (and also an additional 307 wells monitored for levels by DWR) and 69 wells sampled from monthly to triennially for water quality (and an additional 163 wells sampled to meet CDPH requirements for water quality).

Merced Subbasin: The 2008 Merced Groundwater Basin Groundwater Management Plan Update, Merced County, CA (AMEC Geomatrix, 2008) does not include a table, but the plan mentions others that monitor in the basin and the plan includes a figure (figure 35) with a “Proposed Groundwater Monitoring Well Network, Merced Groundwater Basin”. There are 27 wells shown on the map with state well numbers. There is also an Integrated Regional Water Management Plan (RMC, 2013) for the Merced area, but this plan does not include a groundwater monitoring network discussion.

Chowchilla/Madera Subbasins: The Groundwater Management Plan, Madera County (Todd Engineers, 2002) describes a variety of groundwater monitoring programs that exist throughout the county and suggests a meeting of all parties currently collecting groundwater data. Subsequently, in December 2010**,** a Memorandum of Understanding (MOU) (CRCD, 2010) was drafted that recognized the Madera-Chowchilla Basin Regional Groundwater Monitoring Plan. The purpose of the MOU is to “cooperate in the monitoring and reporting of groundwater elevations, groundwater quality, and land surface subsidence as described in their respective GWMPs…”. Part of the MOU also describes that the group party to the MOU prepare a planning document, “Madera-Chowchilla Basin Coordinated Groundwater Monitoring Plan”.

7.2 Summary of Existing Groundwater Monitoring Programs

Figures 7-1 through **7-3** illustrate the sources of available data for wells monitored since 2005 in the Coalition region. **Figure 7-1** shows all wells monitored for groundwater levels or water quality since 2005 within the entire Coalition region. **Figure 7-2** shows sources of available data for wells with groundwater level measurements within the Central Valley Floor area of the Coalition region, and **Figure 7-3** shows sources of available data for wells with groundwater quality measurements within the Central Valley Floor area of the Coalition region. The tables described above also include wells monitored historically. While many historically monitored wells may not be currently monitored, these wells may still be suitable candidates for future trend monitoring, pending availability of construction information and depending on whether access can be obtained. Similarly, wells that may have been historically monitored, or continue to be monitored, for groundwater levels may also be suitable candidates for the future trend monitoring program.

Figures 7-4 through **7-9** illustrate the locations of historically monitored wells for groundwater levels and groundwater quality with a backdrop of the high groundwater vulnerability area, including the Priority 1 areas. Preliminarily, the coverage of existing wells (shallow, deep and unknown depths) appears to include wells located in the Priority 1 areas, other high vulnerability areas, and also low vulnerability areas. It appears that there is a large pool of existing, already monitored wells that can serve as potential candidate wells for the trend monitoring network. A subset of the potential wells would be identified for further examination to assess the suitability of potential candidate wells in meeting the objectives of the trend monitoring program, including: 1) whether wells in desirable locations are currently monitored by others, 2) well construction information is available, and 3) the well is accessible.

Table 7-2 summarizes the recent groundwater level and groundwater quality monitoring that has taken place within the Coalition region since 2005. Groundwater levels in 2,812 wells have been measured by four entities since 2005. Of these wells recently monitored, 1,773 are shallow wells. DWR has measured recent groundwater levels in 1,291 wells and measurements are available from 1,202 wells in the GAMA program. TID has also recently monitored water levels in 278 wells, and USGS has measured water levels in 41 wells since 2005 (**Table 7-2**).

Since 2005, 4,454 wells have been sampled for nitrate and 1,934 wells have been sampled for TDS (**Table 7-2**). Dairy wells make up the largest fraction of wells that have been sampled since 2005 with 1,767 wells sampled for nitrate and 26 sampled for TDS. GAMA data include nitrate samples for 1,388 wells and 900 wells with TDS samples. Since 2005, 1,134 CDPH wells have been sampled for nitrate and 837 wells have been sampled for TDS. TID has sampled 95 wells for nitrate and TDS, and the USGS has sampled 41 wells for nitrate and 47 wells for TDS. MID has sampled 29 wells for both nitrate and TDS.

Table 7-3 summarizes the recent groundwater monitoring since 2005 by location relative to high and low groundwater vulnerability areas. A total of 1,929 wells have been monitored for groundwater levels since 2005 in the ESJHVA, and 87 wells have been monitored recently for groundwater levels within the Tentative High Vulnerability Areas. An additional 462 wells have been monitored for groundwater levels in the low groundwater vulnerability area within the Central Valley Floor, while 334 wells in the Peripheral Area have been monitored for groundwater levels since 2005. The primary entities from which recent groundwater data are available are DWR and through the GAMA program.

Since 2005, 3,010 wells within the ESJHVA have been sampled for nitrate and 1,150 have been sampled for TDS (**Table 7-3**). Within the Tentative High Vulnerability Areas, 171 wells have been sampled for nitrate since 2005 and 45 wells have been sampled for TDS. In low vulnerability areas within the Central Valley Floor, 271 wells have been sampled for nitrate and 168 wells have been sampled for TDS since 2005. Additionally, in the Peripheral Area, 1,002 wells have been sampled for nitrate since 2005 and 571 wells have been sampled for TDS.

Dairy wells make up the largest fraction of wells sampled for nitrate since 2005 in both the ESJHVA and the Tentative High Vulnerability Areas with 1,571 dairy wells sampled for nitrate within the ESJHVA and 113 wells sampled for nitrate within the Tentative High Vulnerability Areas. CDPH and GAMA are the next largest source of nitrate sampling data. Since 2005, 600 CDPH wells in the ESJHVA have been sampled for nitrate, and 681 wells within the ESJHVA in the GAMA program have been sampled for nitrate. In the low vulnerability area within the Central Valley Floor, 105 CDPH wells have been sampled for nitrate since 2005, and 82 wells in the GAMA program have been sampled for nitrate. In the Peripheral Area, 402 CDPH wells have been sampled for nitrate since 2005, and 594 wells in the GAMA program have been sampled for nitrate. CDPH and GAMA represent the largest sources of TDS data since 2005. Within the ESJHVA, 469 CDPH wells have been sampled for TDS and 492 wells in the GAMA program have been sampled for TDS. In the Peripheral Area, 270 CDPH wells have been sampled for TDS and 301 wells in GAMA have been sampled for TDS. Other monitoring entities have also sampled wells since 2005 within the ESJHVA; however, few or no wells have been sampled by these other entities in areas outside the ESJHVA since 2005.

Data provided by DPR for use in this GAR were only available at a spatial resolution accurate to the PLSS section in which the well is located. Based on these data provided by DPR, the spatial distribution of sections within the Coalition region where wells have been sampled for pesticides since 2005 is shown in **Figure 7-10.** Numerous sections throughout the Coalition region have wells with pesticide data since 2005, and several areas of notably higher density of pesticide data exist, particularly in the northwest portion of the Coalition region.

Since 2005, DPR has assembled pesticide results for over 1,800 wells. On average, data for between 200 and 300 wells have been collected annually since 2005 (**Figure 7-11**); data for these wells generally represent between 150 and 200 sections. Most of the recent pesticide data are a result of reporting from CDPH for public supply wells, although limited recent sampling has been conducted by DPR and considerable additional pesticide data were provided by SWRCB during 2006 and 2008 as part of the GAMA program.

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Table 1-1
Groundwater Quality Assessment Report (GAR) Items Identified in WDR

GAR Items Identified in Monitoring and Reporting Program (Appendix B) of the Eastern San Joaquin River Watershed WDR General Order	Where Addressed in GAR
1. Objectives	
A. Provide an assessment of all 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.	Section 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.	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.	Section 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.	Section 3

Table 1-1
Groundwater Quality Assessment Report (GAR) Items Identified in WDR

GAR Items Identified in Monitoring and Reporting Program (Appendix B) of the Eastern San Joaquin River Watershed WDR General Order	Where Addressed in GAR
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.	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
(all data since 1910)

Monitoring Entity	Number of wells	Number of samples	Number with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Samples Pre-1970s	Samples in 1970s	Samples in 1980s	Samples in 1990s	Samples in 2000s	Samples in 2010s
DWR	3,372	112,438	75	159	23	35	0	41	3,114	1,300	163	1,909	39,727	21,849	20,086	18,113	10,519	2,144
GAMA	1,932	32,973	762	0	1,586	0	0	0	346	750	15	1,167	2	0	0	128	26,322	6,521
MID	239	13,944	0	0	0	0	0	0	239	0	4	235	1,841	1,805	2,167	4,534	3,597	0
TID	363	157,817	200	0	0	0	0	163	200	363	0	0	48,753	24,082	24,864	25,401	25,812	8,905
USGS	1,250	8,531	1,070	0	0	0	0	0	1,250	646	427	177	32	2,579	3,193	1,392	1,260	75
Total	7,156	325,703	2,107	159	1,609	35	0	204	5,149	3,059	609	3,488	90,355	50,315	50,310	49,568	67,510	17,645

Table 3-2
Located Public Water Systems Reliant on Groundwater

Public Water System Name	System Number	Status Description	Status Code
Ballico Community Serv. Dist.	2400167	Active	AU
Ceres West Mhp	5000077	Active	AU
Ceres, City Of	5010028	Inactive	IU
City Of Modesto, De Grayson	5010033	Active	AR
Countryside Mobilehome Estates - Adult P	5000086	Active	AU
East Acres Mutual Water Company	2000512	Active	AU
Faith Home Teen Ranch	5000217	Active	AU
Fcpg/Lost Lake Recreation Area	1000097	Active	AU
Foster Farms #5	5000579	Active	AU
Green Run Mobile Estates	5000085	Standby	SU
Hughson, City Of	5010008	Inactive	IU
Islewood Golf Course	1000443	Active	AU
Madera Cmd No 19 Parkwood	2010004	Inactive	IU
Madera Co Sa No 19-Rolling Hills	2010009	Standby	SR
Madera County M.D. #10A - Madera Ranchos	2010008	Active	AU
Madera Valley Water Company	2010010	Active	AU
Madera-City	2010002	Active	AR
Mahal Apartments	2000800	Active	AU
Merced, City Of	2410009	Active	AR
Mobile Plaza Park	5000051	Active	AU
Planada Csd	2410007	Standby	SR
Roberts Ferry School Cafeteria	5000155	Active	AU
Sandy Mush Detention Center D.B.A. John	2400172	Active	AU
Sjr Farming Erreca Turner Island	2400174	Inactive	IU
Valley State Prison For Women	2010801	Active	AR

Data from CDPH California Environmental Health Tracking Program (CEHTP), Drinking Water Systems Geographic Reporting Tool

AU=active untreated, IU=inactive untreated, AR=active raw, SU=standby untreated, SR=standby raw

Raw=water will be treated, Untreated=water will not be treated

Table 4-1
Land Use Classification System

LSCE	DWR				USDA			Applied Nitrogen[d]	
			Mid-1990s[a]	Early 2000s[a]			2012	(lbs nitrogen/ac/year)	
Group Description	Land Use Codes	Land Use Description	% of Valley Floor Land Cover[b]	% of Valley Floor Land Cover[b]	Codes	Land Use Description	% of Valley Floor Land Cover[b]	1973	2005
Non Agricultural	All "U" codes, #, L, NV, NR, NS, NV, NW	**Native vegetation (36%)**, **urban (7%)**, water surface, riparian vegetation, other.	39.9%	38.3%	61, 111, 121, 122, 123, 124, 131, 141, 142, 143, 152, 171, 190, 195	**Grasslands herbaceous (30.22 %)**, **Developed (9%),** barren, forest, water, wetlands, shrubland	44.6%	-	-
Nut Trees	D12, D13, D14	**Almonds (13%)**, walnuts, pistachios	15.5%	17.5%	74, 75, 76, 204	**Almonds (20%)**, pecans, walnuts, pistachios	23.3%	120-148	138-179
Grasses	All "P" codes	**Alfalfa (6%)**, pasture (mixed and native), clover, turf farms	12.4%	11.9%	27, 36, 58, 59	**Alfalfa (7%)**, rye, , clover/wildflowers, sod/grass seed,	7.9%	20[e]	11[e]
Vegetables	F6 (corn) and all "T" codes	**Corn (7%)**, tomatoes, sweet potatoes, artichokes, beans (green), broccoli, bush berries, cabbage, cauliflower, celery, cucumbers, flowers, nursery, Christmas tree farms, lettuce, melons, squash, onions, garlic, peppers, strawberries	8.7%	10.4%	1, 12, 41, 43, 44, 46, 47, 48, 49, 50, 53, 54, 57, 206, 207, 208, 209, 213, 214, 216, 219, 221, 227, 242	**Corn (1.3%),** tomatoes, sweet potatoes, asparagus, blueberries, broccoli, cantaloupes, carrots, cucumbers, garlic, greens, herbs, honeydew melons, lettuce, misc vegs & fruits, onions, peas, peppers, potatoes, strawberries, sugar beets, sweet corn, watermelons	3.0%	*Corn*[c]: 145 *Tomatoes*[c]: 142 *Sweet Potatoes*[c]: 107[e]	*Corn*[c]: 213 *Tomatoes*[c]: 180 *Sweet Potatoes*[c]: 147[e]
Grapes	All "V" codes	Vineyards	7.5%	7.8%	69	Grapes	7.1%	53-57	27-44
Grains/Cotton	All "G" codes and also F1 (Cotton)	**Cotton (2.4%), grain and hay crops (2.3%)**, barley, wheat, oats, misc.	8.2%	5.7%	2, 21, 22, 23, 24, 28, 37, 205	**Cotton (1.1%),** barley, **wheat (3%)** (Durum, Spring, Winter), oats, other hay/non alfalfa, triticale	9.3%	88-109	174-177
Double Crops	-	-		-	225, 226, 235-238	**Oats/Corn (2.6%), Winter Wheat/Corn (1.5%)**, Barley/Corn, Barley/Sorghum, Winter Wheat/Cotton, Winter Wheat/Sorghum	4.1%		
Seeds/beans	All "F" codes **except** F1 (Cotton) and F6 (Corn)	Field crops, dry beans, safflower, sugar beets, grain sorghum, sudan	2.1%	2.9%	4, 5, 6, 42, 33	Dry beans, safflower, sorghum, soybeans, sunflower	0.1%	51	91
Fruit Trees	D1, D2, D3, D5, D6, D7, D8, D9, D10, D, D**	**Peaches and nectarines (0.1%)**, apples, apricots, cherries, , pears, plums, prunes, figs, misc. deciduous, deciduous fruit and nuts	2.9%	2.6%	66, 67, 68, 71, 77, 218, 220, 223	**Cherries (0.1%)**, apples, apricots, nectarines, other tree crops, peaches, pears, plums	0.2%	95-133	102-130
Dairy/ Farmsteads	All "S" codes	**Dairies (0.89%)**, farmsteads, Poultry farms, livestock feed lot operations	2.0%	2.2%	-	-	-	-	-
Citrus/ Subtropics	All "C" codes	**Oranges (0.3%)**, grapefruit, eucalyptus, , olives, kiwis	0.4%'	0.4%	72, 211, 212, 217	Citrus, olives, oranges, pomegranates	0.1%	65-166	95-123
Rice	All "R" codes	Rice	0.4%	0.3%	3	Rice	0.2%	86	130
Total:			100%	100%			100%		

[a] Mid-1990s DWR land use combines data for Stanislaus County (1996), Merced County (1995), and Madera County (1995); Early 2000s DWR land use combines data for Stanislaus County (2004), Merced County (2002), and Madera County (2001).

[b] Land cover values are shown as percent of the Central Valley Floor portion of the Coalition study area.

[c] From DWR Early-2000s land use data, approximately 92% of the total area of Group 7 crops is made up of corn (75%), tomatoes (12%), and sweet potatoes (5%).

[d] Source of applied nitrogen rates: Rosenstock, T.S. and others, 2013, Nitrogen fertilizer use in California: assessing the data, trends and a way forward, California Agriculture, Vol 67 No. 1. pgs 68-79. Online: http://californiaagriculture.ucant.edu/landingpage.cfm?article=ca.E.v067n01p68&fulltext=yesDPI:10.3733/ca.E.v067n01p68

[e] Source of applied nitrogen rates for sweet potatoes and alfalfa, 1975 and 2005: Viers, J.H. and others, 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 California, Davis, prepared for California State Water Resources Control Board.

Table 4-2

Top Agricultural Crop Categories in 2012

Crop Category	Acres	Cumulative Percent	Top 80% Category
Nut Trees	388,001	42.03%	Yes
Grains/Cotton	156,024	58.93%	Yes
Grasses	131,994	73.23%	Yes
Grapes	117,705	85.98%	Yes
Double Crops	68,865	93.44%	No
Vegetables	49,834	98.83%	No
Fruit Trees	4,160	99.28%	No
Rice	2,774	99.59%	No
Citrus/Subtropics	2,370	99.84%	No
Seeds/Beans	1,457	100.00%	No

Data from 2012 USDA cropland data layer

Table 4-3

Summary of Irrigation Practices

Land Use Category	Irrigation Method		
	Basin/Furrow	Micro/Drip	Sprinkler
From Early 2000s Land Use Survey (DWR)			
Citrus/Subtropics	18.5%	7.3%	74.2%
Fruit Trees	40.0%	41.8%	18.2%
Grains/Cotton	93.7%	0.1%	6.1%
Grapes	45.4%	53.8%	0.8%
Grasses	97.8%	0.1%	2.1%
Nut Trees	32.0%	5.4%	62.6%
Rice	100.0%	0.0%	0.0%
Seeds/Beans	85.0%	0.0%	15.0%
Vegetables	91.5%	5.6%	2.9%
Overall Early 2000s From DWR	**65.0%**	**12.2%**	**22.8%**
From Recent Coalition Grower Reporting			
Overall Recent Coalition Data	**29.6%**	**64.0%**	**6.4%**

Data Compiled from DWR Land Use Surveys 2001-2004 and from ESJWQC most recent grower reported irrigation method

Note: irrigation method only reported for 91,154 acres from ESJWQC grower reporting; data on irrigation method from DWR land use survey covers 922,422 acres

Table 5-1

Summary of Assembled Groundwater Quality Data

(all data since 1940)

Nitrate Data																					
Monitoring Entity	Number of wells	Number of samples	Number with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Wells with results over 5 mg/L (as N)	Wells with results over 10 mg/L (as N)	Wells with results over 20 mg/L (as N)	Samples Pre-1970s	Samples in 1970s	Samples in 1980s	Samples in 1990s	Samples in 2000s	Samples in 2010s
Dairy	1,775	2,236	0	441	35	1,299	0	0	0	1,334	441	0	1,107	845	513	0	0	0	0	2,236	0
CDPH	1,235	27,404	0	0	0	0	1,235	0	0	0	1,235	0	438	146	21	0	0	754	3,388	16,910	6,352
DWR	836	1,651	0	0	0	0	29	11	796	0	29	807	240	56	5	1,246	278	127	0	0	0
GAMA	2,049	17,475	0	0	483	0	1,566	0	0	483	1,566	0	615	260	83	611	70	399	1,159	10,463	4,773
MID	29	32	0	0	0	0	0	0	29	0	0	29	16	9	2	0	0	0	0	32	0
TID	108	323	0	0	0	0	0	108	0	108	0	0	106	105	68	0	0	0	55	268	0
USGS	540	1,574	521	0	0	0	0	0	540	320	201	19	166	58	19	631	72	88	73	701	9
Total	6,572	50,695	521	441	518	1,299	2,830	119	1,365	2,245	3,472	855	2,688	1,479	711	2,488	420	1,368	4,675	30,610	11,134

Total Dissolved Solids (TDS) Data																					
Monitoring Entity	Number of wells	Number of samples	Number with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Wells with results over 500 mg/L	Wells with results over 1,000 mg/L	Wells with results over 1,500 mg/L	Samples Pre-1970s	Samples in 1970s	Samples in 1980s	Samples in 1990s	Samples in 2000s	Samples in 2010s
Dairy	34	156	0	0	34	0	0	0	0	34	0	0	25	8	0	0	0	0	0	156	0
CDPH	915	7,175	0	0	0	0	915	0	0	0	915	0	130	35	16	0	0	437	920	4,537	1,281
DWR	1,054	2,466	0	0	0	0	29	0	1,025	0	0	1,054	213	76	51	2,046	289	131	0	0	0
GAMA	1,654	6,555	0	0	254	0	1,400	0	0	254	0	1,400	466	183	122	1,400	124	262	406	3,467	896
MID	29	32	0	0	0	0	0	0	29	0	0	29	5	0	0	0	0	0	0	32	0
TID	108	323	0	0	0	0	0	108	0	108	0	0	102	18	1	0	0	0	55	268	0
USGS	722	3,215	696	0	0	0	0	0	722	429	267	26	167	61	43	842	74	454	364	1,464	17
Total	4,516	19,922	696	0	288	0	2,344	108	1,776	825	1,182	2,509	1,108	381	233	4,288	487	1,284	1,745	9,924	2,194

Table 5-2
Summary of Pesticide Detections

Pesticide	Wells Sampled	Wells with Detection	Wells with Exceedance	Sections Sampled	Sections with Detection	Sections with Exceedance	Concentration in Samples with Detections (µg/L)			Exceedance Threshold Used (µg/L)	Basis for Exceedance Threshold*
							Average	Minimum	Maximum		
1,2-Dichloropropane (Propylene Dichloride)	1107	13	0	567	12	0	0.4	0.03	1.4	5	CA Primary MCL
2,4-DP (Isooctyl Ester)	40	2	0	31	2	0	0.01	0.0	0.01	-	Chemical not in database
3,4-Dichloro Aniline	160	12	0	146	12	0	0.005	0.004	0.01	-	Chemical not in database
ACET (Deisopropylatrazine)	233	41	0	185	37	0	0.14	0.0	0.53	-	Chemical not in database
Alachlor	832	1	0	488	1	0	0.1	0.1	0.1	2	CA Primary MCL
Alachlor ESA	18	2	0	11	2	0	0.494	0.077	0.91	-	Chemical not in database
Aldicarb Sulfone	414	23	21	250	2	2	46	1	1281	3	EPA Primary MCL
Aldicarb Sulfoxide	366	4	0	249	2	0	2.9	2.9	2.9	4	EPA Primary MCL
Atrazine	1292	49	0	712	47	0	0.077	0.004	0.599	1	CA Primary MCL
Bentazon, Sodium Salt	369	4	0	220	4	0	1.72	0.26	3.74	18	CA Primary MCL
Bromacil	941	9	0	531	9	0	0.096	0.01	0.303	-	No value in database
Carbon Disulfide	226	4	0	183	4	0	0.05	0.03	0.07	160	CA Notification
Chlorothalonil	348	1	0	239	1	0	0.02	0.02	0.02	-	No value in database
Chlorthal-Dimethyl	241	2	0	205	1	0	0.46	0.37	0.54	-	No value in database
Coumaphos	2	1	0	2	1	0	1	1	1	-	Chemical not in database
DBCP (Dibromochloropropane)	1786	632	331	675	250	154	0.831	0.001	166	0.2	CA Primary MCL
Deethyl-Atrazine (DEA)	346	58	0	280	56	0	0.028	0.004	0.429	-	No value in database
Demeton	128	1	0	89	1	0	1	1	1	-	No value in database
Desmethylnorflurazon	79	15	0	65	13	0	0.360	0.066	1.86	-	Chemical not in database
Desulfinyl Fipronil	160	1	0	146	1	0	0.005	0.005	0.005	-	Chemical not in database
Diaminochlorotriazine (DACT)	126	46	0	93	38	0	0.243	0.051	1.23	-	Chemical not in database
Diazinon	732	2	2	442	2	2	127.5	0.1	507	1.2	CA Notification
Dicamba	331	1	0	228	1	0	0.01	0.01	0.01	-	No value in database
Dinoseb	388	1	0	243	1	0	0.04	0.04	0.04	7	CA Primary MCL
Diuron	618	32	0	394	29	0	0.16	0.01	1	-	No value in database
Ethylene Dibromide	590	21	14	330	16	12	0.24	0.01	1	0.05	CA Primary MCL
Ethylene Dichloride	29	1	1	29	1	1	2.9	2.9	2.9	0.5	CA Primary MCL
Fipronil	160	1	0	146	1	0	0.011	0.011	0.011	-	Chemical not in database
Fipronil Sulfone	160	1	0	146	1	0	0.008	0.008	0.008	-	Chemical not in database
Hexazinone	429	12	0	328	10	0	0.078	0.008	0.27	-	No exceedance value
Imazethapyr	47	1	0	45	1	0	0.01	0.01	0.01	-	Chemical not in database
Merphos	45	1	0	36	1	0	1	1	1	-	No value in database
Methyl Bromide (Bromomethane)	1047	6	0	538	5	0	2.37	0.54	7.7	-	No value in database
Metolachlor	637	11	0	382	11	0	0.011	0.004	0.036	-	No value in database
Metolachlor ESA	18	9	0	11	7	0	0.527	0.06	1.155	-	Chemical not in database
Metolachlor OXA	18	4	0	11	4	0	0.140	0.072	0.279	-	Chemical not in database
Naled (Dibrom)	33	1	0	28	1	0	5	5	5	-	No value in database
Naphthalene	684	6	1	398	5	1	6.4	0.4	29	17	CA Notification
Norflurazon	217	9	0	175	8	0	0.152	0.01	0.468	-	No value in database
Ortho-Dichlorobenzene	848	2	0	454	2	0	0.69	0.56	1	-	No value in database
Prometon	732	6	0	484	6	0	0.432	0.005	1.7	-	No value in database
Propoxur	156	1	0	127	1	0	5	5	5	30	CA Notification
Simazine	1288	75	1	711	62	1	0.335	0.003	6.6	4	CA Primary MCL

Table 5-2
Summary of Pesticide Detections

Pesticide	Wells Sampled	Wells with Detection	Wells with Exceedance	Sections Sampled	Sections with Detection	Sections with Exceedance	Concentration in Samples with Detections (µg/L)			Exceedance Threshold Used (µg/L)	Basis for Exceedance Threshold*
							Average	Minimum	Maximum		
Tetrachloroethane	590	2	1	339	2	1	26.12	0.84	51.4	1	CA Primary MCL
Tetrachloroethylene	30	2	0	30	2	0	0.2	0.2	0.2	5	CA Primary MCL
Tetrachlorvinphos (Stirofos)	24	1	0	16	1	0	1	1	1	-	No value in database
TPA (2,3,5,6-Tetrachloroterephthalic Acid)	7	3	0	4	2	0	0.817	0.419	1.5	3500	CA Notification
Xylene	817	8	0	430	8	0	1.10	0.61	2.2	1750	CA Primary MCL
TOTAL UNIQUE LOCATIONS	**2732**	**872**	**369**	**997**	**375**	**167**					

Pesticide data are for the period 1979-2011 provided by the California Department of Pesticide Regulation (DPR)

*Exceedance thresholds used are based on values reported in the SWRCB Water Quality Goals Online Database (http://www.waterboards.ca.gov/water_issues/programs/water_quality_goals/search.shtml), when available.
Selection of the threshold value for use to indicate an exceedance is based on a hierarchy consisting of the following order of preference:
CA Primary MCL = California Primary MCL; EPA Primary MCL = EPA's Federal Primary MCL; CA Notification = California Notification Level
No value in database = Chemical is in the database but not possible threshold value reported, Chemical not in database = Chemical was not located in the SWRCB database

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 Sequences 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 Statistics of Multiple Regression Datasets

	Complete Data set	Count	Min	Max	St. Dev.	Average	Median
All Wells	Untransformed Nitrate	5001	<0.01	340.54	14.09	8.81	4.07
	Square Root Nitrate	5001	0.01	18.45	1.74	2.41	2.02
Shallow Wells	Untransformed Nitrate	2027	0.01	340.54	18.70	13.73	7.40
	Square Root Nitrate	2027	0.07	18.45	2.10	3.06	2.72
	Outliers Excluded (Untransformed Concentrations >60)	Count	Min	Max	St. Dev.	Average	Median
All Wells	Untransformed Nitrate	4955	<0.01	60.00	10.62	8.03	4.07
	Square Root Nitrate	4955	0.01	7.75	1.60	2.34	2.02
Shallow Wells	Untransformed Nitrate	1987	0.01	59.00	13.17	12.14	7.20
	Square Root Nitrate	1987	0.07	7.68	1.89	2.93	2.68

Table 6-3

Independent Variable Correlation Matrices

Correlation Matrix for Shallow Wells Model (excluding outliers)

Variable	Year	Soil Hydraulic Conductivity (SSURGO)	Vertical Hydraulic Conductivity (CVHM Lay. 1)	Spring Depth to Ground-water	Net Recharge (CVHM)	Slope
Year	1.00	-0.02	0.00	-0.18	-0.07	-0.07
Soil Hydraulic Conductivity (SSURGO)	-0.02	1.00	0.22	-0.05	-0.14	0.11
Vertical Hydraulic Conductivity (CVHM Layer 1)	0.00	0.22	1.00	-0.33	-0.26	-0.14
Spring Depth to Ground-water	-0.18	-0.05	-0.33	1.00	**0.50**	0.17
Net Recharge (CVHM)	-0.07	-0.14	-0.26	**0.50**	1.00	0.03
Slope	-0.07	0.11	-0.14	0.17	0.03	1.00

Correlation Matrix for All Wells Model (excluding outliers)

Variable	Year	Soil Hydraulic Conductivity (SSURGO)	Vertical Hydraulic Conductivity (CVHM Lay. 1)	Spring Depth to Ground-water	Net Recharge (CVHM)	Slope
Year	1.00	0.03	0.02	-0.19	-0.05	0.01
Soil Hydraulic Conductivity (SSURGO)	0.03	1.00	0.21	-0.13	-0.11	0.09
Vertical Hydraulic Conductivity (CVHM Layer 1)	0.02	0.21	1.00	-0.24	-0.16	-0.14
Spring Depth to Ground-water	-0.19	-0.13	-0.24	1.00	**0.46**	0.12
Net Recharge (CVHM)	-0.05	-0.11	-0.16	**0.46**	1.00	0.02
Slope	0.01	0.09	-0.14	0.12	0.02	1.00

Correlation Matrix for Shallow Wells Model (with outliers)

Variable	Year	Soil Hydraulic Conductivity (SSURGO)	Vertical Hydraulic Conductivity (CVHM Lay. 1)	Spring Depth to Ground-water	Net Recharge (CVHM)	Slope
Year	1.00	-0.02	0.01	-0.18	-0.07	-0.07
Soil Hydraulic Conductivity	-0.02	1.00	0.22	-0.05	-0.14	0.10
Vertical Hydraulic Conductivity (CVHM	0.01	0.22	1.00	-0.33	-0.26	-0.14
Spring Depth to Ground-water	-0.18	-0.05	-0.33	1.00	**0.50**	0.18
Net Recharge (CVHM)	-0.07	-0.14	-0.26	**0.50**	1.00	0.03
Slope	-0.07	0.10	-0.14	0.18	0.03	1.00

Correlation Matrix for All Wells Model (with outliers)

Variable	Year	Soil Hydraulic Conductivity (SSURGO)	Vertical Hydraulic Conductivity (CVHM Lay. 1)	Spring Depth to Ground-water	Net Recharge (CVHM)	Slope
Year	1.00	0.03	0.02	-0.20	-0.05	0.01
Soil Hydraulic Conductivity	0.03	1.00	0.21	-0.13	-0.11	0.09
Vertical Hydraulic Conductivity (CVHM	0.02	0.21	1.00	-0.24	-0.16	-0.14
Spring Depth to Ground-water	-0.20	-0.13	-0.24	1.00	**0.46**	0.12
Net Recharge (CVHM)	-0.05	-0.11	-0.16	**0.46**	1.00	0.02
Slope	0.01	0.09	-0.14	0.12	0.02	1.00

Table 6-4
Summary of Results from Multiple Linear Regression Analyses

	Candidate Model Description	[1]Multiple R-squared	[1]Overall Regression p-value	[1]Standard Error	Dependent Variable	Independent Variable	[1]Coefficient	[1]p-value	n	MCL Exceedance Capture Rate
1	Shallow Wells Only, Square Root Transformed (NO3 as N) stepwise backward elimination of hydrogeologic variables, continuous land use category by %, discarding of extreme observations (>60 mg/L; value of 6x MCL - represents less than 0.9% of dataset)	0.16/0.14	<0.0005	1.74/1.75	Most recent NO3 (as N) observation (square root transformed)	Year (most recent observation)	0.0202/0.0205	<0.0005	1987	LU 95/96: 68% at 75th percentile
						Soil saturated hydraulic conductivity (harmonic mean) (feet/day)	0.0151/0.0216	0.023/0.001		LU 01/04: 69% at 75th percentile
						Depth to water (spring) (feet)	-0.0023/-0.0031	0.046/0.007		**Max Model: 68% at 75th percentile**
						Slope (degrees)	-0.1222/-0.1152	0.0008/0.002		
2	All Wells, Square Root Transformed (NO3 as N) stepwise backward elimination of hydrogeologic variables, continuous land use category by %, discarding of extreme observations (>60 mg/L; value of 6x MCL - represents less than 0.9% of dataset)	0.19/0.18	<0.0005	1.43/1.45	Most recent NO3 (as N) observation (square root transformed)	Year (most recent observation)	0.0150/0.0152	<0.0005	4955	LU 95/96: 69% at 75th percentile
						Soil saturated hydraulic conductivity (harmonic mean) (feet/day)	0.0105/0.0133	0.0031/0.0002		
						Vertical hydraulic conductivity (CVHM Layer 1) (feet/day)	0.8054/0.8395	0.085/0.075		LU 01/04: 68% at 75th percentile
						Depth to water (spring) (feet)	-0.0036/-0.0037	<0.0005		
						Slope (degrees)	-0.0460/-0.0450	<0.0005		**Max Model: 68% at 75th percentile**
3	All Wells, Untransformed (NO3 as N) stepwise backward elimination of hydrogeologic variables, continuous land use category by %, discarding of extreme observations (>60 mg/L; value of 6x MCL - represents less than 0.9% of dataset)	0.21/0.20	<0.0005	9.39/9.47	Most recent NO3 (as N) observation (untransformed)	Year (most recent observation)	0.084/0.085	<0.0005	4955	LU 95/96: 68% at 75th percentile
						Soil saturated hydraulic conductivity (harmonic mean) (feet/day)	0.067/0.083	0.004/0.0003		
						Vertical hydraulic conductivity (CVHM Layer 1) (feet/day)	6.612/6.588	0.030/0.032		LU 01/04:68% at 75th percentile
						Depth to water (spring) (feet)	-0.029/-0.03	<0.0005		**Max: 68% at 75tn percentile**
						Slope (degrees)	-0.183/-0.165	0.029/0.051		
4	USGS All Wells, Square Root Transformed (NO3 as N) stepwise backward elimination of hydrogeologic variables, continuous land use category by %, discarding of extreme observations (>60 mg/L; value of 6x MCL - represents less than 0.9% of dataset)	0.23/0.20	<0.0005	1.00/1.02	Most recent NO3 (as N) observation (square root transformed)	Year (most recent observation)	0.0132/0.0145	<0.0005	488	LU 95/96: 15% at 75th percentile
						Well depth (feet)	-0.0014/-0.0015	<0.0005		LU 01/04: 15% at 75th percentile
						Net Recharge (feet/year)	0.1837/0.1917	0.025/0.022		**Max: 15% at 75th percentile**
						Slope (degrees)	-0.1014/-0.097	0.0001/0.003		

Table 6-4
Summary of Results from Multiple Linear Regression Analyses

Candidate Model Description	[1]Multiple R-squared	[1]Overall Regression p-value	[1]Standard Error	Dependent Variable	Independent Variable	[1]Coefficient	[1]p-value	n	MCL Exceedance Capture Rate
5 All Wells by DWR Groundwater Subbasin Areas, Square Root Transformed (NO3 as N), stepwise backward elimination of hydrogeologic variables, land use category by %, discarding of extreme observations (>60 mg/L; value of 6x MCL - represents less than 0.9% of dataset)									
Turlock & Modesto Subbasins	0.21/0.20	<0.0005	1.54/1.55	Most recent NO3 (as N) observation (square root transformed)	Year (most recent observation)	0.0123/0.0128	<0.0005	2950	
					Soil saturated hydraulic conductivity (harmonic mean) (feet/day)	0.0103/0.0135	0.028/0.004		
					Depth to water (spring) (feet)	-0.0069/-0.007	<0.0005		
					Net Recharge (feet/year)	-0.1105/-0.0873	0.034/0.096		
					Slope (degrees)	-0.0419/-0.0418	0.005		
Merced Subbasin	0.14/0.12	<0.0005	1.29/1.30	Most recent NO3 (as N) observation (square root transformed)	Year (most recent observation)	0.0146/0.0156	<0.0005	995	
					Soil saturated hydraulic conductivity (harmonic mean) (feet/day)	0.0180/0.0188	0.025/0.015		
					Net Recharge (feet/year)	0.5812/0.5723	<0.0005		
					Slope (degrees)	-/0.1226	0.098		
Chowchilla & Madera Subbasins	0.20/0.22	<0.0005	1.04/1.03	Most recent NO3 (as N) observation (square root transformed)	Year (most recent observation)	0.0127/0.0112	<0.0005	1051	
					Vertical hydraulic conductivity (CVHM Layer 1) (feet/day)	-3.5693/-3.2245	0.014/0.023		
					Depth to water (spring) (feet)	0.0018/0.0018	0.058/0.045		
					Net Recharge (feet/year)	0.1746/0.2447	0.028/0.002		

Notes:

[1] Multiple regression analysis output are reported based on results from DWR land use snapshots for mid-1990s followed by result for DWR land use early 2000s snapshot.

Table 6-5
Potential Sources of Variability in Multiple Regression Analysis

Dependent Variable	
Groundwater quality sampling procedures	
Groundwater quality analysis methods/precision	
Timing of sample (year, month, day)	
Datapoint location error/uncertainty	
Data reporting error	
Details of well construction and operation (seal, well type, use, etc.)	
Localized groundwater impacts (nearby septic, spill, etc.)	
Hydrogeologic Independent Variables	
Soil saturated hydraulic conductivity	Depth to Water
Soil mapping, thickness	Timing of water level measurements (year, month, day; well or nearby well pumping?)
Measurement of soil hydraulic properties	Depth of well for water level measurements
Heterogeneity of soil characteristics	Spatial distribution and interpolation of depth to water datapoints
Vertical hydaulic conductivity of CVHM Layer 1	Degree of confinement in the perforated zone
Subsurface material interpretation and description (from driller log)	Slope
Lateral interpolation of subsurface from driller log data	Mapping of elevation (USGS topographic mapping from which DEM and slope are derived)
Translation of subsurface materials to values of vertical hydraulic conductivity	Net Recharge
Spatial resolution of data (1-mile grid)	CVHM simulation output (numerous potential sources of uncertainty in model output)
Land Use Variables	
Survey timing	
Spatial data precision/resolution	
Differences in agriculatural practices within land use category	

Table 6-6
Summary of Wells with Nitrate Exceedances by Vulnerability of Location

Well Characteristics	Total Number of Wells	Number of Wells with a Nitrate Exceedance by Vulnerability		Percent of Wells with a Nitrate Exceedance by Vulnerability	
		High Vulnerability	*Low Vulnerability*	*High Vulnerability*	*Low Vulnerability*
Deep Zone	447	432	15	97%	3%
Shallow Zone	938	922	16	98%	2%
Unknown Depth Zone	59	58	1	98%	2%
Dairy	844	821	23	97%	3%
CDPH	130	125	5	96%	4%
DWR	52	51	1	98%	2%
GAMA	246	243	3	99%	1%
Local Entity	114	114	0	100%	0%
USGS	58	58	0	100%	0%
>1/4 mile from Irrigated Lands	135	133	2	99%	1%
<1/4 mile from Irrigated Lands	812	792	20	98%	2%
Within Irrigated Lands	497	487	10	98%	2%
Last Test Pre-2000s	115	114	1	99%	1%
Last Test in 2000s	1329	1298	31	98%	2%
ESJ High Vulnerability Area	**1444**	**1412**	**32**	**98%**	**2%**

Table 6-7
Wells Within Tentative High Vulnerability Areas

Tentative High Vulnerability Area	Well ID	Data Source	Well Type	Tests Prior to 2000		Tests After 2000		Total No. Tests
				Below Nitrate MCL	Above Nitrate MCL	Below Nitrate MCL	Above Nitrate MCL	
Area A	A1	Dairy	Agricultural				1	1
	A2	Dairy	Agricultural				1	1
	A3	Dairy	Agricultural				1	1
	A4	Dairy	Domestic				1	1
	A5	Dairy	Domestic				1	1
	A6	Dairy	Domestic				1	1
	A7	Dairy	Monitoring			3	1	4
Area B	B1	Dairy	Agricultural				1	1
	B2	Dairy	Domestic				1	1
	B3	Dairy	Domestic				1	1
	B4	Dairy	Monitoring				1	1
	B5	Dairy	Monitoring				1	1
	B6	Dairy	Monitoring				1	1
Area C	C1	Dairy	Agricultural				1	1
	C2	Dairy	Agricultural				1	1
	C3	Dairy	Agricultural				1	1
	C4	Dairy	Agricultural				1	1
	C5	Dairy	Agricultural				1	1
	C6	Dairy	Agricultural				2	2
	C7	Dairy	Domestic				1	1
	C8	Dairy	Domestic				1	1
	C9	Dairy	Domestic				1	1
	C10	Dairy	Domestic				1	1
	C11	Dairy	Domestic				1	2
	C12	Dairy	Domestic				2	2
	C13	Dairy	Domestic			1	1	2
Area D	D1	CDPH	Public Water Supply			3	1	4
	D2	CDPH	Public Water Supply			36	2	38
	D3	CDPH	Public Water Supply	9		20	1	30
	D4	CDPH	Public Water Supply	8	1	3	11	23
Area E	E1	CDPH	Public Water Supply			15	1	16
Area F	F1	DWR	Unknown	3	1			4

Table 6-8
Comparison of Vunerability Designations

Area Description	Total Acres	Within Irrigated Lands (1,047,574 Acres)			
		High Vulnerability (Acres)	Low Vulnerability (Acres)	High Vulnerability (%)	Low Vulnerability (%)
ESJ High Vulnerability Area (ESJHVA) (Hydrogeologic High Vulnerability Area Plus Buffer)	784,277	576,757	470,817	55%	45%
Additional Tentative High Vulnerability Areas	70,540	52,615	---	75%	---
Total Tentative High Vulnerability Area (ESJHVA plus tentative areas; area to be considered as the high vulnerability area in this GAR)	854,817	629,372	418,202	60%	40%
Combined DPR and SWRCB Areas	791,311	568,212	479,362	54%	46%
SWRCB Hydrogeologically Vulnerable Areas	416,790	295,898	751,676	28%	72%
DPR Groundwater Protection Areas	487,667	354,254	693,320	34%	66%

Table 6-9
Summary of Well Nitrate Exceedances Captured by Vulnerability Designations

Vulnerability Designation	Total Number of Wells	Number of Wells with a Nitrate Exceedance by Vulnerability		Percent of Wells with a Nitrate Exceedance by Vulnerability	
		High Vulnerability	*Low Vulnerability*	*High Vulnerability*	*Low Vulnerability*
Wells with Nitrate Concentration 10 mg/L (as Nitrogen) or Greater					
ESJ High Vulnerability Area	**1444**	**1412**	**32**	**98%**	**2%**
SWRCB Hydrogeologically Vulnerable Areas	1444	305	1139	21%	79%
DPR Groundwater Protection Areas (all)	1444	1030	414	71%	29%
Leaching Potential		931		64%	
Runoff Potential		98		7%	
Leaching or Runoff Potential		1		0%	
Combined DPR and SWRCB Areas	1444	1182	262	82%	18%
Wells with Nitrate Concentration 5 mg/L (as Nitrogen) or Greater					
ESJ High Vulnerability Area	**2583**	**2395**	**188**	**93%**	**7%**
SWRCB Hydrogeologically Vulnerable Areas	2583	787	1796	30%	70%
DPR Groundwater Protection Areas (all)	2583	1645	938	64%	36%
Leaching Potential		1447		56%	
Runoff Potential		194		8%	
Leaching or Runoff Potential		4		0.2%	
Combined DPR and SWRCB Areas	2583	2062	521	80%	20%

Table 6-10
Comparison of Pesticide Exceedances Within the Central Valley Floor by Vulnerability of Location

Area Description	Percent of Total Area of Sections with a Pesticide Exceedance that is Within Vulnerability Designation		Wells with a Pesticide Exceedance that are in Sections that are 50% Within Vulnerability Designation (all wells within sections are assigned to the high/low vulnerability category for the section based on the category that covers a dominant fraction [>50%] of the section)		Wells with a Pesticide Exceedance that are in Sections Where Any Part of the Section is Within the High Vulnerability Designation (all wells within sections are assigned to the high vulnerability category if any part of the section is within the relevant designated high vulnerability area)	
	High Vulnerability	*Low Vulnerability*	*High Vulnerability*	*Low Vulnerability*	*High Vulnerability*	*Low Vulnerability*
ESJ High Vulnerability Area	**96%**	**4%**	**97% (357 wells)**	**3% (10 wells)**	**100% (367 wells)**	**0% (0 wells)**
SWRCB Hydrogeologically Vulnerable Areas	60%	40%	62% (226 wells)	38% (141 wells)	69% (253 wells)	31% (114 wells)
DPR Groundwater Protection Areas	65%	35%	66% (244 wells)	34% (123 wells)	66% (244 wells)	34% (123 wells)
Leaching Potential	*62%*		*64% (236 wells)*		*64% (236 wells)*	*64% (236 wells)*
Runoff Potential	*3%*		*2% (8 wells)*		*2% (8 wells)*	*2% (8 wells)*
Leaching or Runoff Potential	*0%*		*0% (0 wells)*		*0% (0 wells)*	*0% (0 wells)*
Combined DPR and SWRCB Areas	90%	10%	89% (327 wells)	11% (40 wells)	92% (339 wells)	8% (28 wells)

Table 6-11

Matrix for Prioritization of High Groundwater 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	**Groundwater Vulnerability Percentile** Includes evaluation and ranking of areas according to hydeogeologic groundwater vulnerability percentile.	Vulnerability percentile	0 to 10 (low to high) based on groundwater vulnerability percentile; (percentile: 0-10=0, 10-20=1, 20-30=2, 30-40=3, 40-50=4, 50-60=5, 60-75=8, 75-100=10)	15%	High - Represents weighting of importance of hydrogeologic characteristics
Existing Groundwater Quality Conditions	Legacy or ambient conditions of the groundwater.	**Observed Groundwater Quality Concentrations** Includes an evaluation and ranking of areas based on recent observed groundwater NO3 concentrations.	Average 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; (NO3 [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 NO3 concentration.	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 NO3 concentrations observations that are above the drinking water MCL.	Distance from nearest NO3 MCL Exceedance	0 to 10 (low to high) inversely related to distance from nearest NO3 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 - weighting is low to avoid double-counting since measured concentration is 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.	Percent of wells with a pesticide detection within a section	0 to 10 (low to high) based on percent of wells with a pesticide detection; 5 (neutral) for sections without any pesticide observations; (percent: 0%=0, 0.1-10%=2, 10-20%=4, 20-30%=6, 30-40%=8, >40=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 2012 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 2012 USDA land use designation) in accordance with irrigation method statistics derived from DWR land use survey irrigation method data (2001-2004) and Coalition membership 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 high vulnerability areas 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 high vulnerability (based on 2012 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 from public water systems reliant on groundwater as identified with CDPH's Drinking Water Systems Geographic Reporting Tool (http://www.ehib.org/page.jsp?page_key=61).	Distance, within 1 mile, from public drinking water system relatiant 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 6-12
Summary of Priority Areas

Description	Priority 1 (Acres)	Priority 2 (Acres)	Priority 3 (Acres)	Total (Acres)
East San Joaquin Water Quality Coalition High Vulnerability Area (ESJHVA)	144,362	267,333	372,621	784,316
Irrigated Lands Within ESJHVA (from FMMP)	79,325	224,554	270,917	574,796
Land Use Category Within ESJHVA (from USDA)				
Nut Trees	*44,121*	*85,397*	*95,804*	*225,322*
Grains/Cotton	*9,440*	*35,215*	*41,420*	*86,075*
Grasses	*7,257*	*23,733*	*43,739*	*74,729*
Double Crops	*4,452*	*31,617*	*21,221*	*57,290*
Grapes	*3,566*	*10,656*	*43,944*	*58,166*
Vegetables	*2,884*	*15,923*	*13,110*	*31,917*
Fruit Trees	*1,101*	*1,234*	*421*	*2,756*
Citrus/Subtropics	*136*	*686*	*606*	*1,428*
Seeds/Beans	*41*	*257*	*550*	*848*
Rice	*9*	*1,645*	*276*	*1,931*
All Irrigated Land Use Categories	*73,008*	*206,364*	*261,091*	*540,462*
Non Agricultural	*71,344*	*60,949*	*111,388*	*243,681*

Note: Irrigated lands area calculations are based on FMMP 2010 data; land use category calculations are based on USDA 2012 cropland data.
Due to differences between FMMP and USDA datasets, total crop acres from USDA are different than irrigated acres from FMMP.

Table 7-1

Summary of Historic Groundwater Monitoring

(since 1910)

Wells With Historic Groundwater Level Measurements

Monitoring Entity	Number of wells	Number of samples	Wells with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Wells Sampled Pre-1970s	Wells Sampled in 1970s	Wells Sampled in 1980s	Wells Sampled in 1990s	Wells Sampled in 2000s	Wells Sampled in 2010s
DWR	3,372	112,438	75	159	23	35	0	41	3,114	1,300	163	1,909	1,892	2,064	1,655	1,333	1,123	1,291
GAMA	1,932	32,973	762	0	1,586	0	0	0	346	750	15	1,167	2	0	0	4	1,790	1,205
MID	239	13,944	0	0	0	0	0	0	239	0	4	235	233	234	228	225	197	0
TID	363	157,817	200	0	0	0	0	163	200	363	0	0	338	253	314	305	297	278
USGS	1,250	8,531	1,070	0	0	0	0	0	1,250	646	427	177	16	953	262	258	130	41
Total	7,156	325,703	2,107	159	1,609	35	0	204	5,149	3,059	609	3,488	2,481	3,504	2,459	2,125	3,537	2,815

Wells With Historic Nitrate Samples

Monitoring Entity	Number of wells	Number of samples	Wells with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Wells Sampled Pre-1970s	Wells Sampled in 1970s	Wells Sampled in 1980s	Wells Sampled in 1990s	Wells Sampled in 2000s	Wells Sampled in 2010s
Dairy	1,775	2,236	0	441	35	1,299	0	0	0	1,334	441	0	0	0	0	0	1,775	0
CDPH	1,235	27,404	0	0	0	0	1,235	0	0	0	1,235	0	0	0	216	344	1,160	991
DWR	836	1,651	0	0	0	0	29	11	796	0	29	807	607	250	127	0	0	0
GAMA	2,049	17,475	0	0	483	0	1,566	0	0	483	1,566	0	296	61	159	266	1,057	989
MID	29	32	0	0	0	0	0	0	29	0	0	29	0	0	0	0	29	0
TID	108	323	0	0	0	0	0	108	0	108	0	0	0	0	0	54	105	0
USGS	540	1,574	521	0	0	0	0	0	540	320	201	19	306	62	85	55	147	7
Total	6,572	50,695	521	441	518	1,299	2,830	119	1,365	2,245	3,472	855	1,209	373	587	719	4,273	1,987

Wells With Historic Total Dissolved Solids (TDS) Samples

Monitoring Entity	Number of wells	Number of samples	Wells with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Wells Sampled Pre-1970s	Wells Sampled in 1970s	Wells Sampled in 1980s	Wells Sampled in 1990s	Wells Sampled in 2000s	Wells Sampled in 2010s
Dairy	34	156	0	0	34	0	0	0	0	34	0	0	0	0	0	0	34	0
CDPH	915	7,175	0	0	0	0	915	0	0	0	915	0	0	0	213	332	829	598
DWR	1,054	2,466	0	0	0	0	29	0	1,025	0	0	1,054	847	254	130	0	0	0
GAMA	1,654	6,555	0	0	254	0	1,400	0	0	254	0	1,400	371	66	169	238	881	415
MID	29	32	0	0	0	0	0	0	29	0	0	29	0	0	0	0	29	0
TID	108	323	0	0	0	0	0	108	0	108	0	0	0	0	0	54	105	0
USGS	722	3,215	696	0	0	0	0	0	722	429	267	26	371	60	149	117	161	9
Total	4,516	19,922	696	0	288	0	2,344	108	1,776	825	1,182	2,509	1,589	380	661	741	2,039	1,022

Table 7-2
Summary of Recent Groundwater Monitoring
(since 2005)

Groundwater Level Measurements Since 2005											
Monitoring Entity	Number of wells	Number of Samples	Number with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone
DWR	1,291	44,011	65	131	23	33	36	1,068	989	136	166
GAMA	1,202	24,271	482	0	985	0	0	217	473	10	719
MID	0	0	0	0	0	0	0	0	0	0	0
TID	278	156,908	200	0	200	0	78	0	278	0	0
USGS	41	640	41	0	0	0	0	41	33	8	0
Total	2,812	225,830	788	131	1,208	33	114	1,326	1,773	154	885

Nitrate Samples Since 2005															
Monitoring Entity	Number of wells	Number of samples	Number with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Wells with results over 5 mg/L (as N)	Wells with results over 10 mg/L (as N)	Wells with results over 20 mg/L (as N)
Dairy	1,767	2,217	0	441	27	1,299	0	0	0	1,326	441	0	1,101	843	512
CDPH	1,134	26,482	0	0	0	0	1,134	0	0	0	1,134	0	403	131	20
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GAMA	1,388	15,092	0	0	409	0	979	0	0	409	979	0	421	190	69
MID	29	32	0	0	0	0	0	0	29	0	0	29	16	9	2
TID	95	300	0	0	0	0	0	95	0	95	0	0	93	92	61
USGS	41	578	41	0	0	0	0	0	41	38	3	0	16	10	4
Total	4,454	44,701	41	441	436	1,299	2,113	95	70	1,868	2,557	29	2,050	1,275	668

Total Dissolved Solids (TDS) Samples Since 2005															
Monitoring Entity	Number of wells	Number of samples	Number with known depth	Irrigation Wells	Monitoring Wells	Residential Wells	Public Supply Wells	Other Well Types	Unknown Well Type	Shallow Zone	Deep Zone	Unknown Depth Zone	Wells with results over 500 mg/L	Wells with results over 1,000 mg/L	Wells with results over 1,500 mg/L
Dairy	26	137	0	0	26	0	0	0	0	26	0	0	19	7	0
CDPH	837	6,900	0	0	0	0	837	0	0	0	0	837	118	33	16
DWR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GAMA	900	4,231	0	0	244	0	656	0	0	244	0	656	335	159	107
MID	29	32	0	0	0	0	0	0	29	0	0	29	5	0	0
TID	95	300	0	0	0	0	0	95	0	95	0	0	89	17	1
USGS	47	1,130	47	0	0	0	0	0	47	41	6	0	37	21	17
Total	1,934	12,730	47	0	270	0	1,493	95	76	406	6	1,522	603	237	141

Table 7-3
Summary of Recent Groundwater Monitoring by Vulnerability Area
(since 2005)

Wells with Groundwater Level Measurements Since 2005					
Monitoring Entity	Number of wells	Wells in High Vulnerability Areas (ESJHVA)	Wells in Tentative High Vulnerability Areas	Wells in Low Vulnerability Areas (within Central Valley Floor)	Wells Outside of the Central Valley Floor
DWR	1,291	818	86	386	1
GAMA	1,202	795	1	73	333
MID	0	0	0	0	0
TID	278	278	0	0	0
USGS	41	38	0	3	0
Total	2,812	1,929	87	462	334

Wells with Nitrate Samples Since 2005					
Monitoring Entity	Number of wells	Wells in High Vulnerability Areas (ESJHVA)	Wells in Tentative High Vulnerability Areas	Wells in Low Vulnerability Areas (within Central Valley Floor)	Wells Outside of the Central Valley Floor
Dairy	1,767	1,571	113	77	6
CDPH	1,134	600	27	105	402
DWR	0	0	0	0	0
GAMA	1,388	681	31	82	594
MID	29	27	0	2	0
TID	95	95	0	0	0
USGS	41	36	0	5	0
Total	4,454	3,010	171	271	1,002

Wells with Total Dissolved Solids (TDS) Samples Since 2005					
Monitoring Entity	Number of wells	Wells in High Vulnerability Areas (ESJHVA)	Wells in Tentative High Vulnerability Areas	Wells in Low Vulnerability Areas (within Central Valley Floor)	Wells Outside of the Central Valley Floor
Dairy	26	25	1	0	0
CDPH	837	469	22	76	270
DWR	0	0	0	0	0
GAMA	900	492	22	85	301
MID	29	27	0	2	0
TID	95	95	0	0	0
USGS	47	42	0	5	0
Total	1,934	1,150	45	168	571

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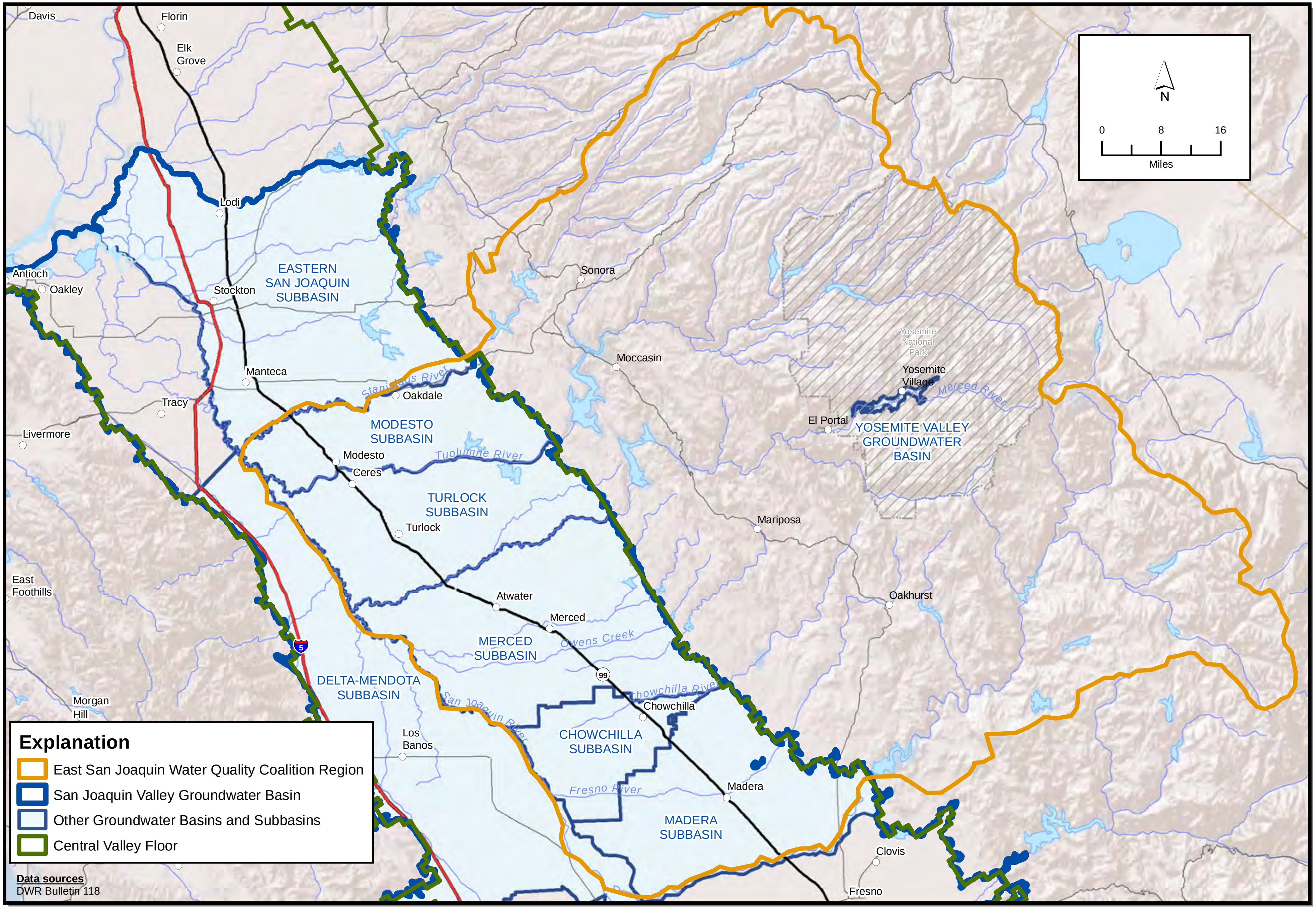
Figure 1-1
East San Joaquin Water Quality Coalition
Location Map



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 1-2 DWR Designated Groundwater Basins and Subbasins.mxd

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Figure 1-2
DWR Designated Groundwater Basins and Subbasins

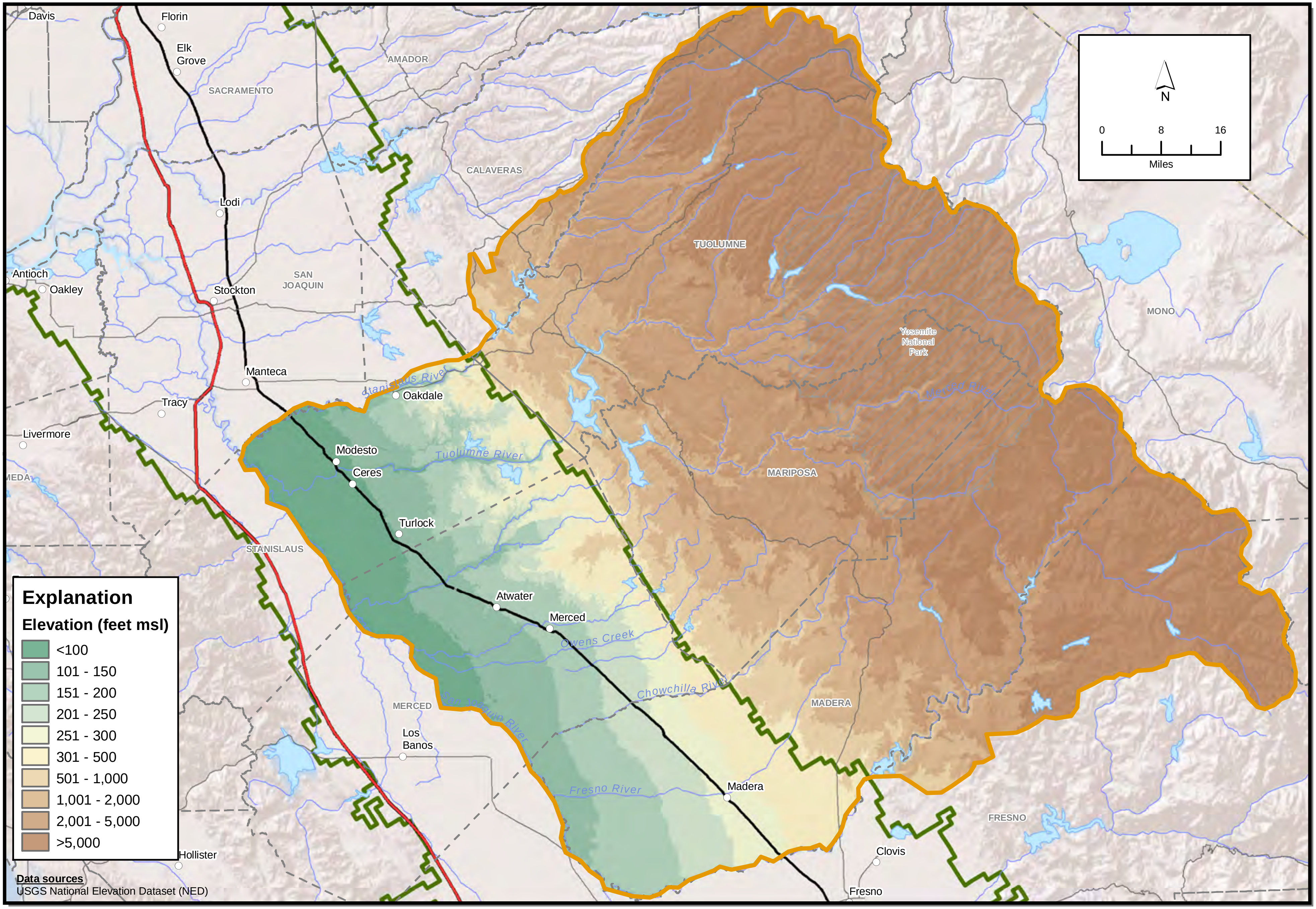

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Figure 2-1
Elevation Map

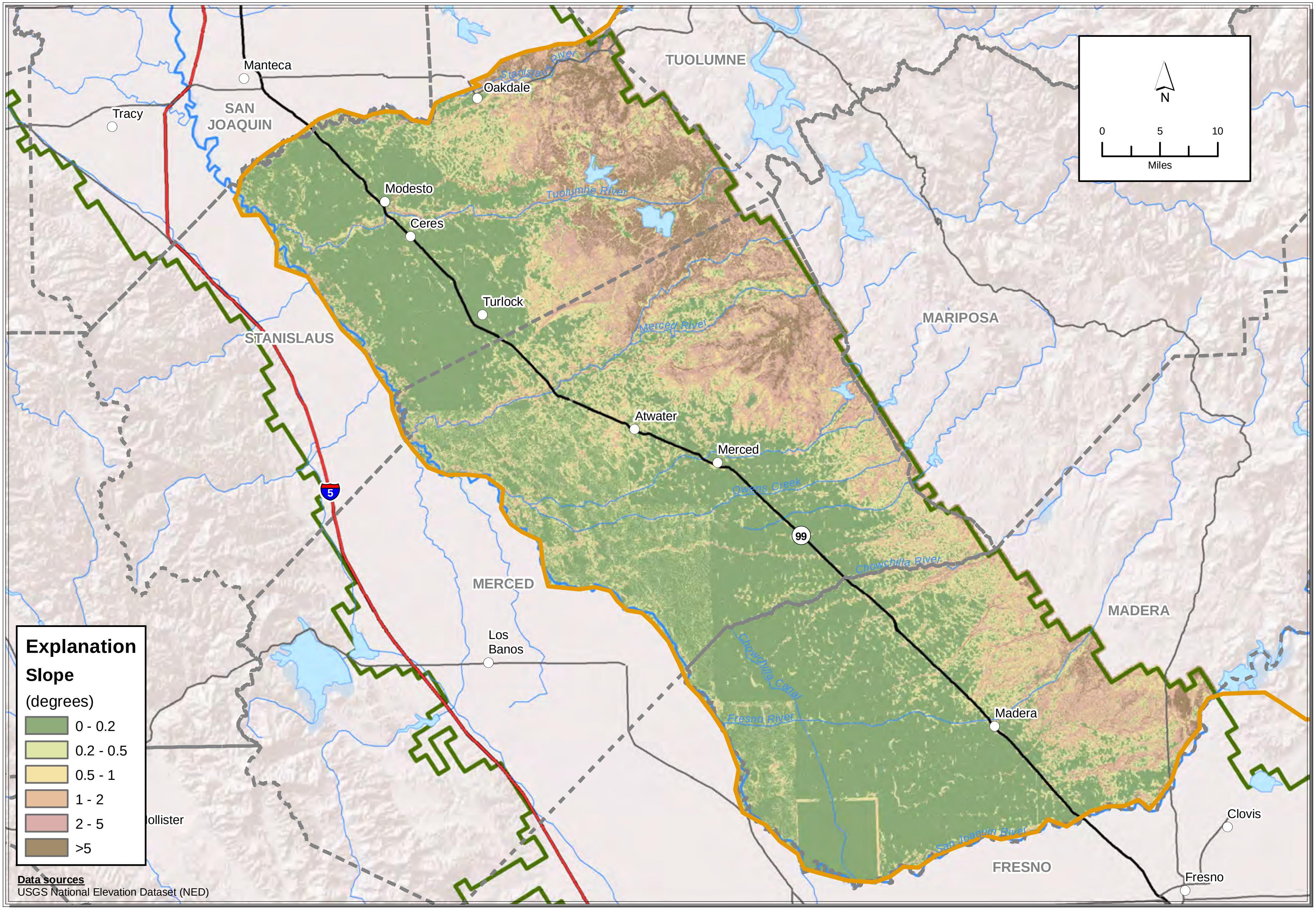

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Figure 2-2
Slope Map

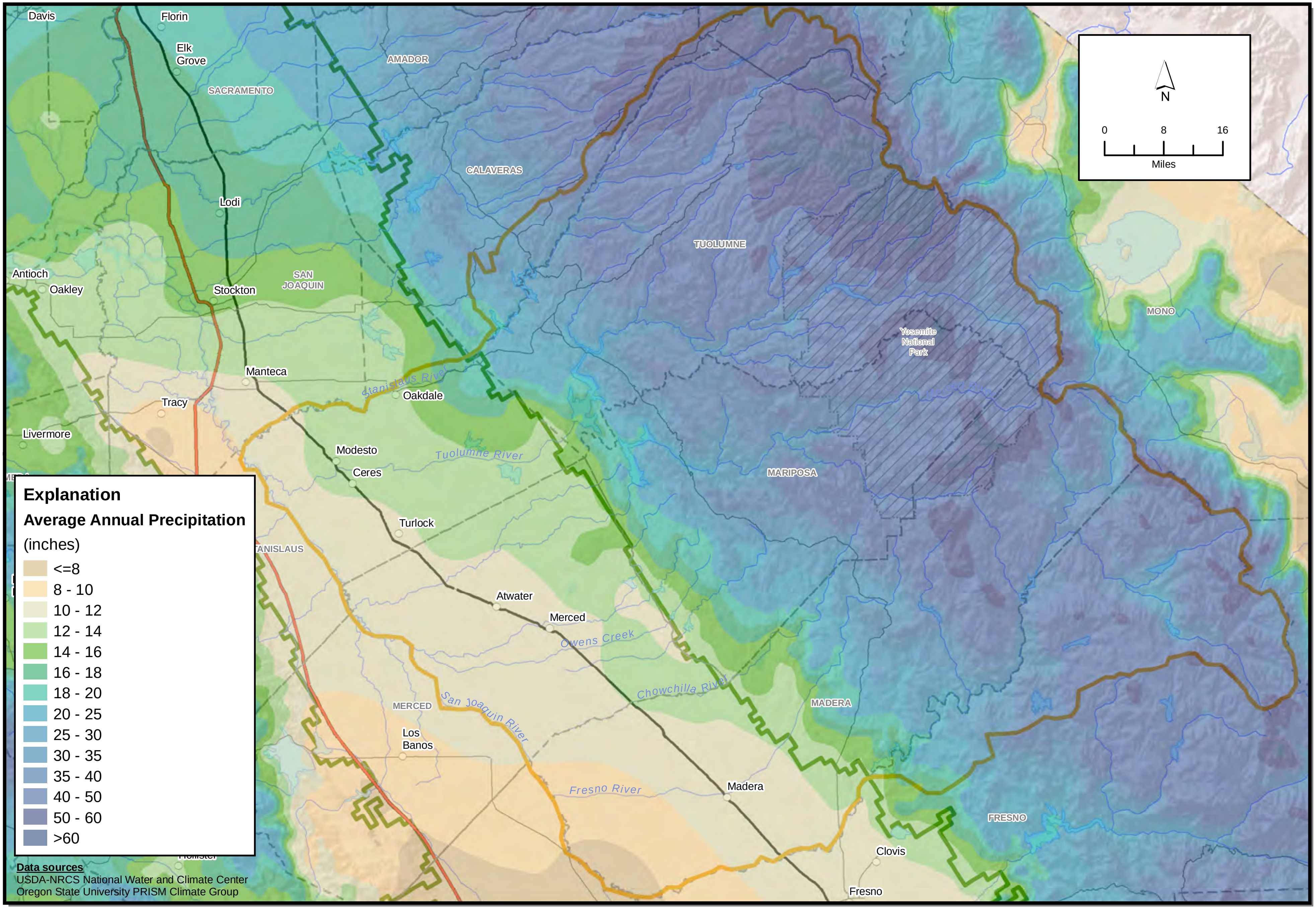

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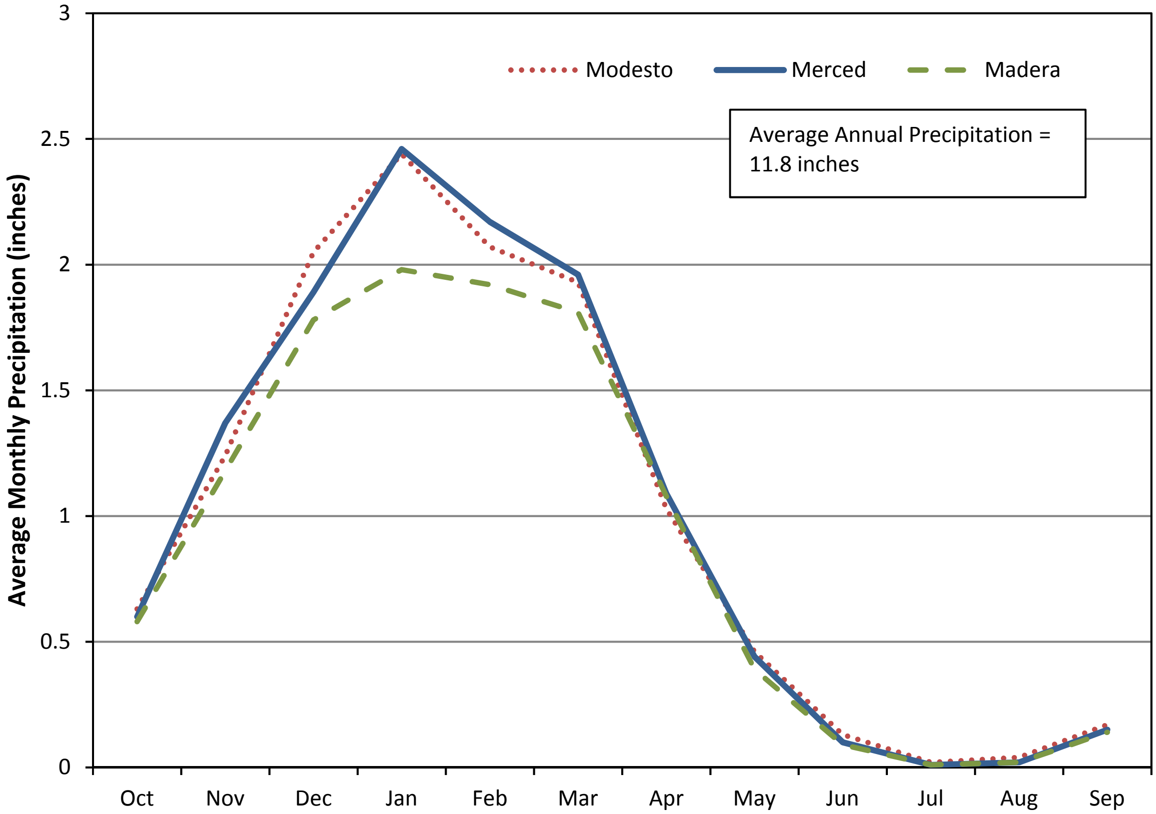
Figure 2-3
Precipitation Map

Figure 2-4
Average Monthly Precipitation



Data from Western Regional Climate Center

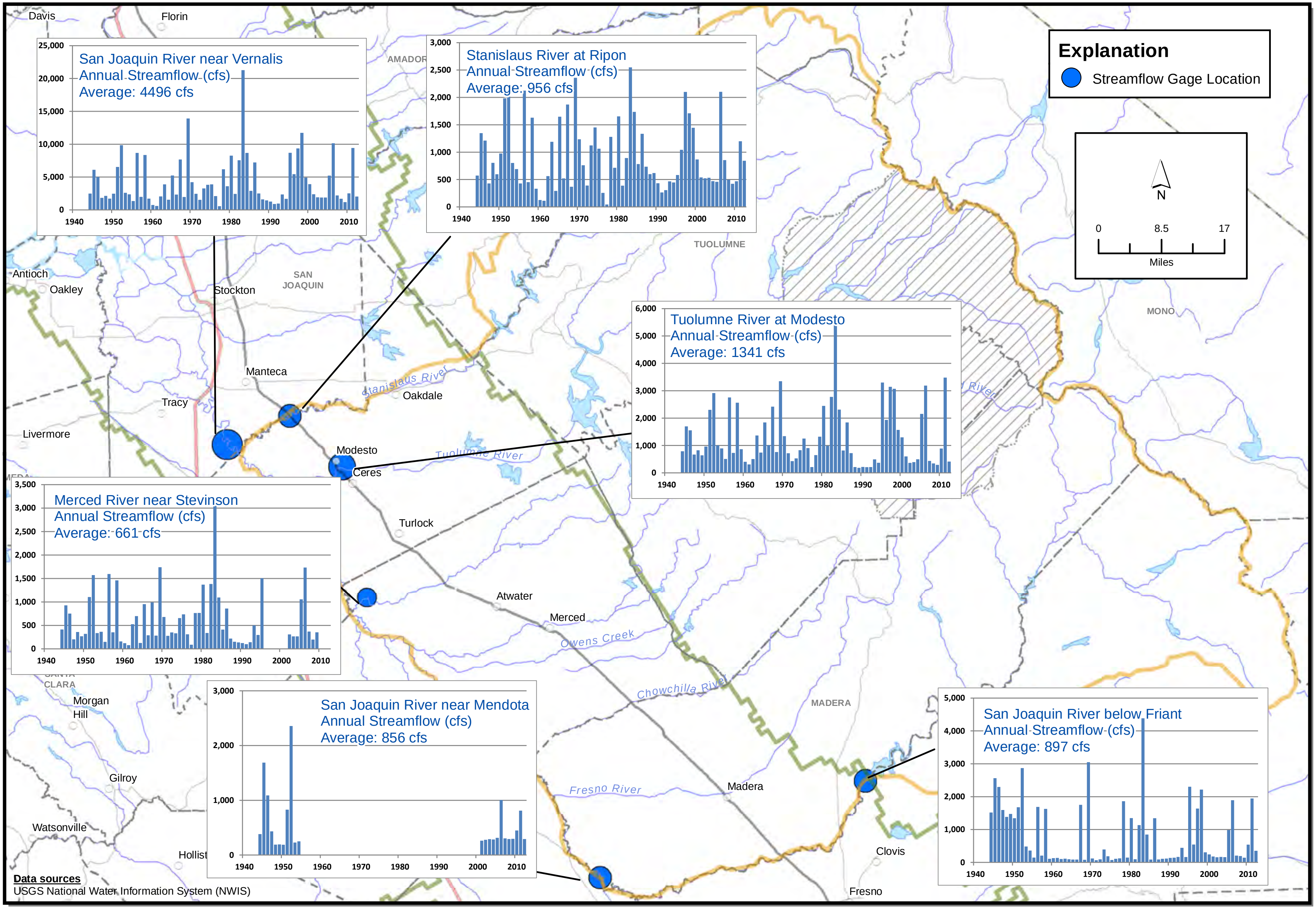


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Figure 2-5
Major Surface Waterways and Annual Streamflow

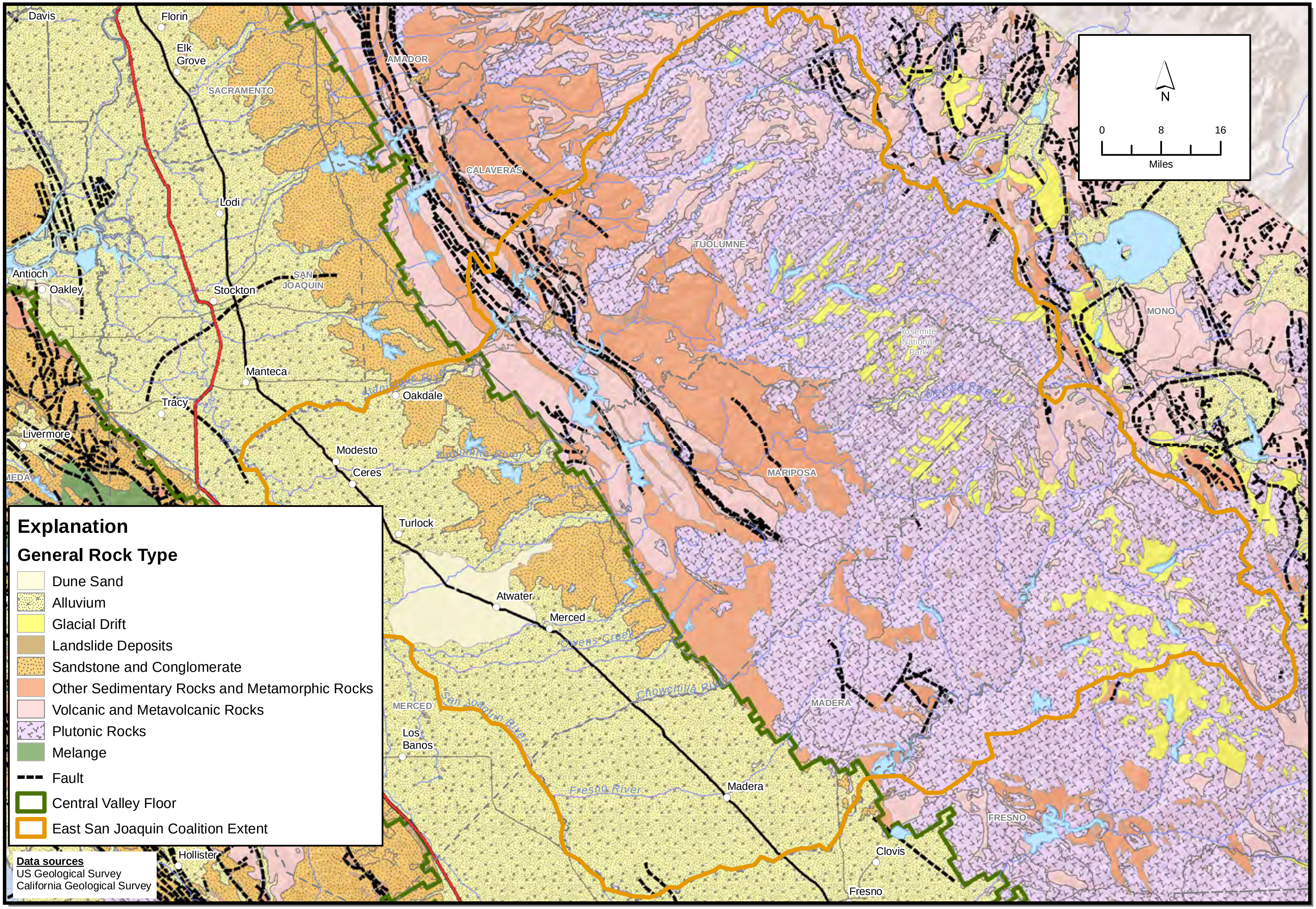

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Figure 3-1
Generalized Geologic Map

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Figure 3-2
Geologic Map of the Central Valley Floor Area

Compiled Geologic Map Explanation

San Francisco - San Jose Quadrangle

Symbol	Unit
Q	Alluvium
Qdp	Dos Palos Alluvium
Qf	Alluvial fan deposits
Qsl	San Luis Ranch Alluvium
Qp	Patterson Alluvium
Qtl	Turlock Lake Formation *(Nonmarine sand, silt, and gravel)*
Pl	Laguna Formation *(Consolidated alluvium)*
Qm	Modesto Formation
Qr	Riverbank Formation
Qlb	Los Banos Alluvium
QTnm	North Merced Gravel *(Thin pediment veneer)*
Jjp	Jasper Point Formation *(Chert, tuff, pillow basalt; marine)*
ms	Metasedimentary rocks*
ls	Crystalline limestone and dolomite*
Pzcc	Calaveras Complex *(Metasedimentary rocks)*
mv	Metavolcanic rocks*
Mtm	Table Mountain Latite
Tm	Mehrten Formation *(Andesitic conglomerate)*
Tvs	Valley Springs Formation *(Rhyolitic tuff and sedimentary rocks)*
Ei	Ione Formation *(Quartzose sandstone and kaolinitic clay; mostly nonmarine)*
Tg	"Auriferous" Gravels
Pl	Locatelli Formation *(Marine sandstone and conglomerate)*
Kl	Lower Cretaceous marine sandstone and shale
Mzg	Granitic rocks
Mzgb	Gabbroic rocks
um	Ultramafic rocks
Jm	Mariposa Formation *(Slate, graywacke, and conglomerate; marine)*
Jsm	Salt Springs and Merced Falls Slates
Jms	Jurassic(?) metasedimentary rocks
Jch	Copper Hill Volcanics
Jlr	Logtown Ridge Volcanics
Jgo	Gopher Ridge Volcanics
Jpb	Penon Blanco Volcanics
Jmv	Jurassic metavolcanic rocks

Santa Cruz, Mariposa, and Fresno Quadrangles

Symbol	Unit
Qal	Alluvium
Qsc	Stream channel deposits (GREAT VALLEY)
Qf	Fan deposits (GREAT VALLEY)
Qb	Basin deposits (GREAT VALLEY)
Qc	Pleistocene nonmarine
QP	Plio-Pleistocene nonmarine
Qpv	Pleistocene volcanic: Qpv^r —rhyolite; Qpv^a—andesite; Qpv^b —basalt; Qpv^p —pyroclastic rocks
Tc	Tertiary nonmarine
Pmv	Permian metavolcanic rocks
Ec	Eocene nonmarine
E	Eocene marine
Tv	Tertiary volcanic: Tv^r —rhyolite; Tv^a —andesite; Tv^b —basalt; Tv^p —pyroclastic rocks
Ju	Upper Jurassic marine
m / ls	Pre-Cretaceous metamorphic rocks (ls = limestone or dolomite)
ms	Pre-Cretaceous metasedimentary rocks
gr-m	Pre-Cenozoic granitic and metamorphic rocks
Pv	Paleozoic metavolcanic rocks
Cv	Carboniferous metavolcanic rocks

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.
3. Strand, R.G., 1967, Geologic Atlas of California - Mariposa Quadrangle, California Geological Survey, Geologic Atlas of California Map No. 009, 1:250,000 scale.
4. Matthews, R.A. and Burnett, J.L., 1965, Geologic Atlas of California - Fresno Quadrangle, California Geological Survey, Geologic Atlas of California Map No. 005, 1:250,000 scale.

Figure 3-2 (Explanation)
Geologic Map of the Central Valley Floor Area

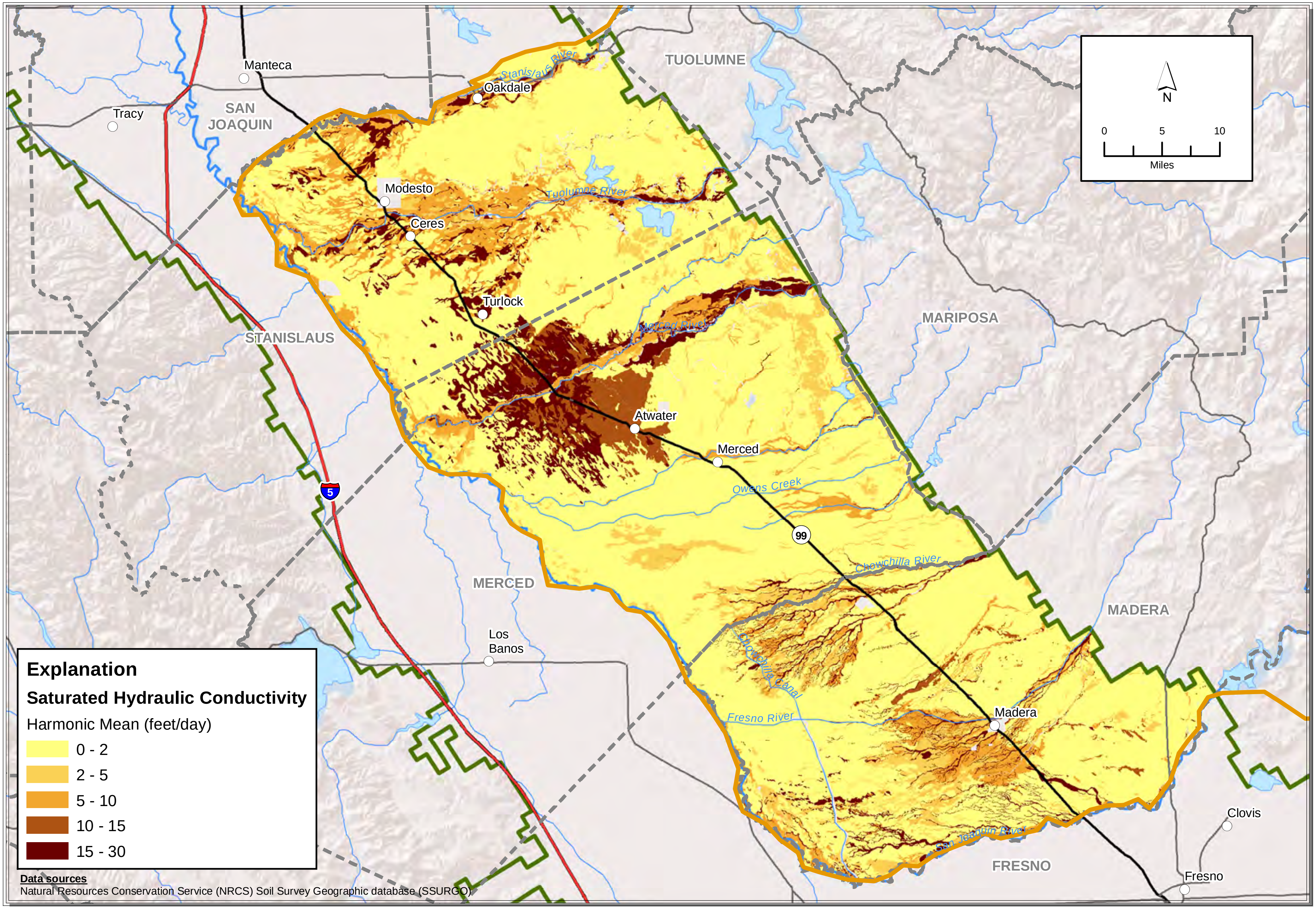

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Figure 3-3
Soil Hydraulic Conductivity

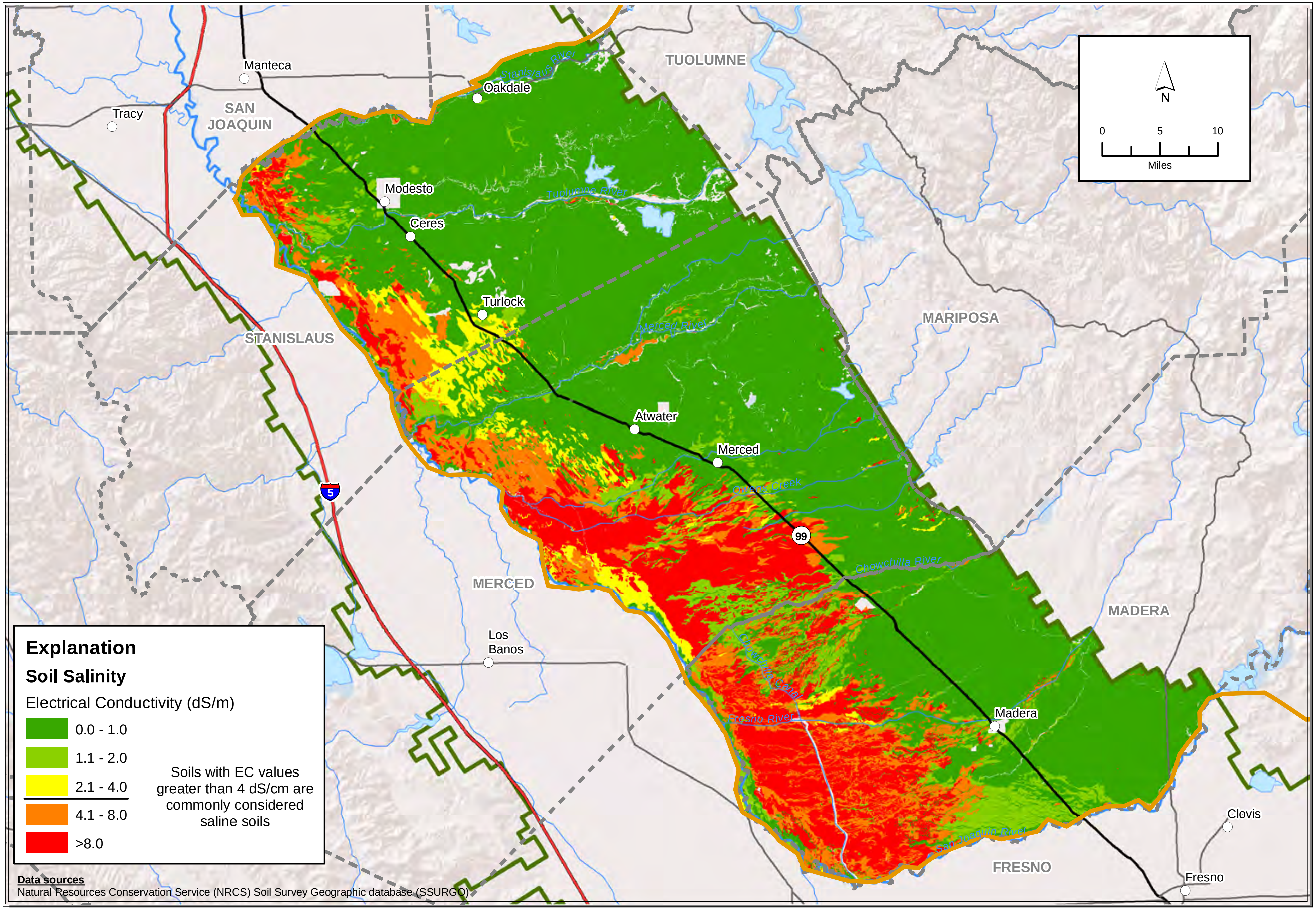

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Figure 3-4
Soil Salinity

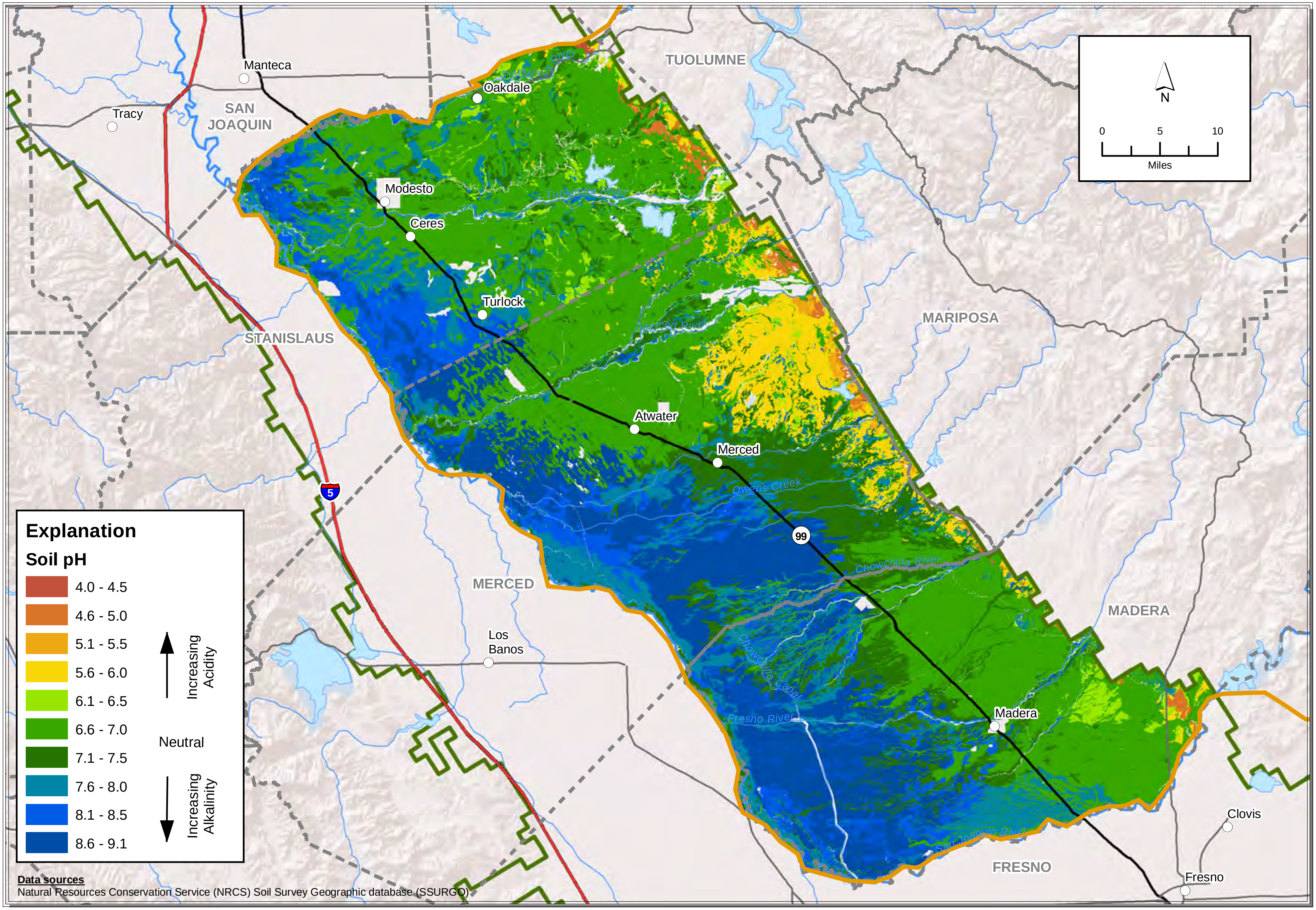

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Figure 3-5
Soil pH

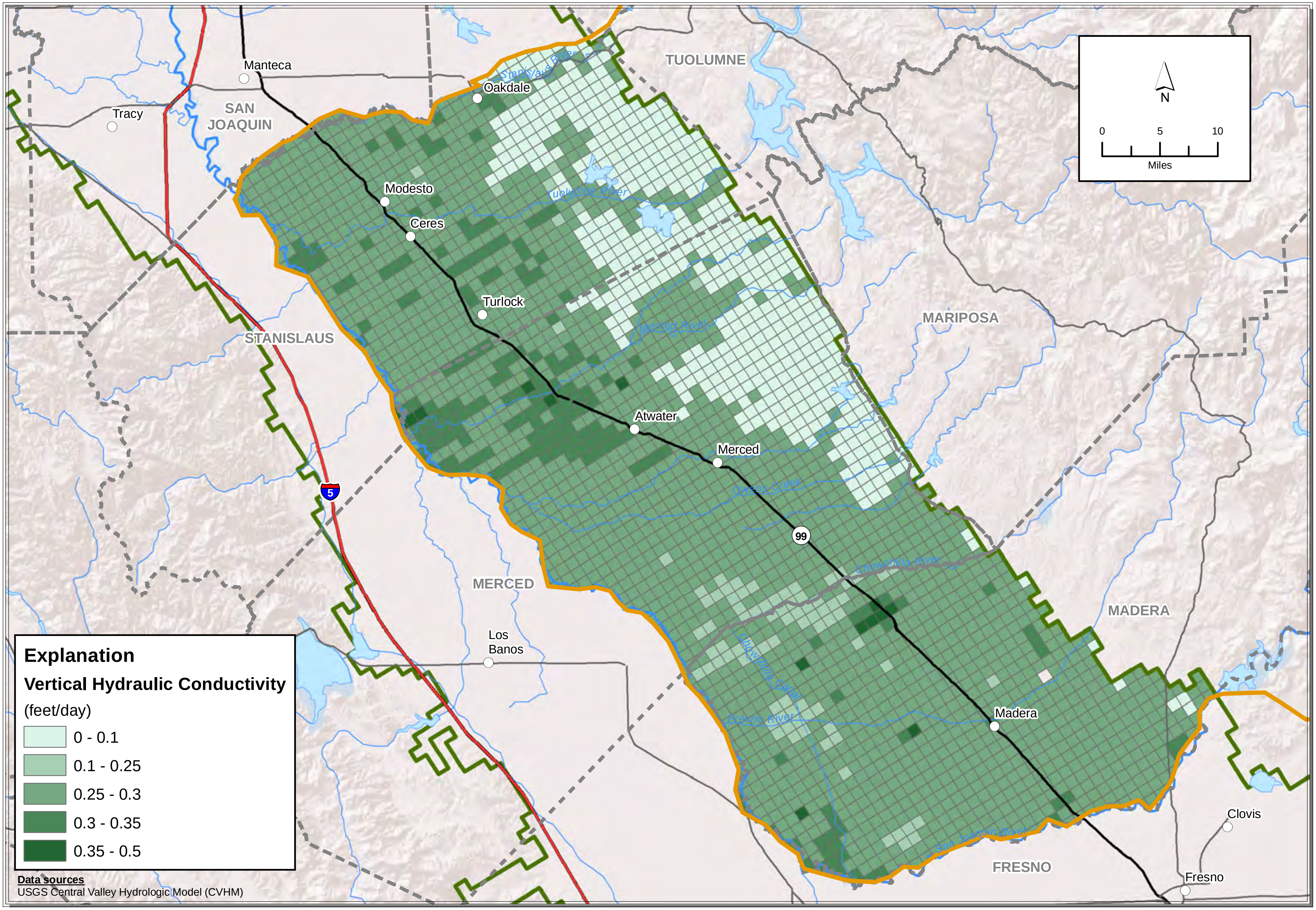

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Figure 3-6
Vertical Hydraulic Conductivity of CVHM Layer 1

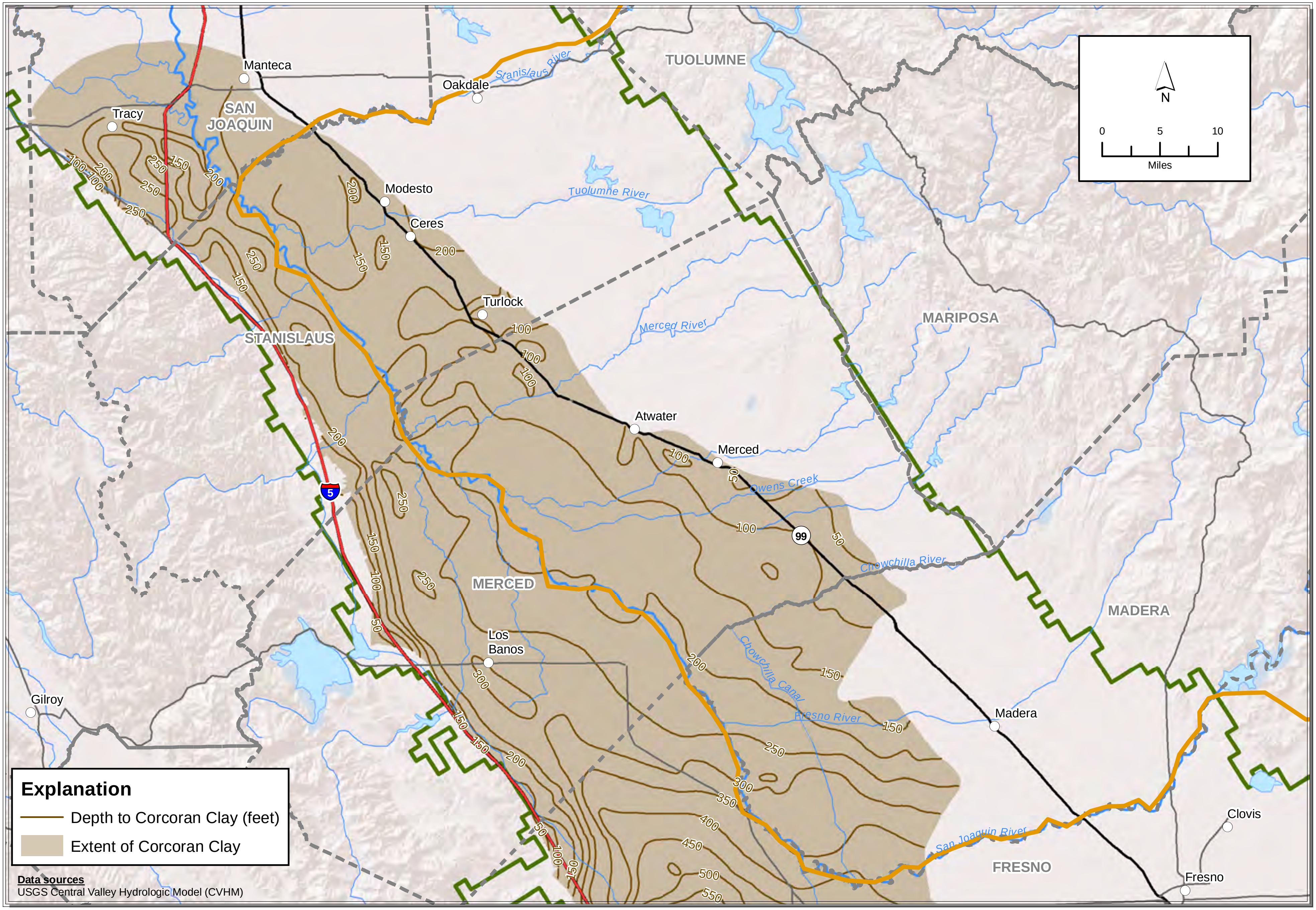

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Figure 3-7a
Corcoran Clay Characteristics: Extent and Depth

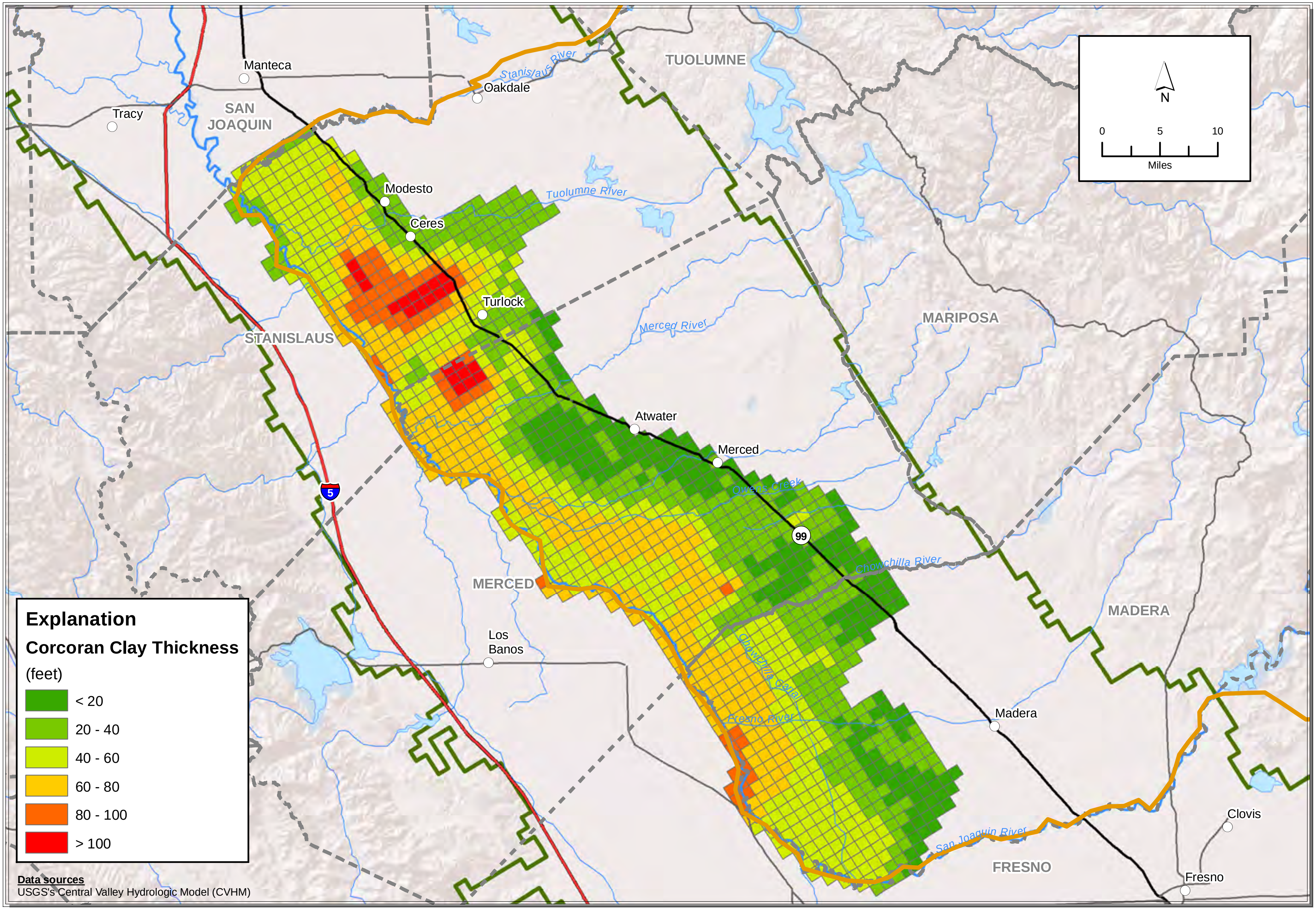

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Figure 3-7b
Corcoran Clay Characteristics: Thickness

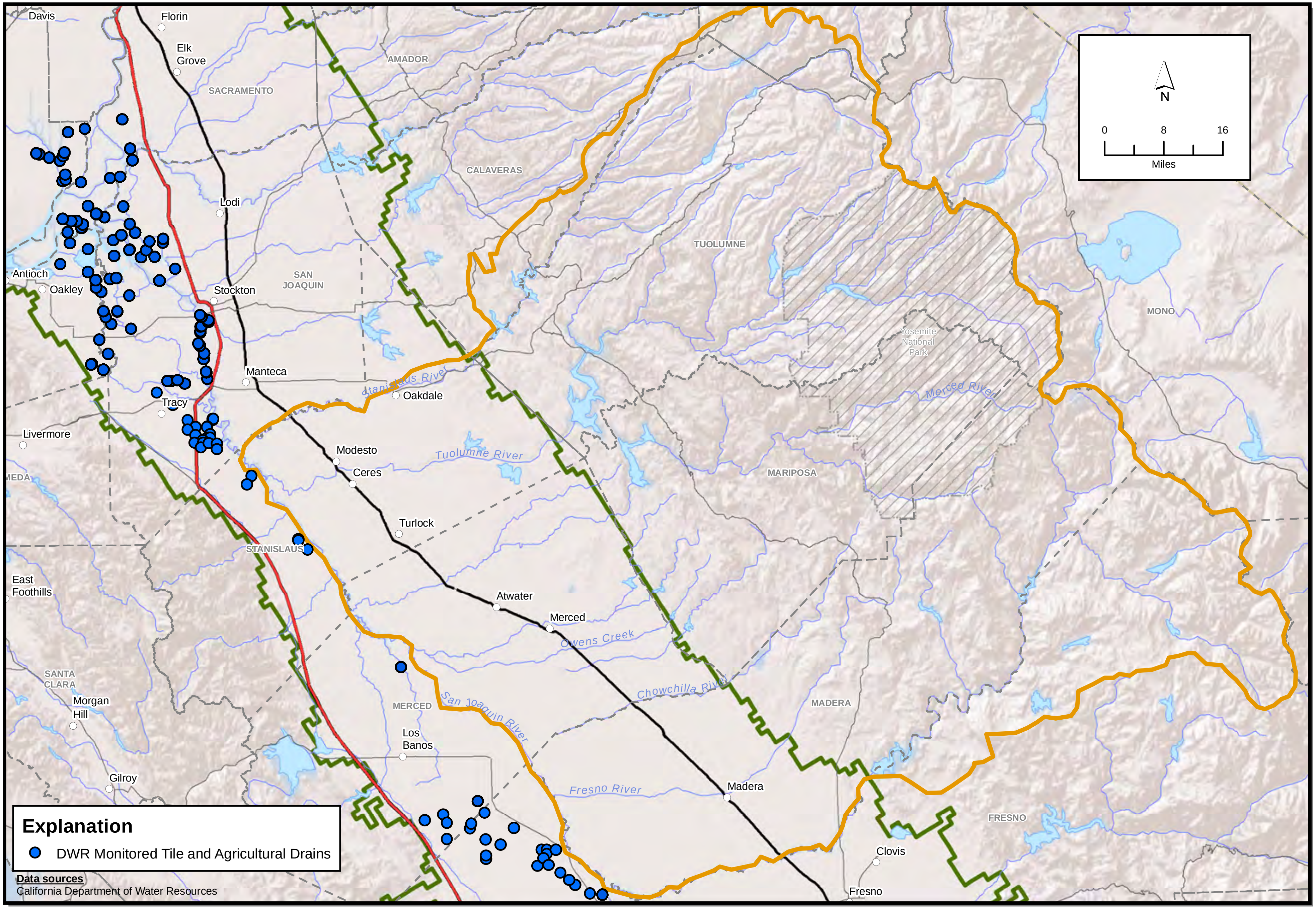

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Figure 3-8
Known Tile Drain Locations

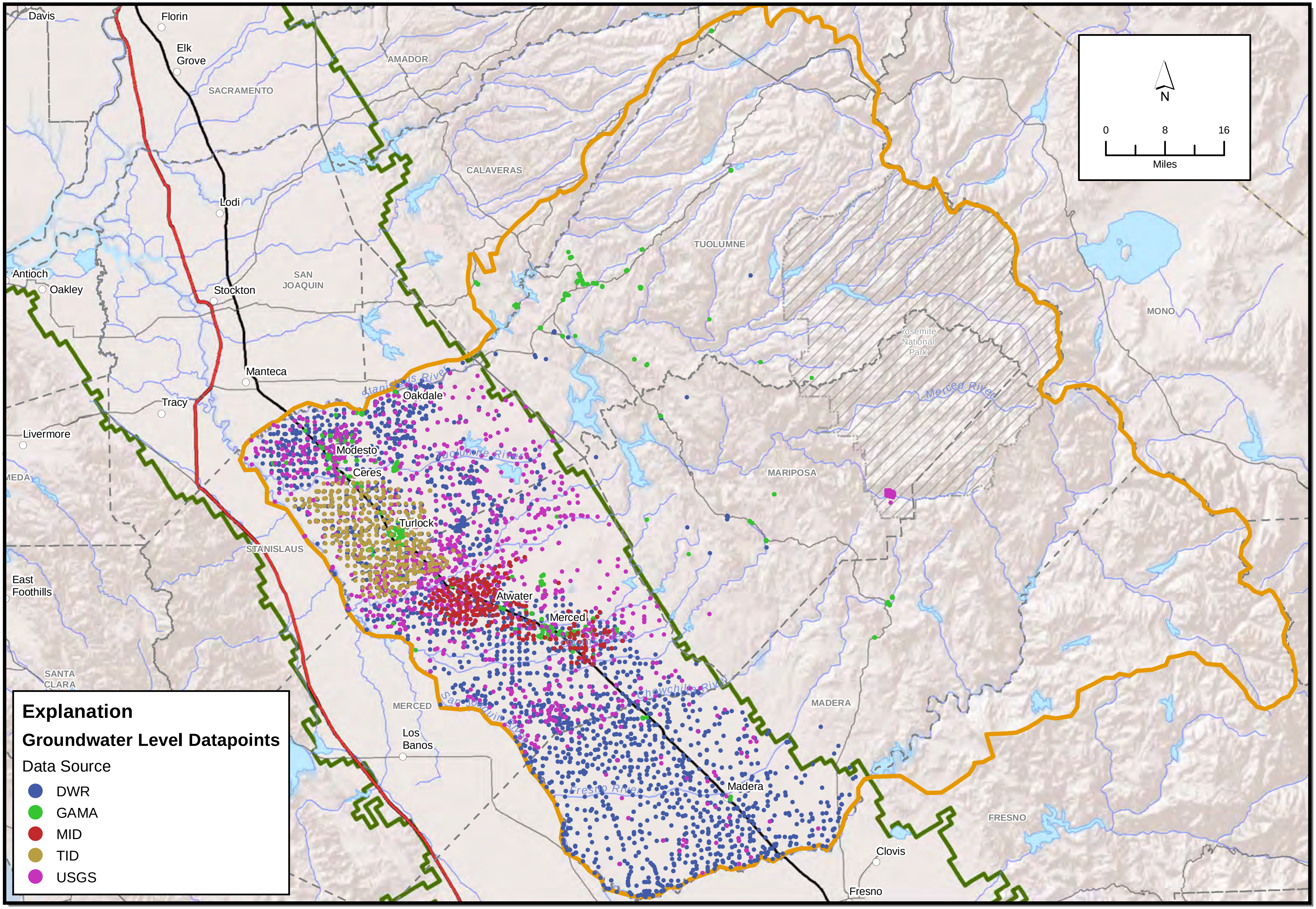

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Figure 3-9
Water Level Data by Source

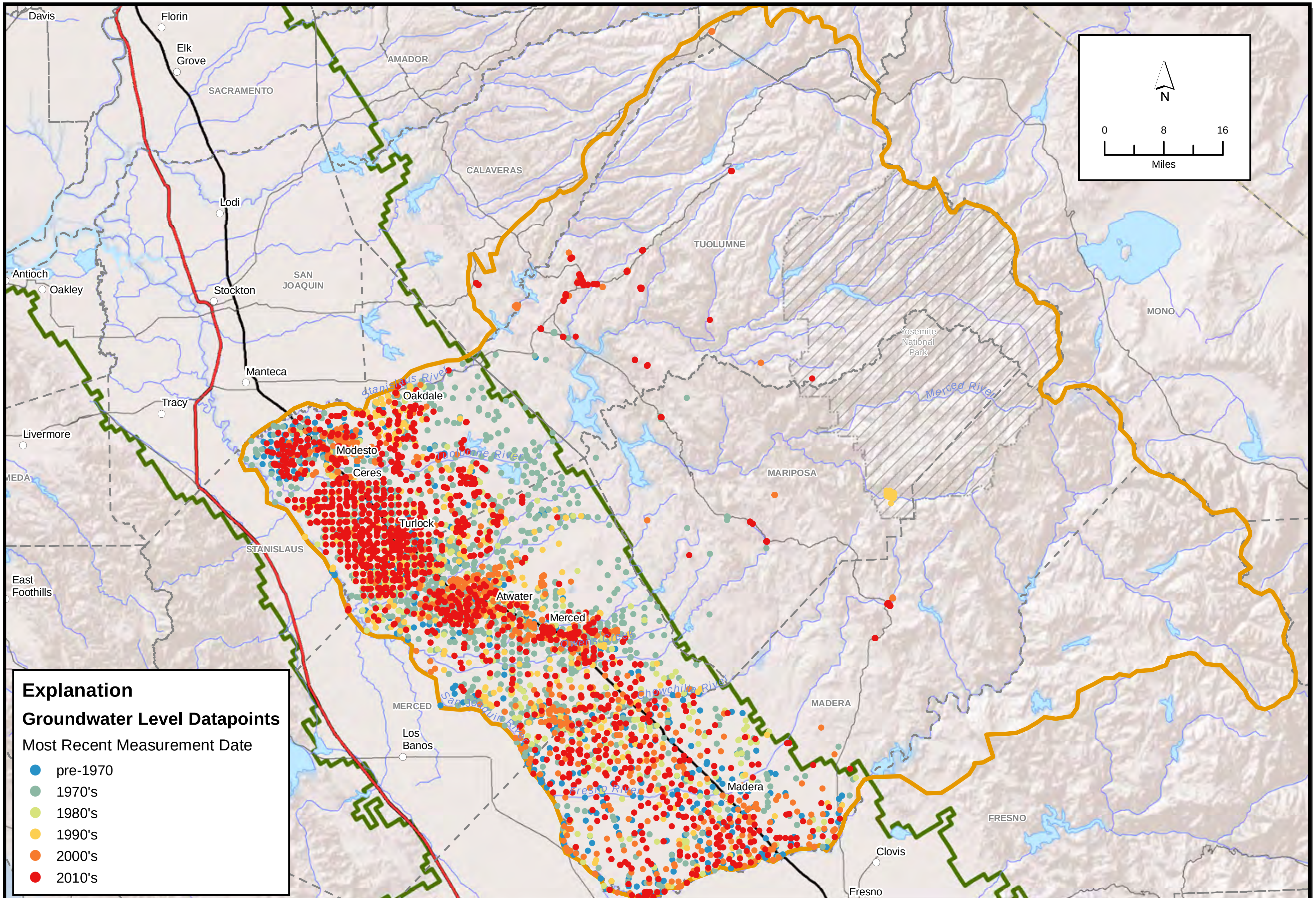

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Figure 3-10
Water Level Data by Year

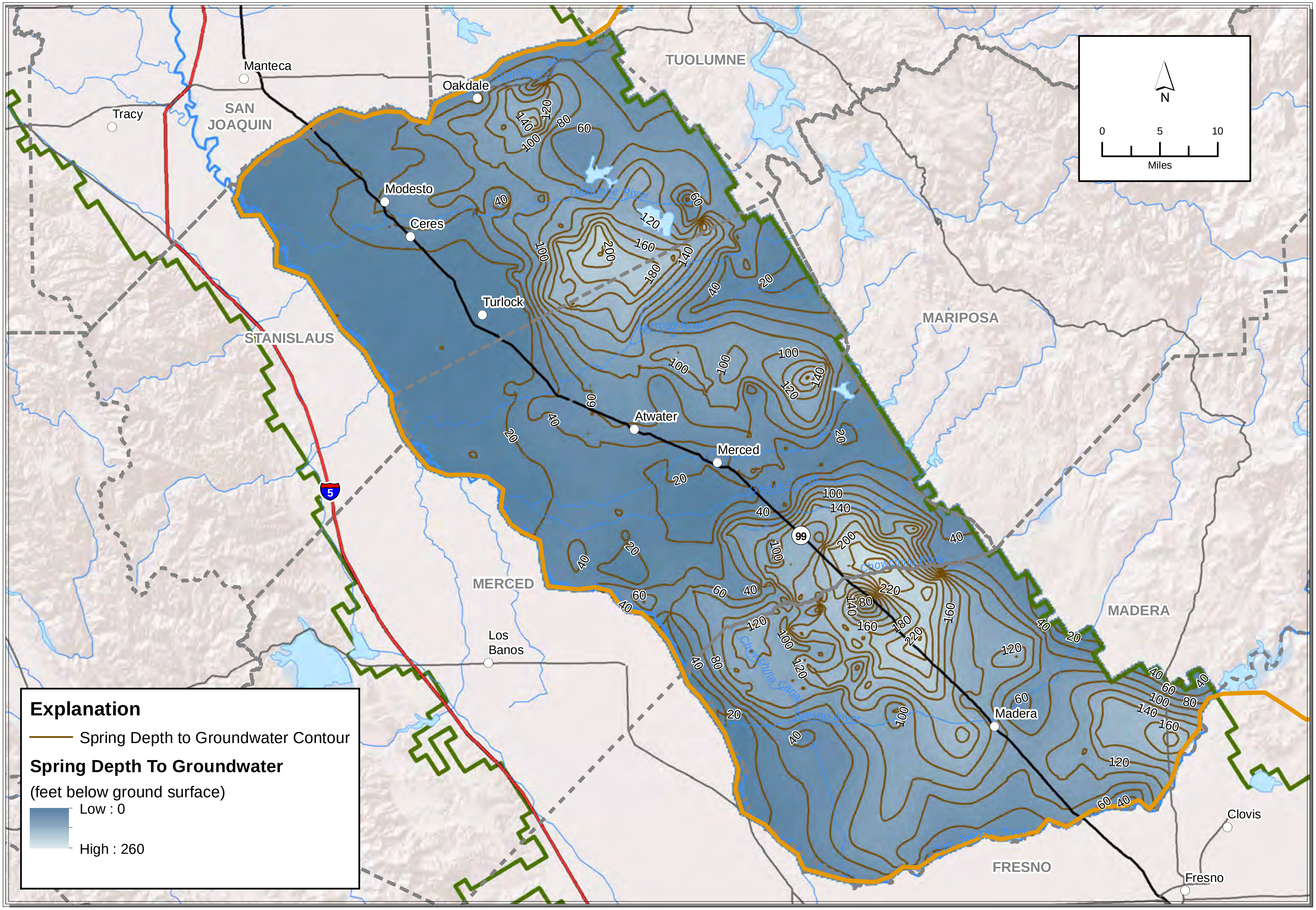

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Figure 3-11
Spring Depth to Groundwater Contours: Central Valley Floor

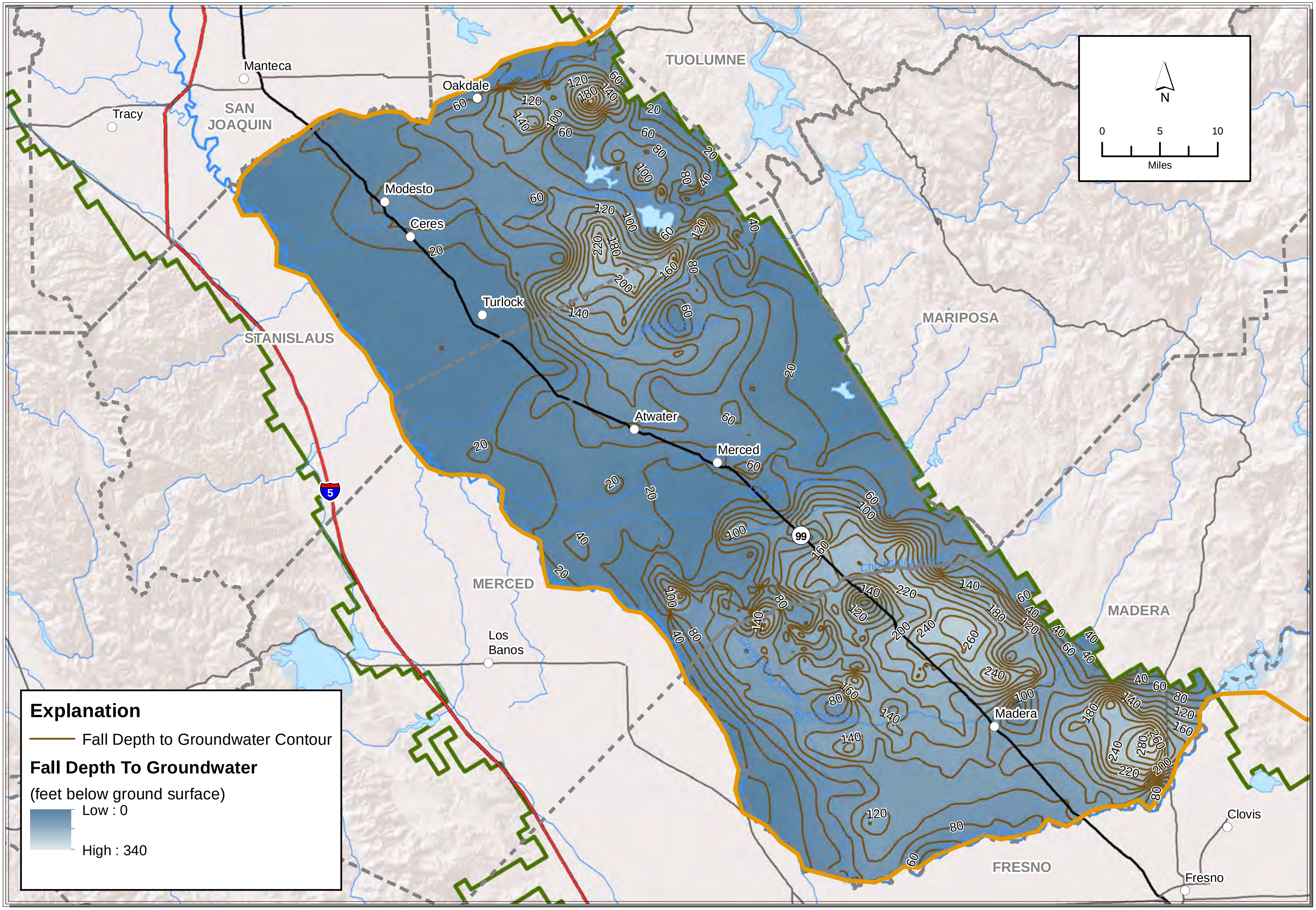

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Figure 3-12
Fall Depth to Groundwater Contours: Central Valley Floor

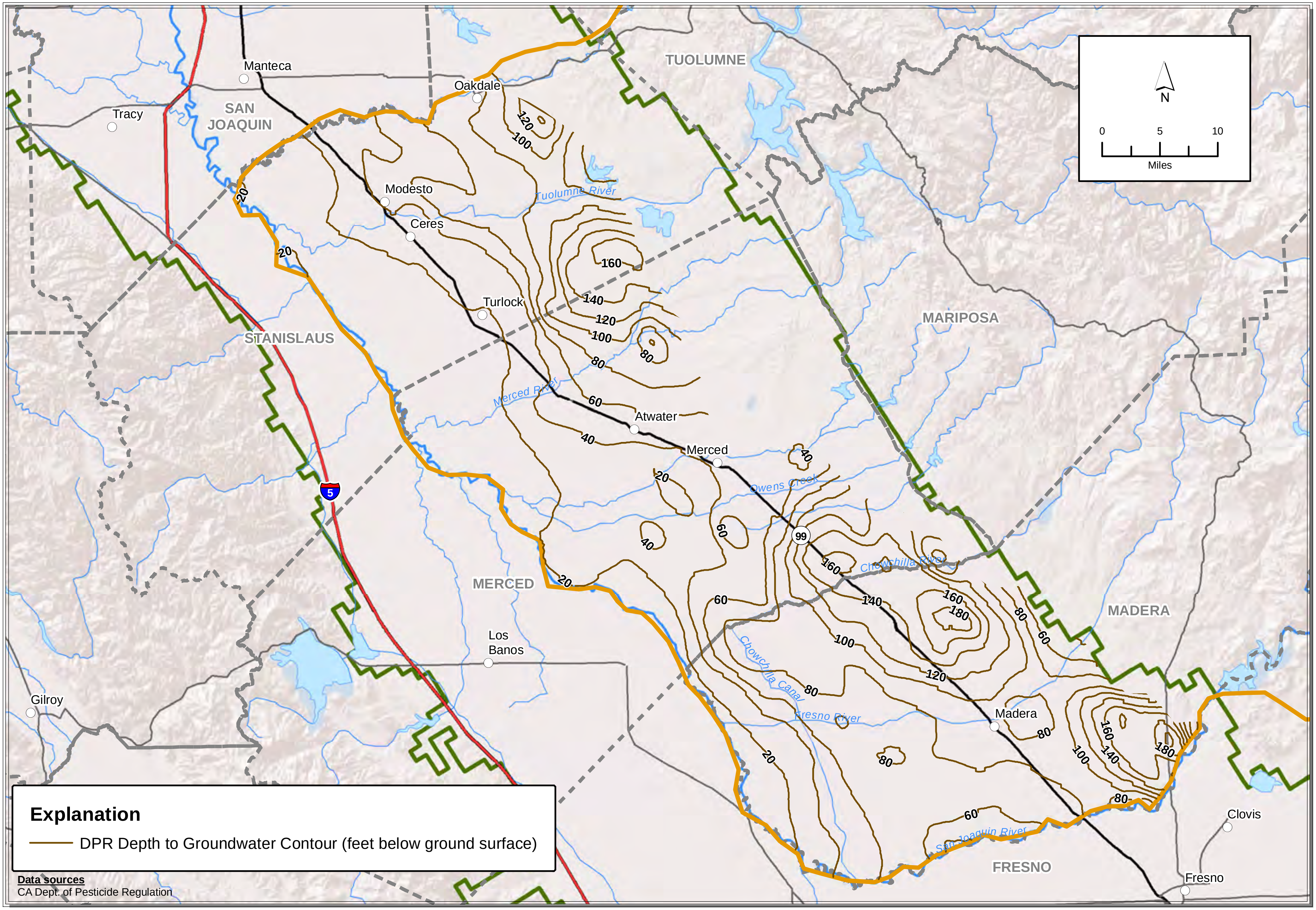

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Figure 3-13
DPR Depth to Groundwater Contours

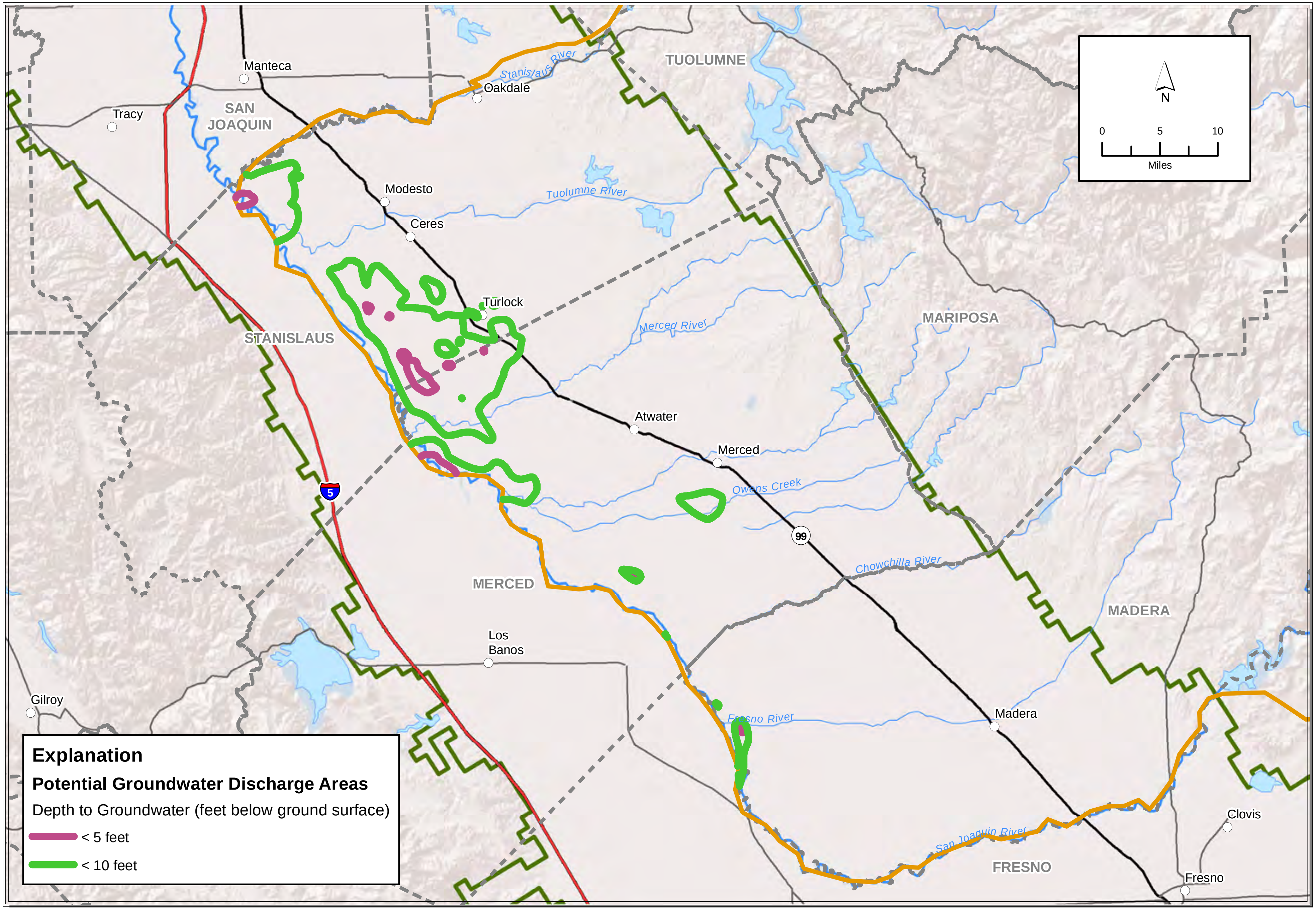

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Figure 3-14
Potential Groundwater Discharge Areas

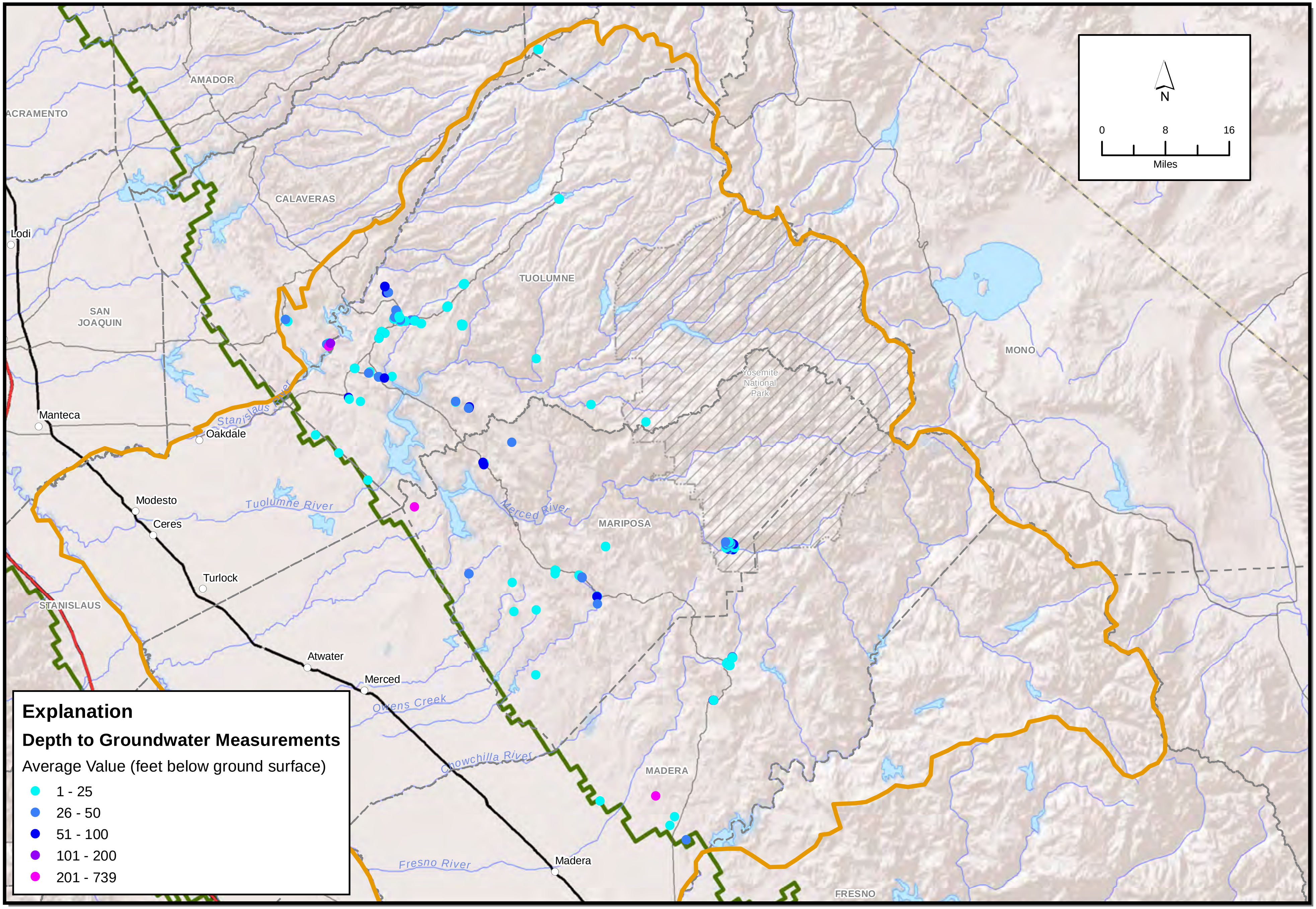

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Figure 3-15
Depth to Groundwater Measurements: Peripheral Area

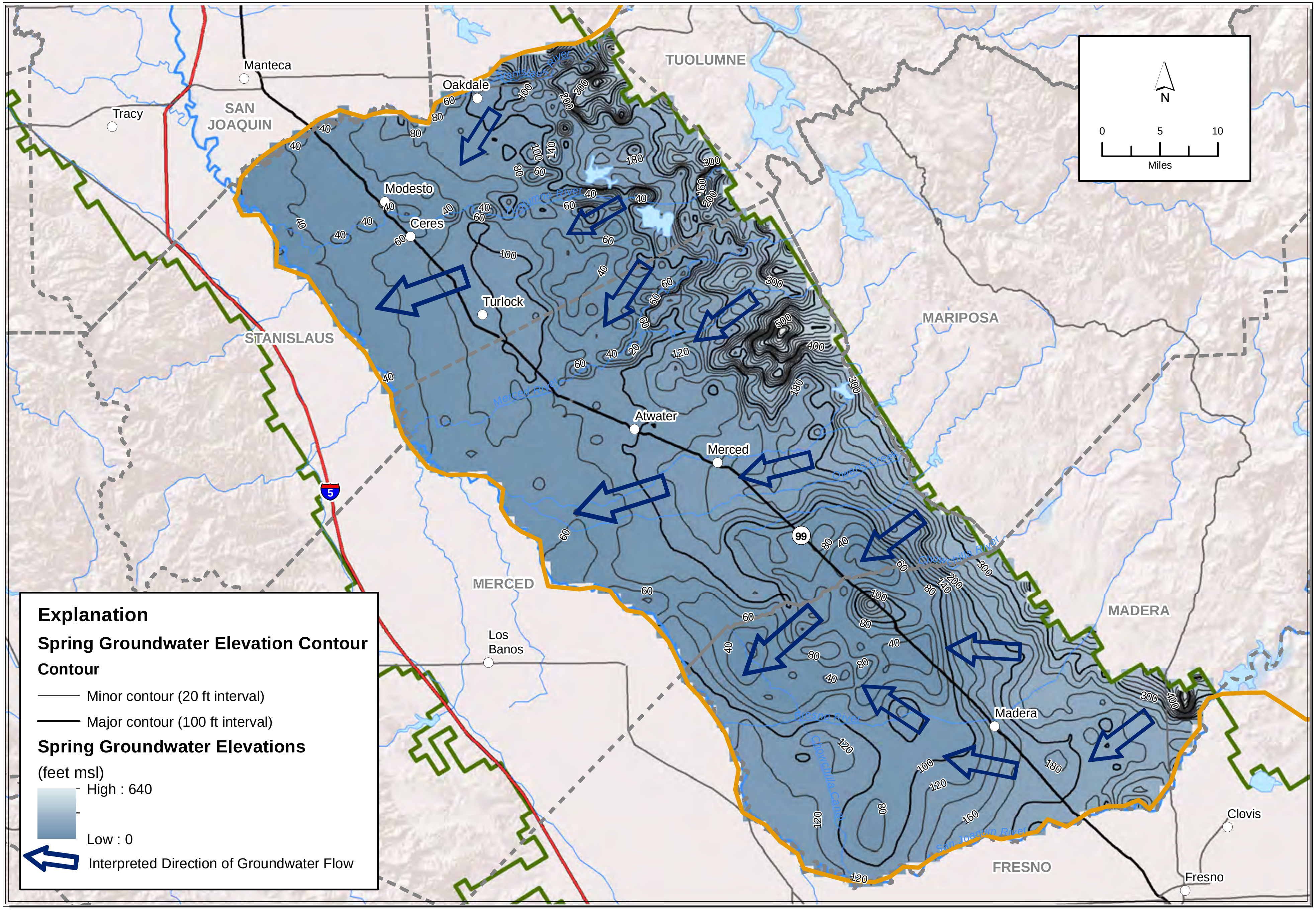

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Figure 3-16
Spring Groundwater Elevation Contours: Central Valley Floor

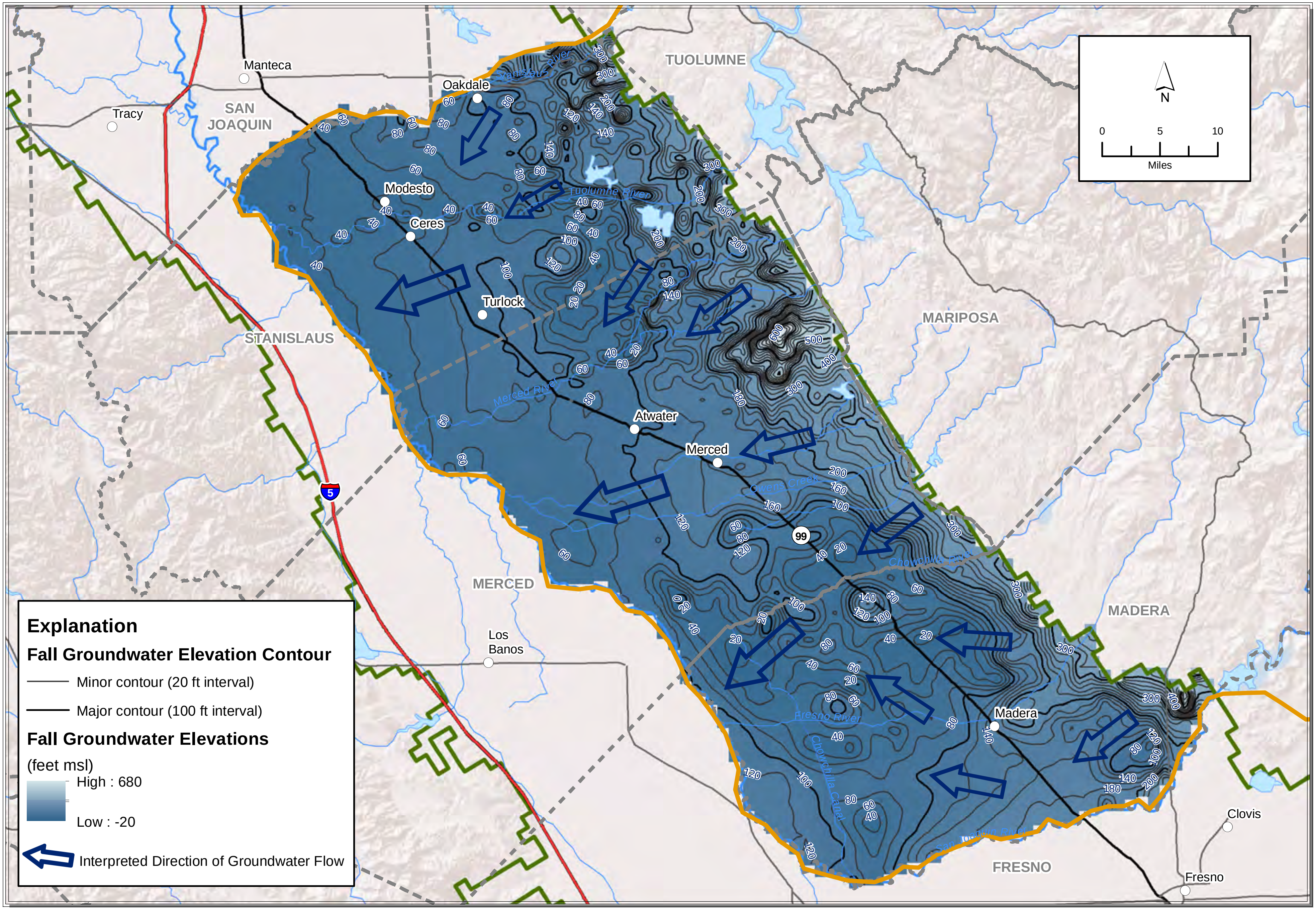

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Figure 3-17
Fall Groundwater Elevation Contours: Central Valley Floor

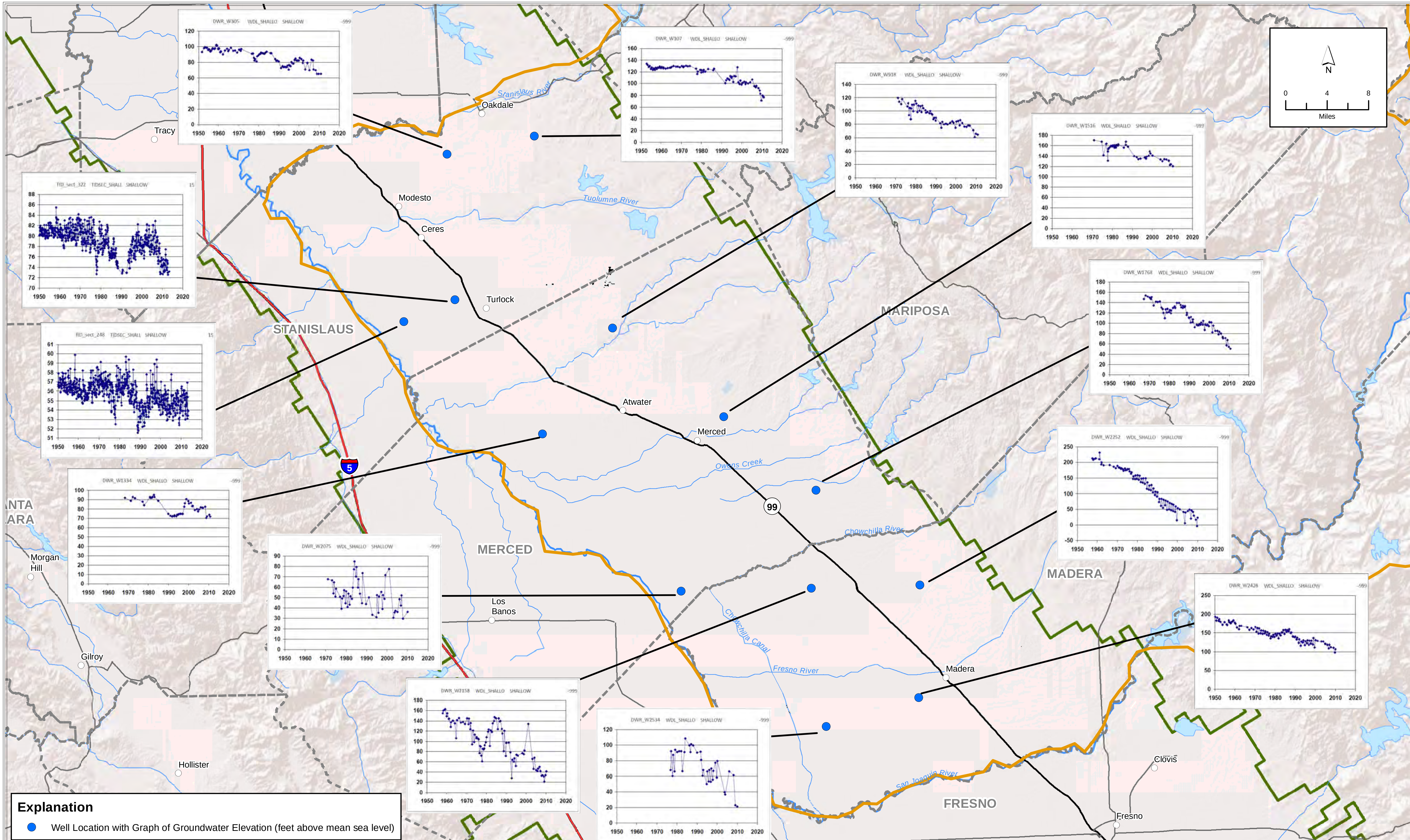

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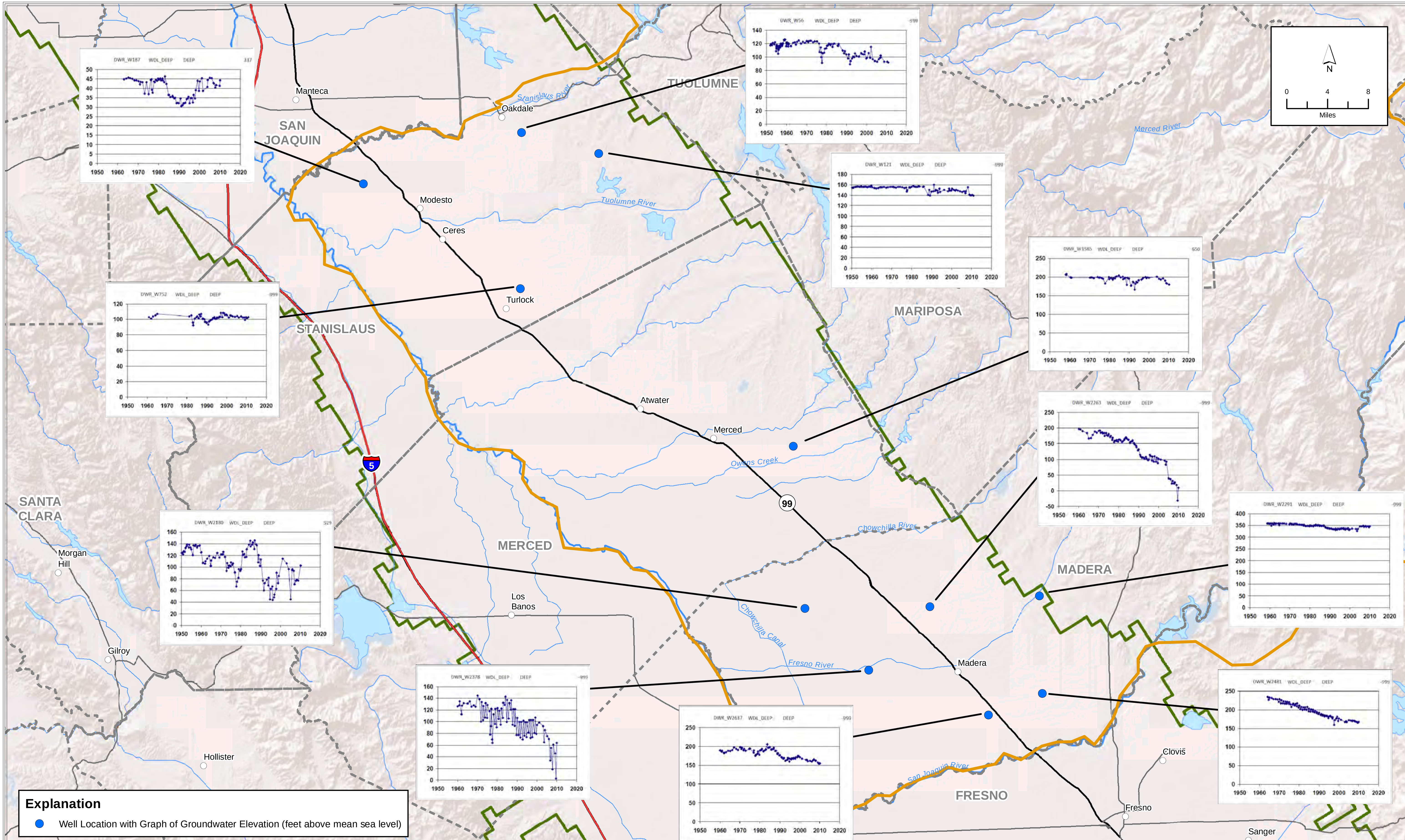
Figure 3-18

Select Graphs of Groundwater Levels in the Central Valley Floor: Shallow Wells



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 3-19 Select Graphs of Groundwater Levels in Central Valley Floor Deep Wells.mxd

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Figure 3-19
Select Graphs of Groundwater Levels in the Central Valley Floor: Deep Wells

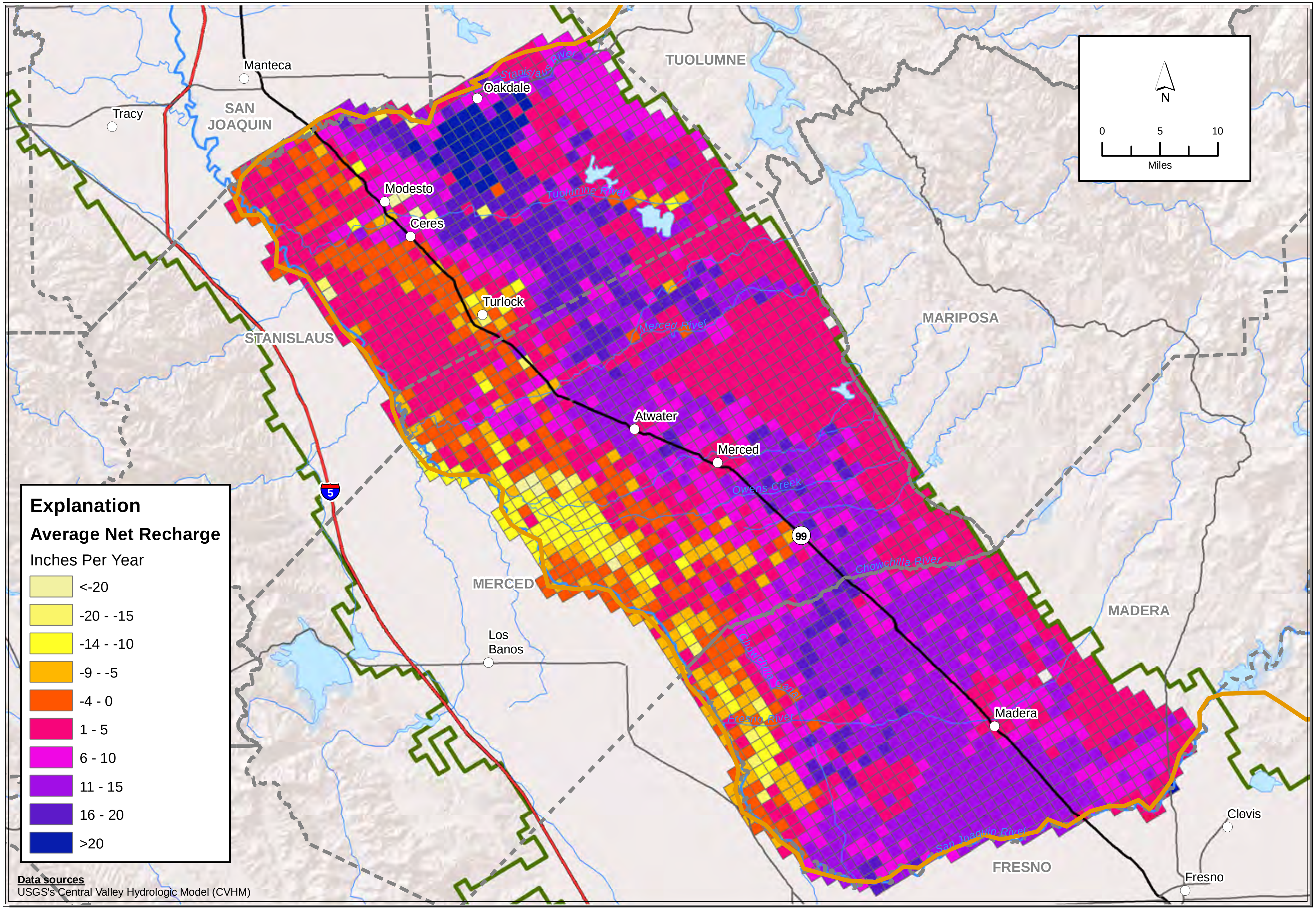

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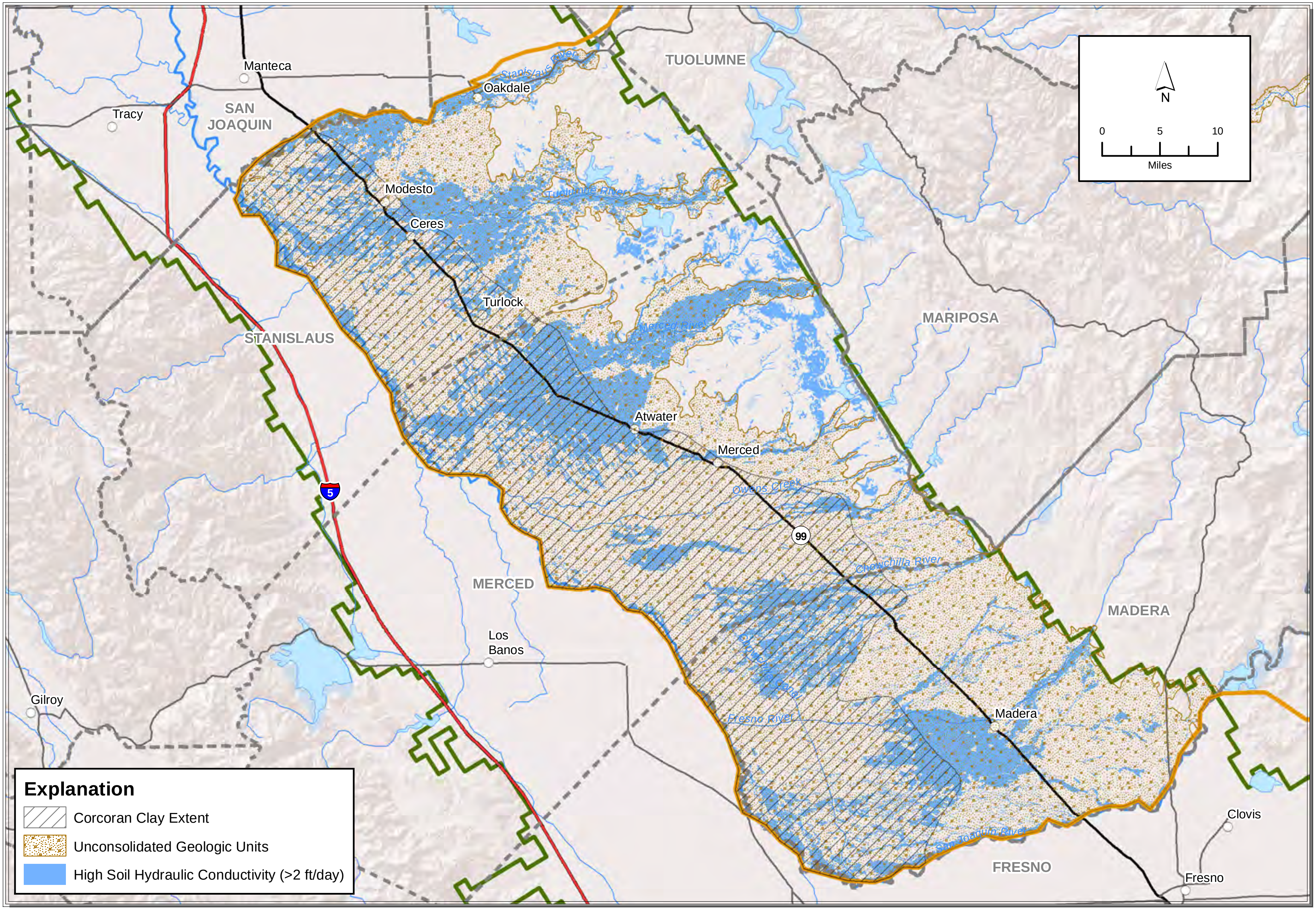
Figure 3-20
Groundwater Recharge as Simulated by CVHM



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 3-21 Potential Recharge Areas.mxd

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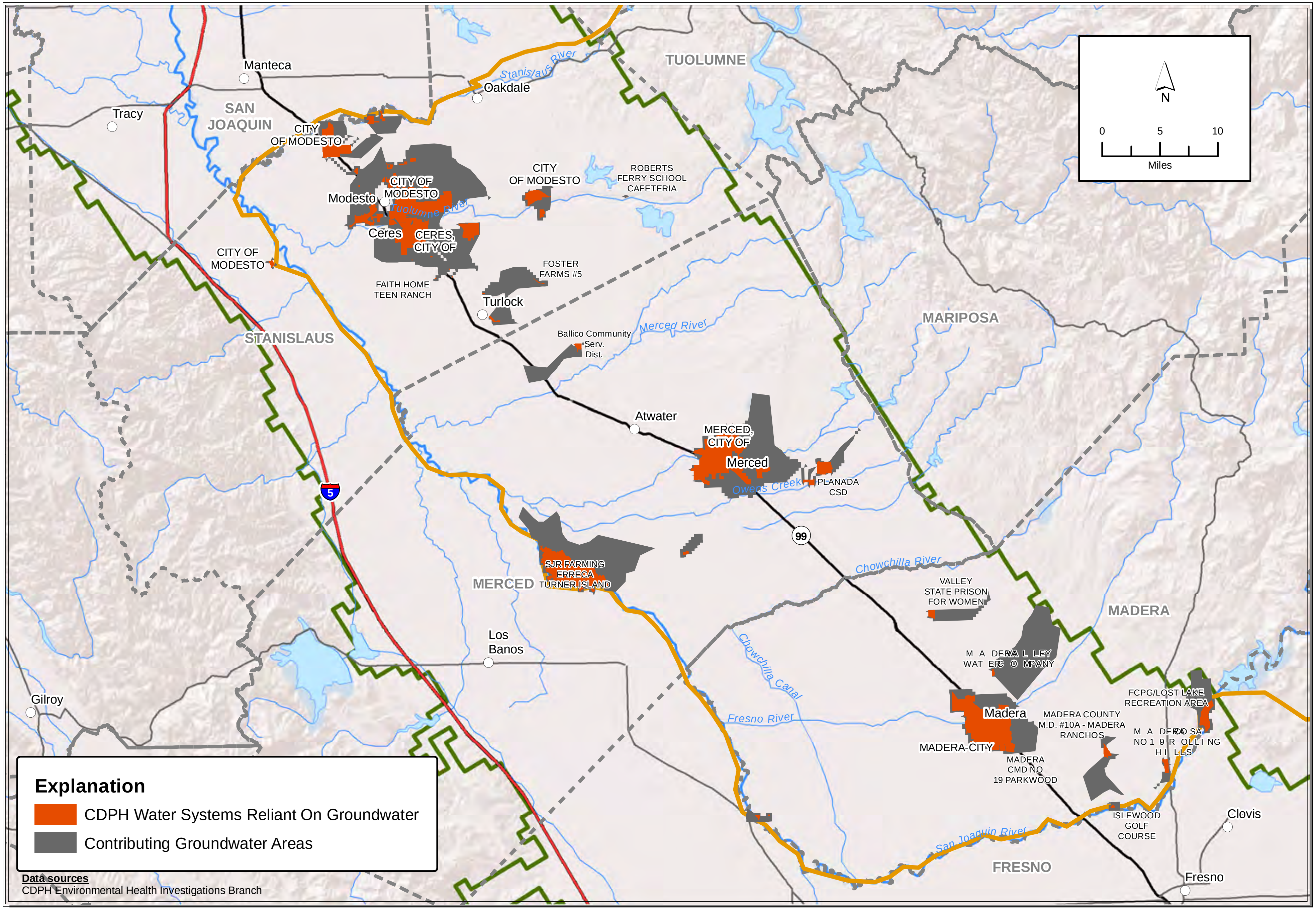
Figure 3-21
Areas with Higher Potential for Groundwater Recharge



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 3-22 Contributing Groundwater Areas for Urban and Rural Communities.mxd

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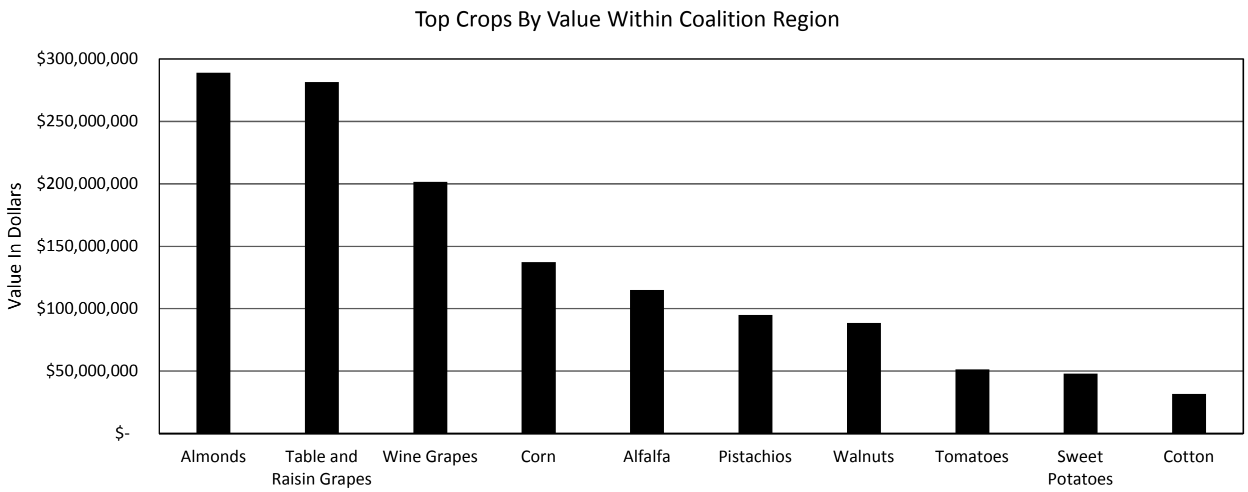
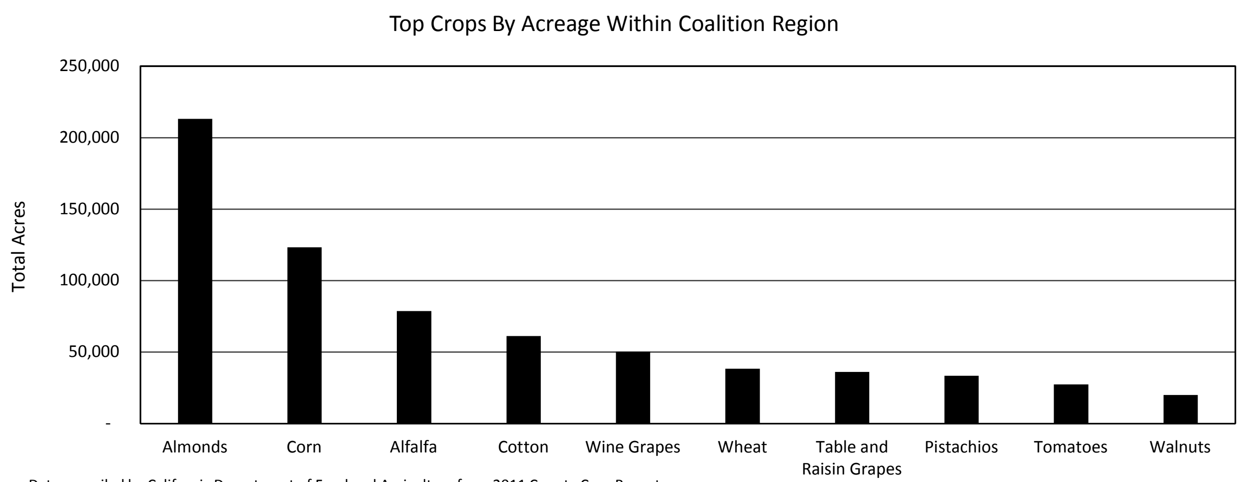
Figure 3-22
Contributing Groundwater Areas for Urban and Rural Communities

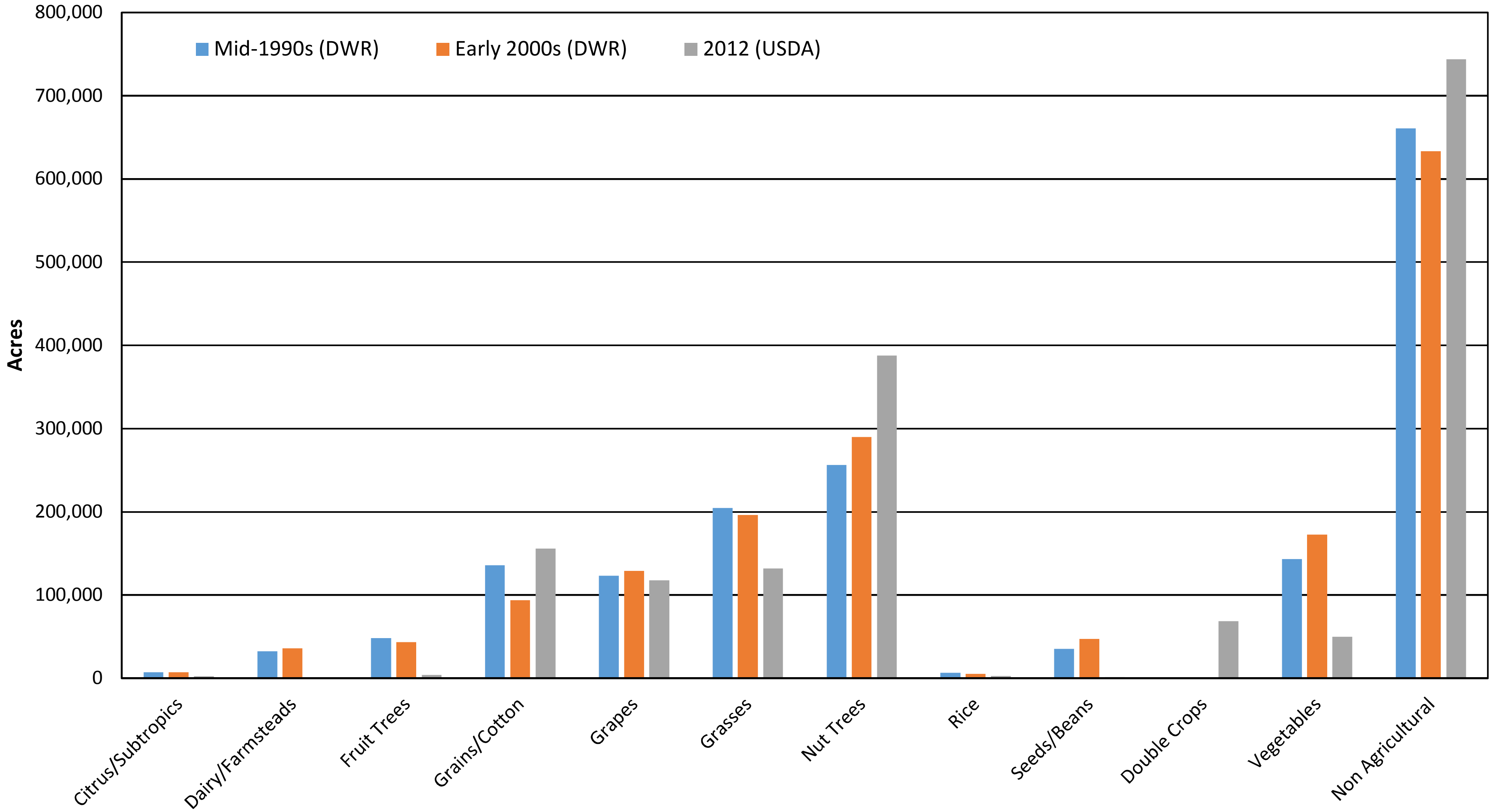
Figure 4-1
Summary of Primary Commodities





Data compiled by California Department of Food and Agriculture from 2011 County Crop Reports

Figure 4-2
Change in Land Use in the Central Valley Floor



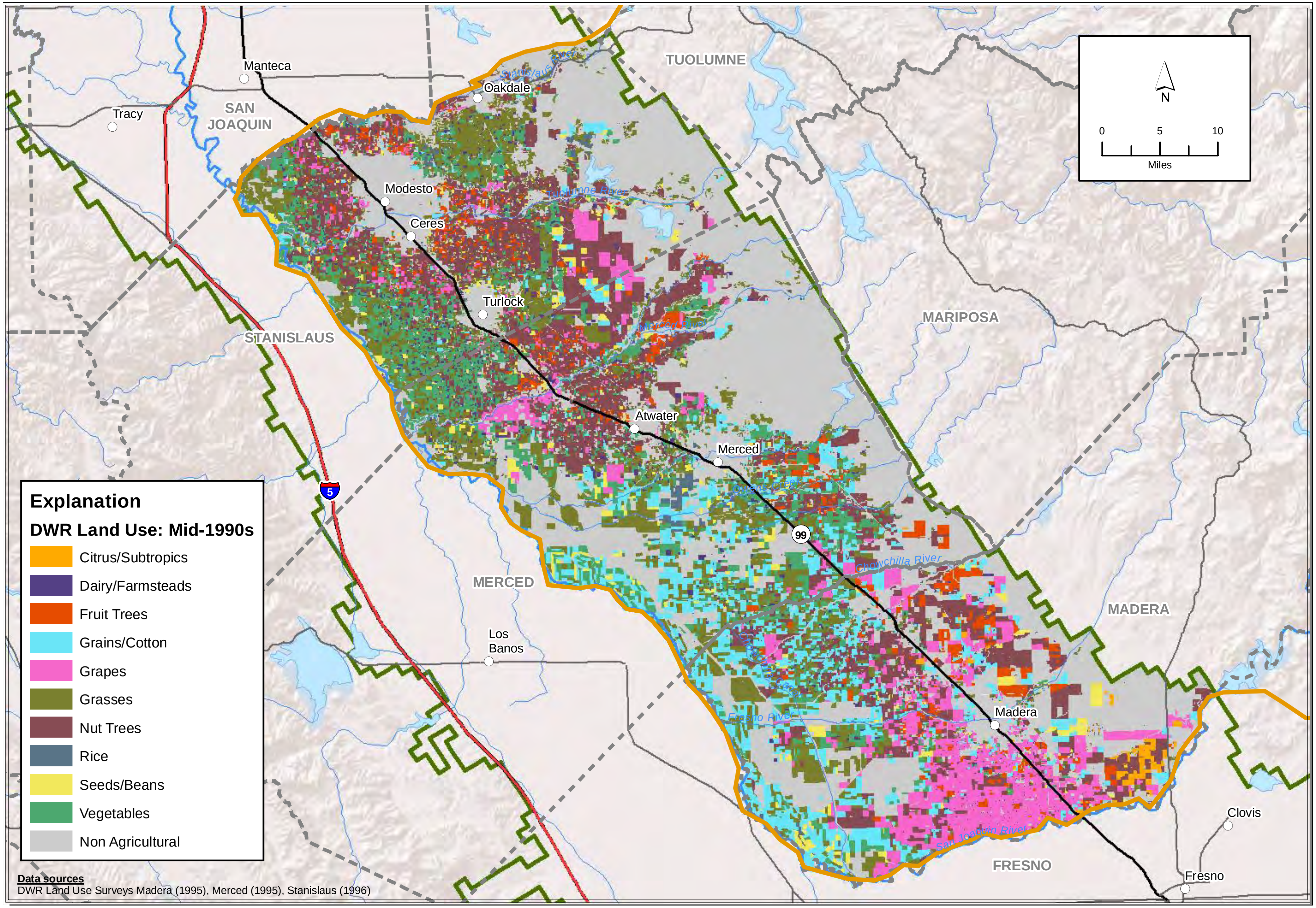


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Figure 4-3
Land Use: Mid-1990s

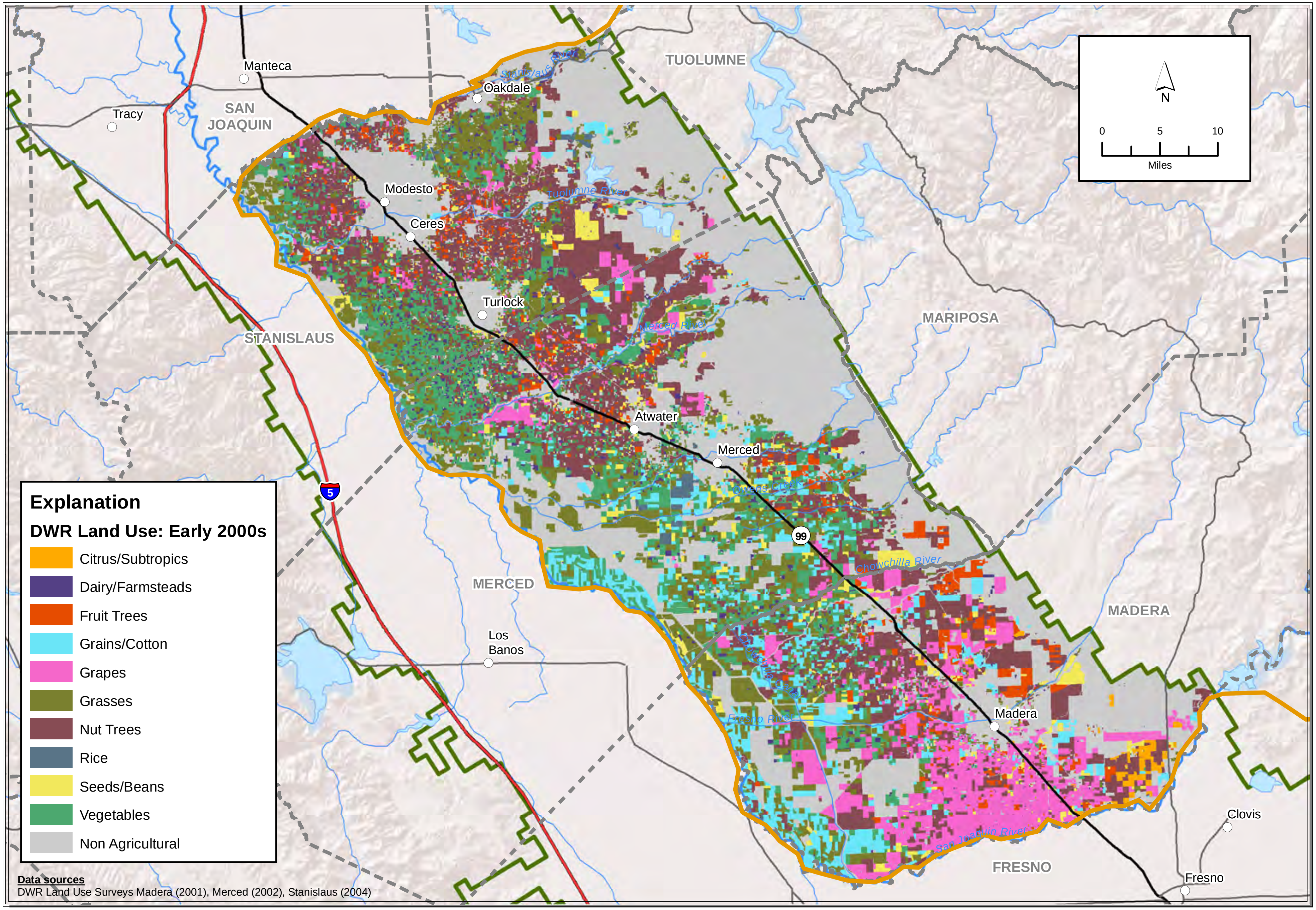

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Figure 4-4
Land Use: Early 2000s

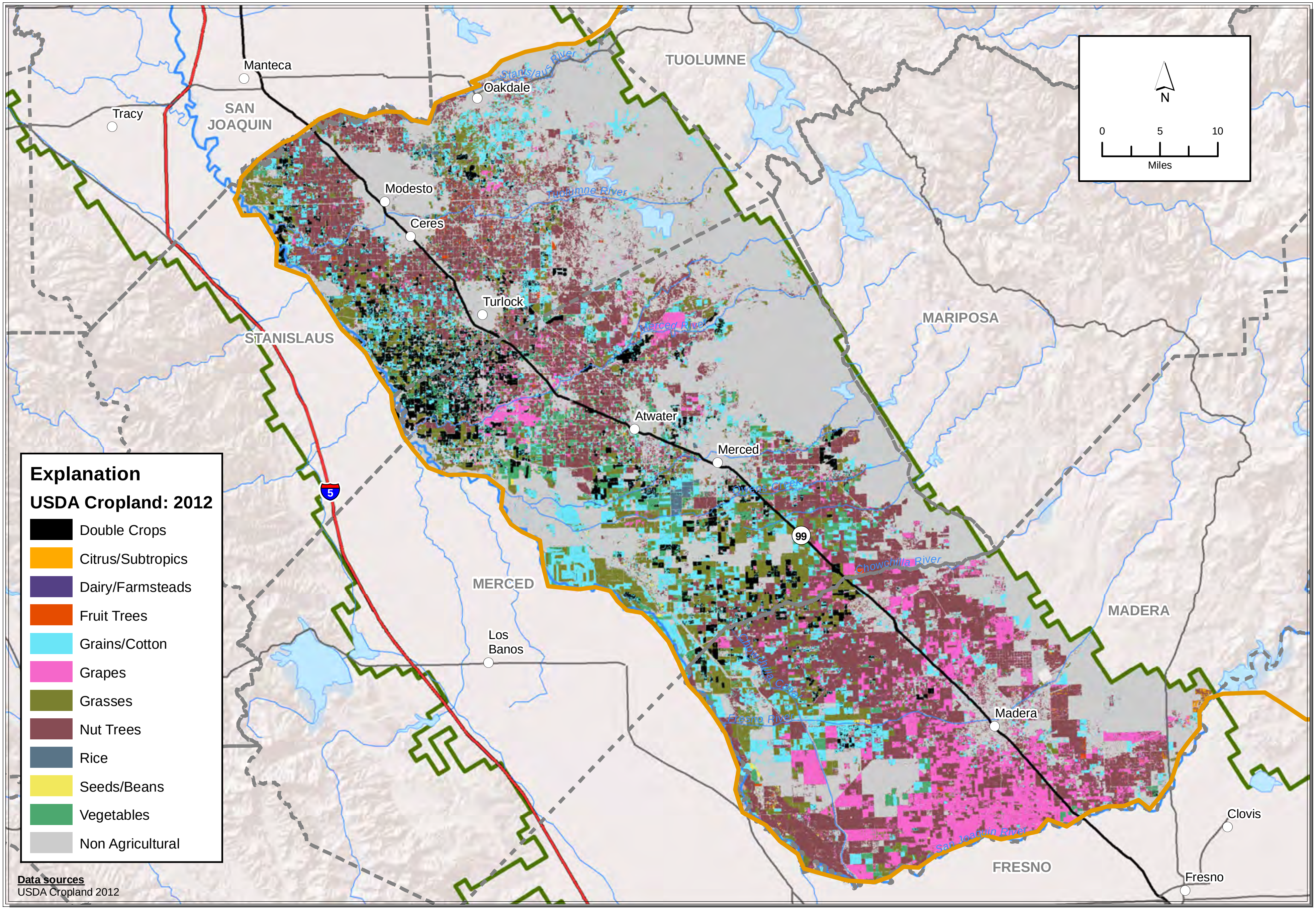

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Figure 4-5
Land Use: 2012

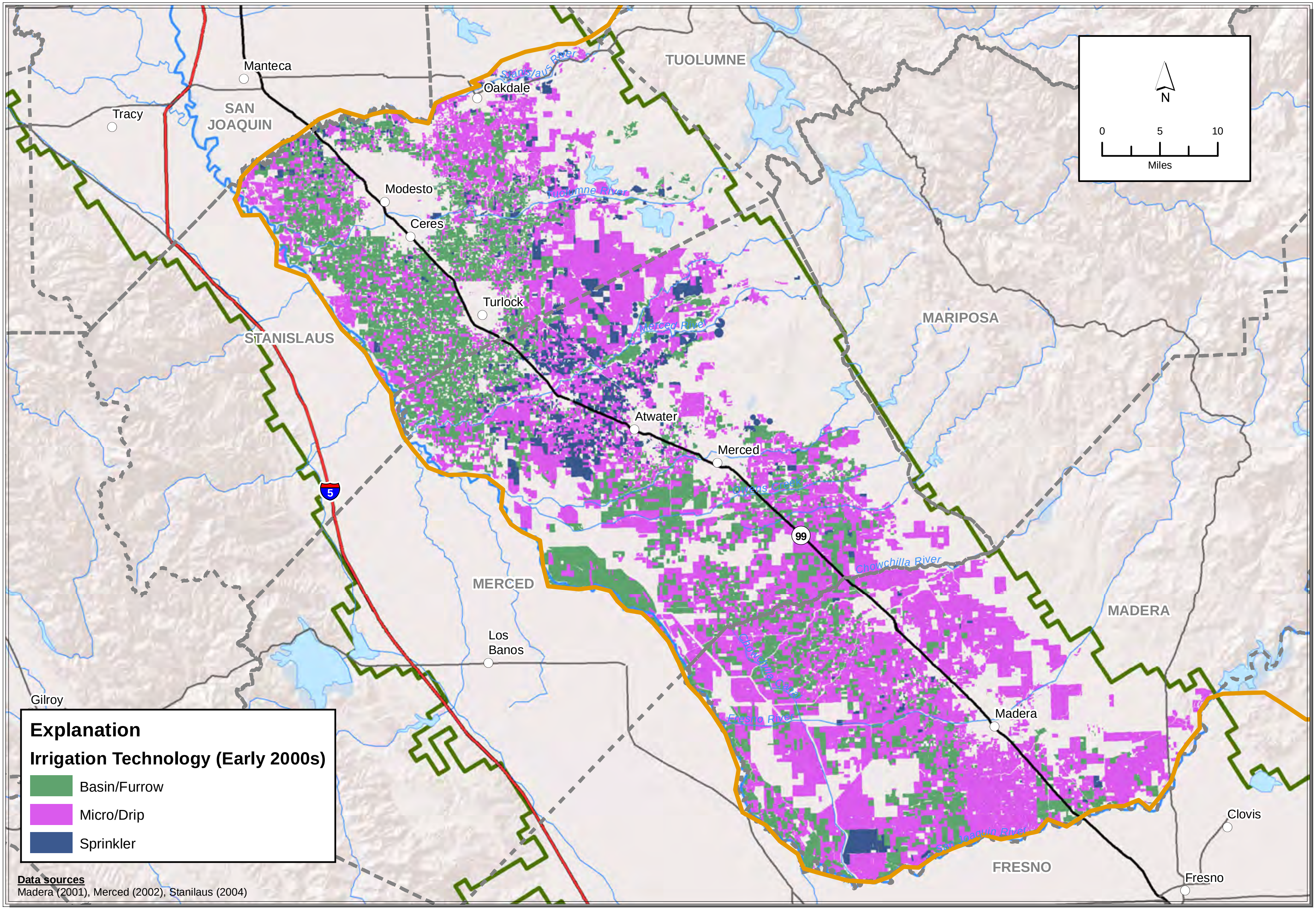

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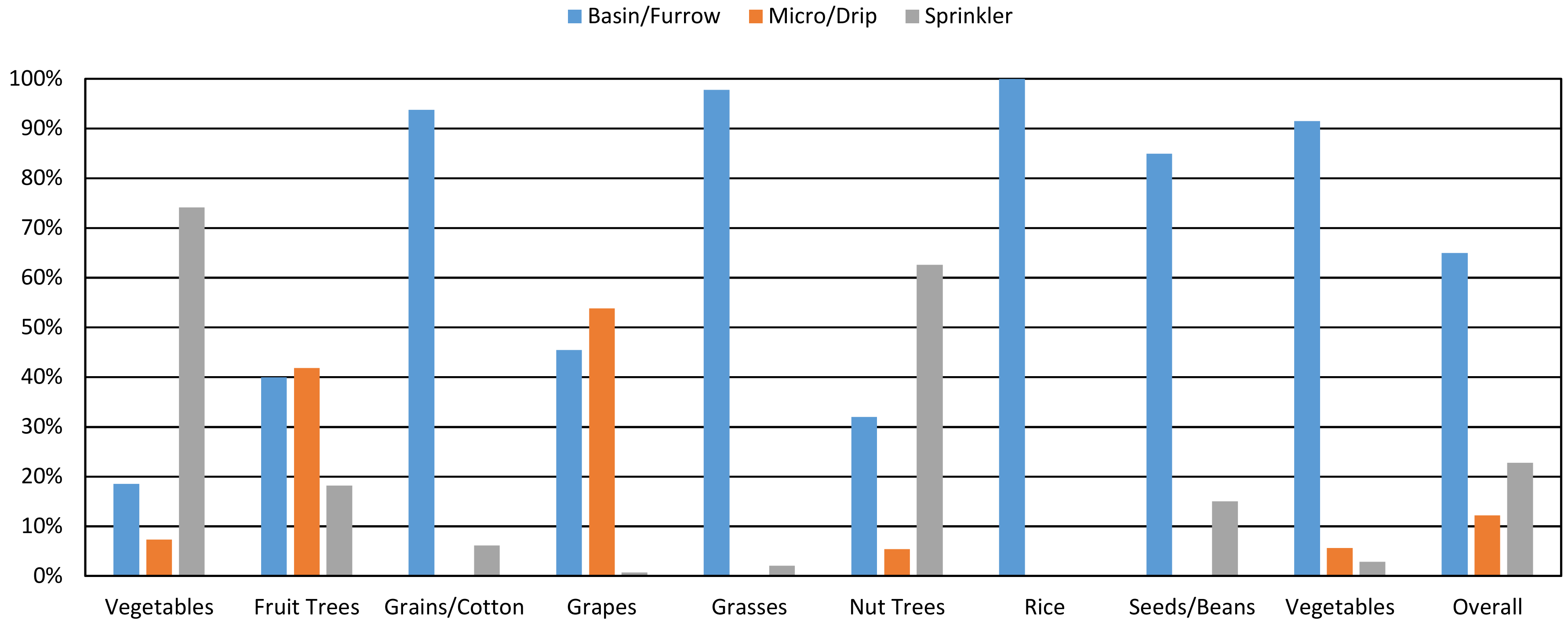
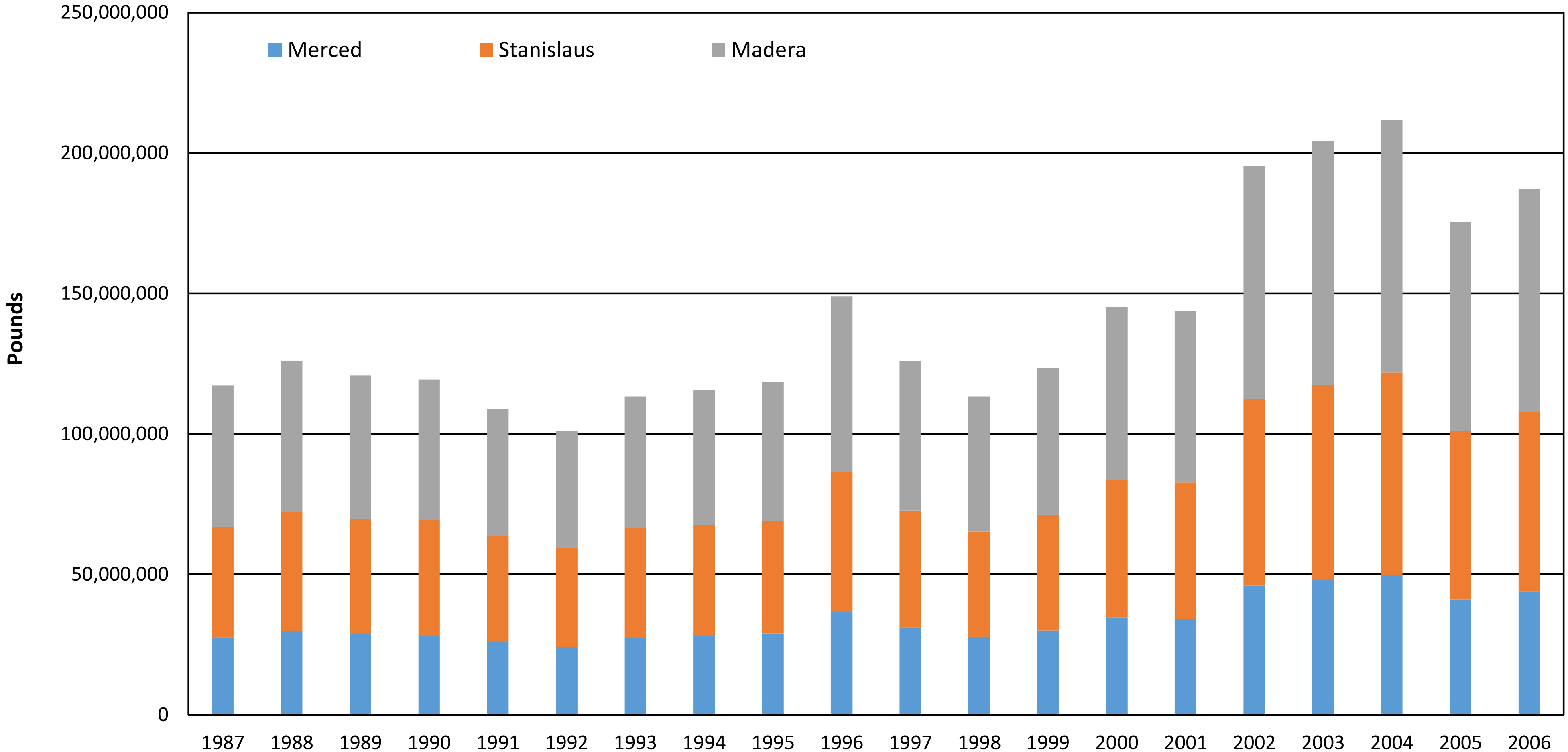
Figure 4-6
Irrigation Practices

Figure 4-7
Summary of Irrigation Practices By Land Use



Data Compiled from DWR Land Use Surveys 2001-2004

Figure 4-8
Trend in Nitrogen Fertilizer Use



Data from Gronberg and Spahr (2012)

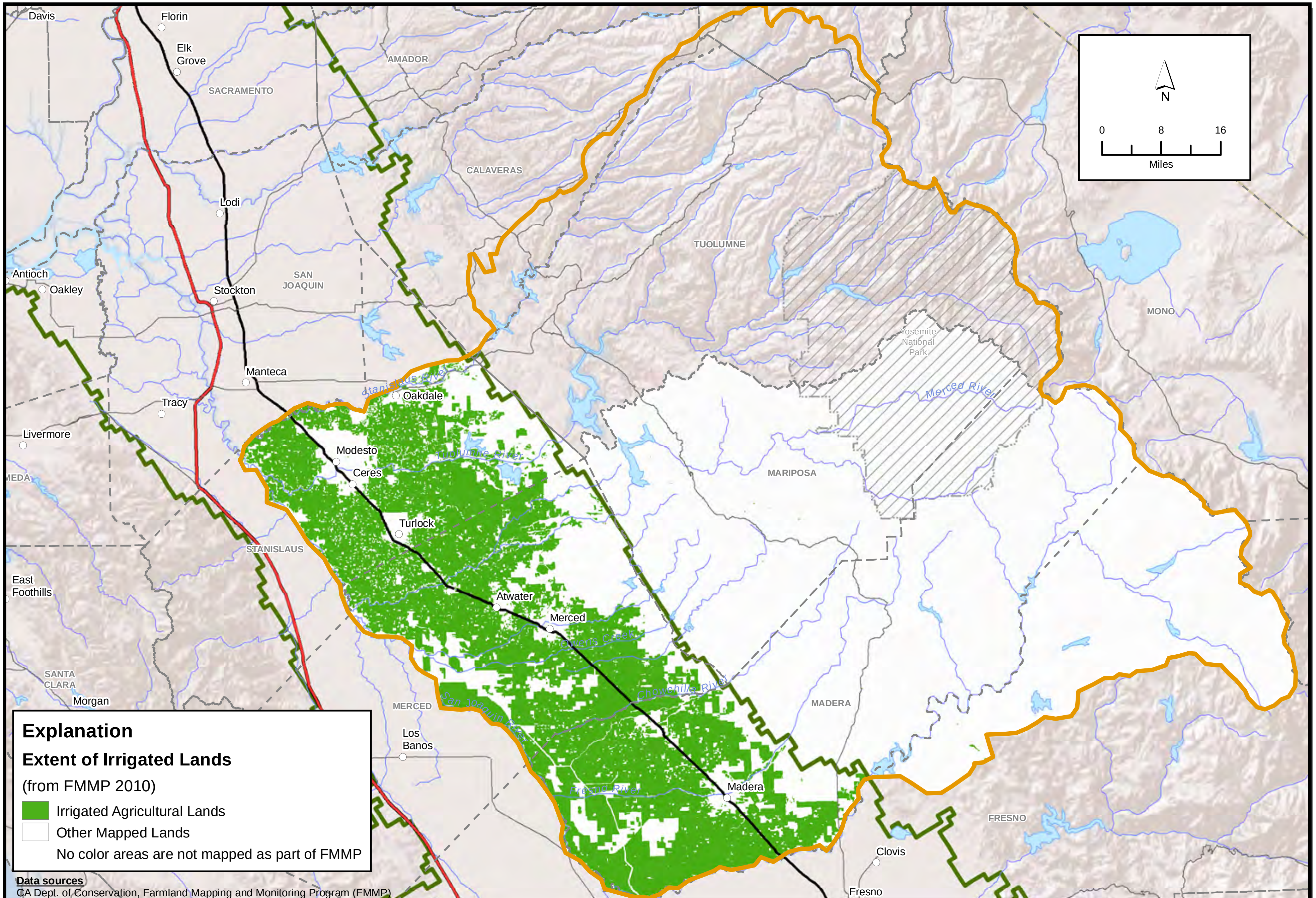


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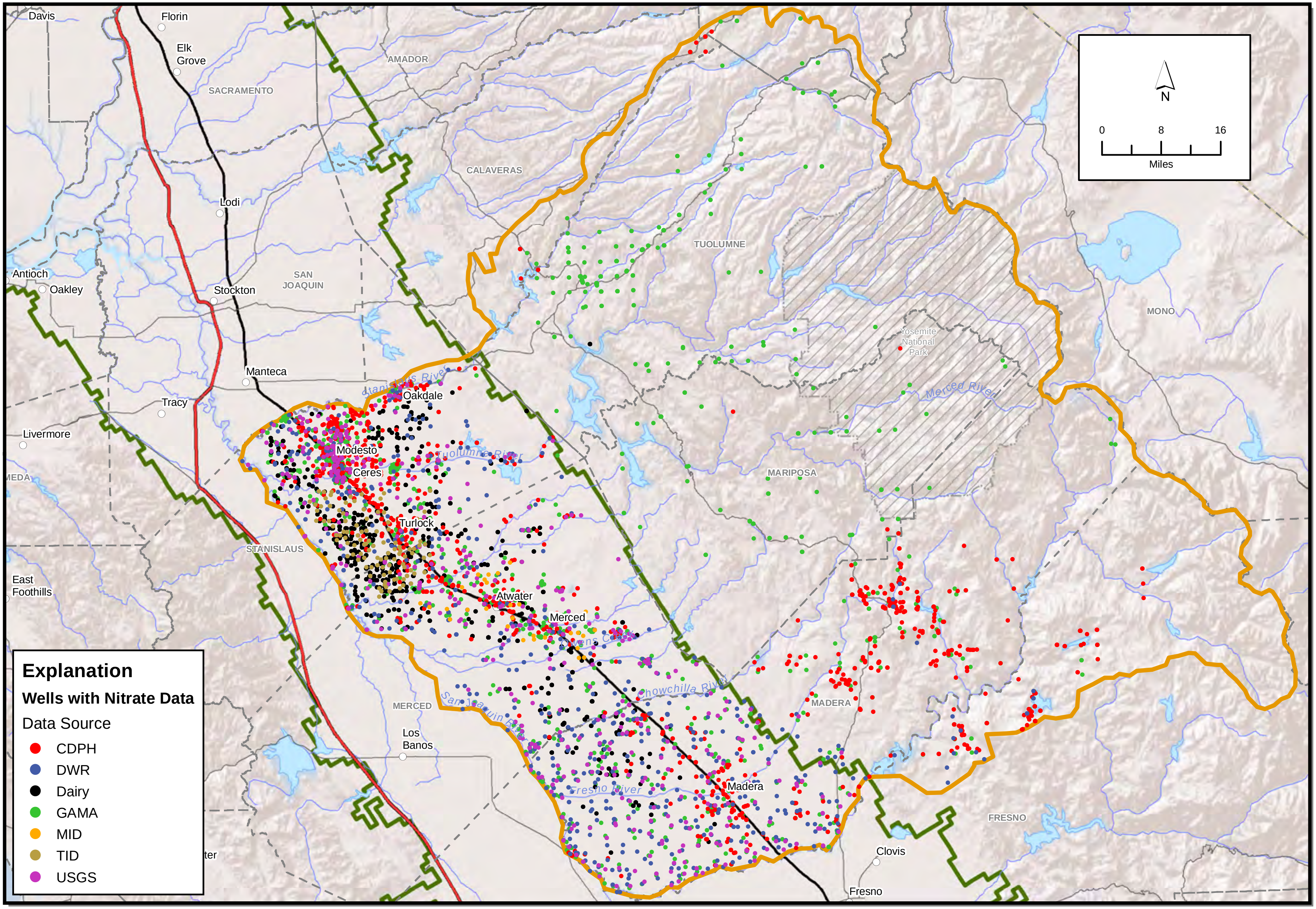
Figure 4-9
Extent of Irrigated Lands



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 5-1a Groundwater Quality Data by Source Nitrate.mxd

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Figure 5-1a
Groundwater Quality Data by Source: Nitrate

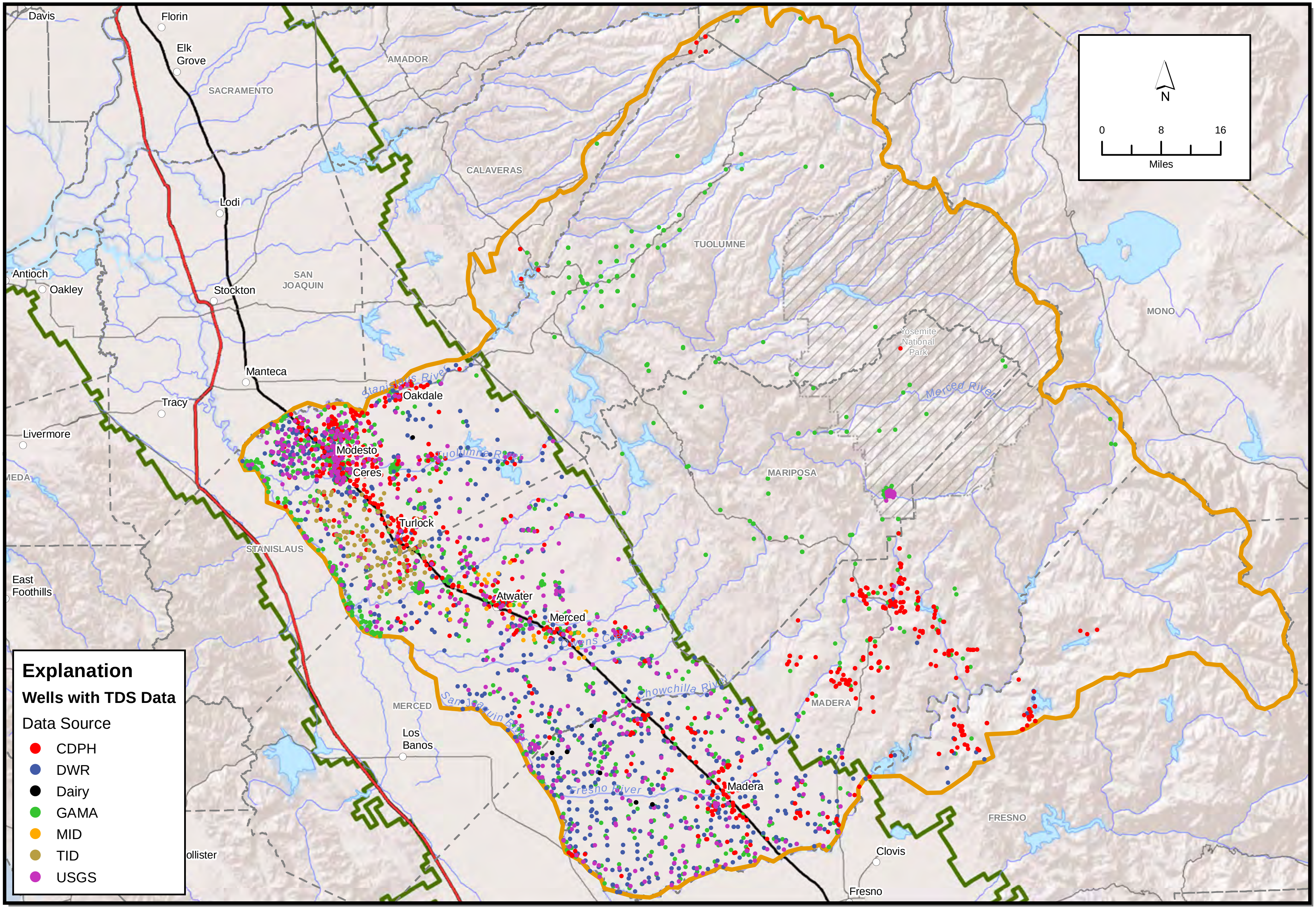

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Figure 5-1b
Groundwater Quality Data by Source: TDS

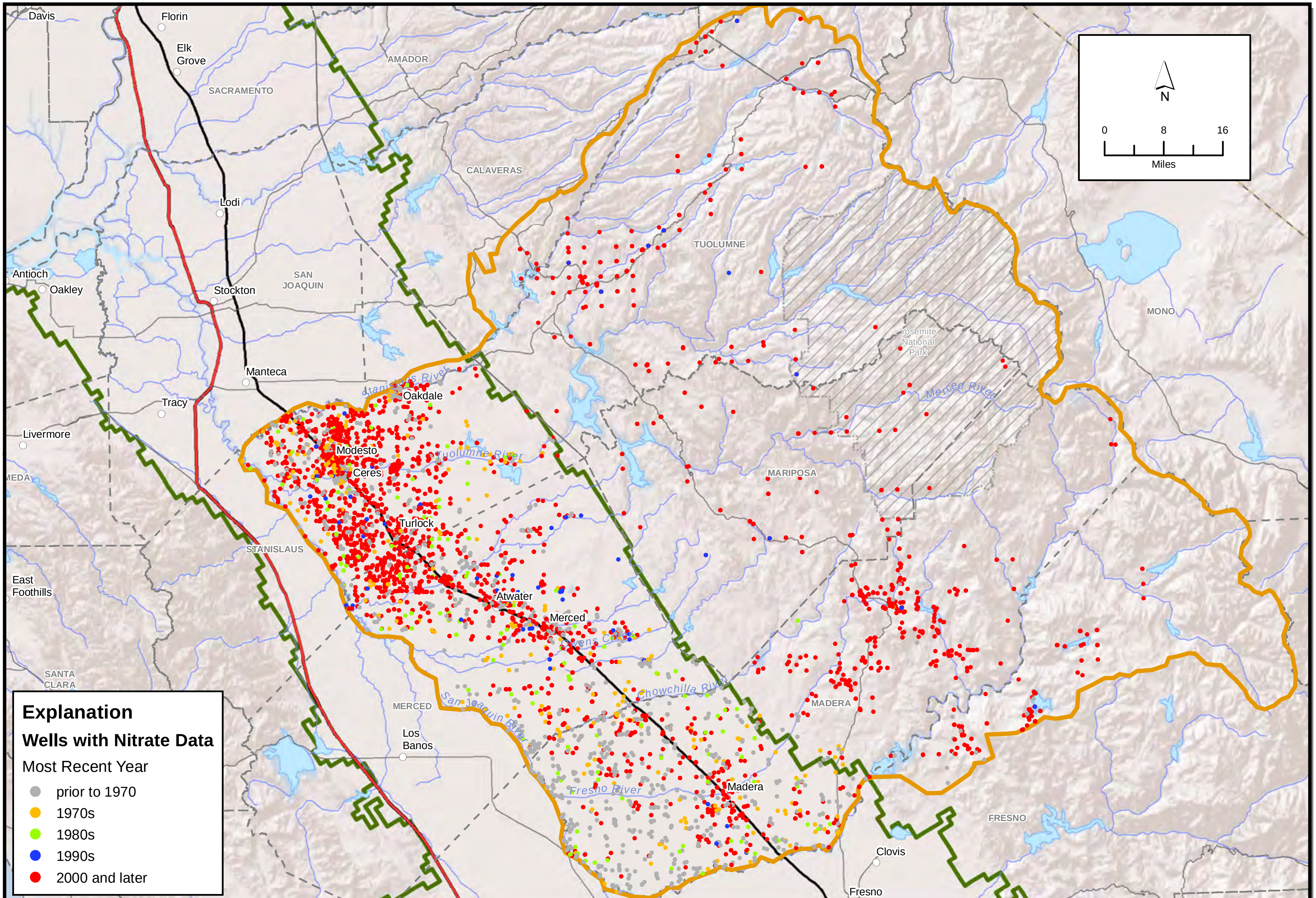

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Figure 5-2a
Groundwater Quality Data by Most Recent Year: Nitrate

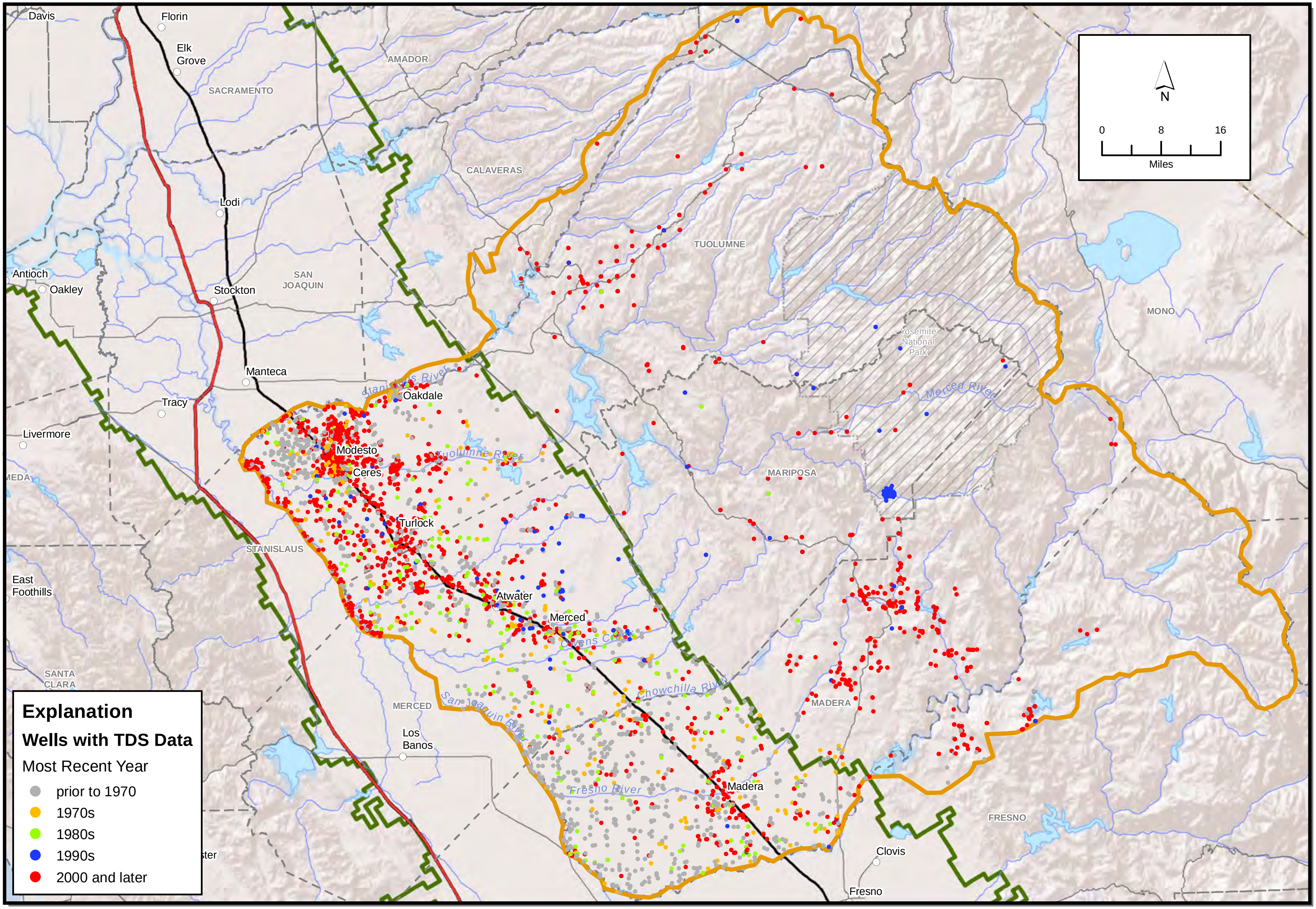

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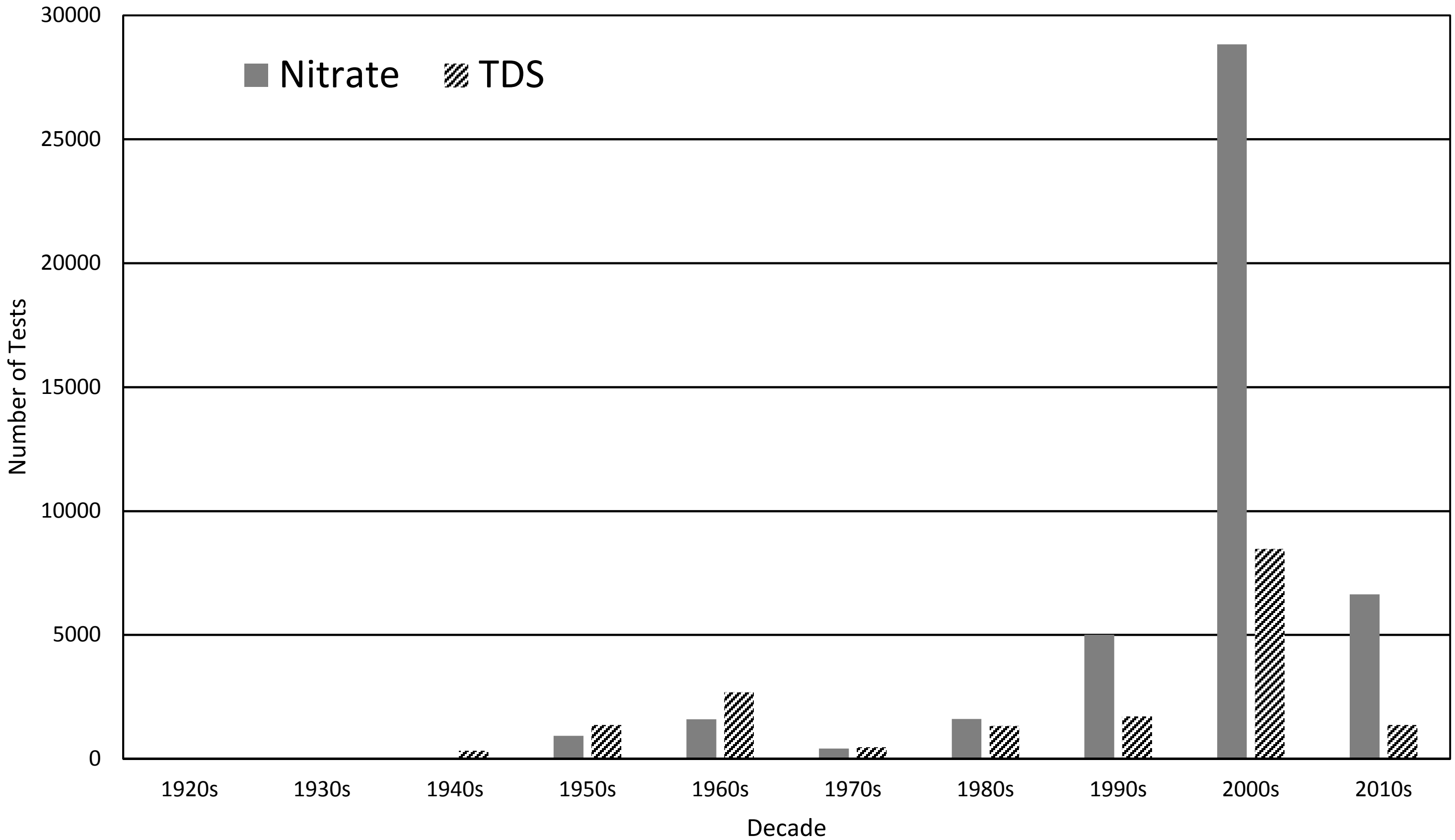
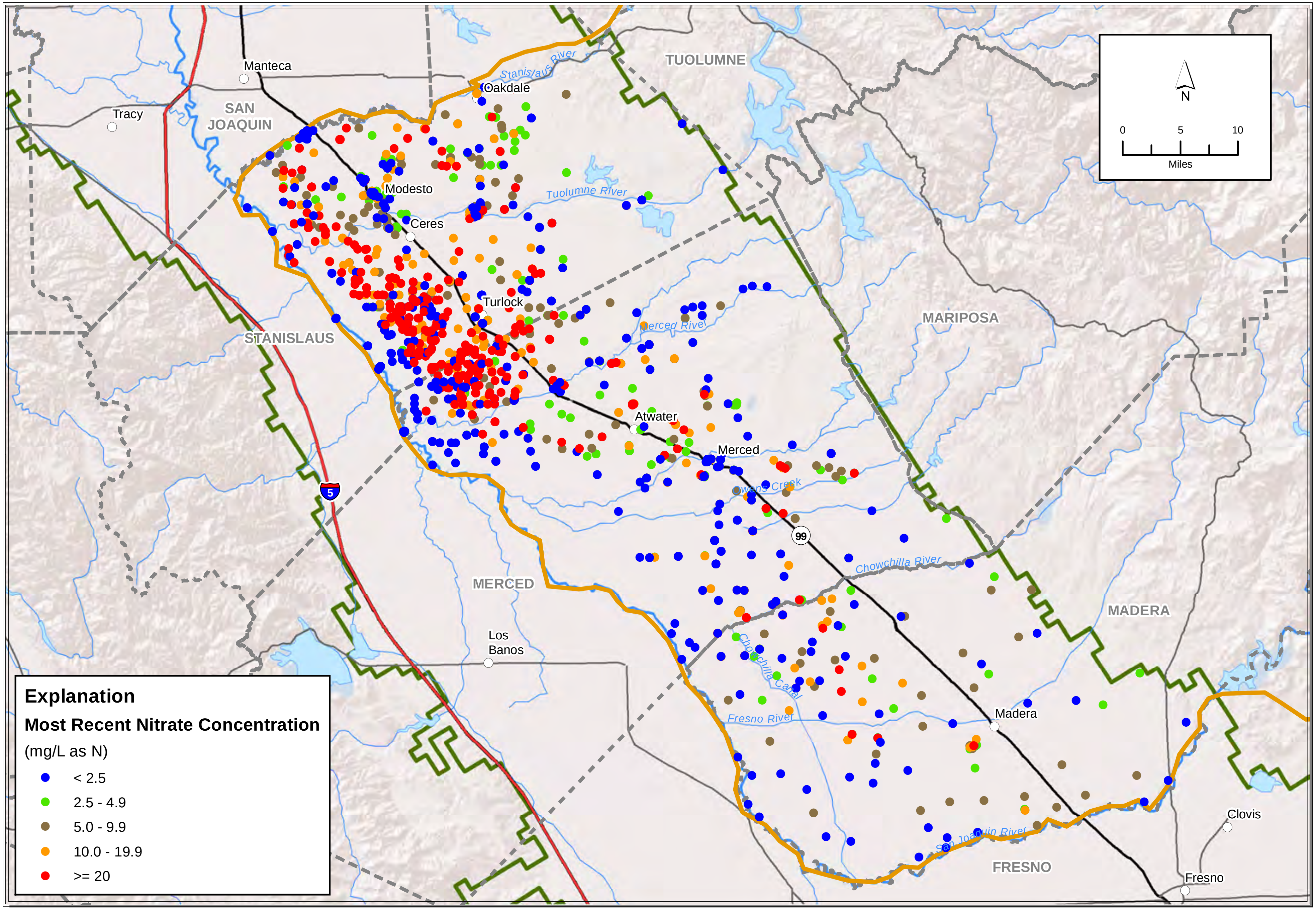
Figure 5-2b
Groundwater Quality Data by Most Recent Year: TDS

Figure 5-3
Number of Groundwater Quality Tests by Decade





Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 5-4 Nitrate Concentrations in Central Valley Floor Shallow Wells.mxd

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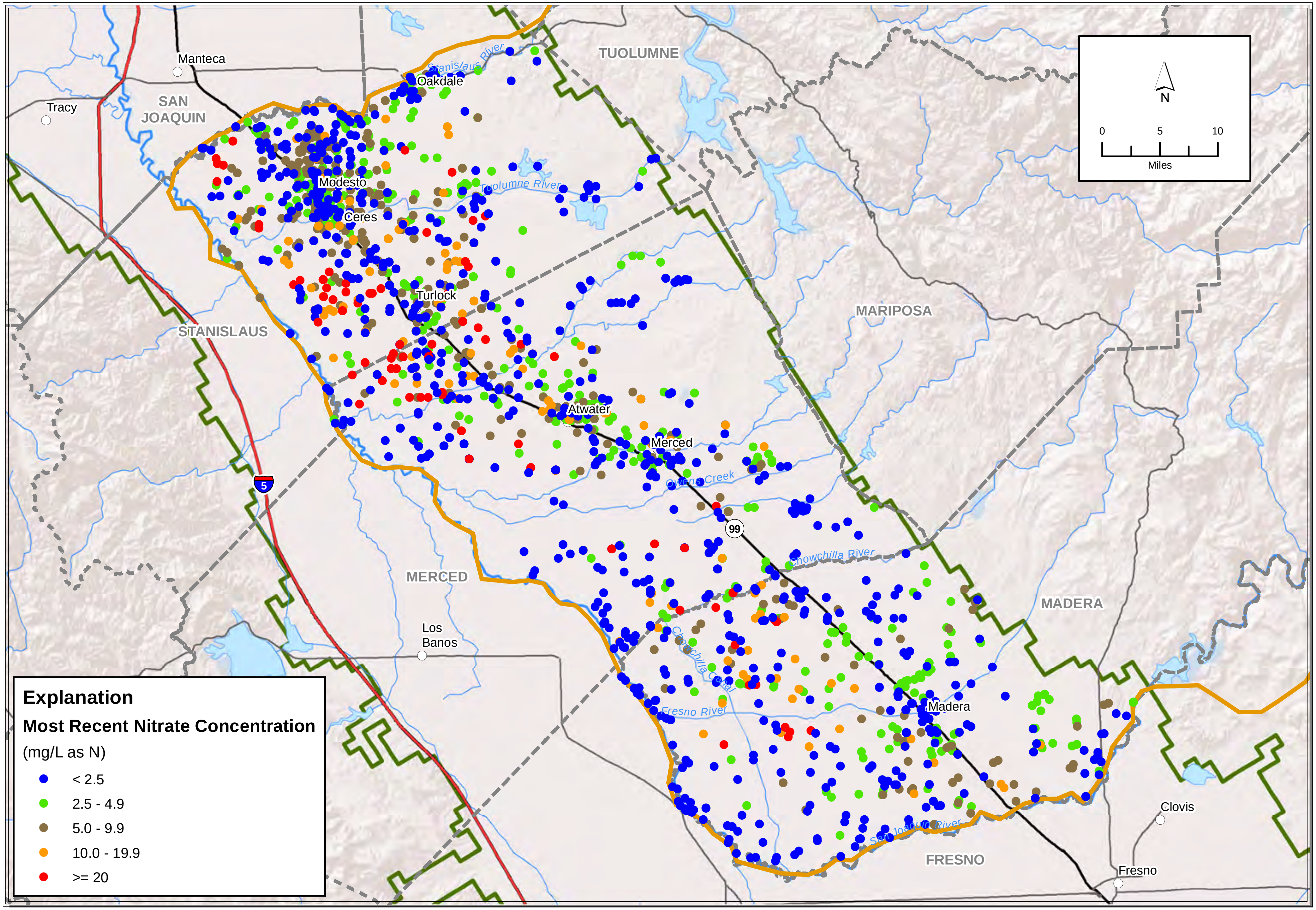
Figure 5-4
Nitrate Concentrations in the Central Valley Floor: Shallow Wells



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 5-5 Nitrate Concentrations in Central Valley Floor Deep Wells.mxd

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Figure 5-5

Nitrate Concentrations in the Central Valley Floor: Deep Wells

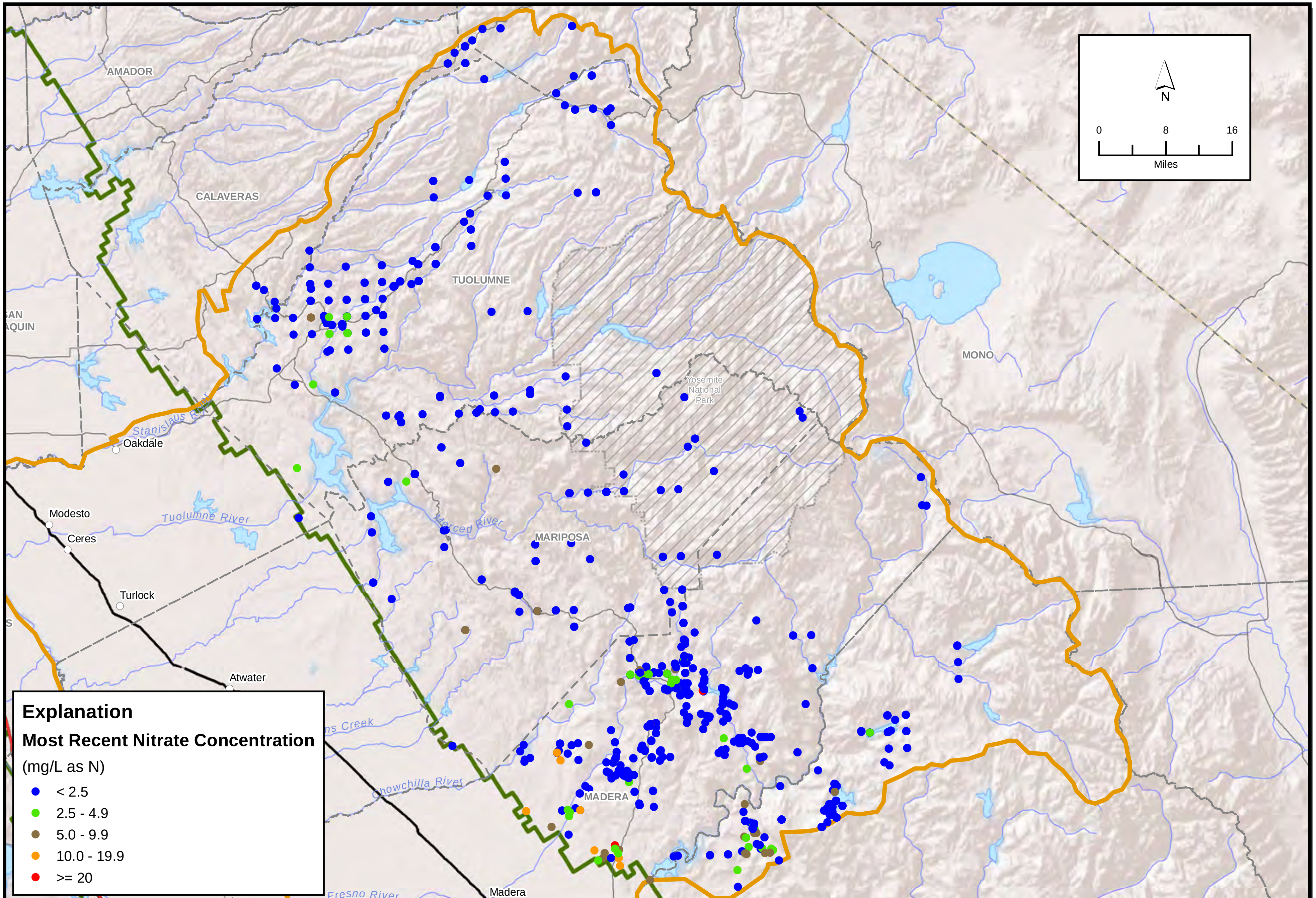

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Figure 5-6
Nitrate Concentrations in the Peripheral Area

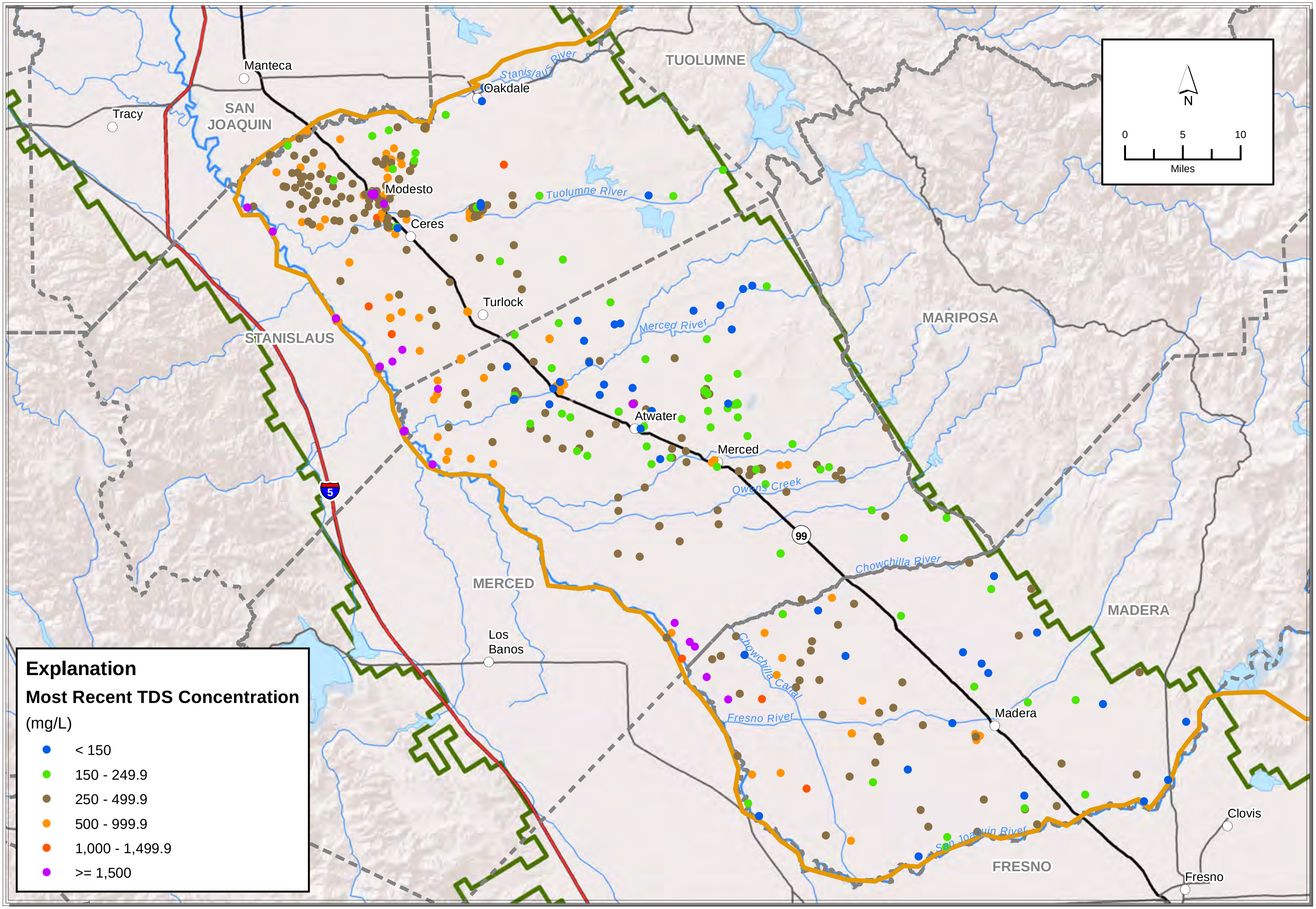

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Figure 5-7

TDS Concentrations in the Central Valley Floor: Shallow Wells

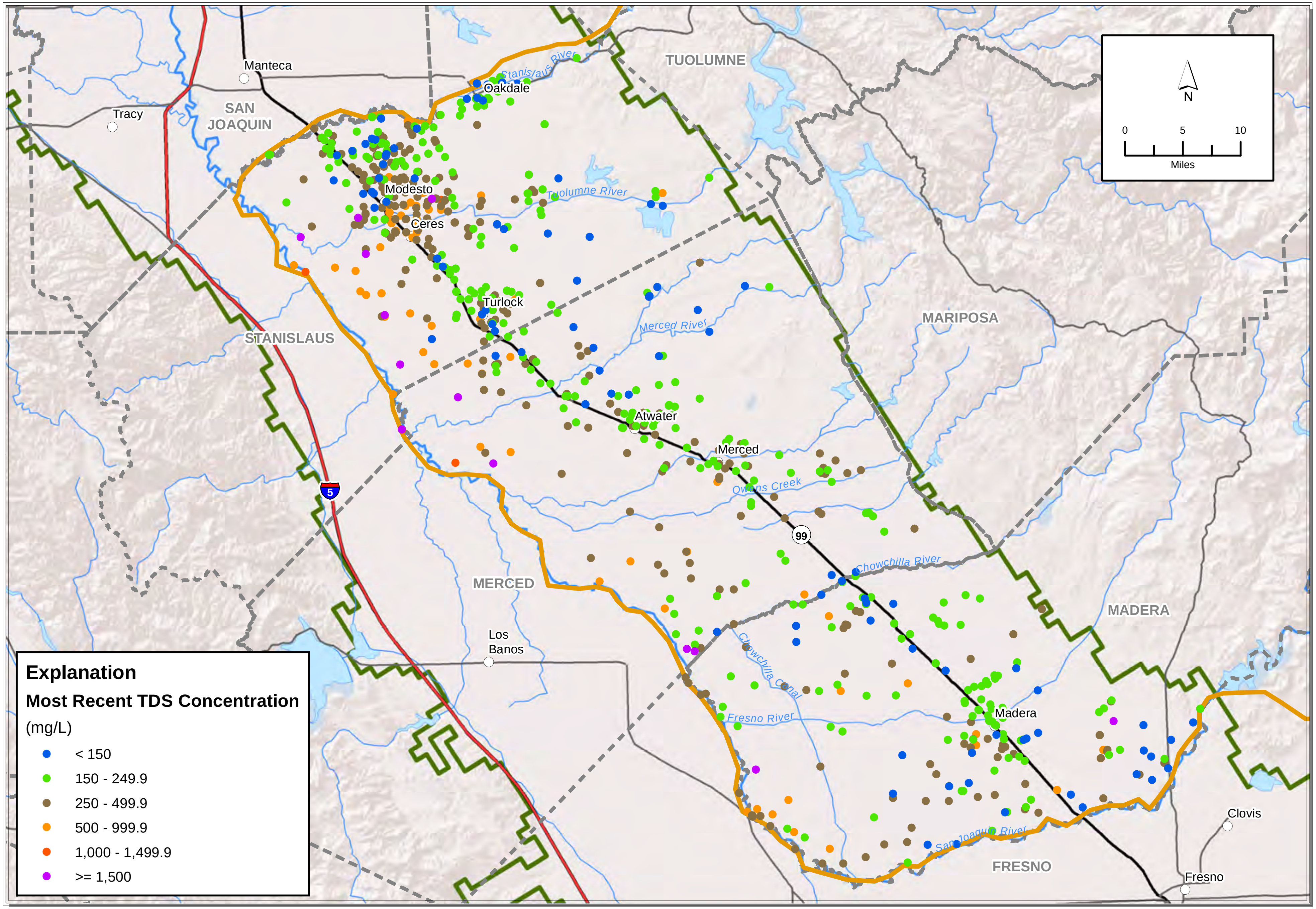

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Figure 5-8
TDS Concentrations in the Central Valley Floor: Deep Wells

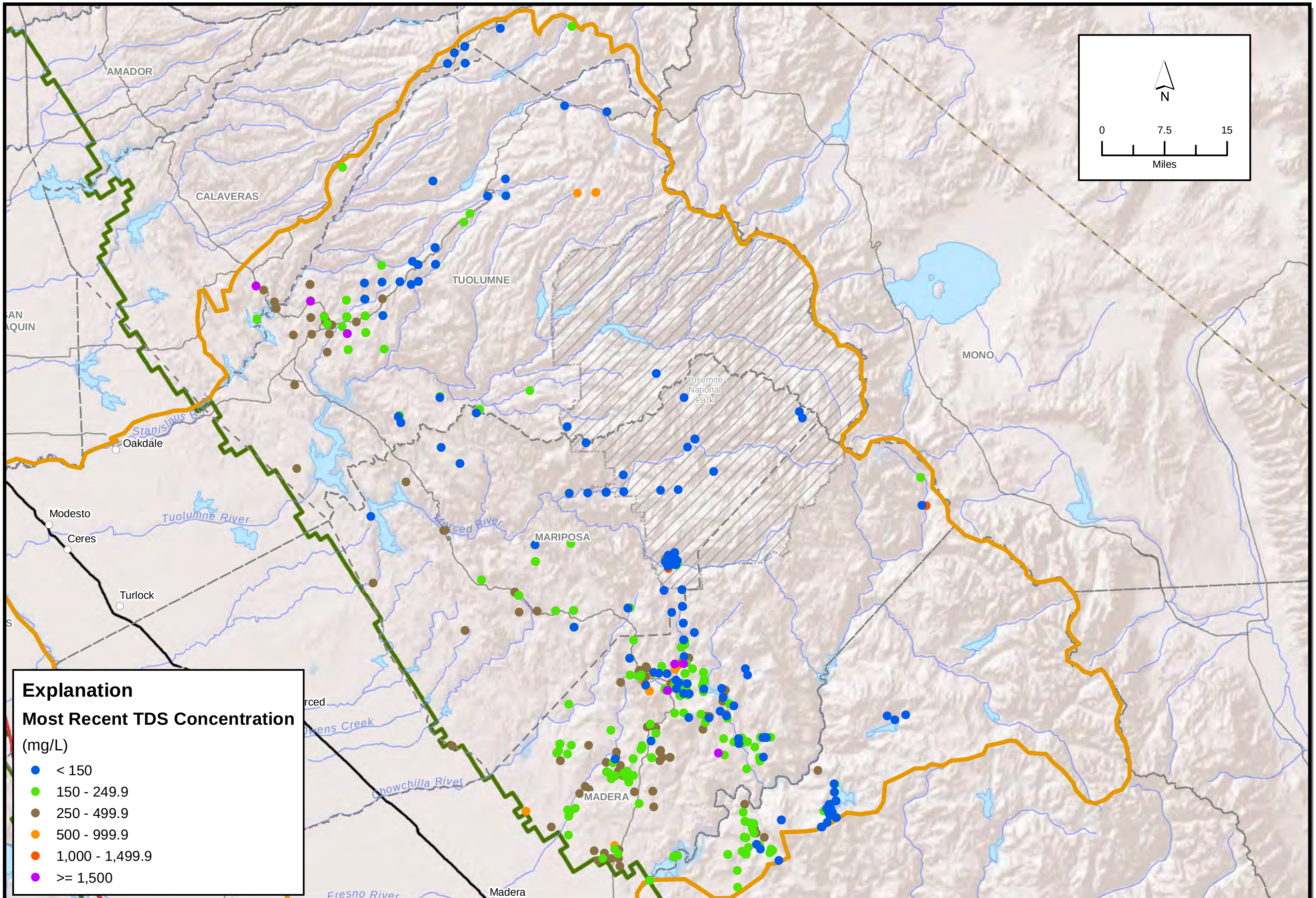

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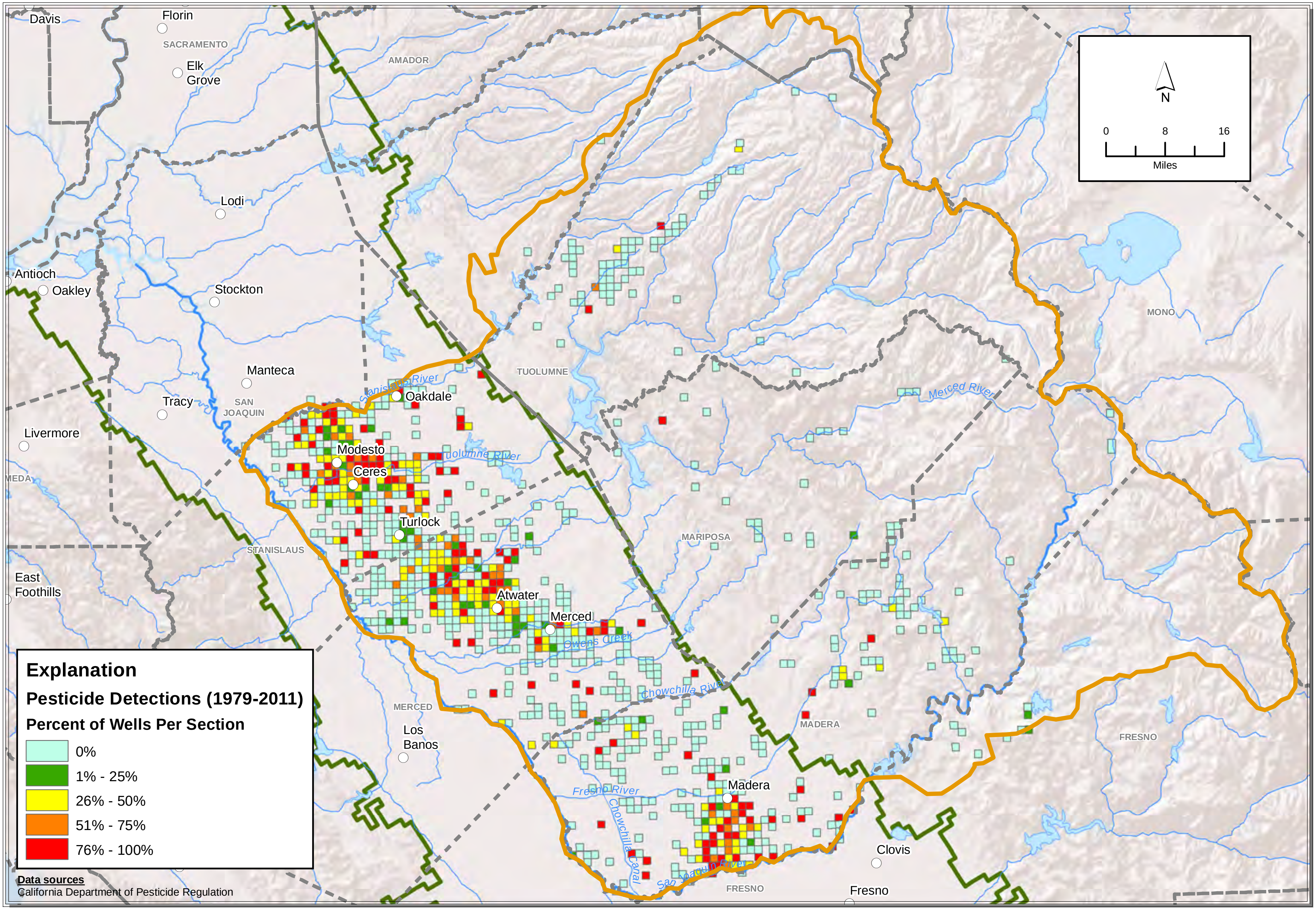
Figure 5-9
TDS Concentrations in the Peripheral Area



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 5-10a Pesticide Detections in Central Valley Floor.mxd

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Figure 5-10a

Pesticide Detections: Percent of Wells With A Pesticide Detection Per Section

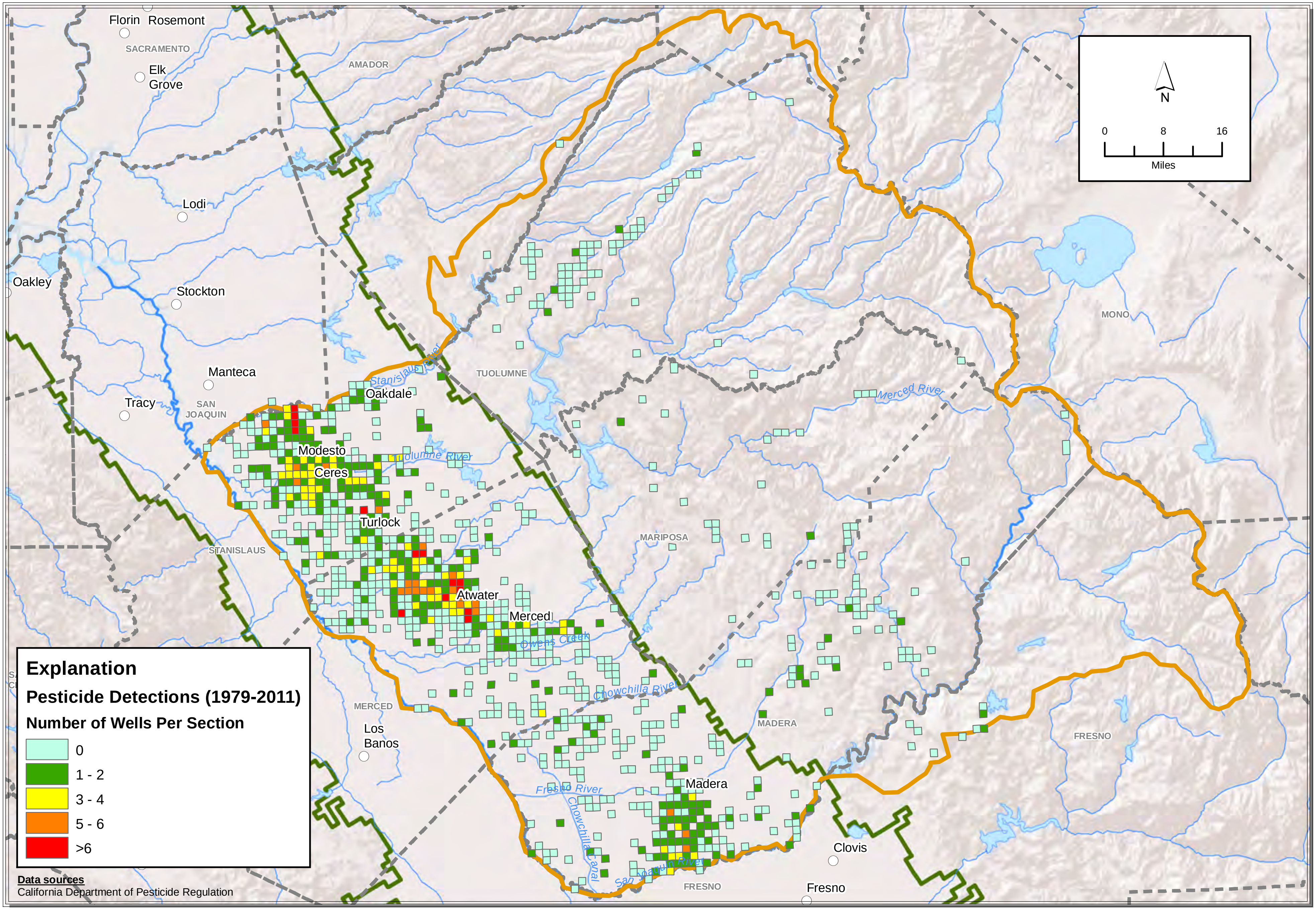

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Figure 5-10b

Pesticide Detections: Number of Wells With A Pesticide Detection Per Section

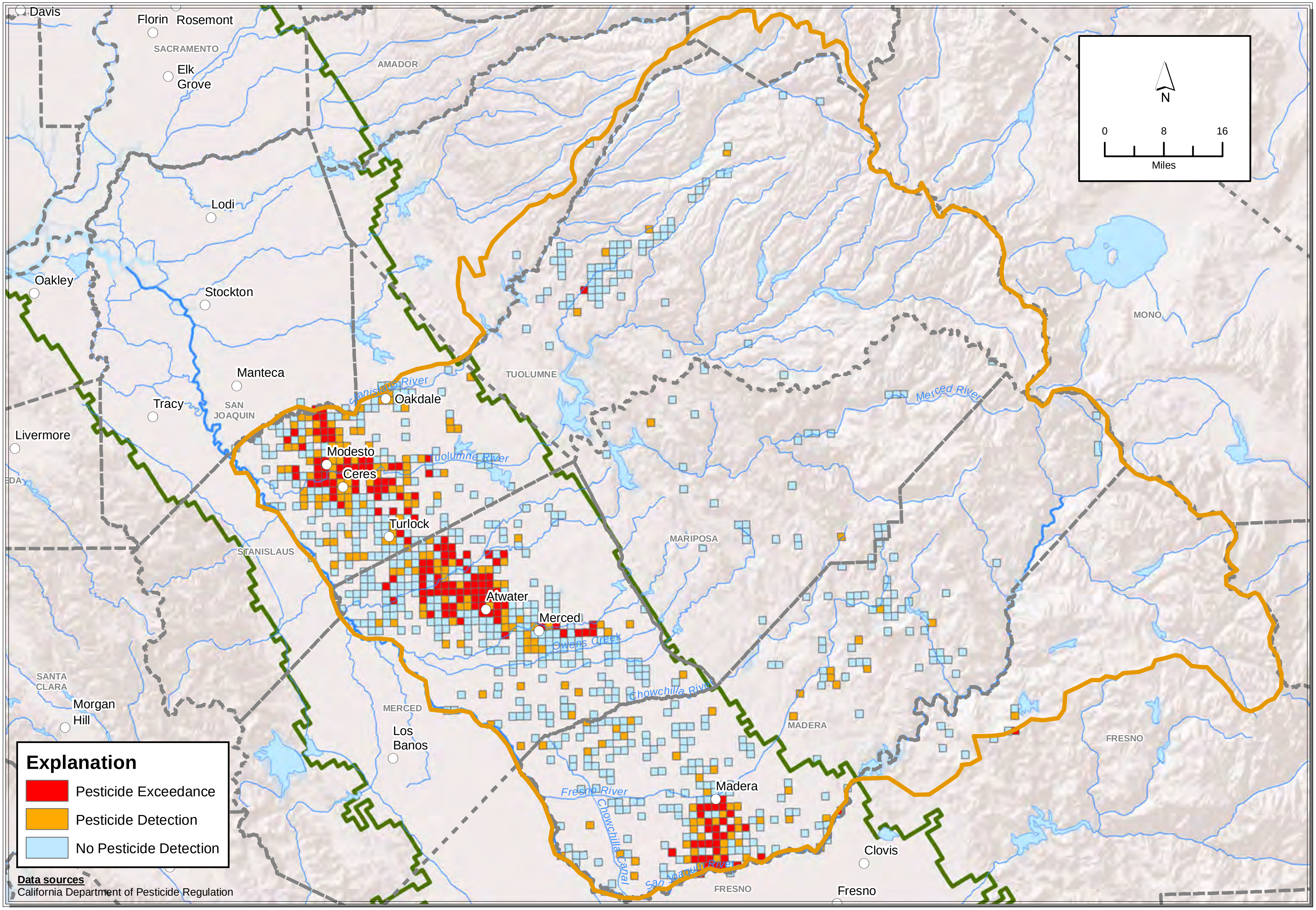

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Figure 5-10c
Pesticide Detection Or Exceedance By Section

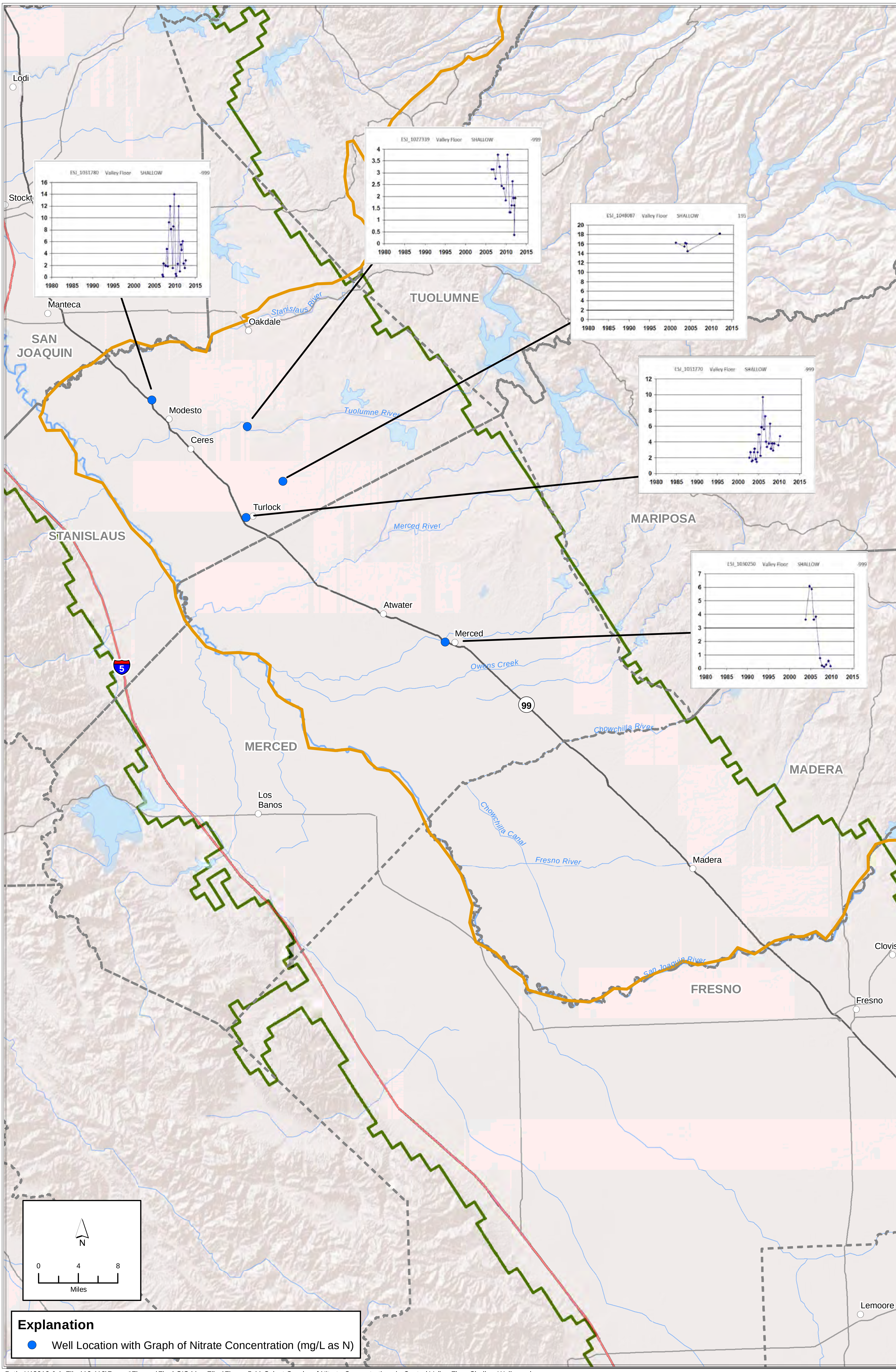

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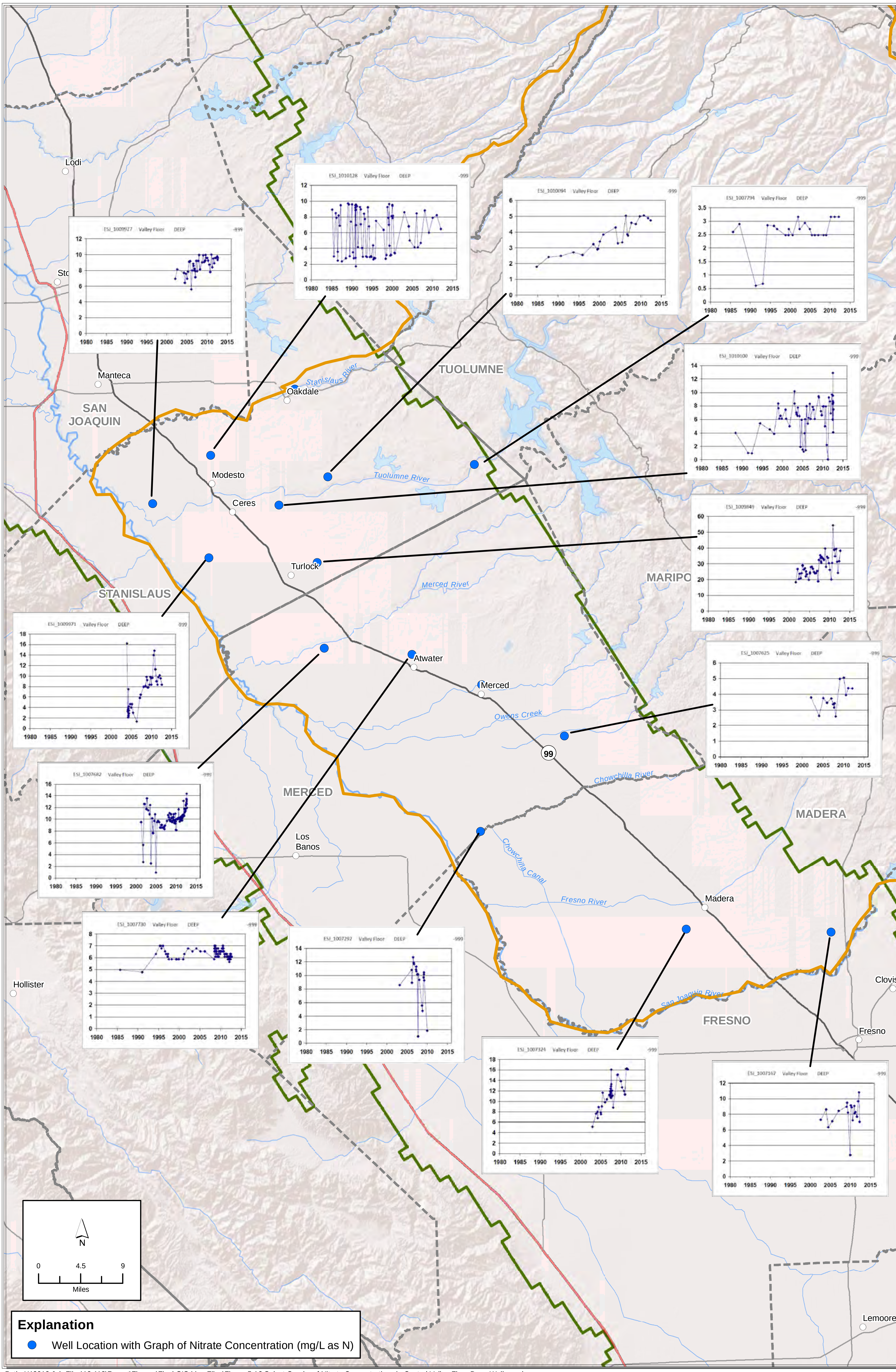
Figure 5-11
Select Graphs of Nitrate Concentrations in the Central Valley Floor: Shallow Wells



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 5-12 Select Graphs of Nitrate Concentrations in Central Valley Floor Deep Wells.mxd

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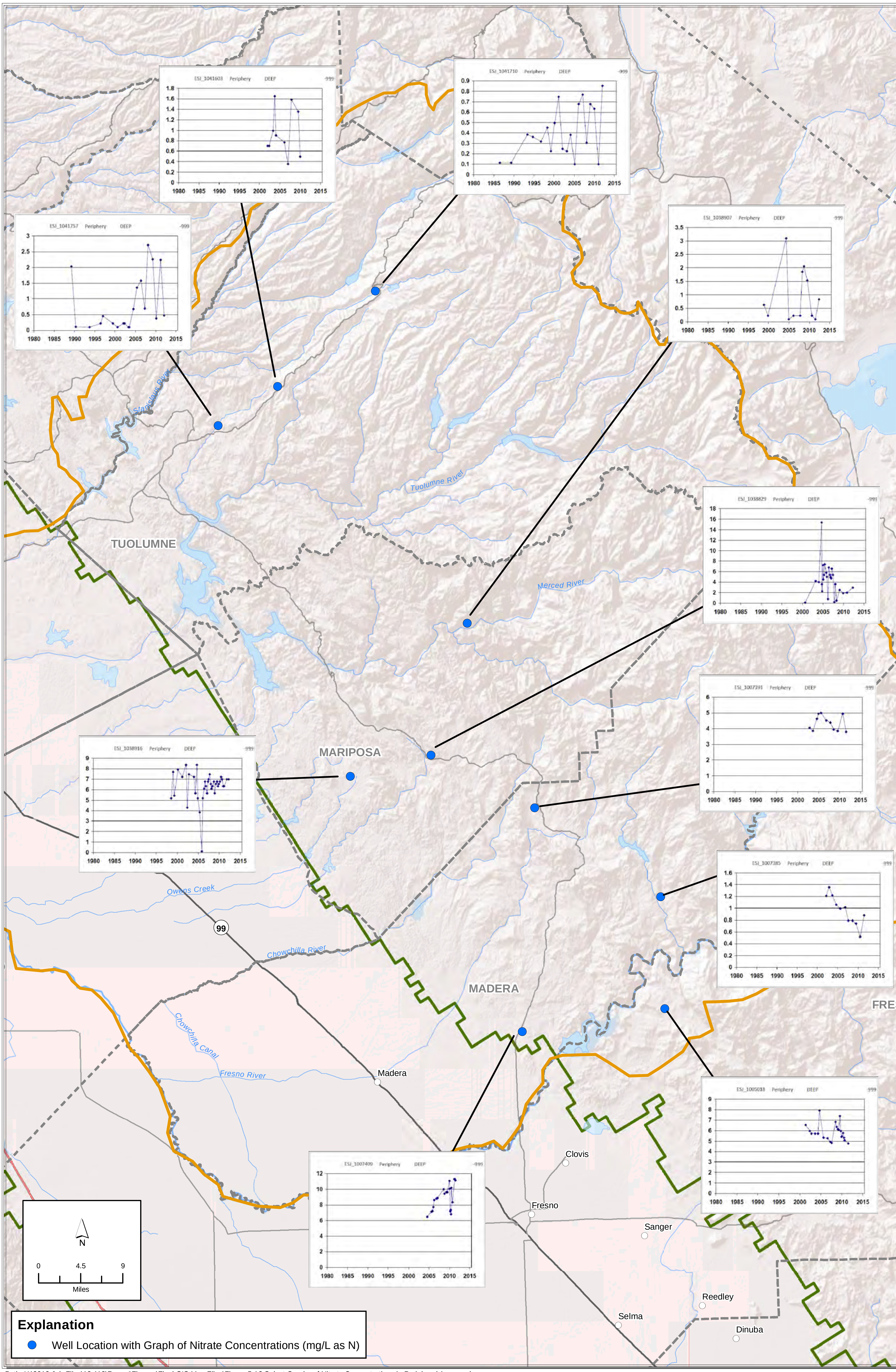
Figure 5-12
Select Graphs of Nitrate Concentrations in the Central Valley Floor: Deep Wells



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 5-13 Select Graphs of Nitrate Concentrations in Peripheral Area.mxd

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Figure 5-13
Select Graphs of Nitrate Concentrations in the Peripheral Area: Wells of All Depths

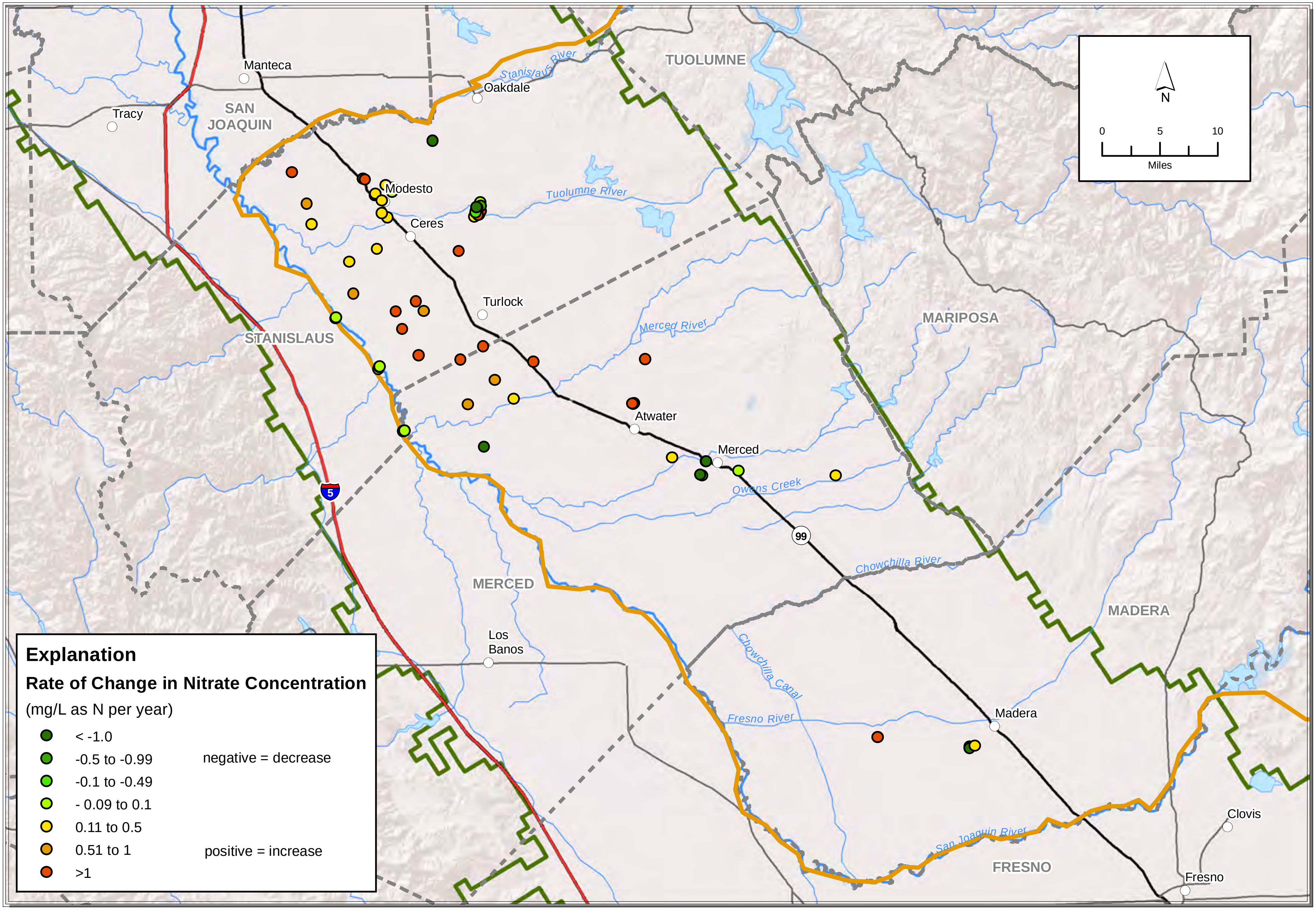

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Figure 5-14
Significant Temporal Trends in Nitrate Concentrations in Central Valley Floor: Shallow Wells

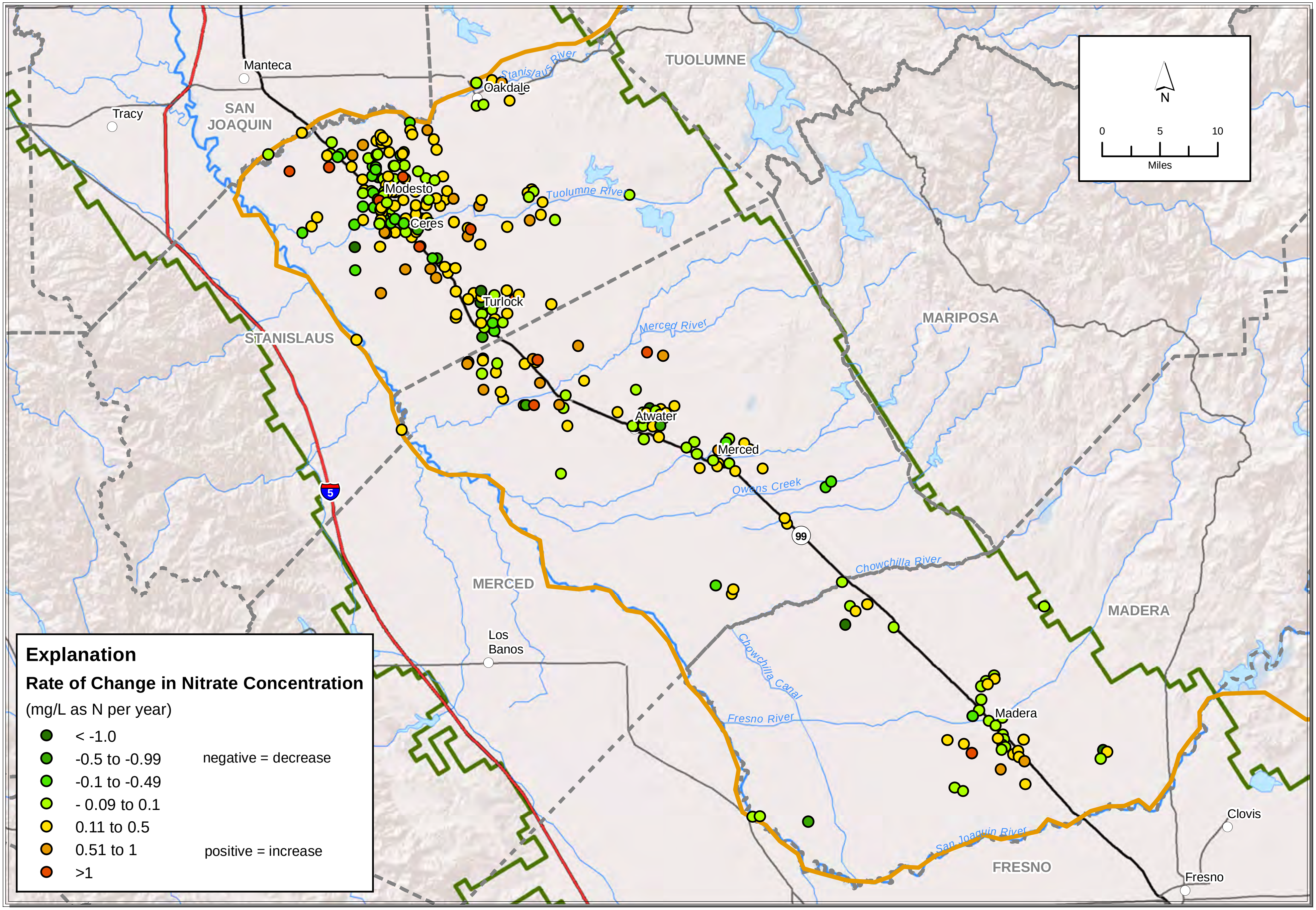

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Figure 5-15
Significant Temporal Trends in Nitrate Concentrations in the Central Valley Floor: Deep Wells

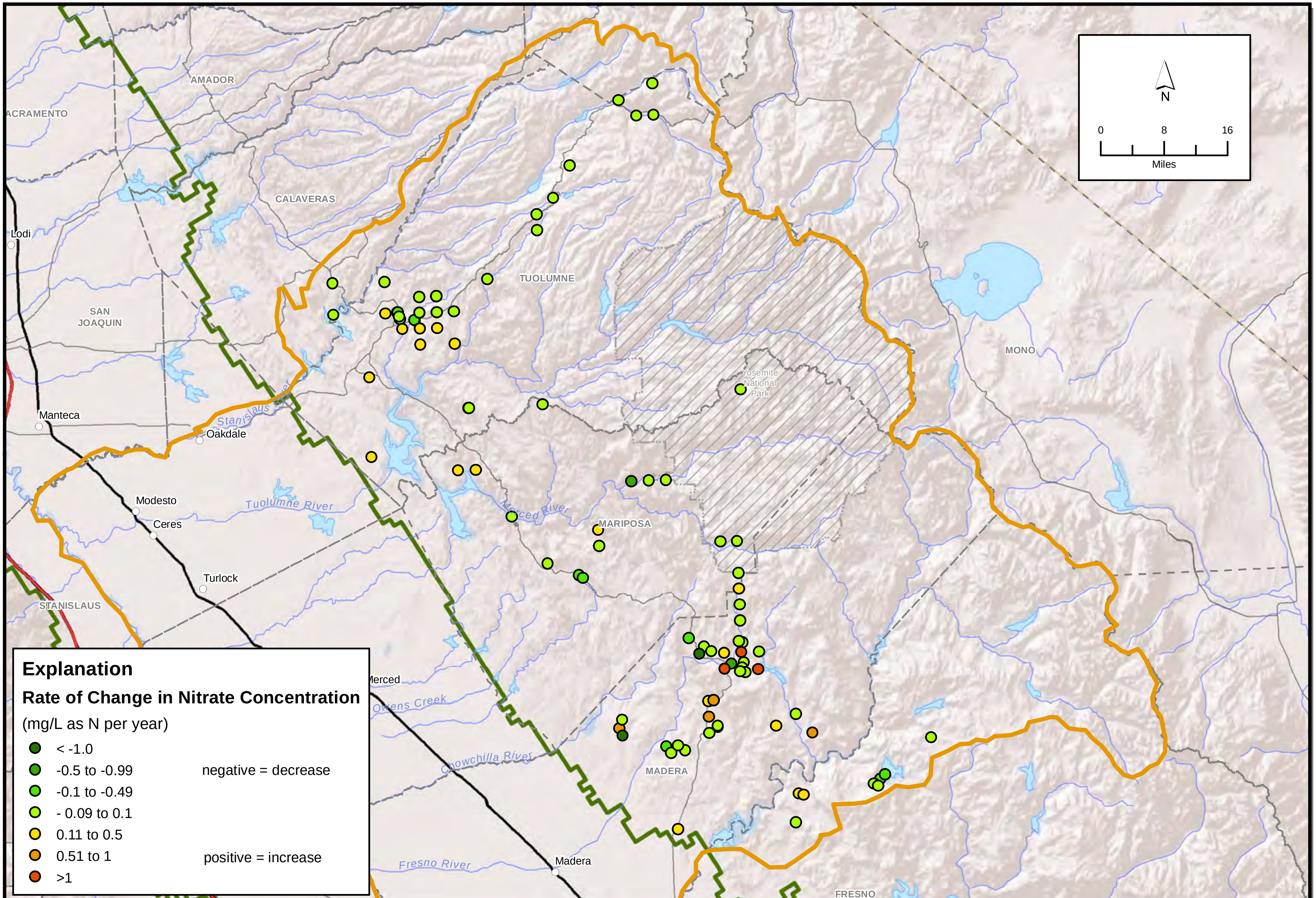

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Figure 5-16
Significant Temporal Trends in Nitrate Concentrations in the Peripheral Area: All Wells

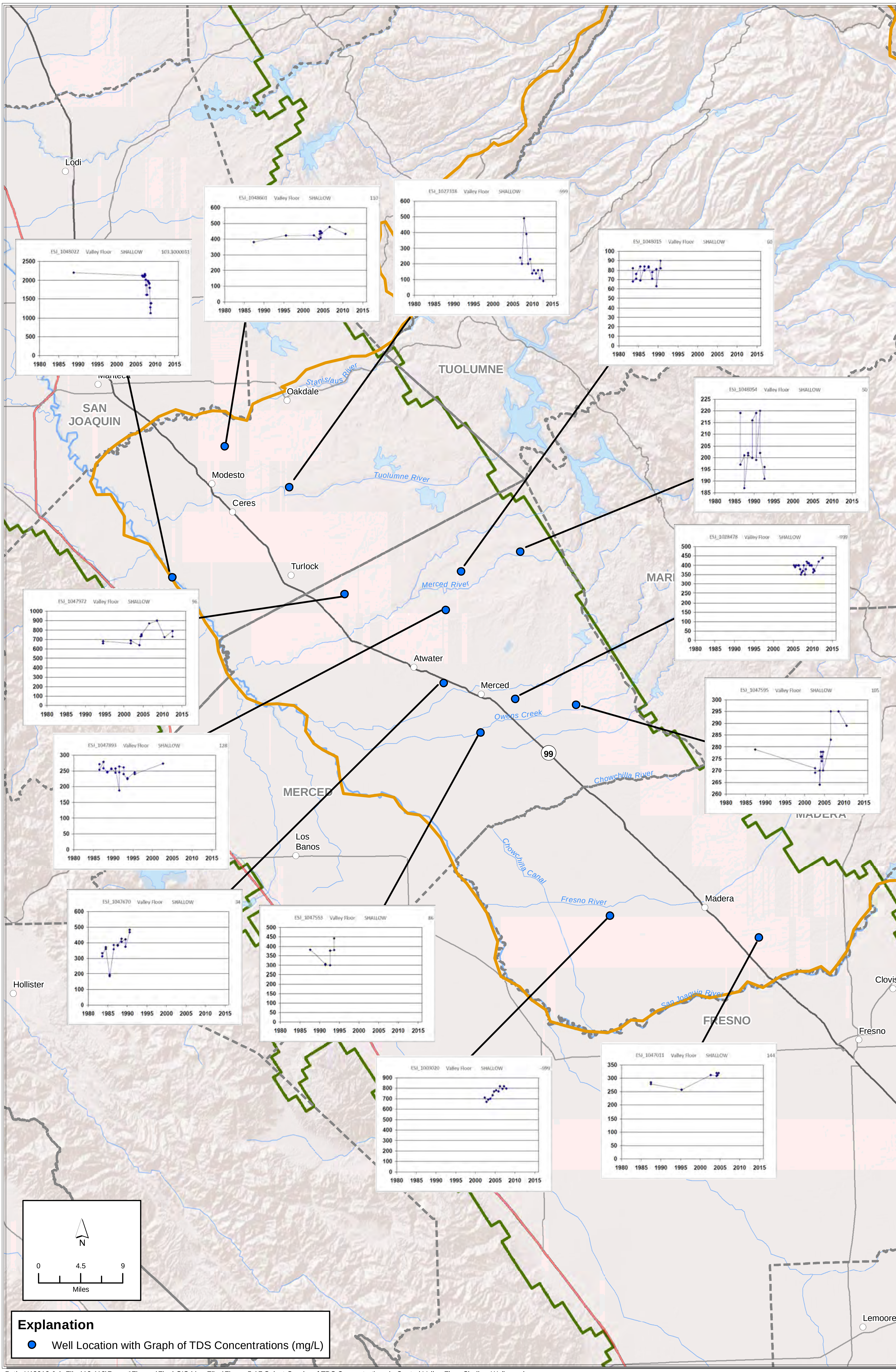

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Figure 5-17
Select Graphs of TDS Concentrations in the Central Valley Floor: Shallow Wells

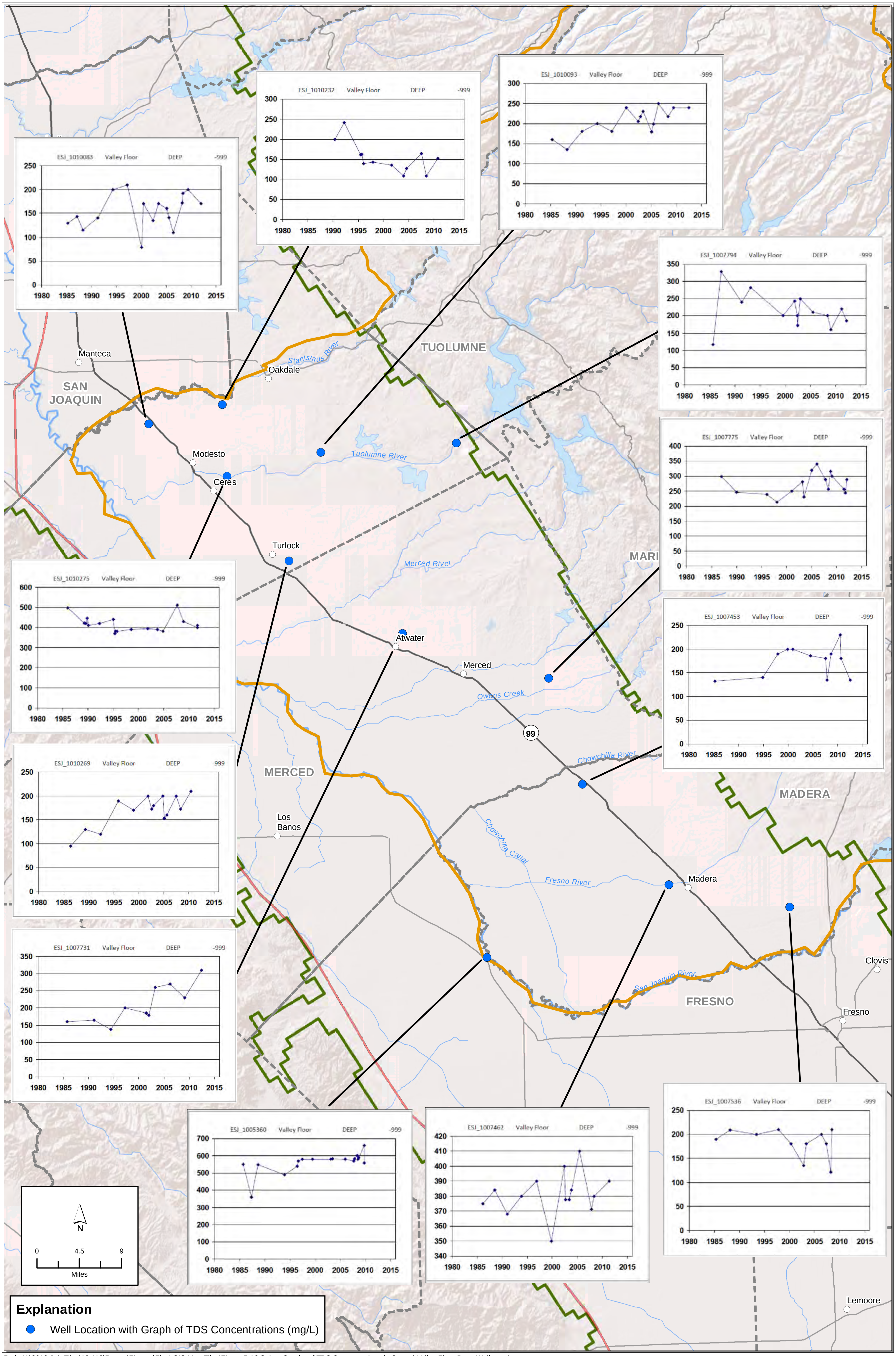

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Figure 5-18
Select Graphs of TDS Concentrations in the Central Valley Floor: Deep Wells

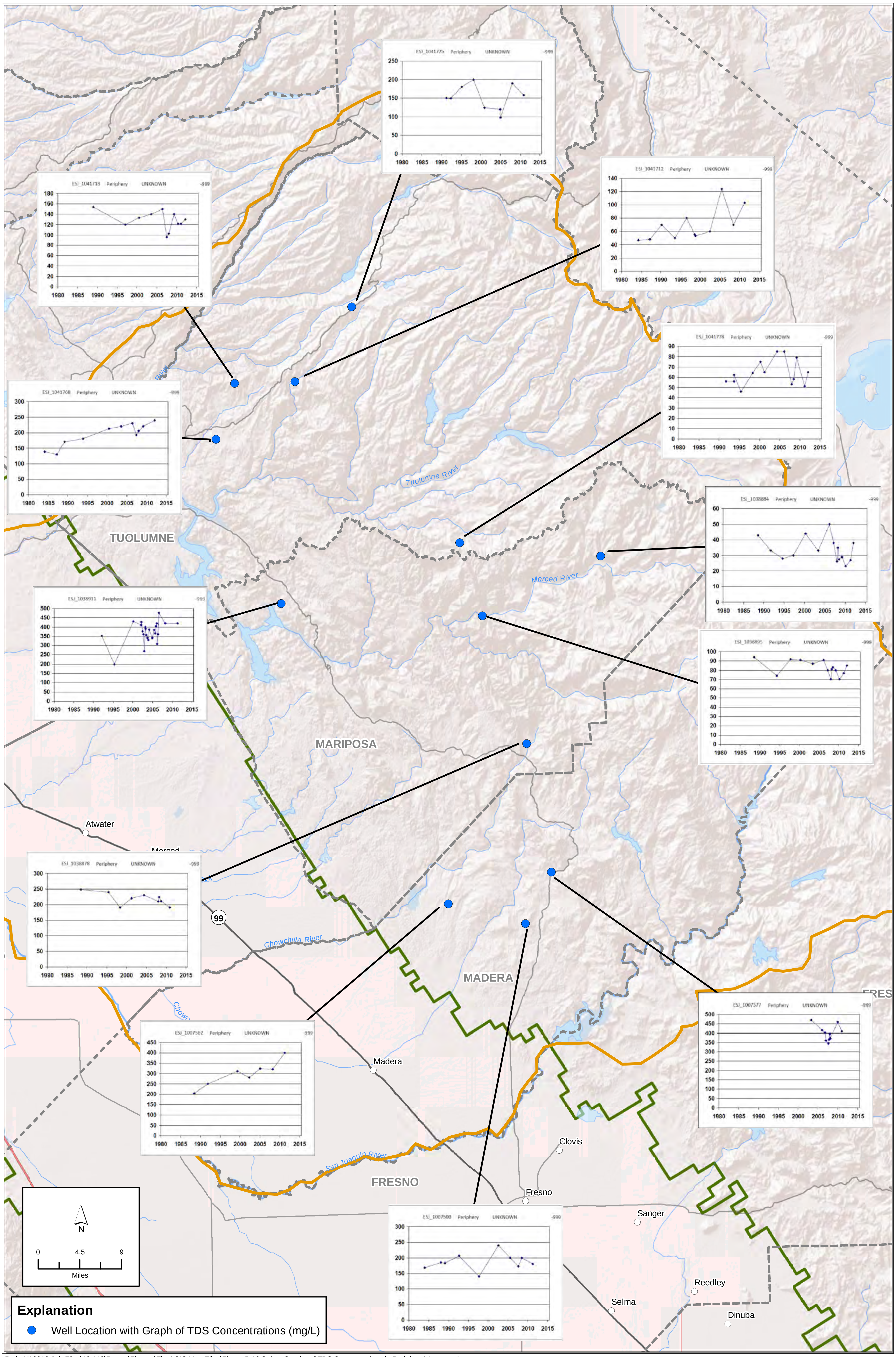

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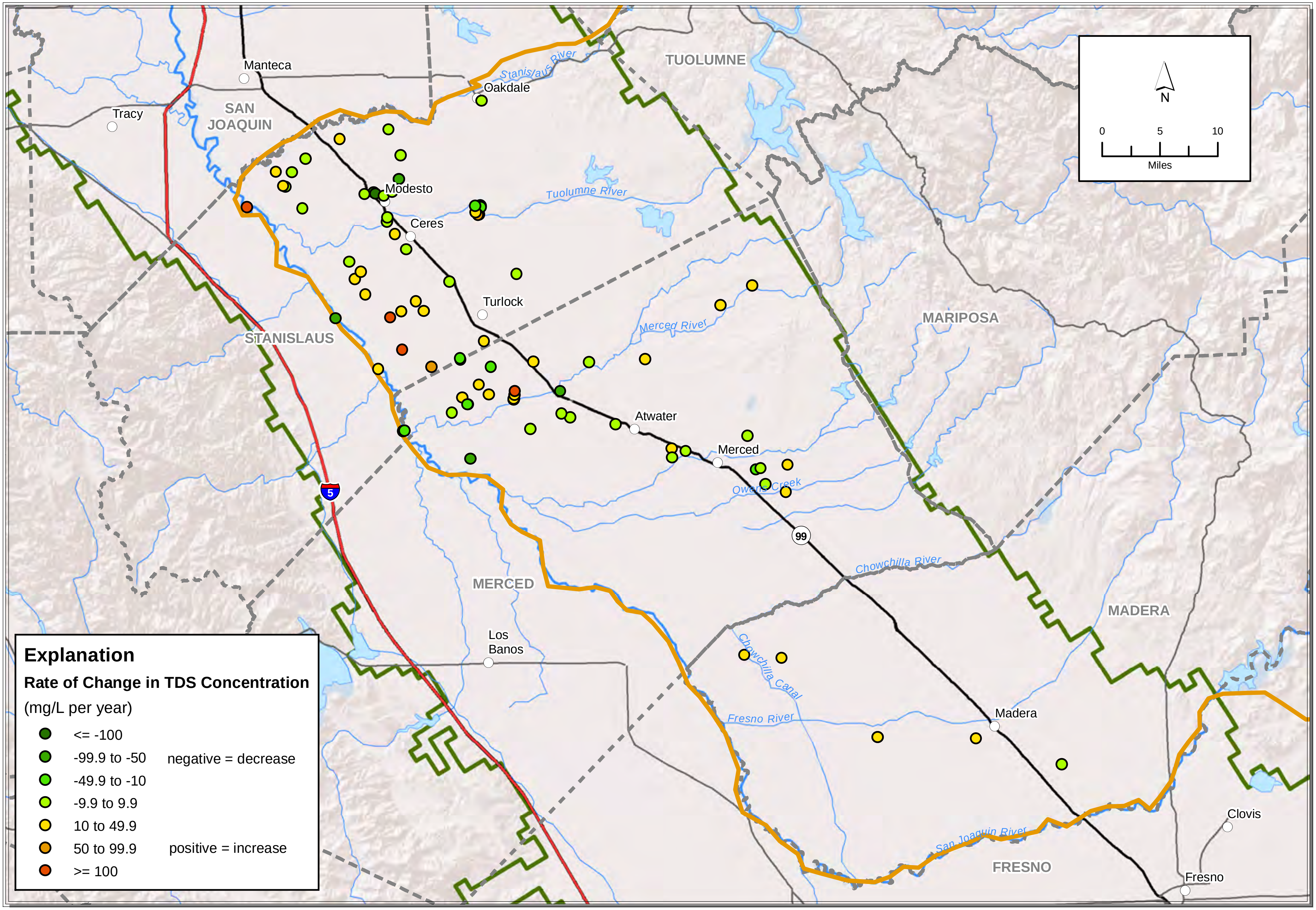
Figure 5-19
Select Graphs of TDS Concentrations in the Peripheral Area: Wells of All Depths



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 5-20 Significant Temporal Trends in TDS Concentrations in the Central Valley Floor Shallow Wells.mxd

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Figure 5-20
Significant Temporal Trends in TDS Concentrations in the Central Valley Floor: Shallow Wells

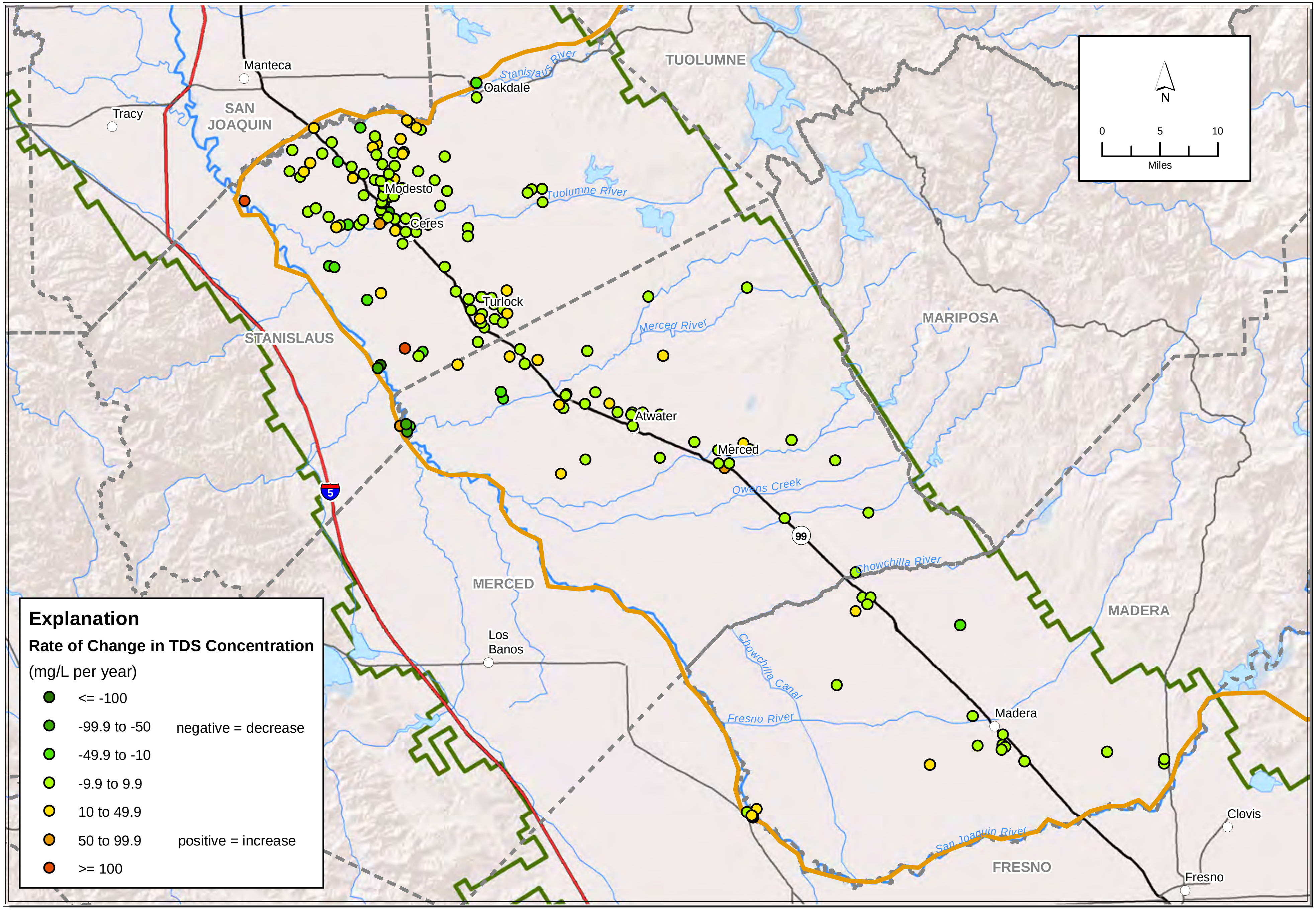

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Figure 5-21
Significant Temporal Trends in TDS Concentrations in the Central Valley Floor: Deep Wells

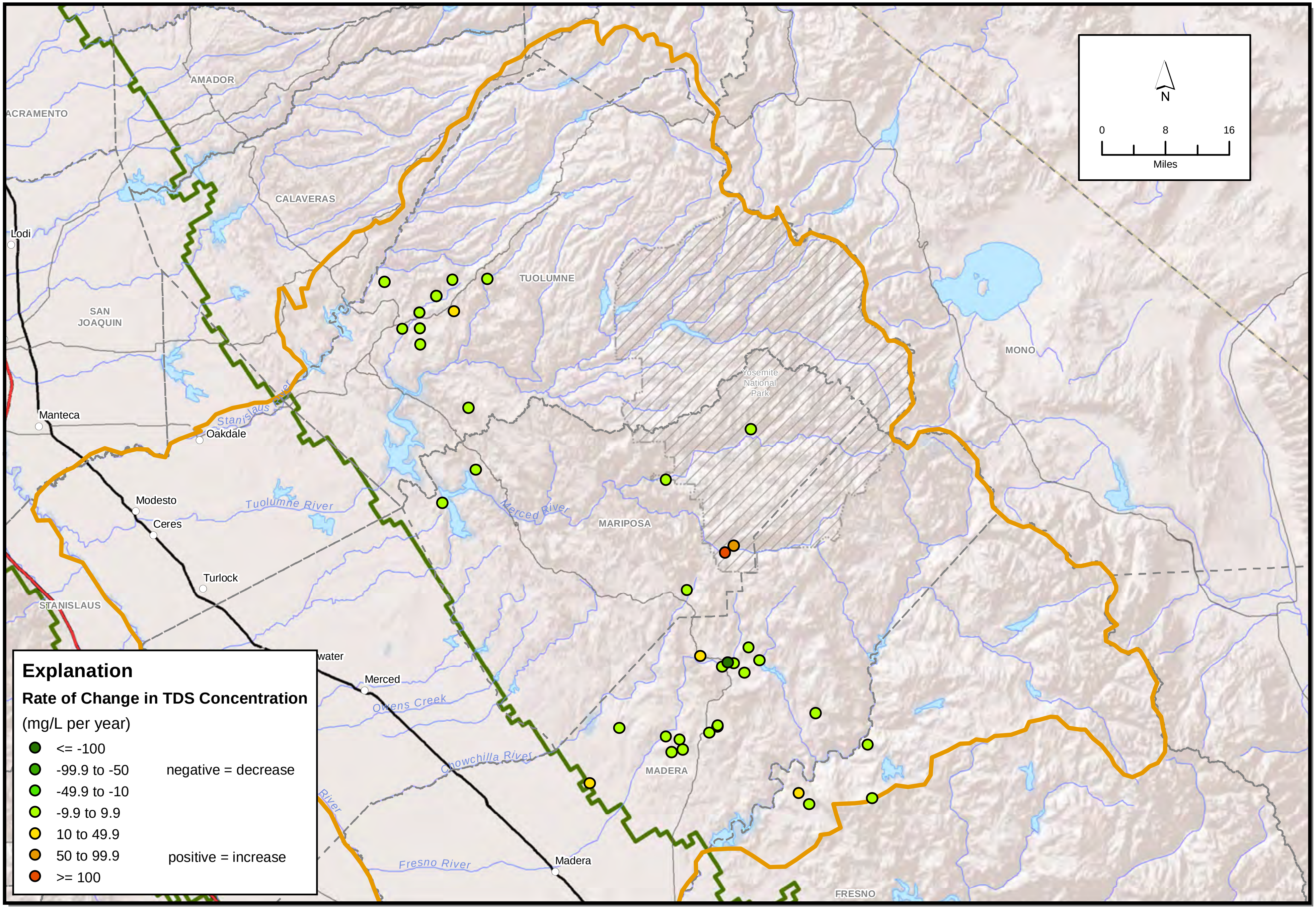

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Figure 5-22
Significant Temporal Trends in TDS Concentrations in the Peripheral Area: Wells of All Depths

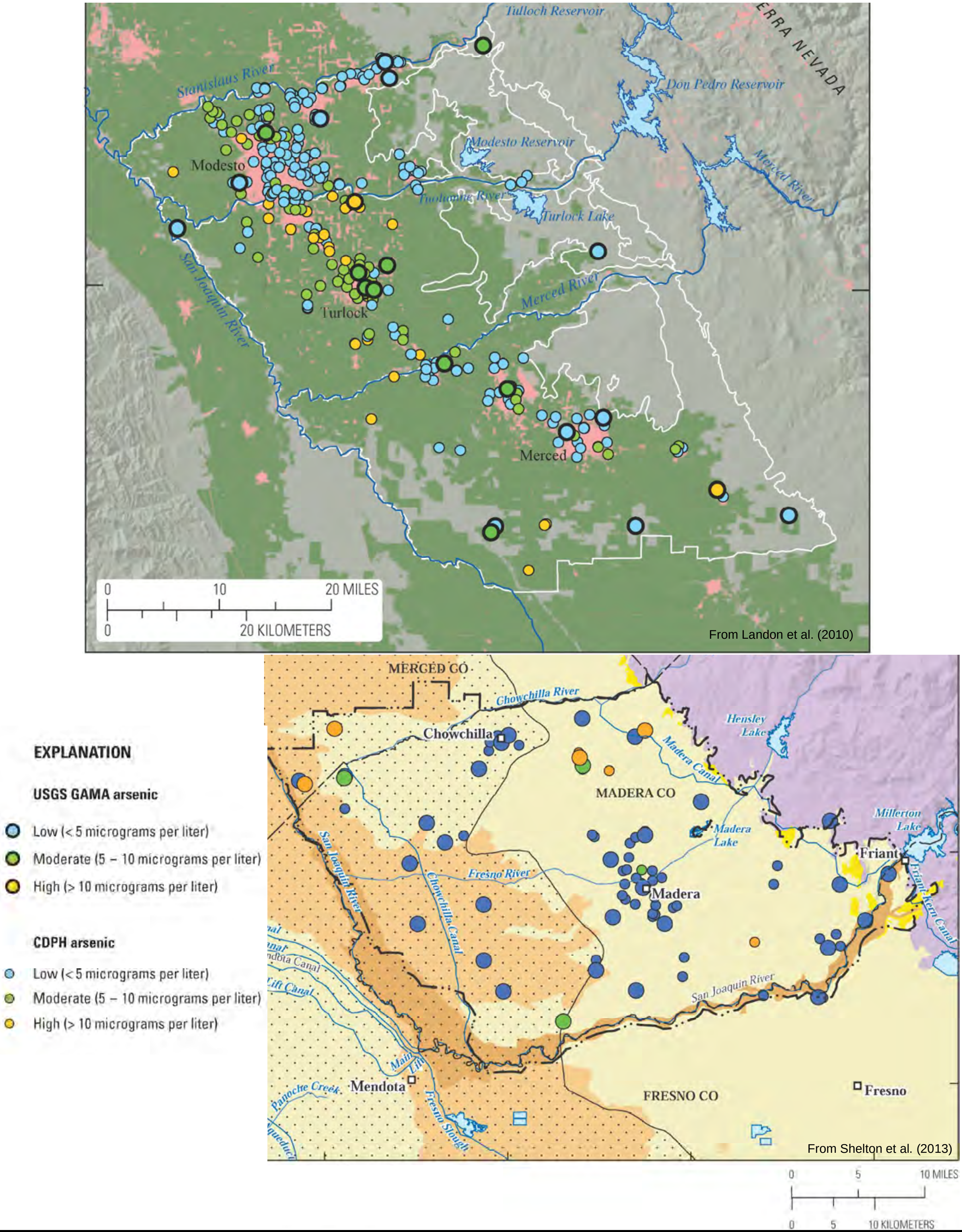

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Figure 5-23a
Other Groundwater Quality Data: Arsenic

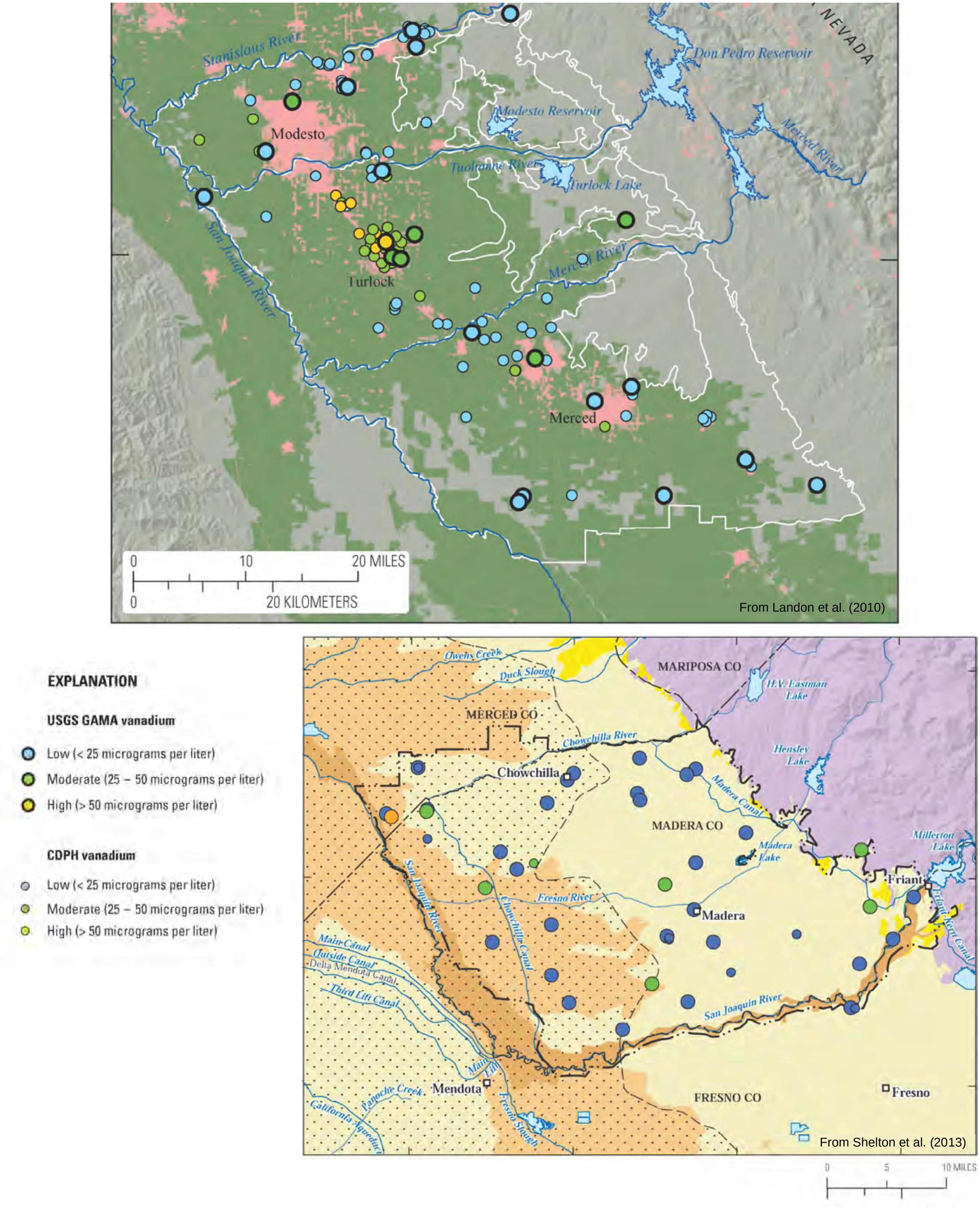

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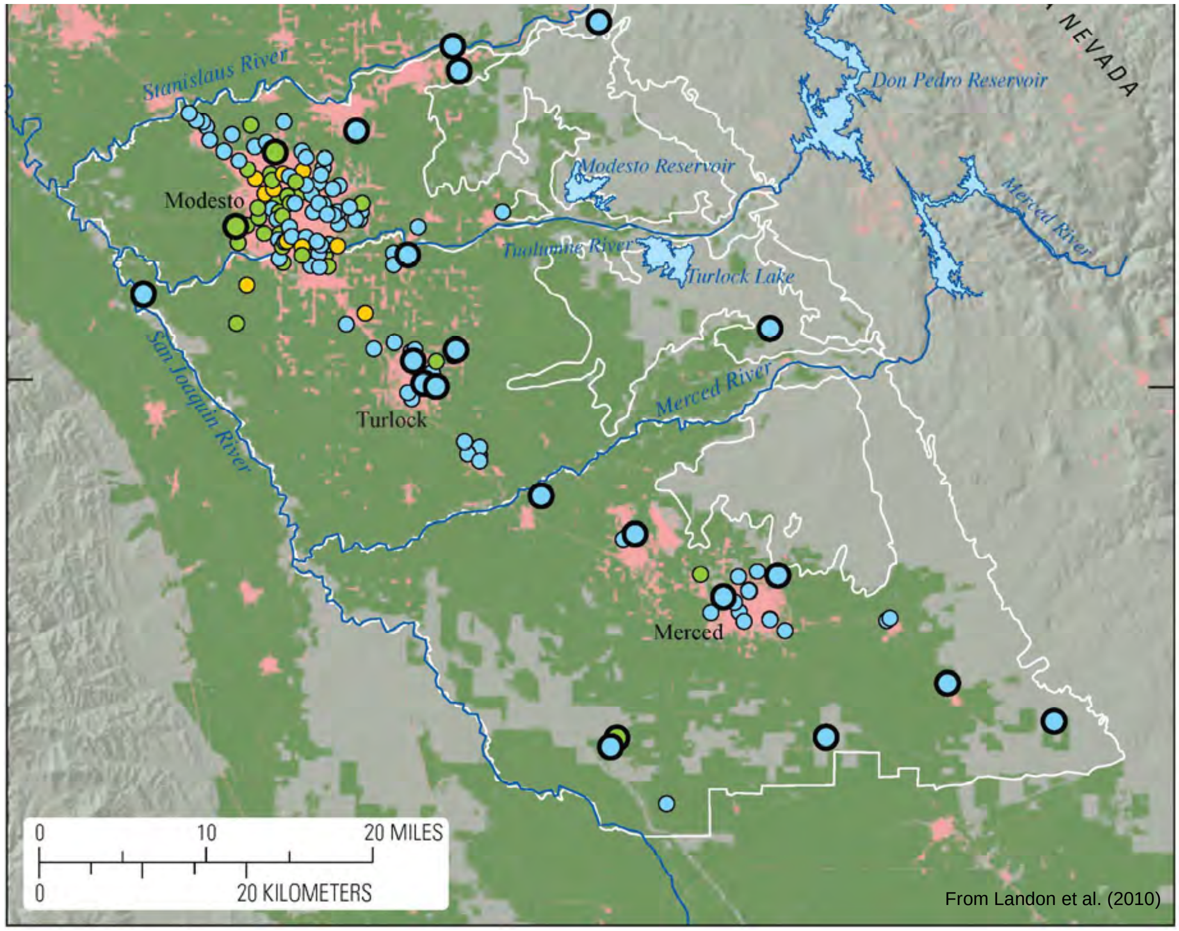
Figure 5-23b
Other Groundwater Quality Data: Vanadium



EXPLANATION

USGS GAMA uranium

- Low (< 15 micrograms per liter)
- Moderate (15 – 30 micrograms per liter)
- High (> 30 micrograms per liter)

CDPH uranium

- Low (< 15 micrograms per liter)
- Moderate (15 – 30 micrograms per liter)
- High (> 30 micrograms per liter)

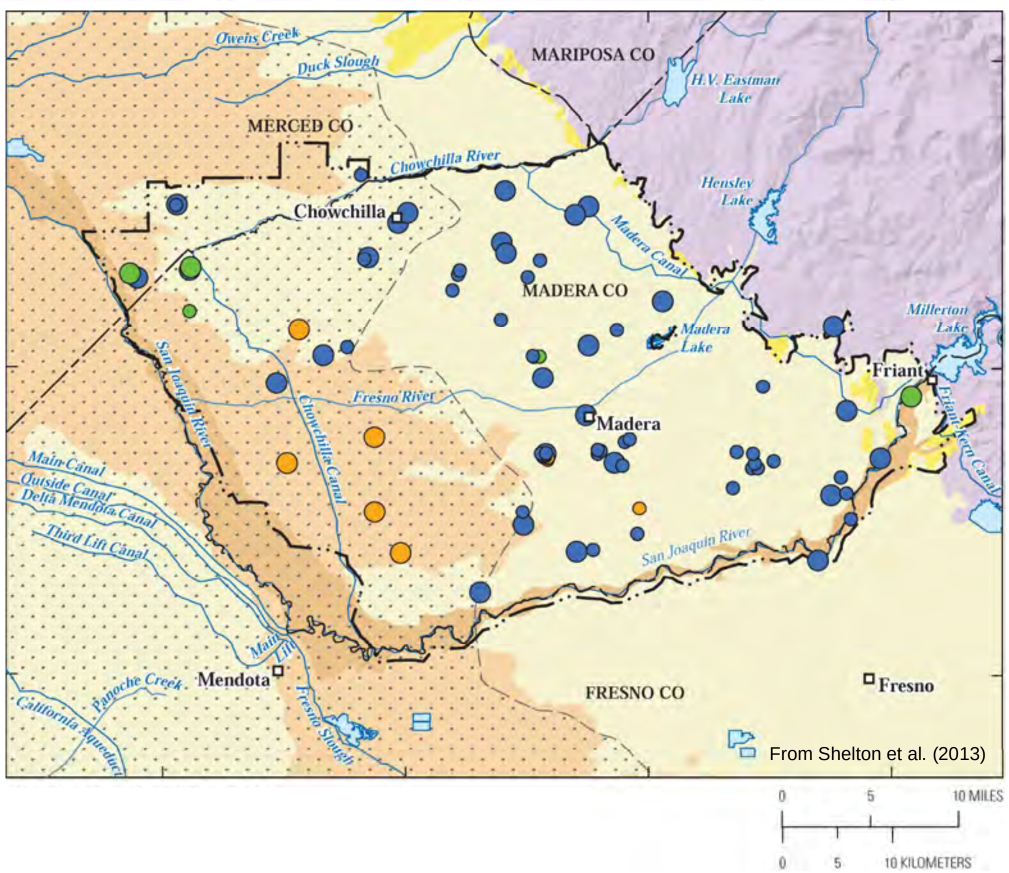


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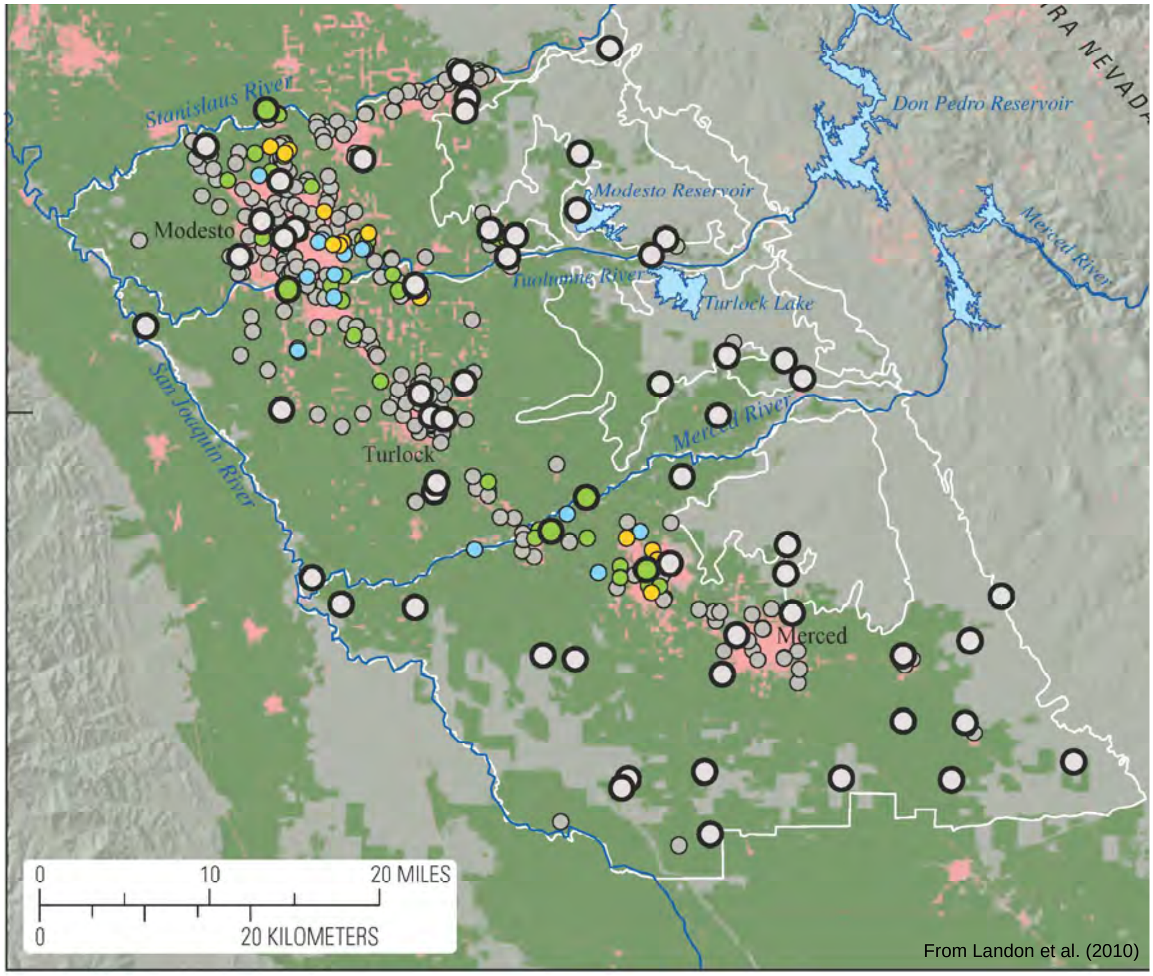
Figure 5-23c
Other Groundwater Quality Data: Uranium



EXPLANATION

USGS GAMA DBCP

- Not detected (< 0.03 micrograms per liter)
- Moderate (0.03 – 0.20 micrograms per liter)

CDPH DBCP

- Low or not detected (< 0.01 micro-grams per liter)
- Low (0.01 - 0.02 micrograms per liter)
- Moderate (0.03 – 0.20 micro-grams per liter)
- High (> 0.20 micrograms per liter)

Fumigants
Maximum relative-concentration (RC) by well

RC category*	Wells USGS GAMA	Wells CDPH (data in 3-year period 2/12/2005–2/12/2008)
Not detected	○	○
Low	○	○
Moderate		○
High	○	

Fumigants include:
1,2-dibromo-3-chloropropane (DBCP)
1,2-dibromoethane (EDB)
1,2,3-trichloropropane (1,2,3-TCP)
1,2-dichloropropane (1,2-DCP)

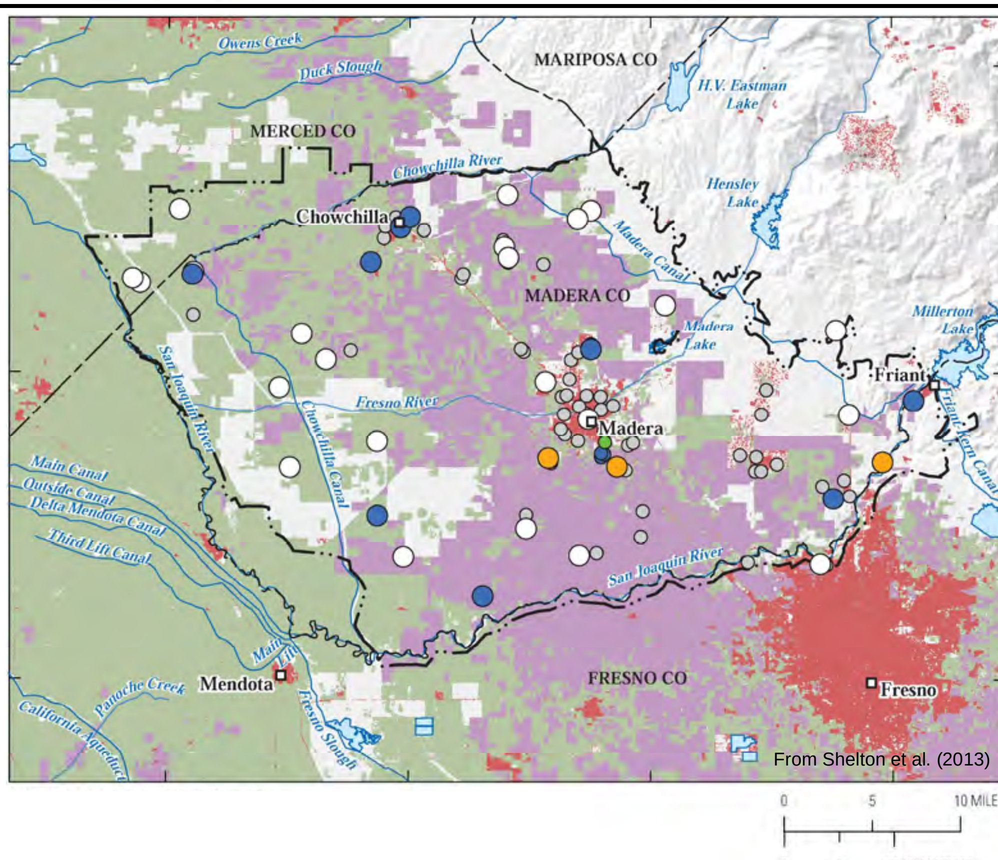
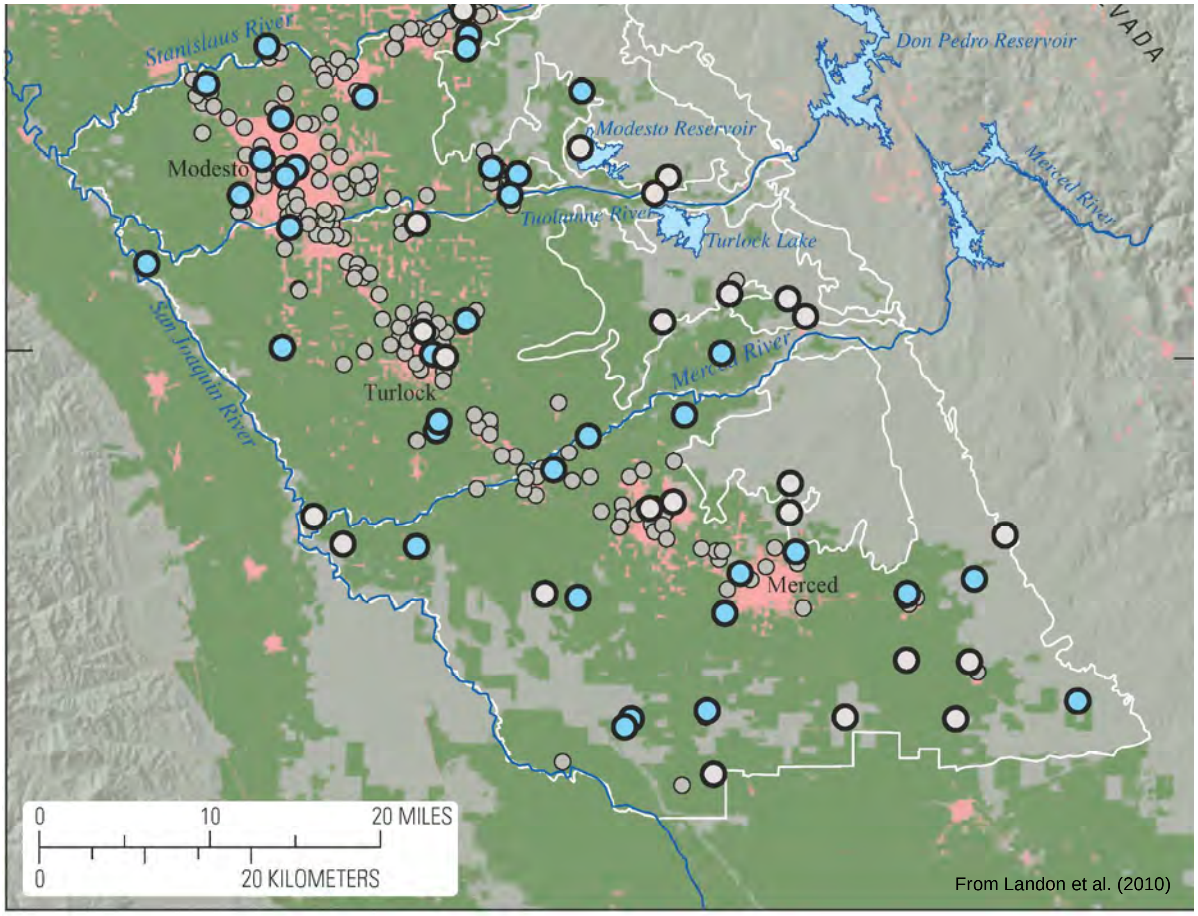
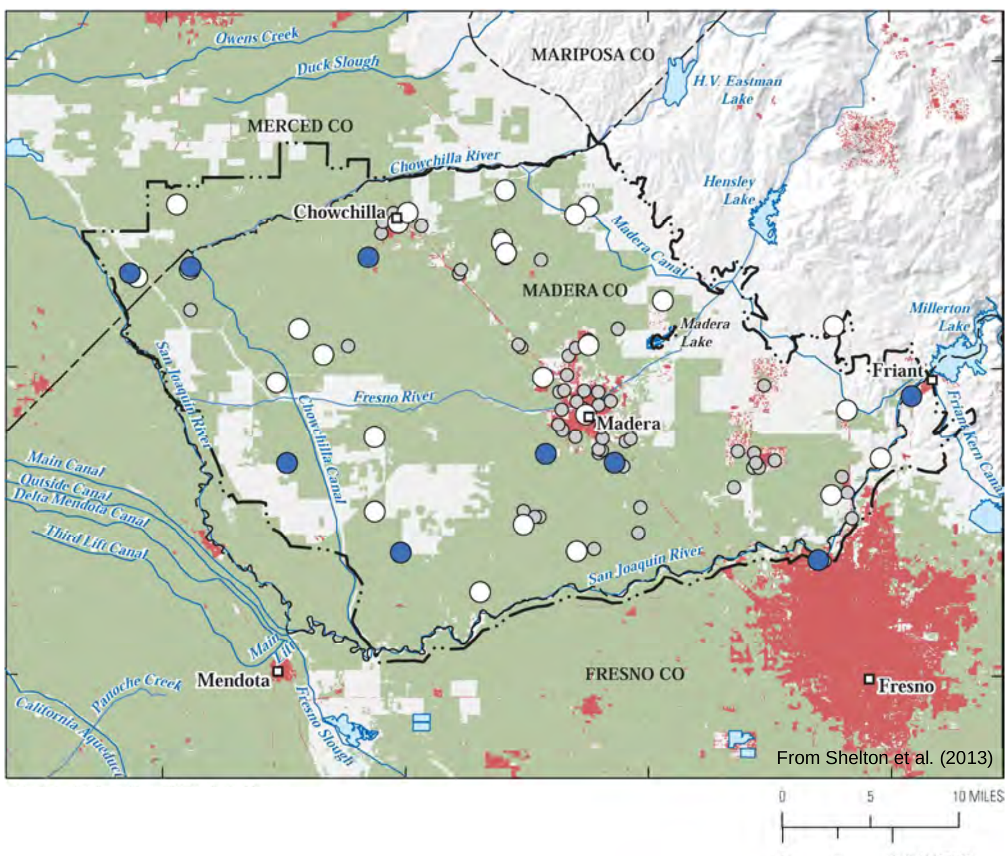


Figure 5-23d
Other Groundwater Quality Data: DBCP/Fumigants





EXPLANATION

USGS GAMA herbicides

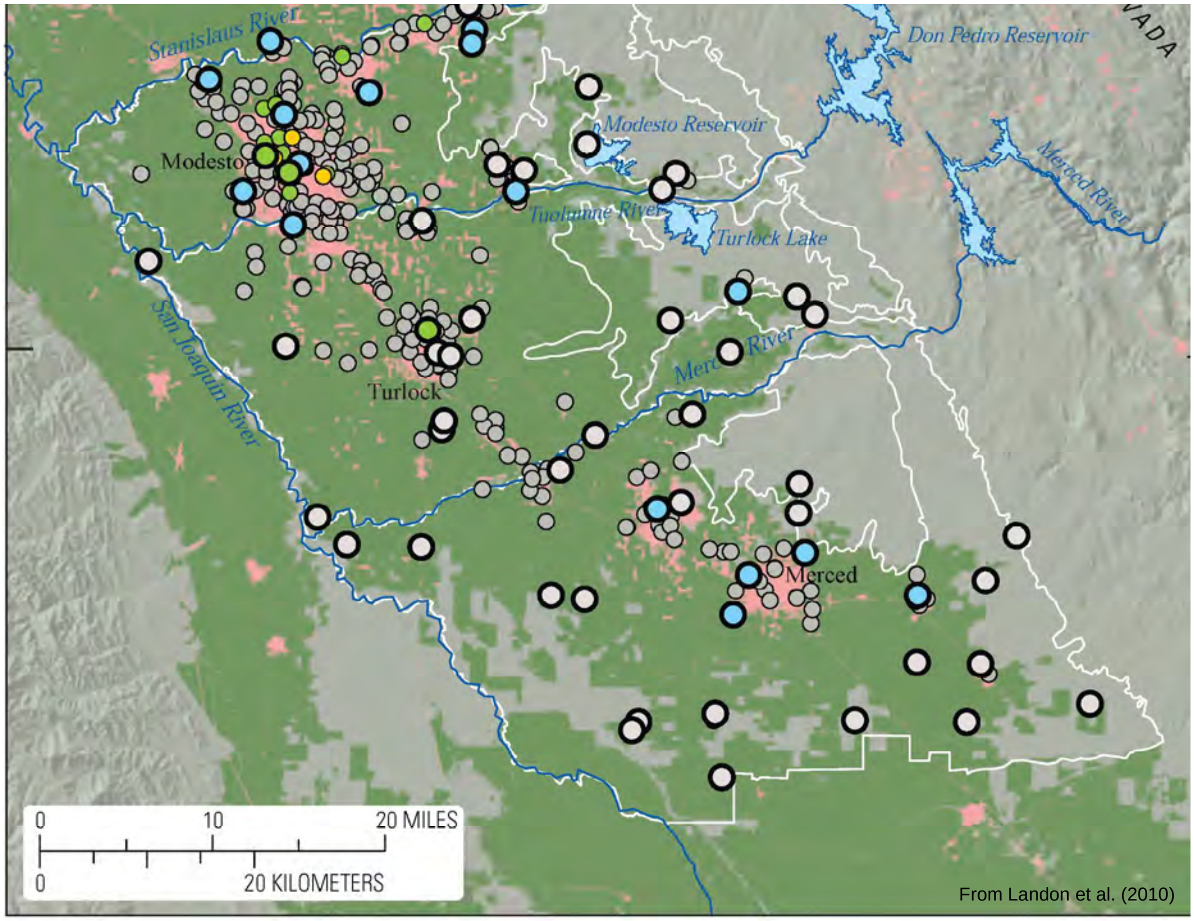
- Not detected
- Low (< 0.01 – 0.10 micrograms per liter)

CDPH herbicides

- Not high (< 0.1 micrograms per liter)

Figure 5-23e

Other Groundwater Quality Data: Herbicides



USGS GAMA solvents

- Not detected
- Low (< 0.1)
- Moderate (> 0.1 – 1.0)

CDPH solvents

- Low or not detected (< 0.1)
- Moderate (0.1 – 1.0)
- High (> 1.0)

Solvents include:
tetrachloroethylene (PCE)
carbon tetrachloride
trichloroethylene (TCE)
dichloromethane
dibromomethane
cis-1,2-dichloroethene
n-propylbenzene

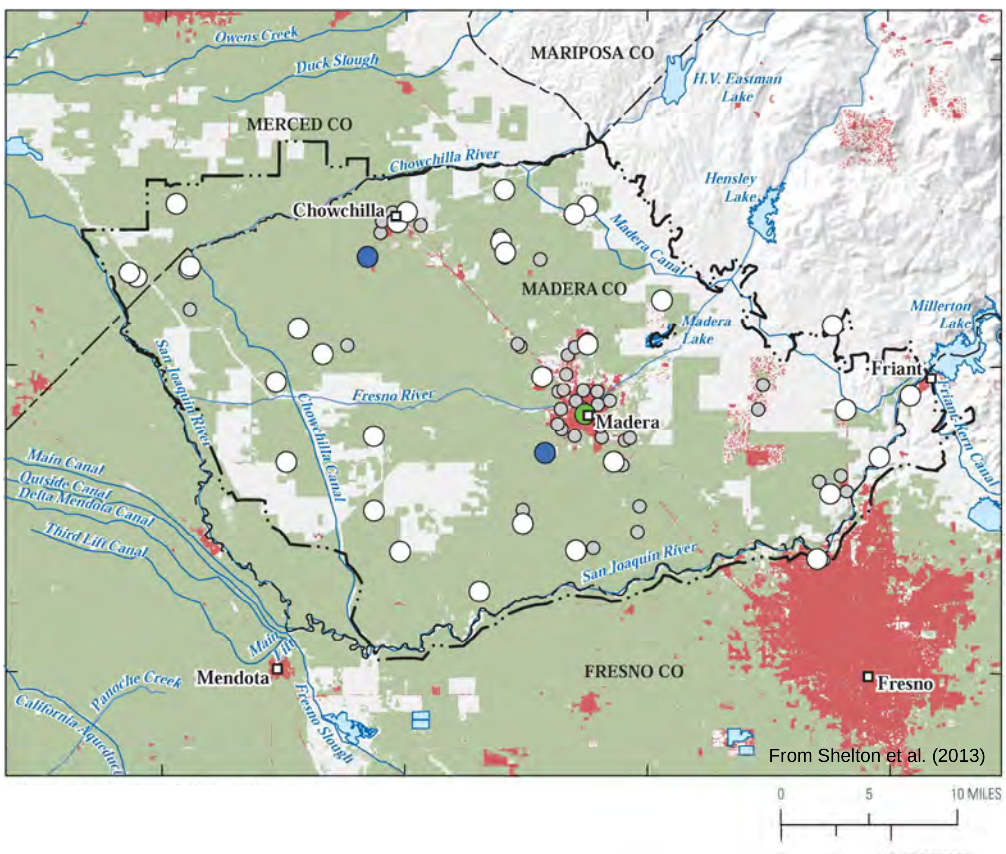


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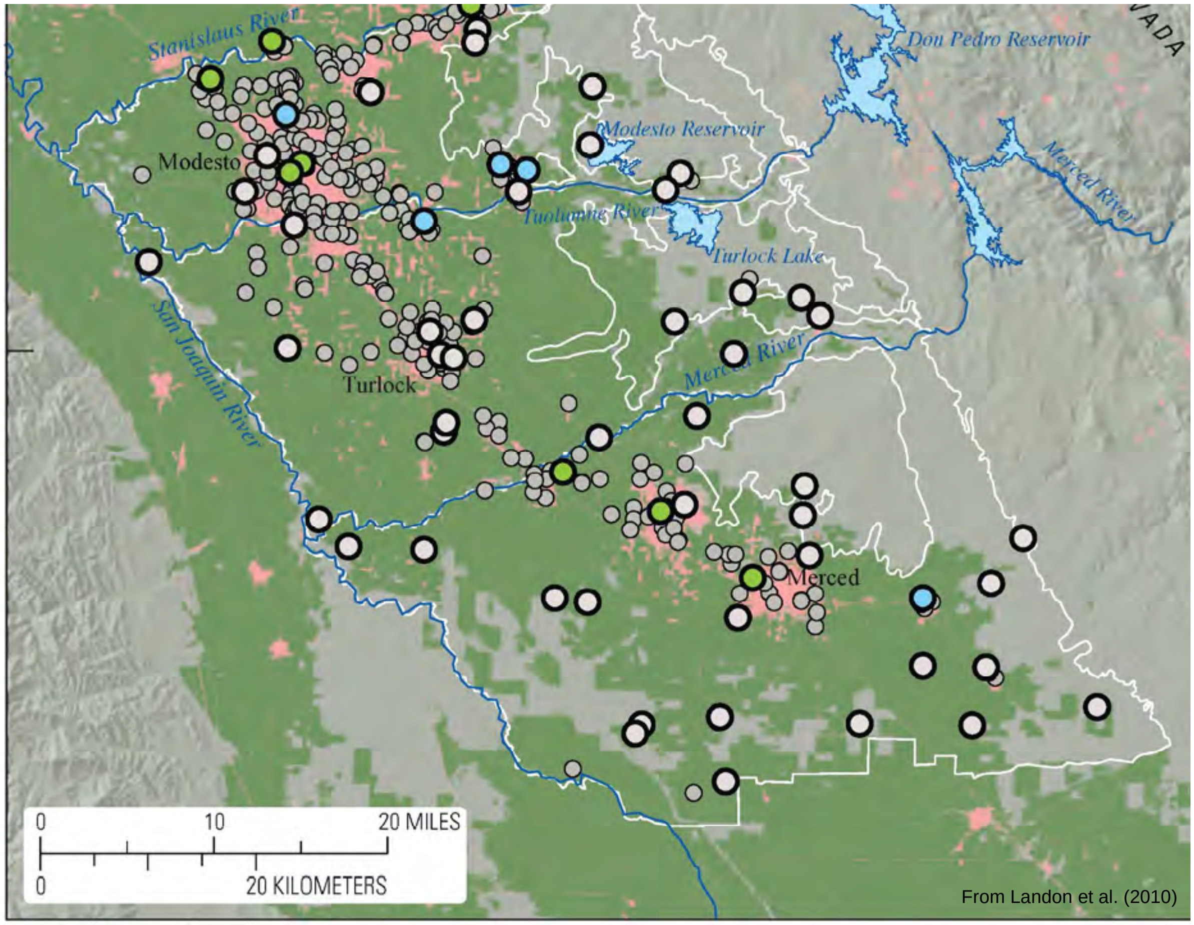
Figure 5-23f
Other Groundwater Quality Data: Solvents



EXPLANATION

USGS GAMA perchlorate

- Not detected (< 0.5 micrograms per liter)
- Low (0.5 – 0.6 micrograms per liter)
- Moderate (0.6 – 1.5 micrograms per liter)

CDPH perchlorate

- Not detected (< 4.0 micrograms per liter)

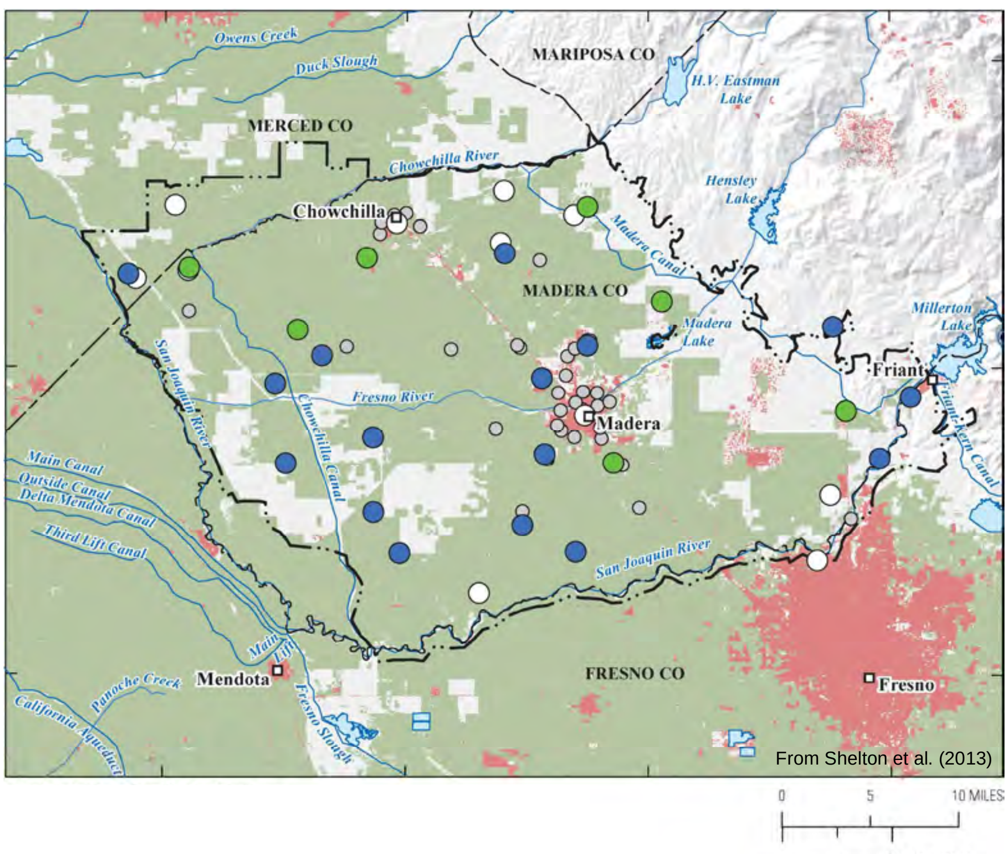


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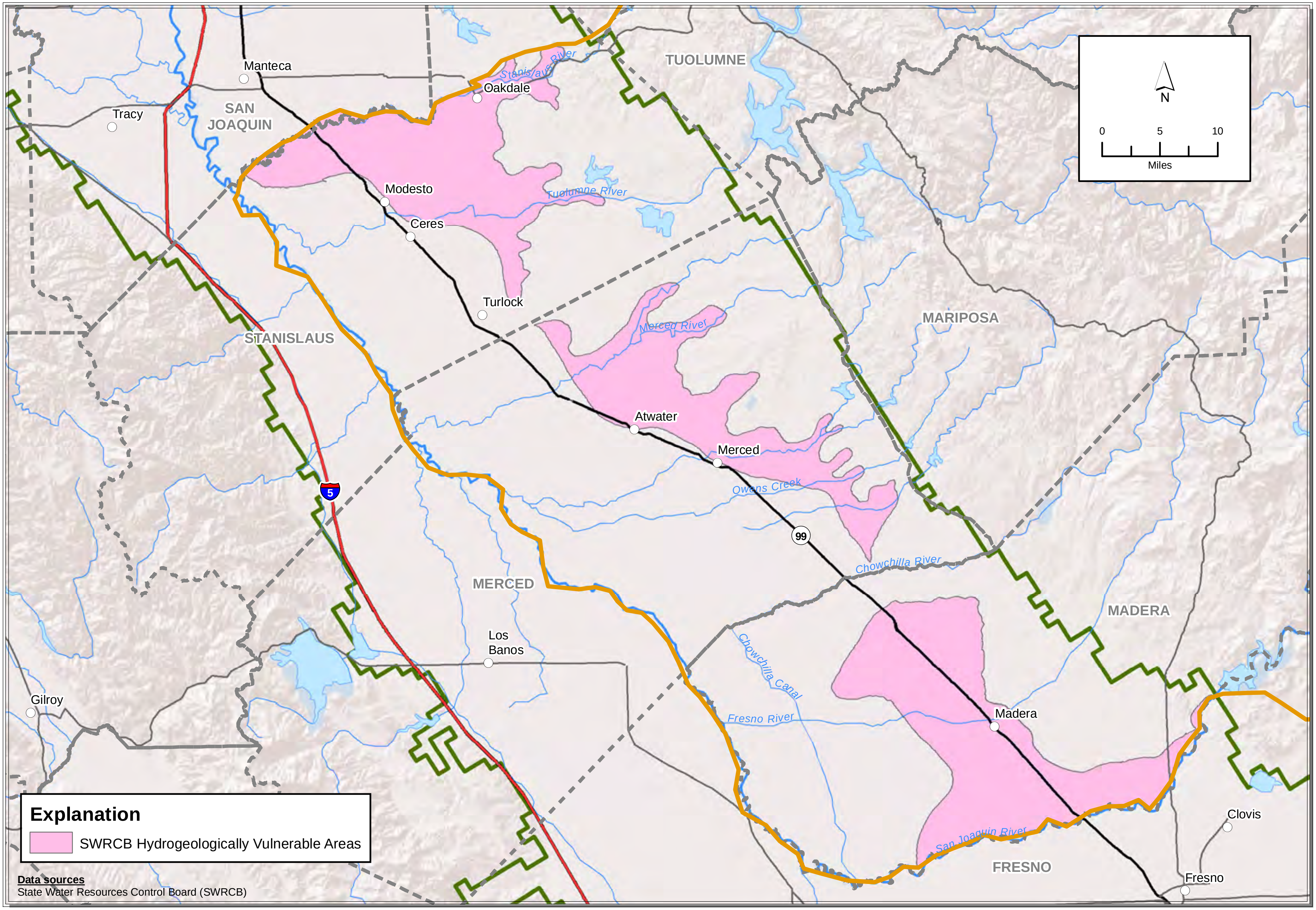
Figure 5-23g
Other Groundwater Quality Data: Perchlorate



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 6-1 SWRCB Hydrogeologically Vulnerable Areas.mxd

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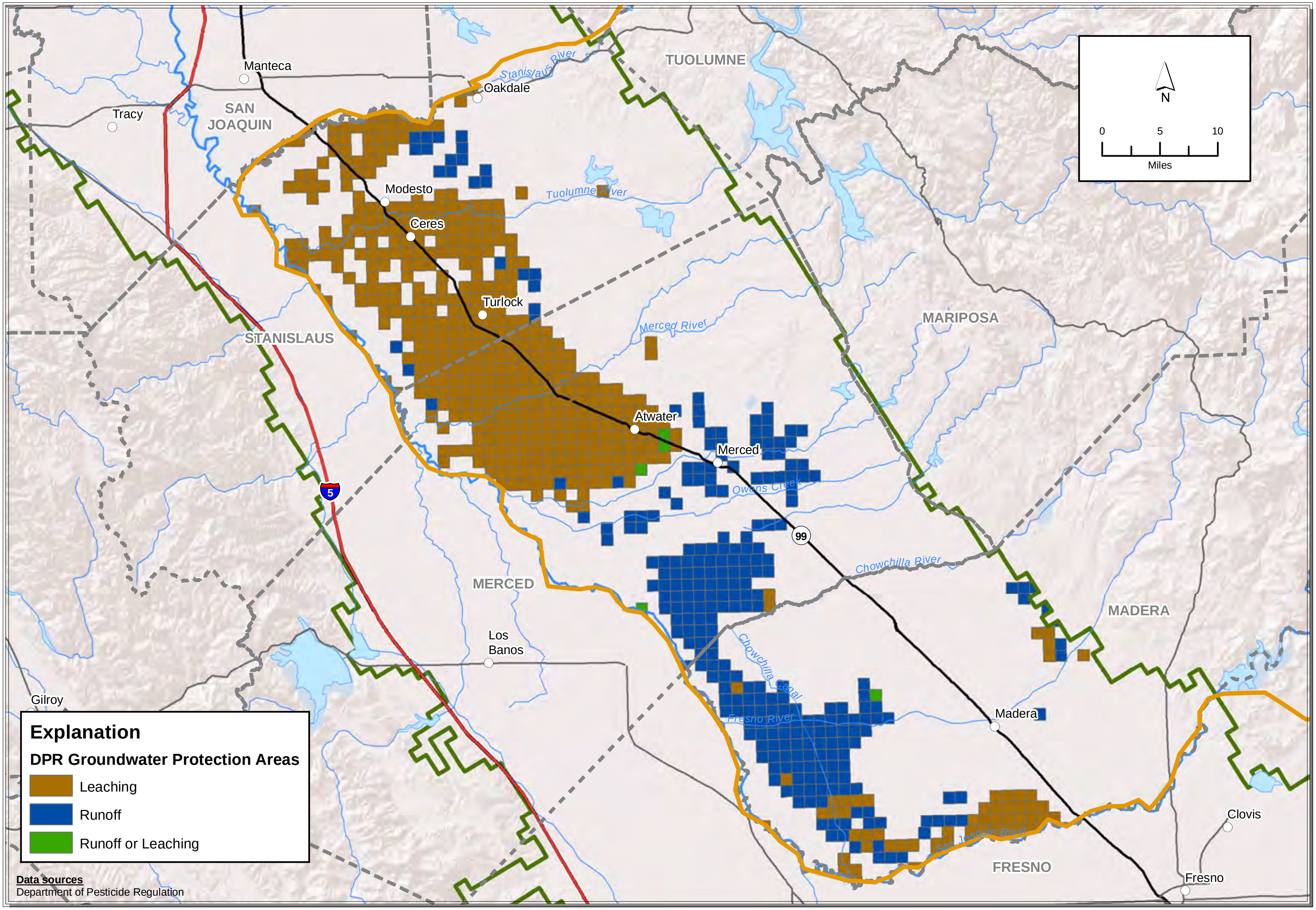
Figure 6-1
SWRCB Hydrogeologically Vulnerable Areas



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 6-2 DPR Groundwater Protection Areas.mxd

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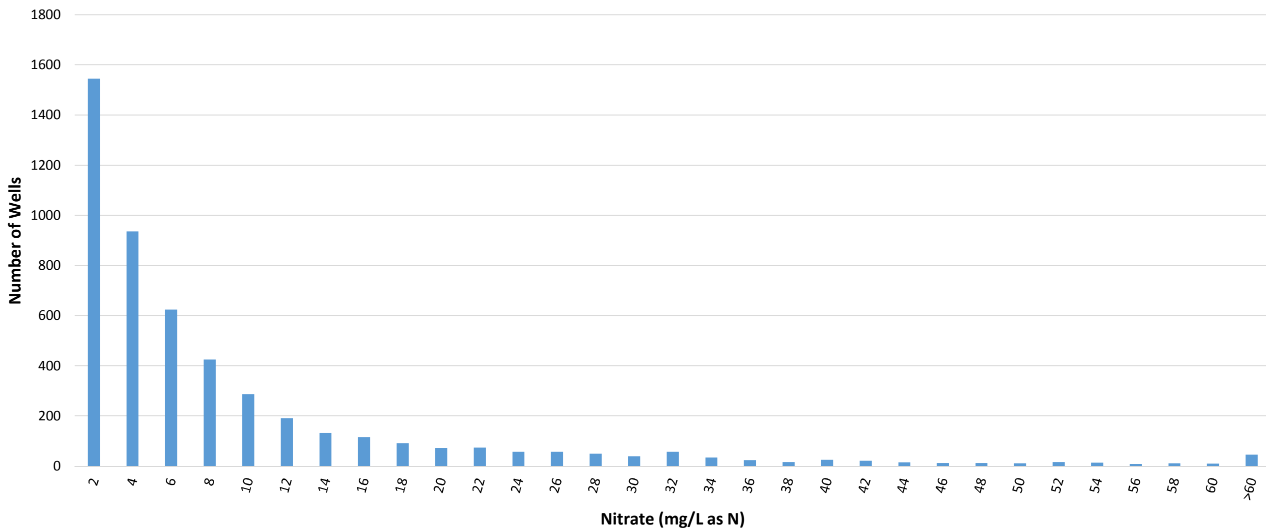
Figure 6-2
DPR Groundwater Protection Areas

Figure 6-3
Frequency Distribution of Nitrate Concentrations
(Untransformed vs. Square-Root Transformed)



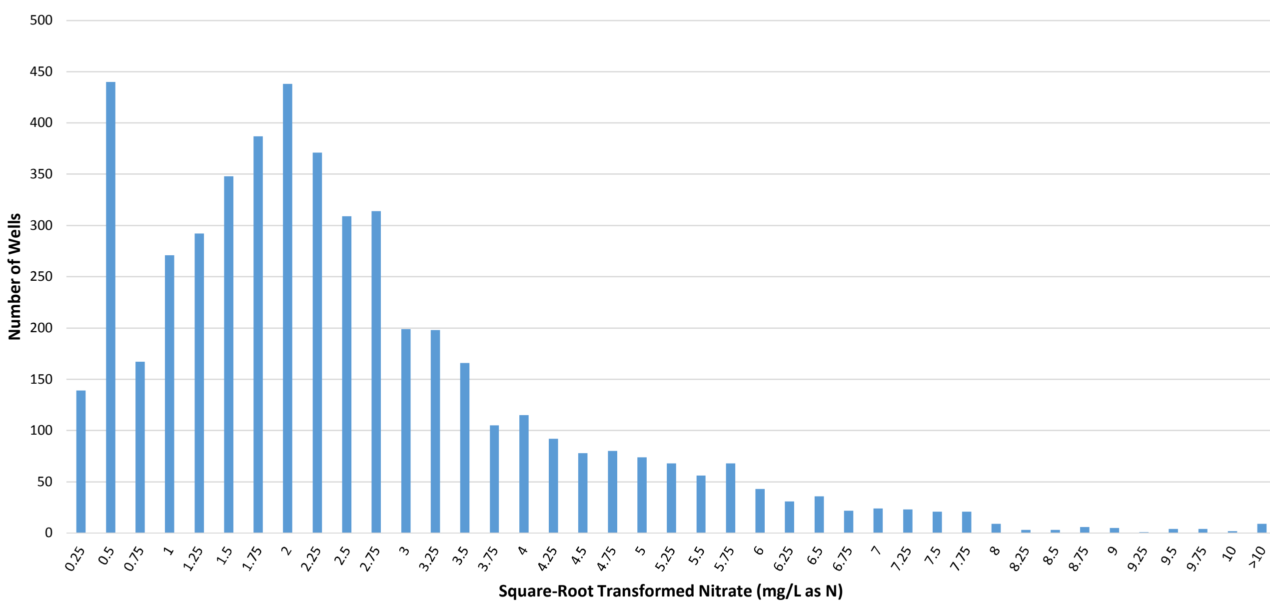
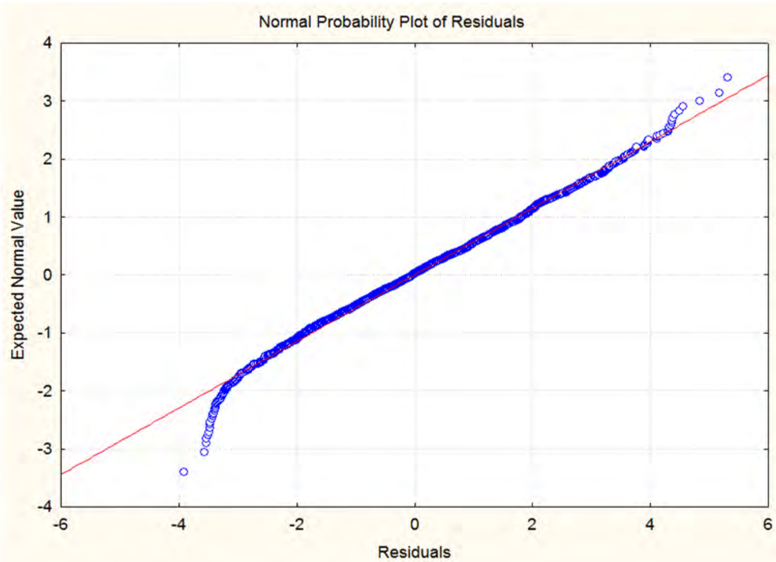
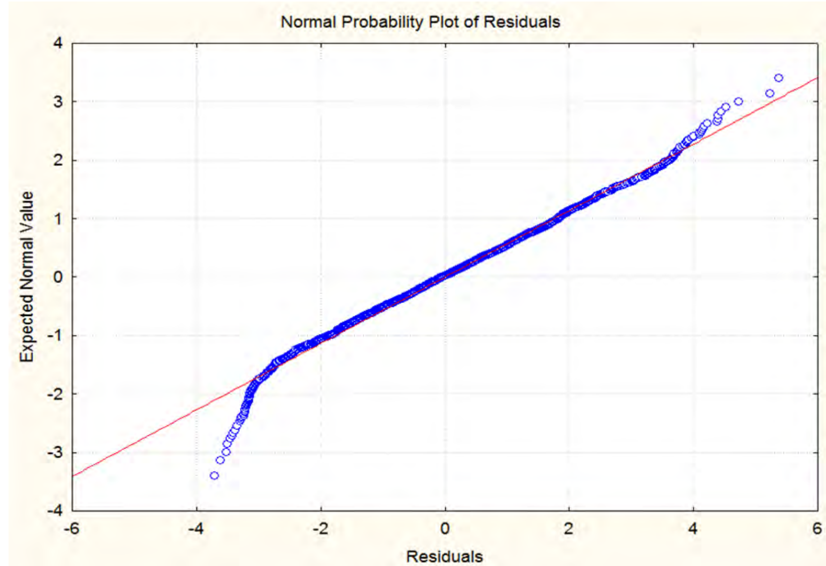


Figure 6-4
Normal Probability Plots of Residuals for Different Models

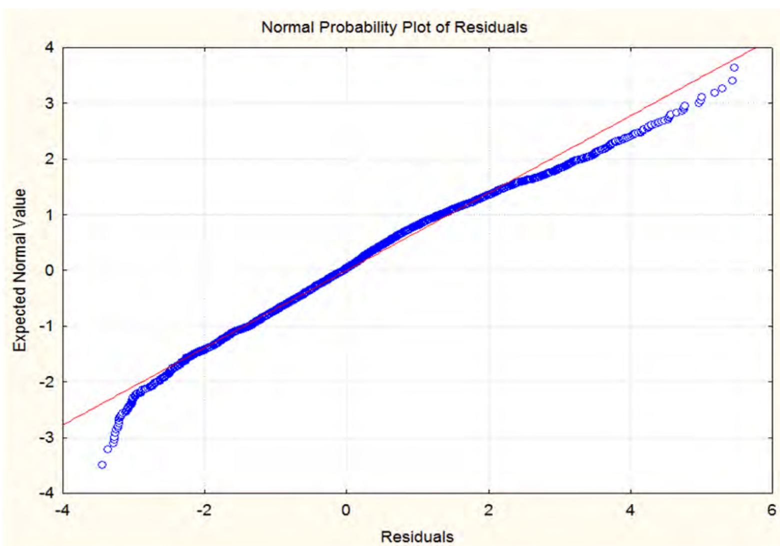
Shallow Wells Model: Mid-1990s



Shallow Wells Model: Early 2000s



All Wells Model: Mid-1990s



All Wells Model: Early 2000s

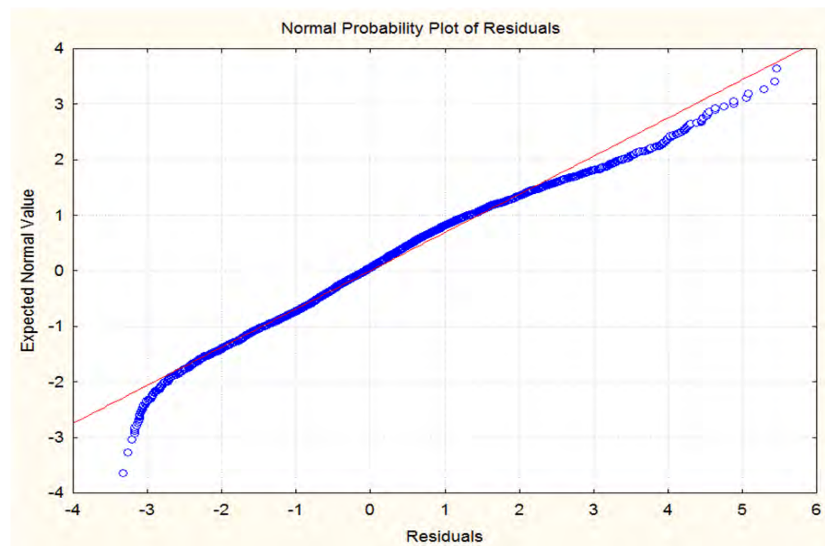
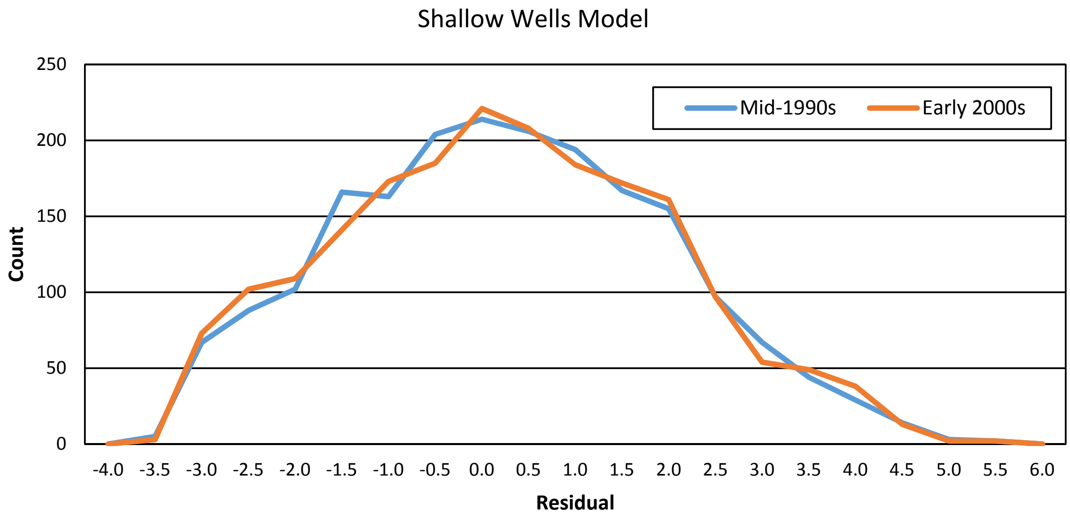


Figure 6-5
Frequency Distribution of Model Residuals



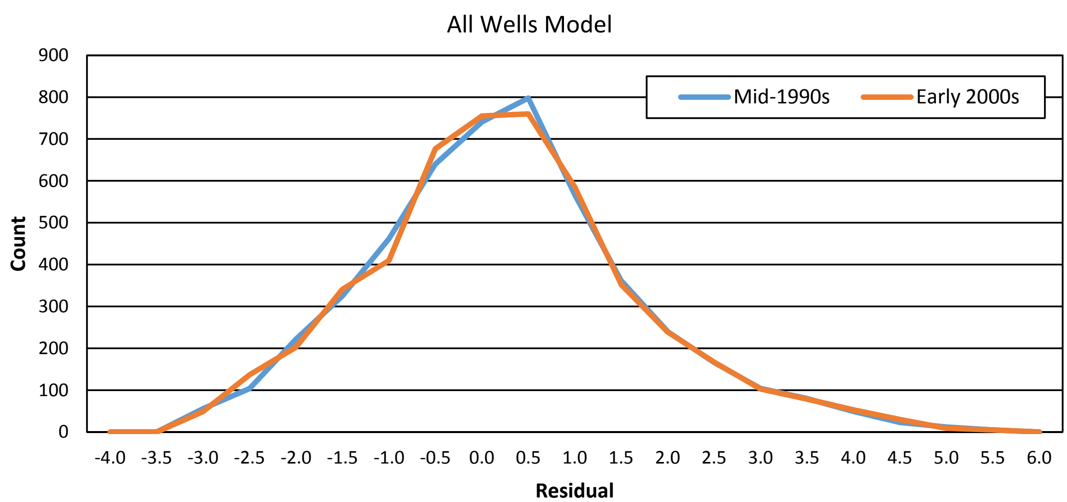


Figure 6-6
Shallow Wells Model: Observed versus Predicted Values

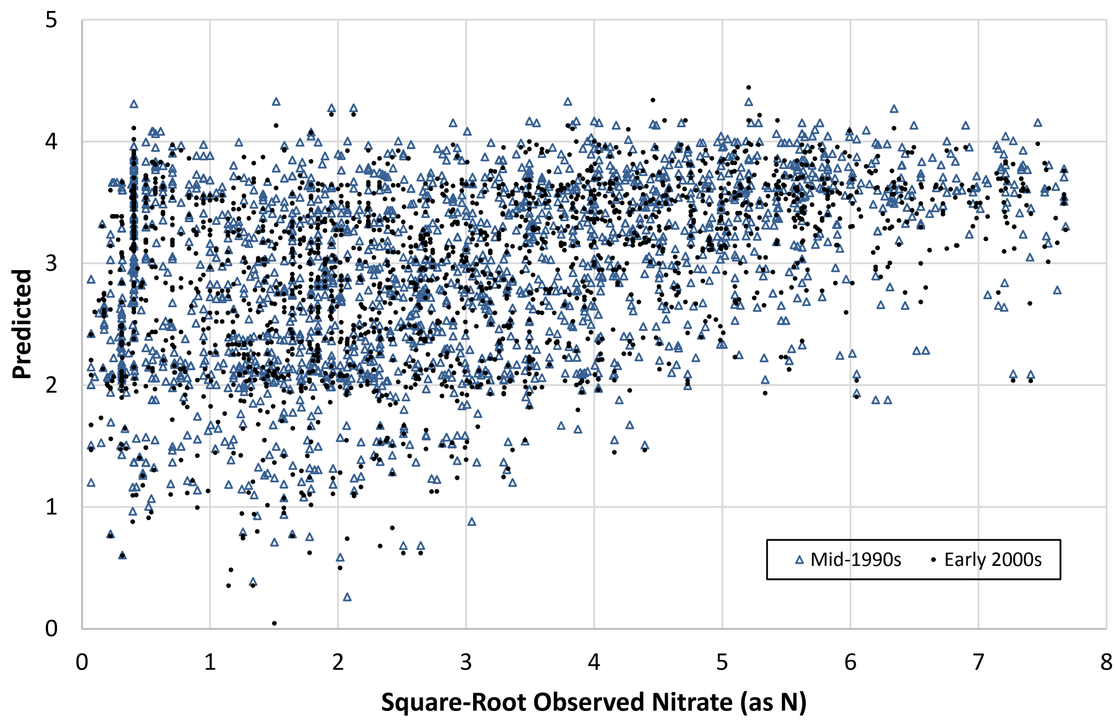
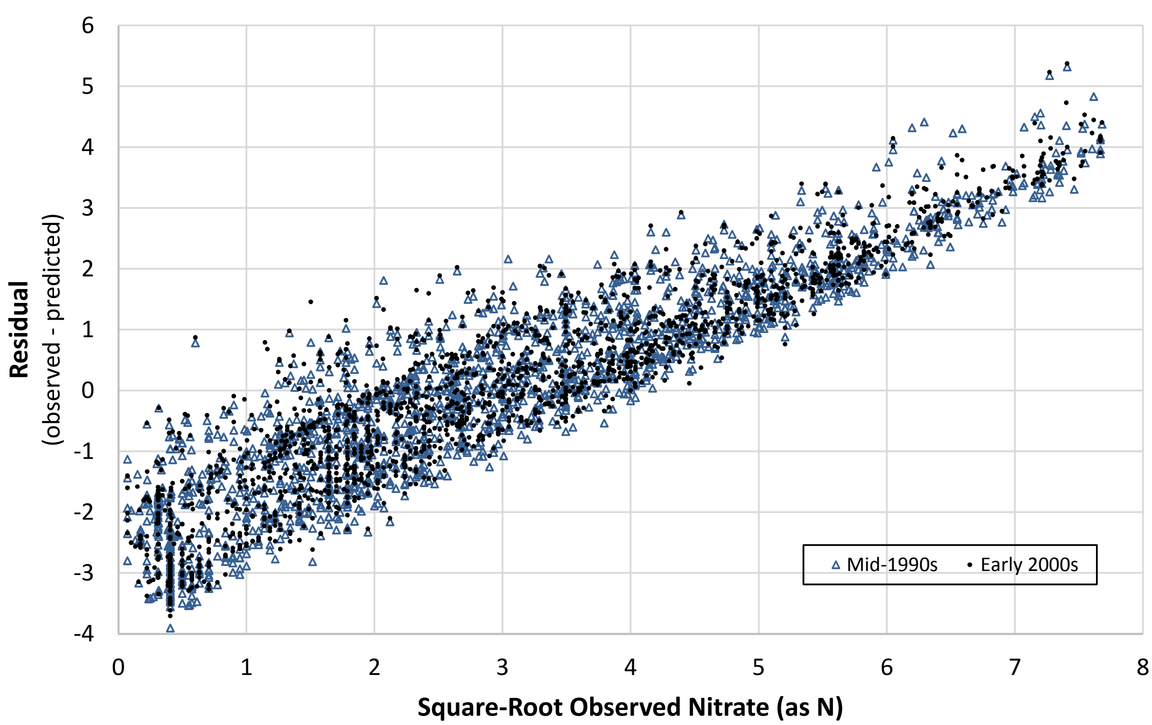
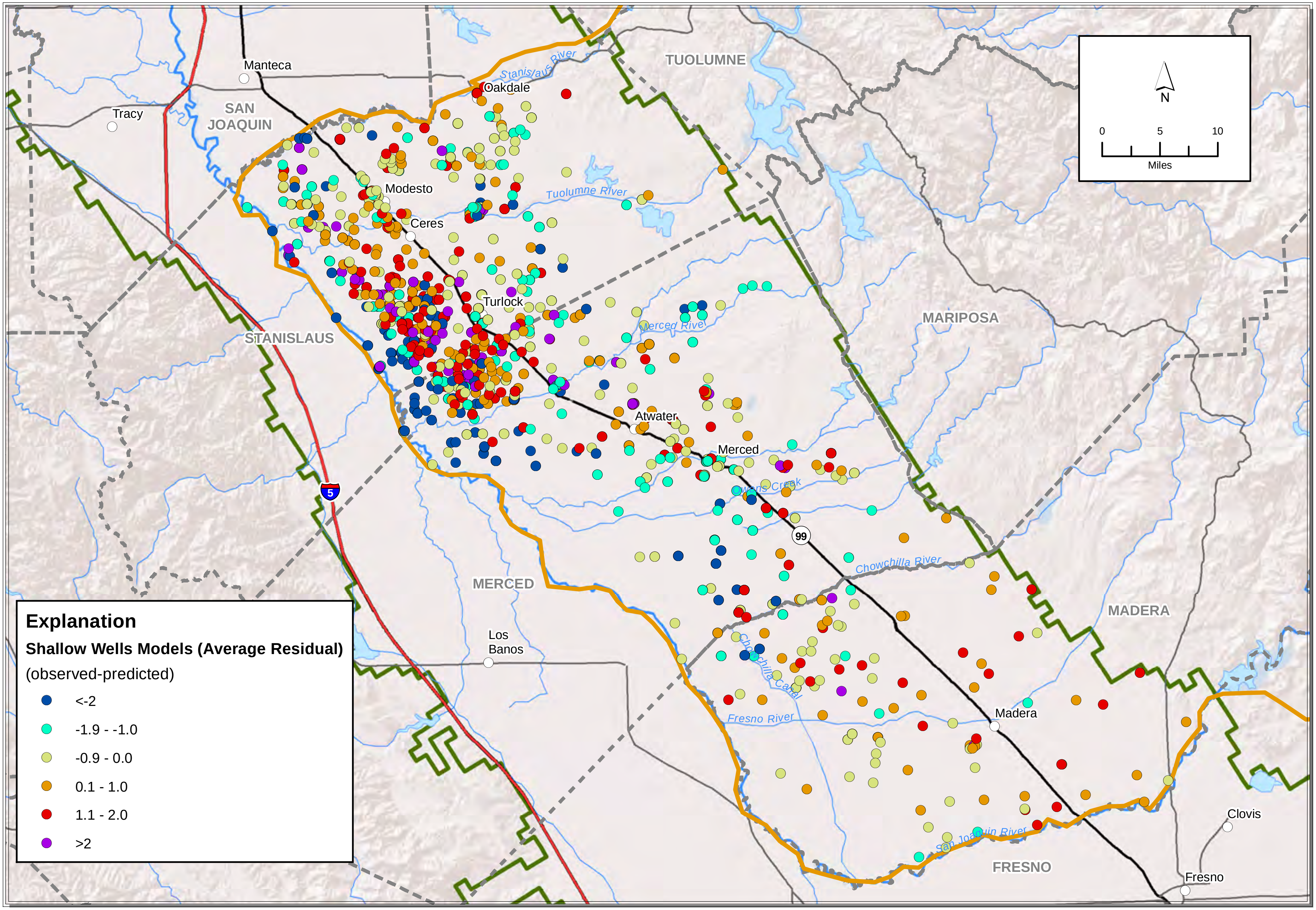


Figure 6-7
Shallow Wells Model: Observed versus Residual Values





Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 6-8 Shallow Wells Model Spatial Distribution of Model Residuals.mxd

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Figure 6-8
Shallow Wells Model: Spatial Distribution of Model Residuals

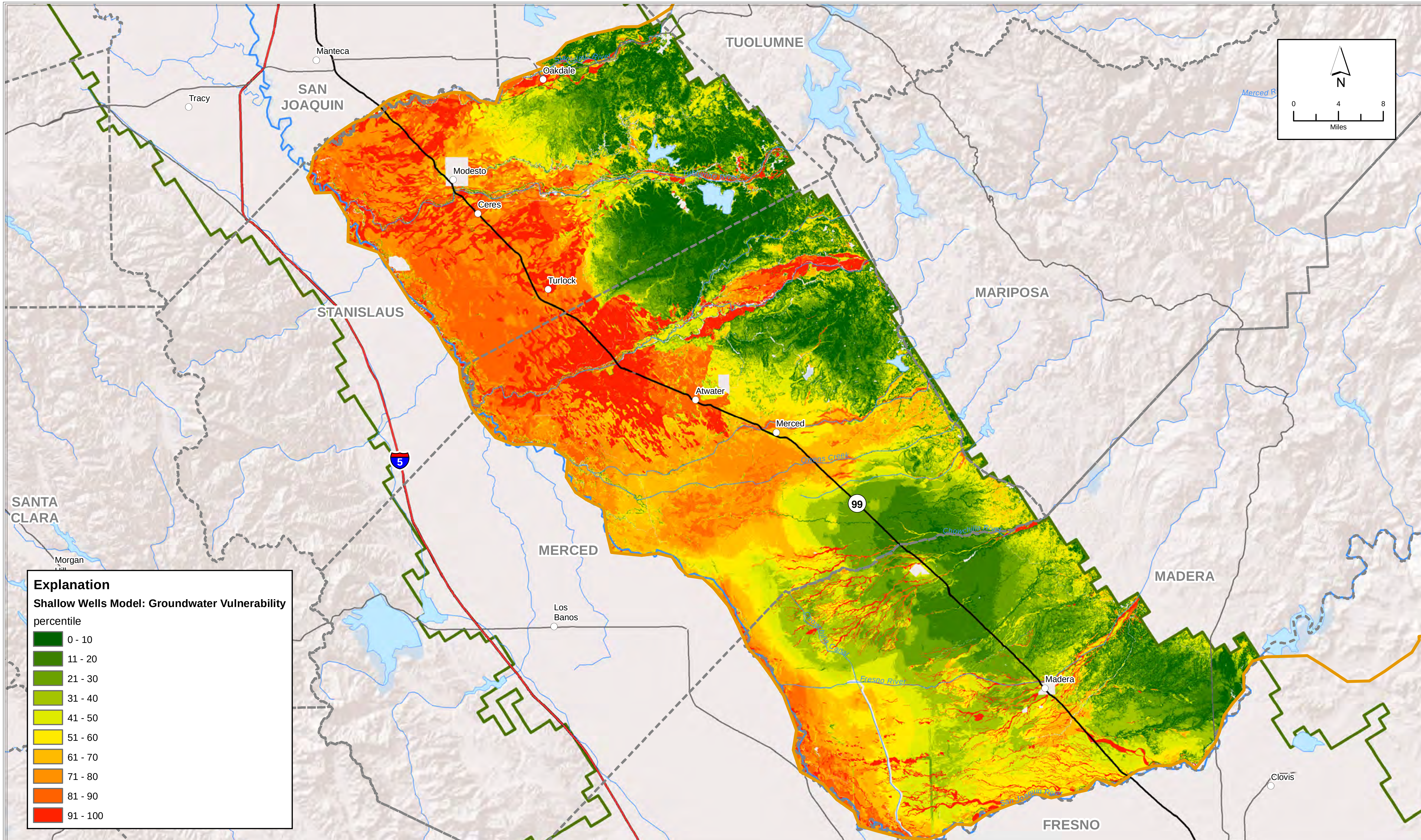

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Figure 6-9
Shallow Wells Model: Groundwater Vulnerability

Figure 6-10
Shallow Wells Model: Groundwater Vulnerability at Locations with a Nitrate Exceedance

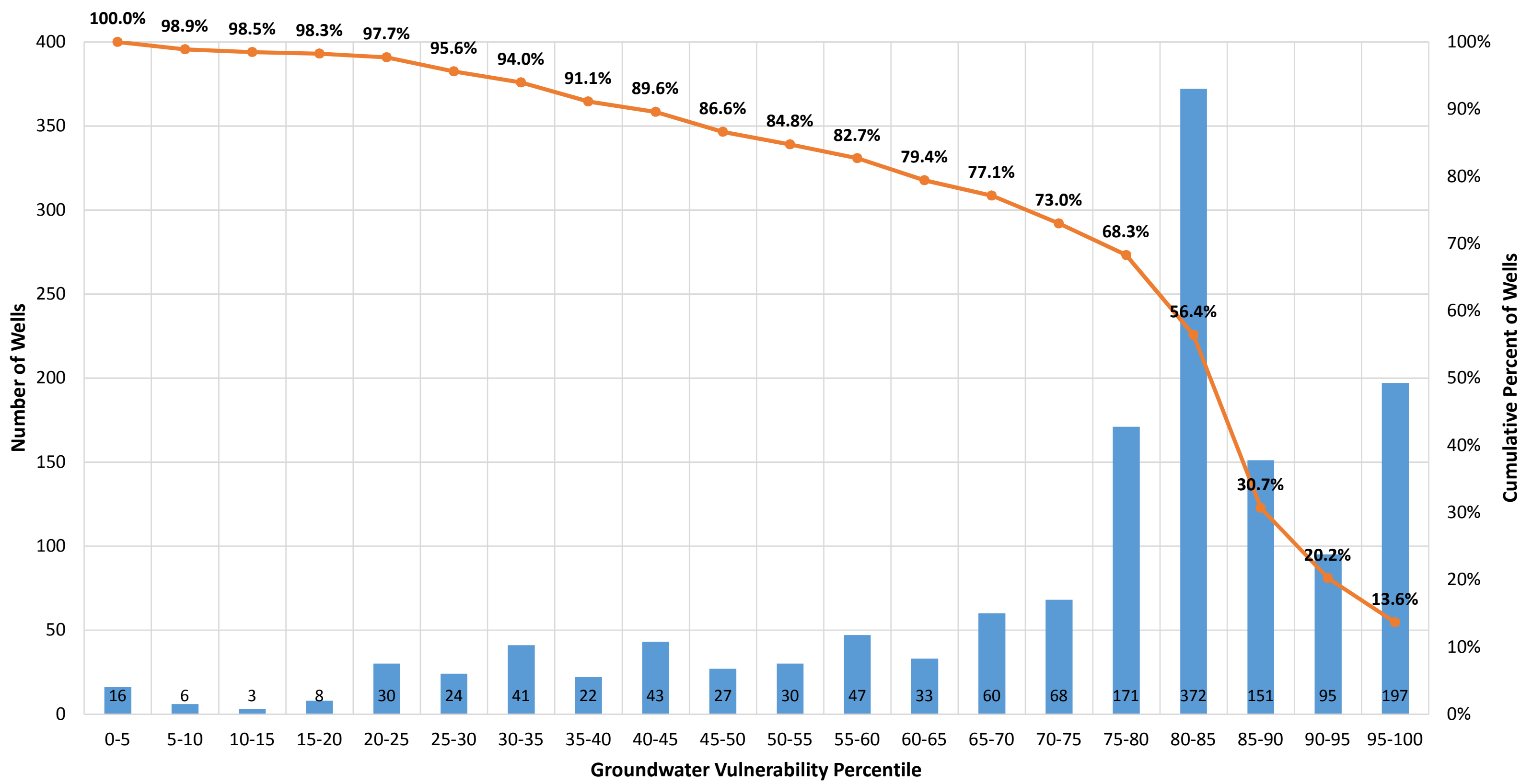


Figure 6-11

Shallow Wells Model: Distance from Exceedances to 75th Percentile Vulnerability Area

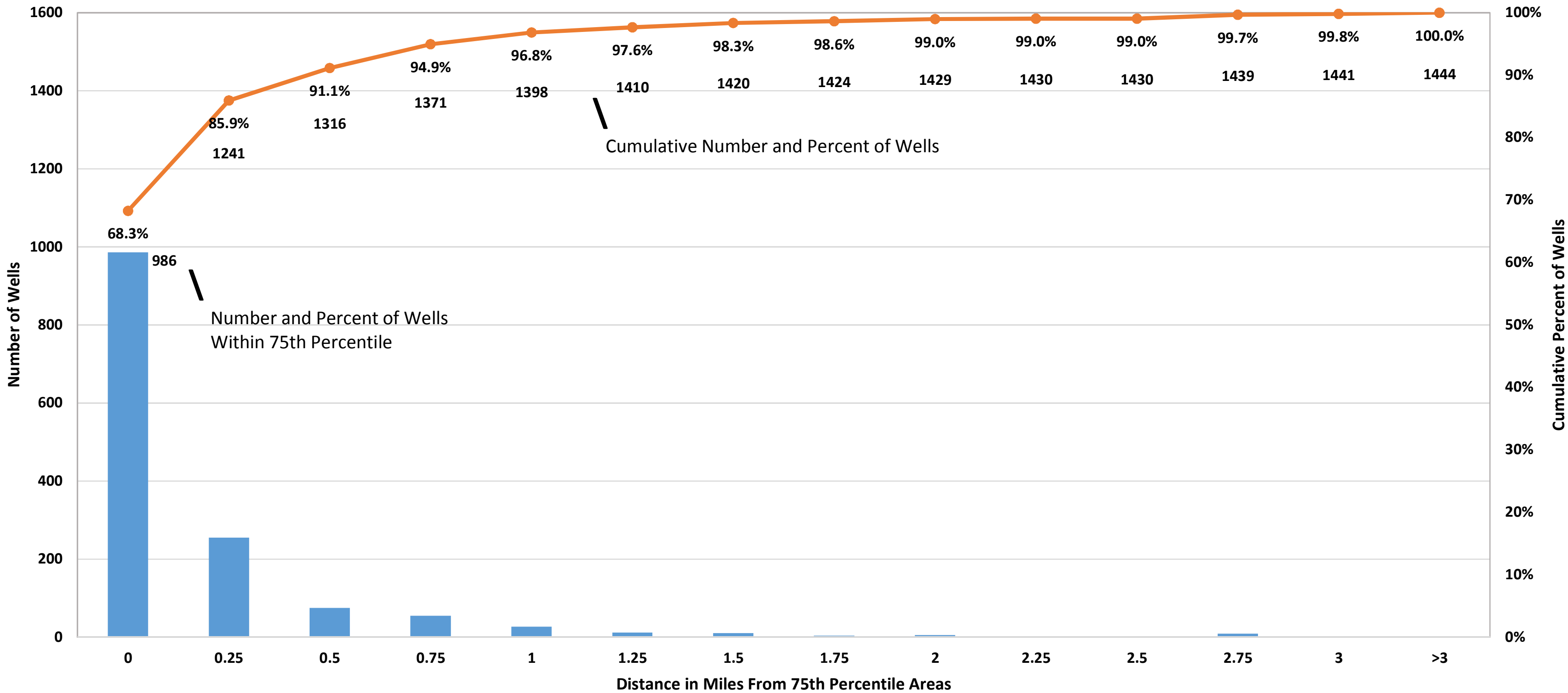


Figure 6-12
Shallow Wells Model: Groundwater Vulnerability Percentile versus Observed Nitrate Concentration

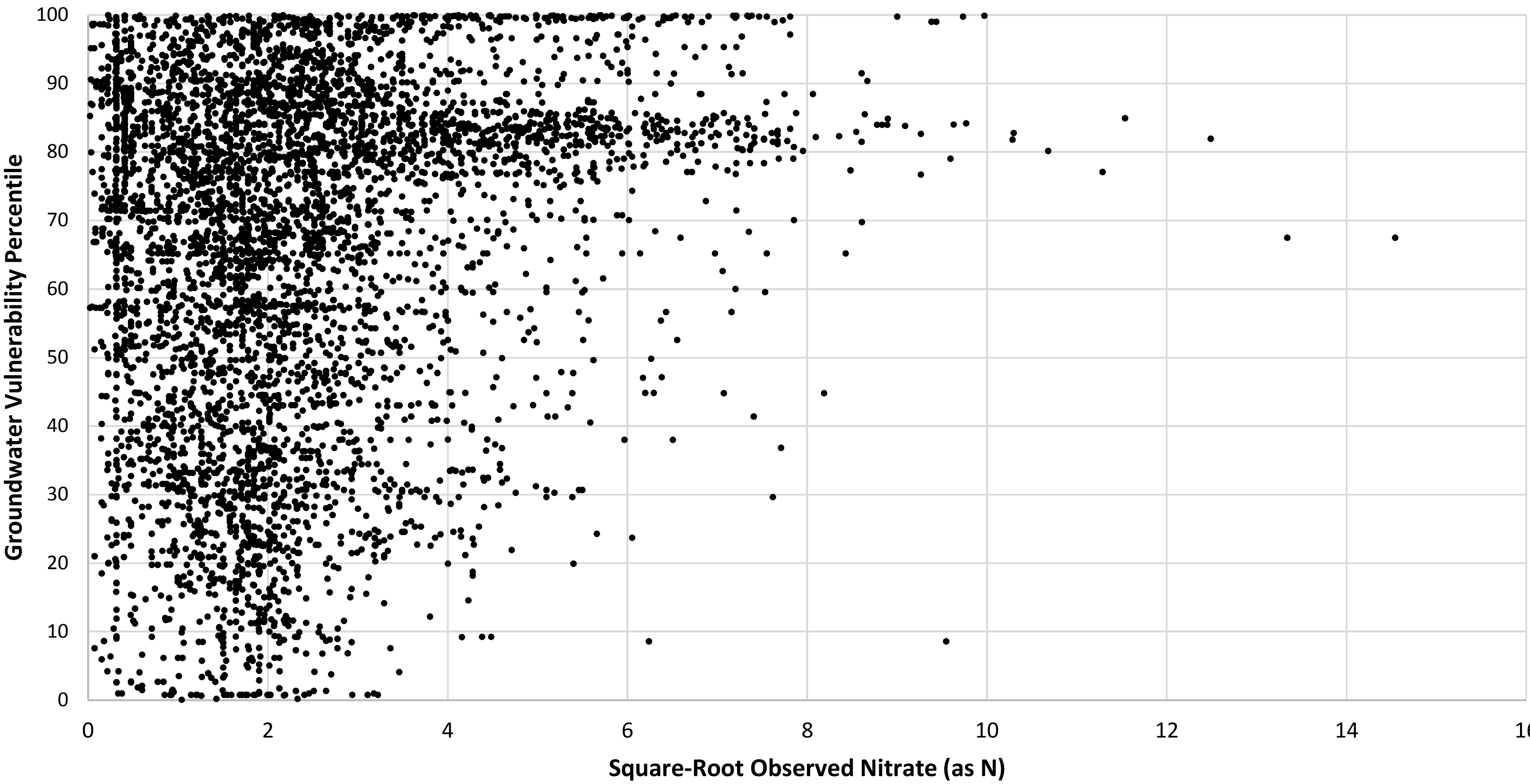


Figure 6-13
All Wells Model: Observed versus Predicted Values

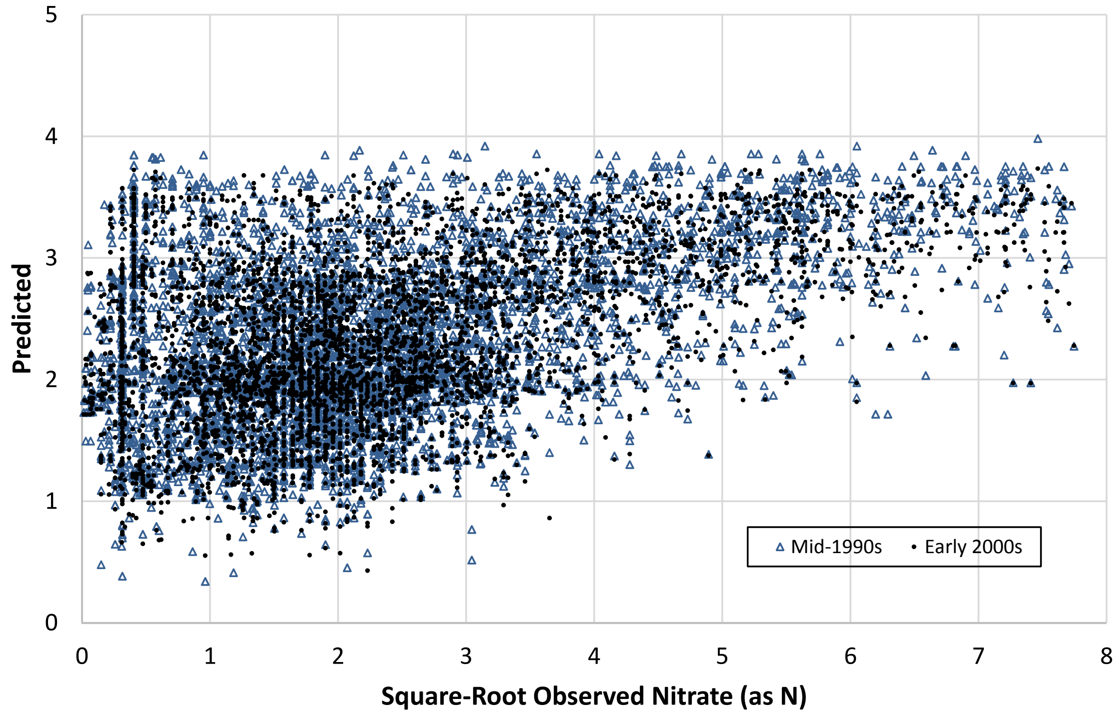
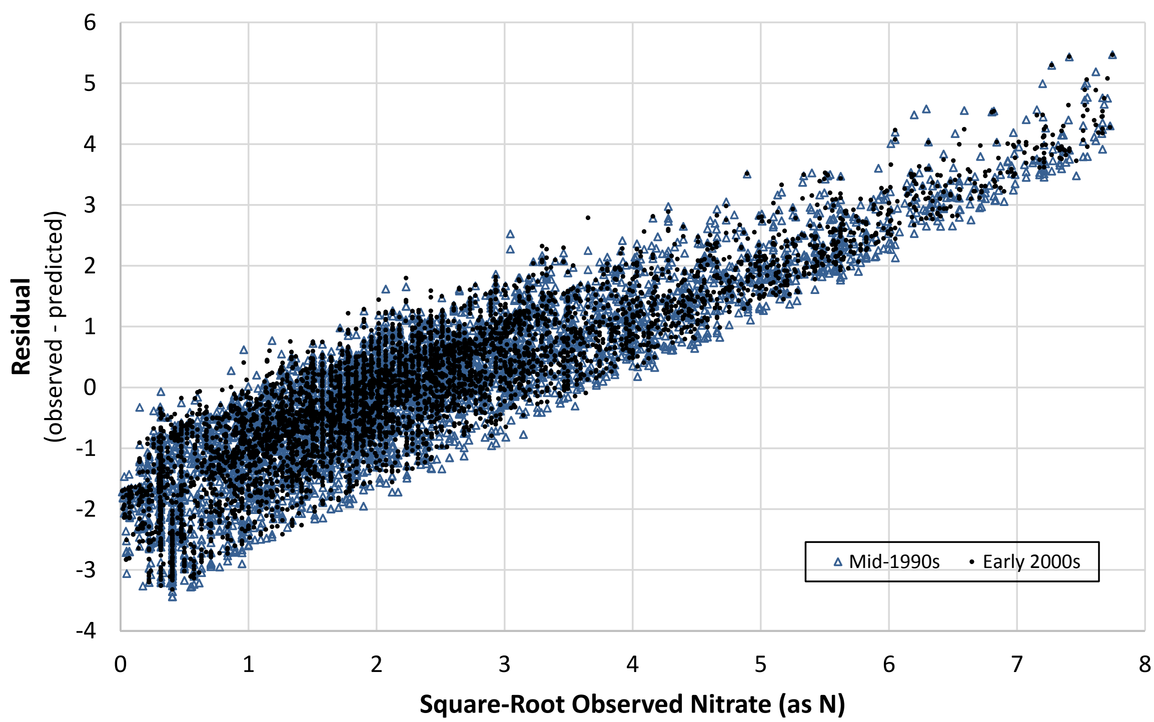


Figure 6-14
All Wells Model: Observed versus Residual Values



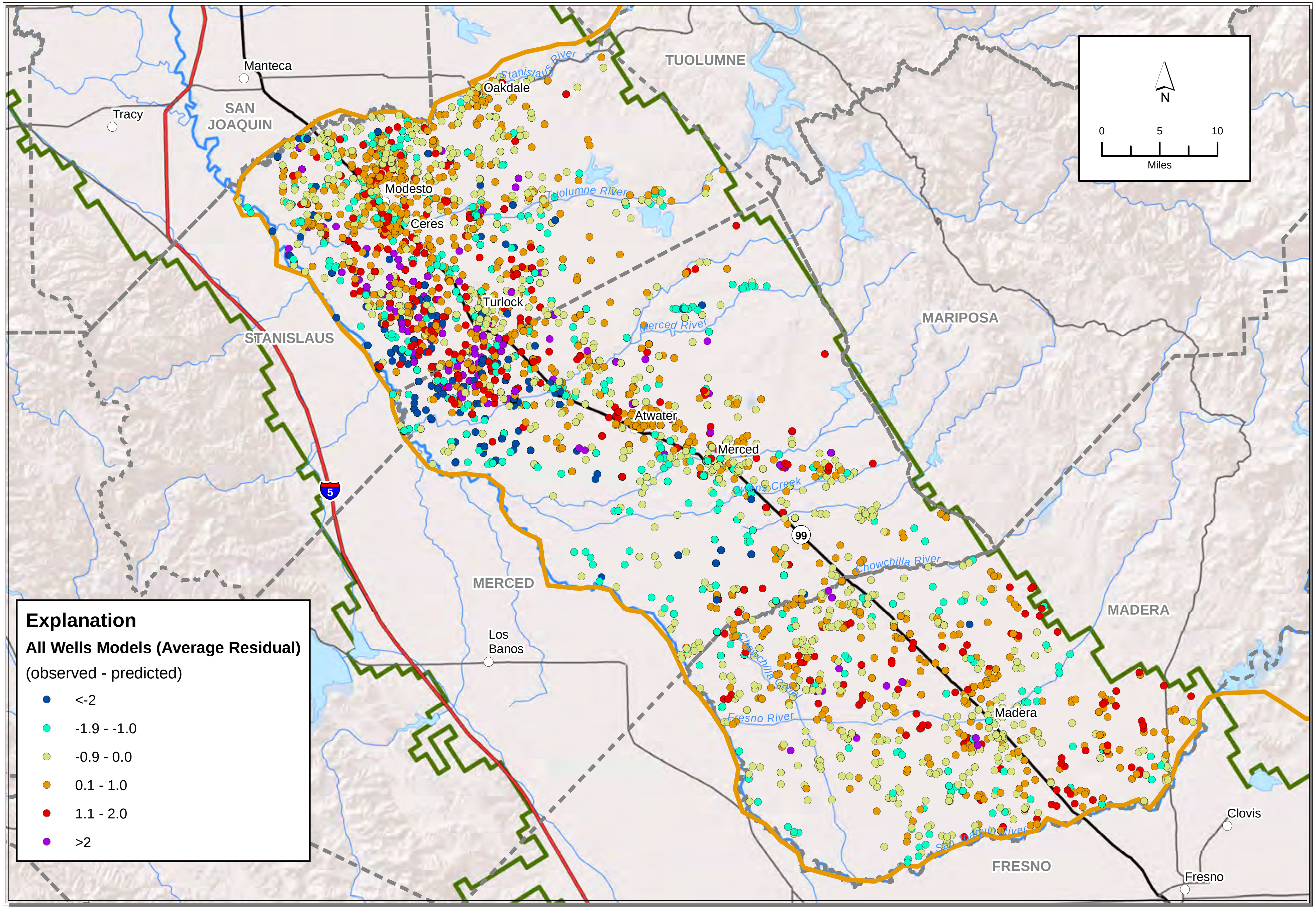


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Figure 6-15
All Wells Model: Spatial Distribution of Model Residuals

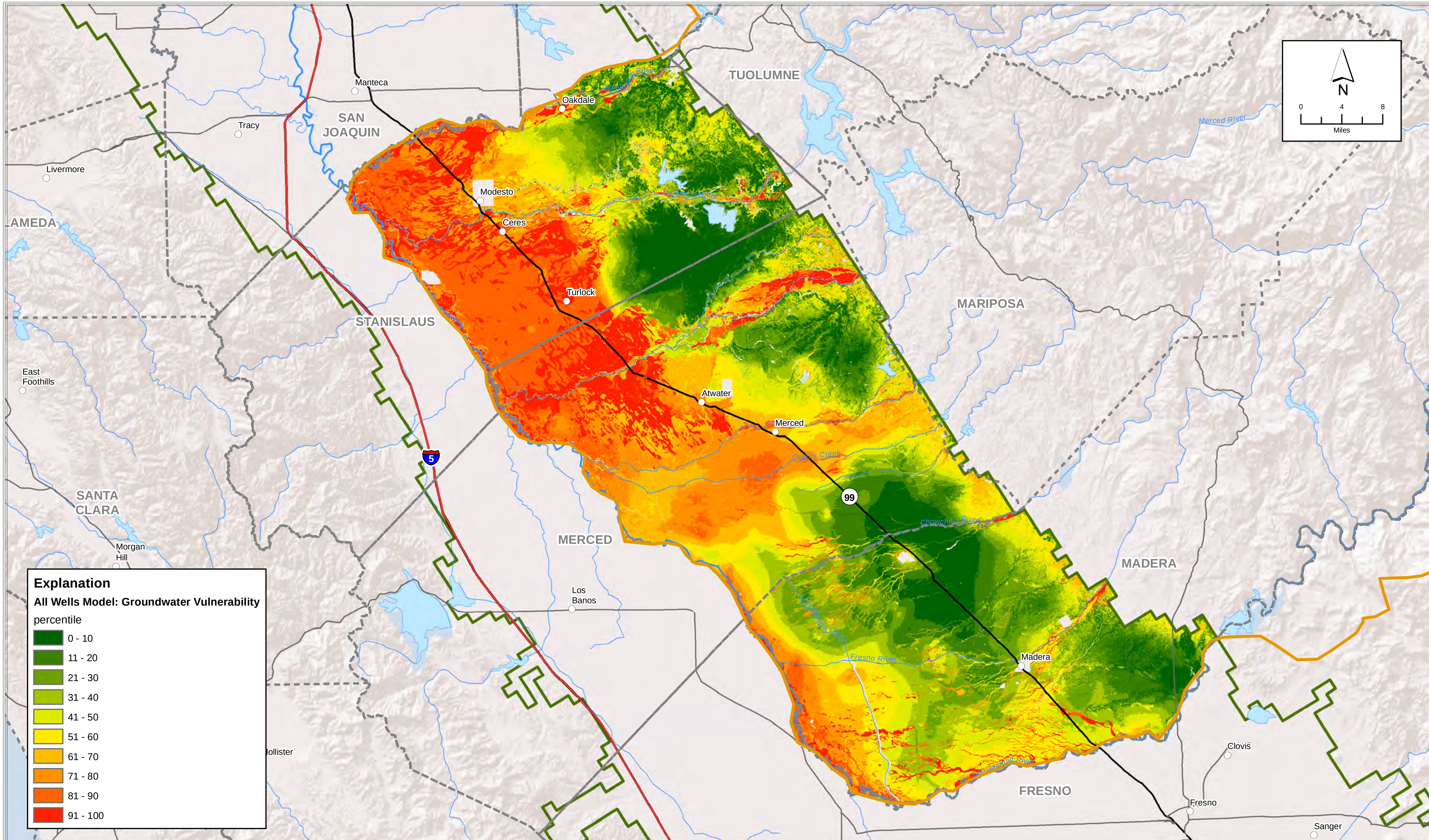

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Figure 6-16
All Wells Model: Groundwater Vulnerability

Figure 6-17
All Wells Model: Groundwater Vulnerability at Locations with a Nitrate Exceedance

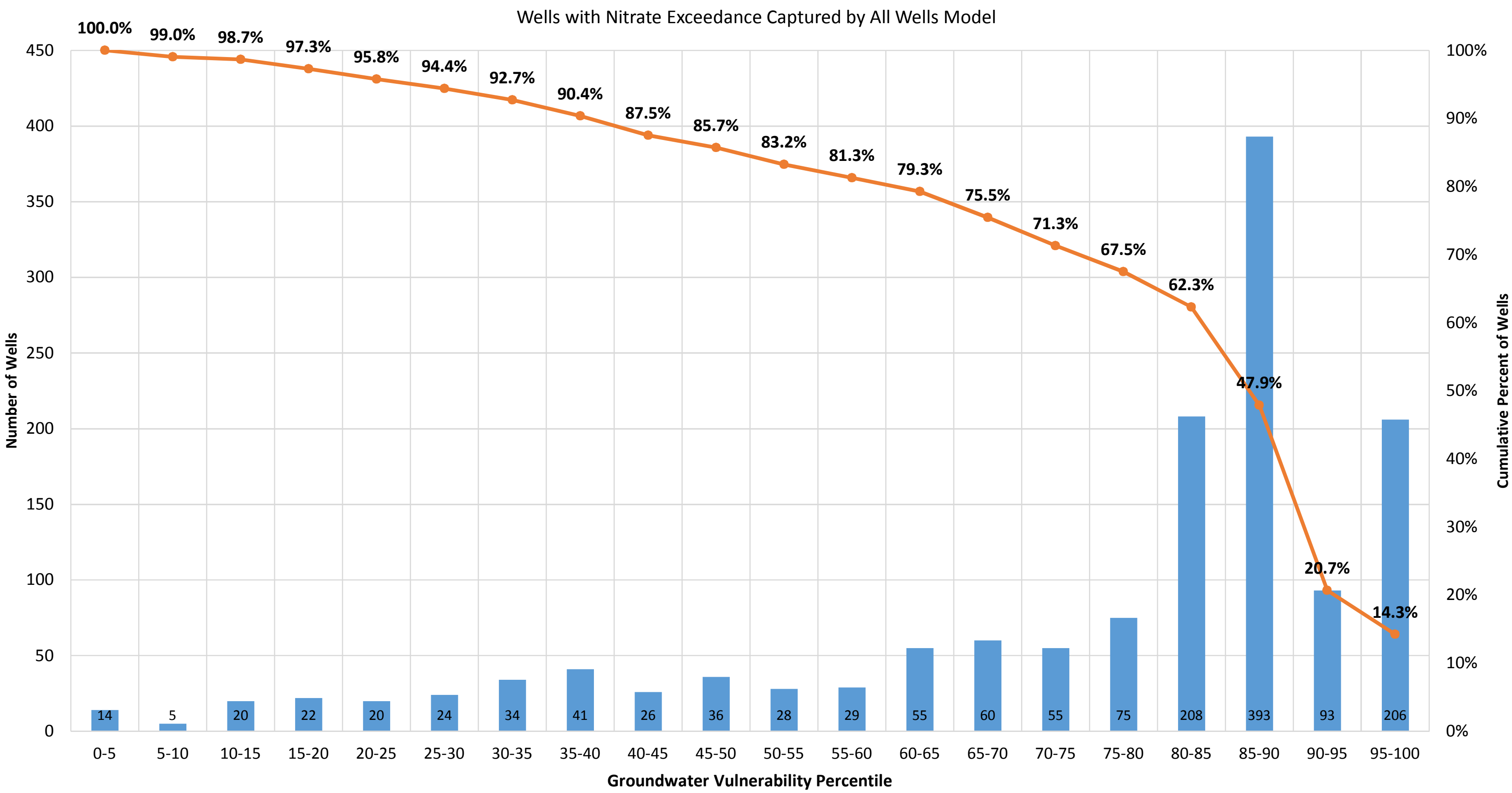


Figure 6-18
All Wells Model: Distance from Exceedances to the 75th Percentile Vulnerability Area

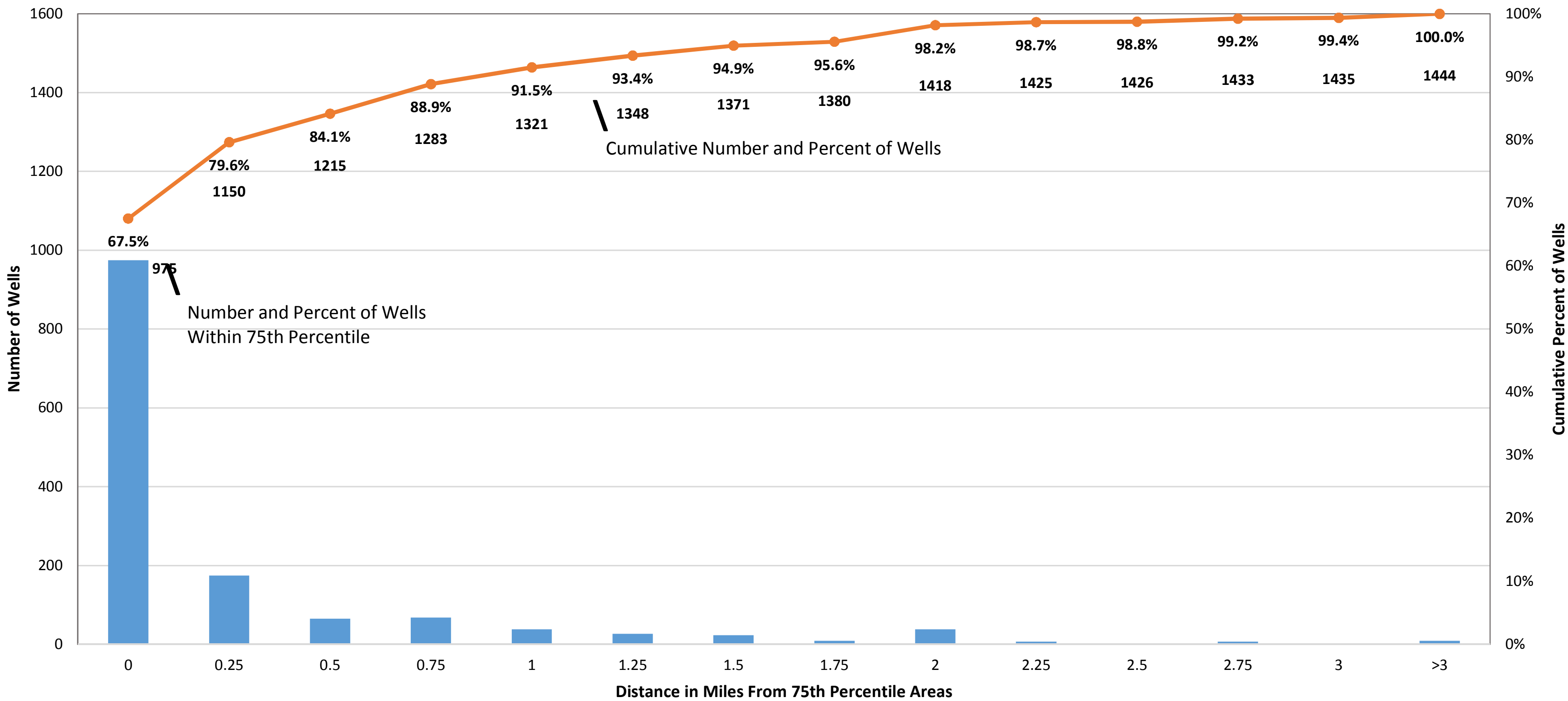
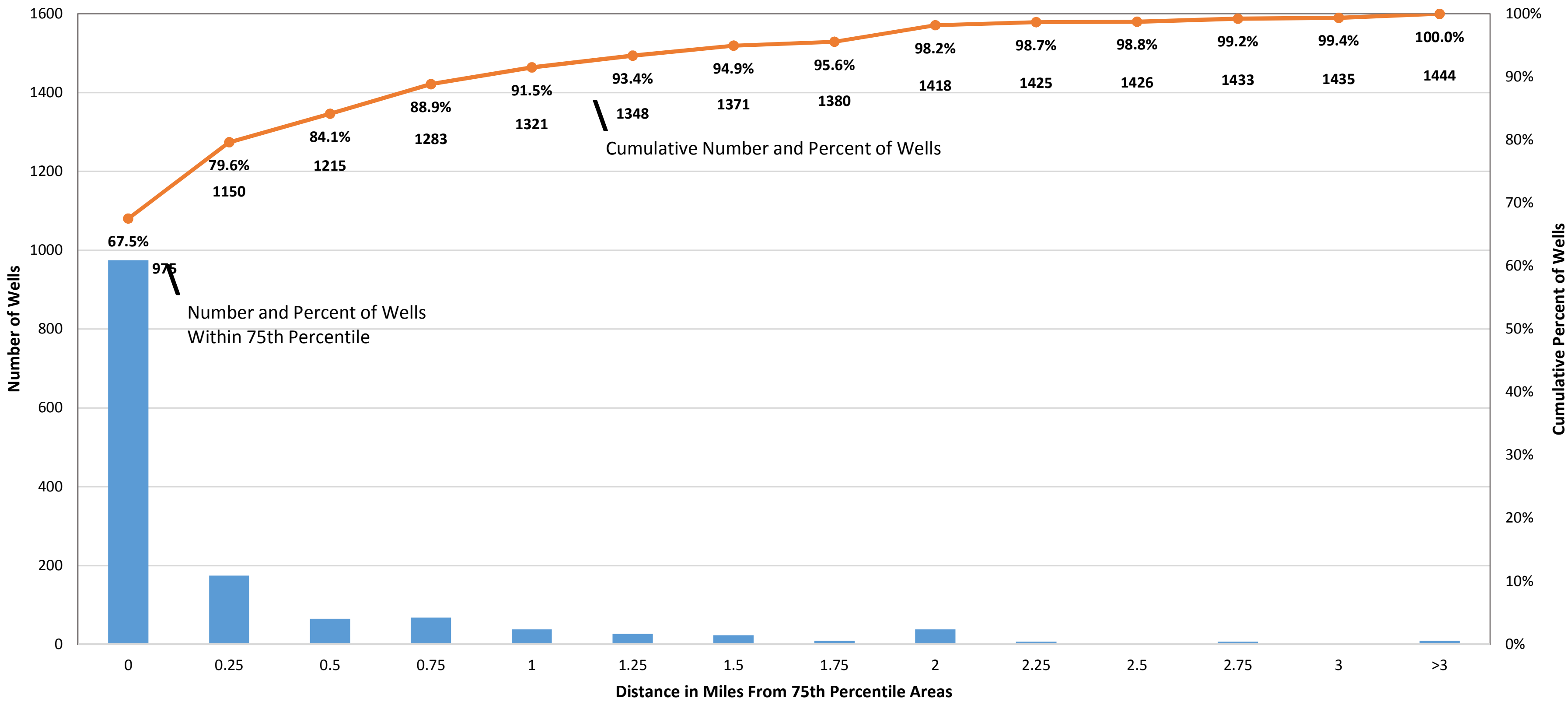


Figure 6-18
All Wells Model: Distance from Exceedances to 75th Percentile Vulnerability Area



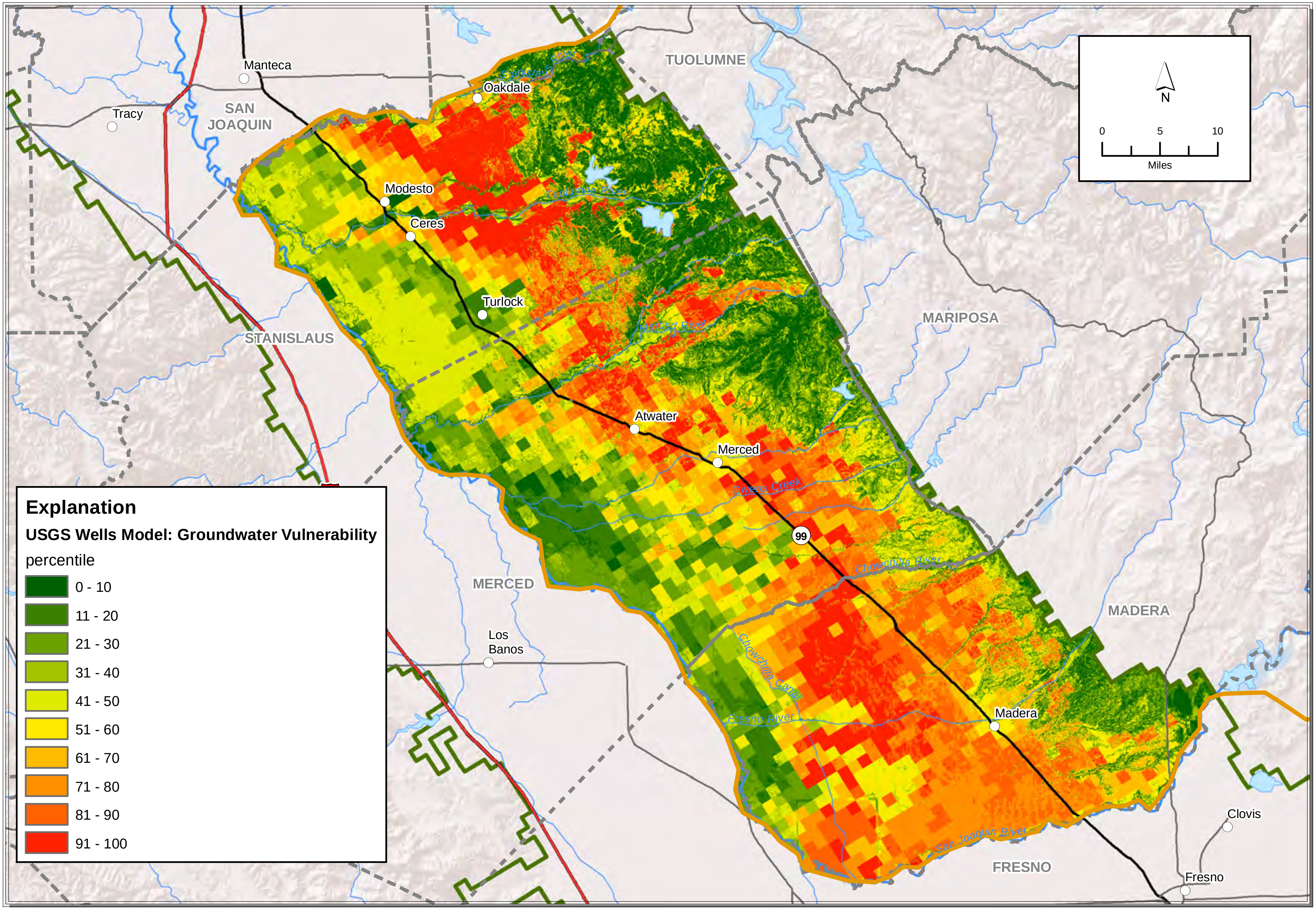


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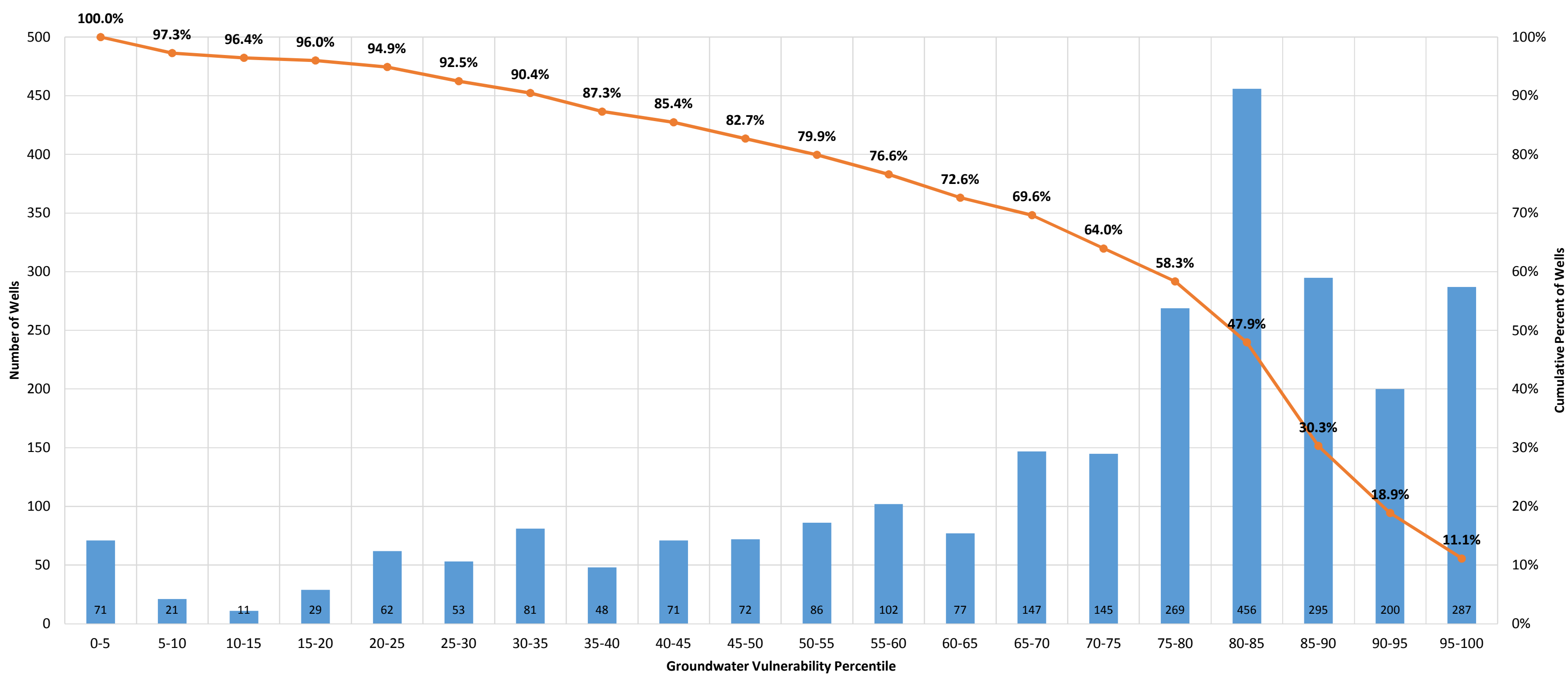
Figure 6-19
USGS Wells Model Groundwater Vulnerability

Figure 6-20
Shallow Wells Model: Groundwater Vulnerability at Locations with a Nitrate Concentration At or Above 5 mg/L (as N)



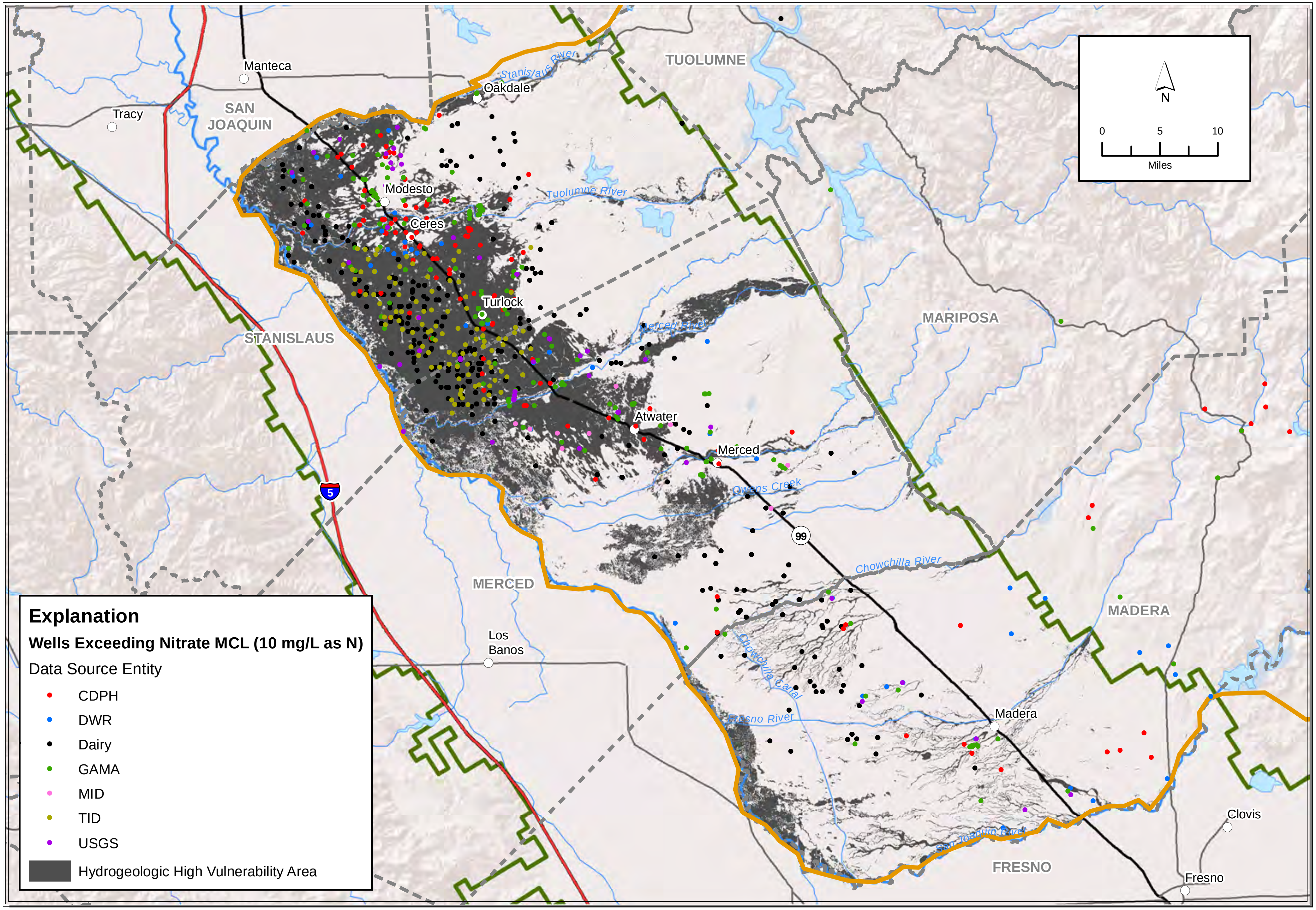


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Figure 6-21
Hydrogeologic High Vulnerability Area

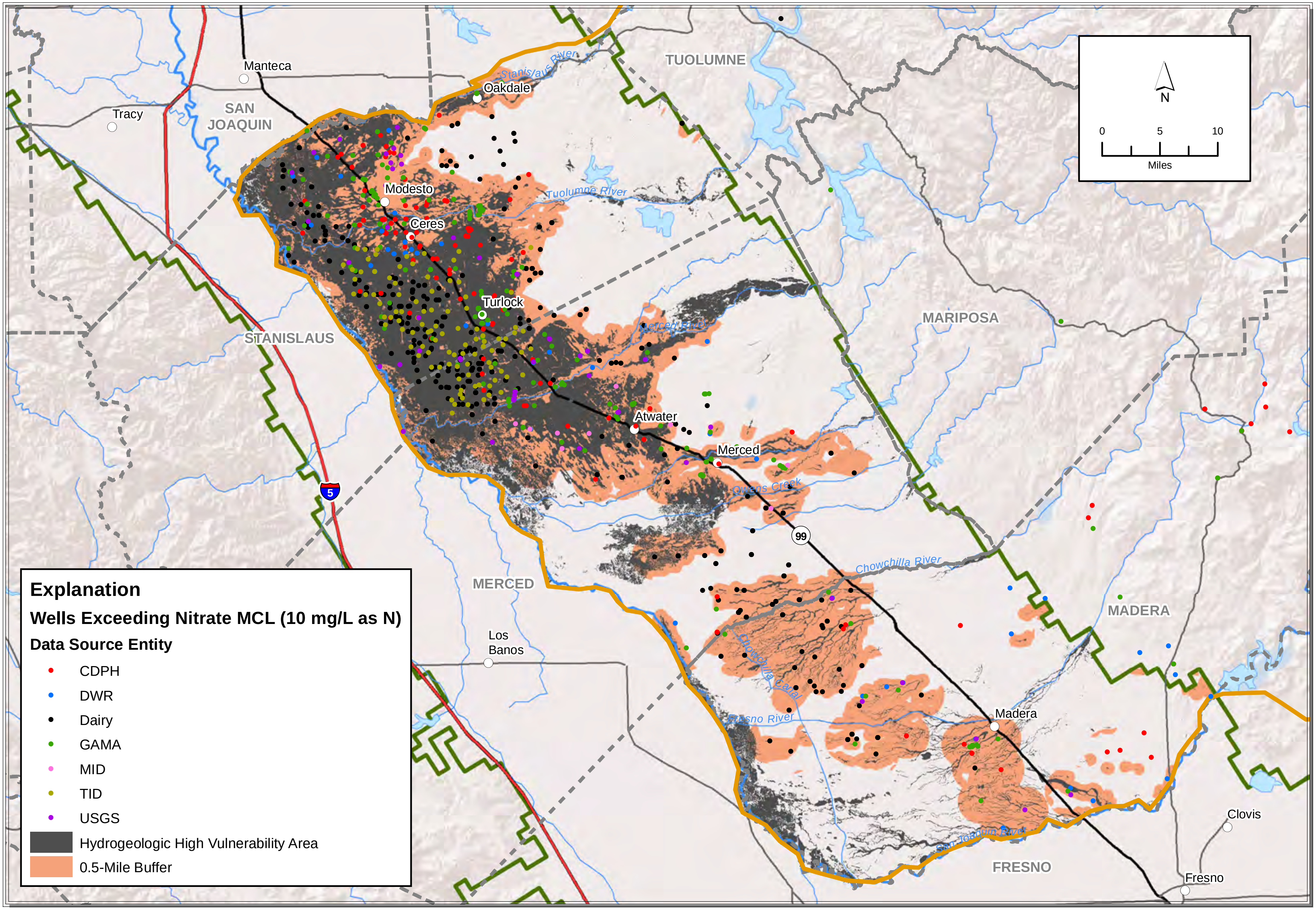

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Figure 6-22
Hydrogeologic High Vulnerability Area With Buffer Area

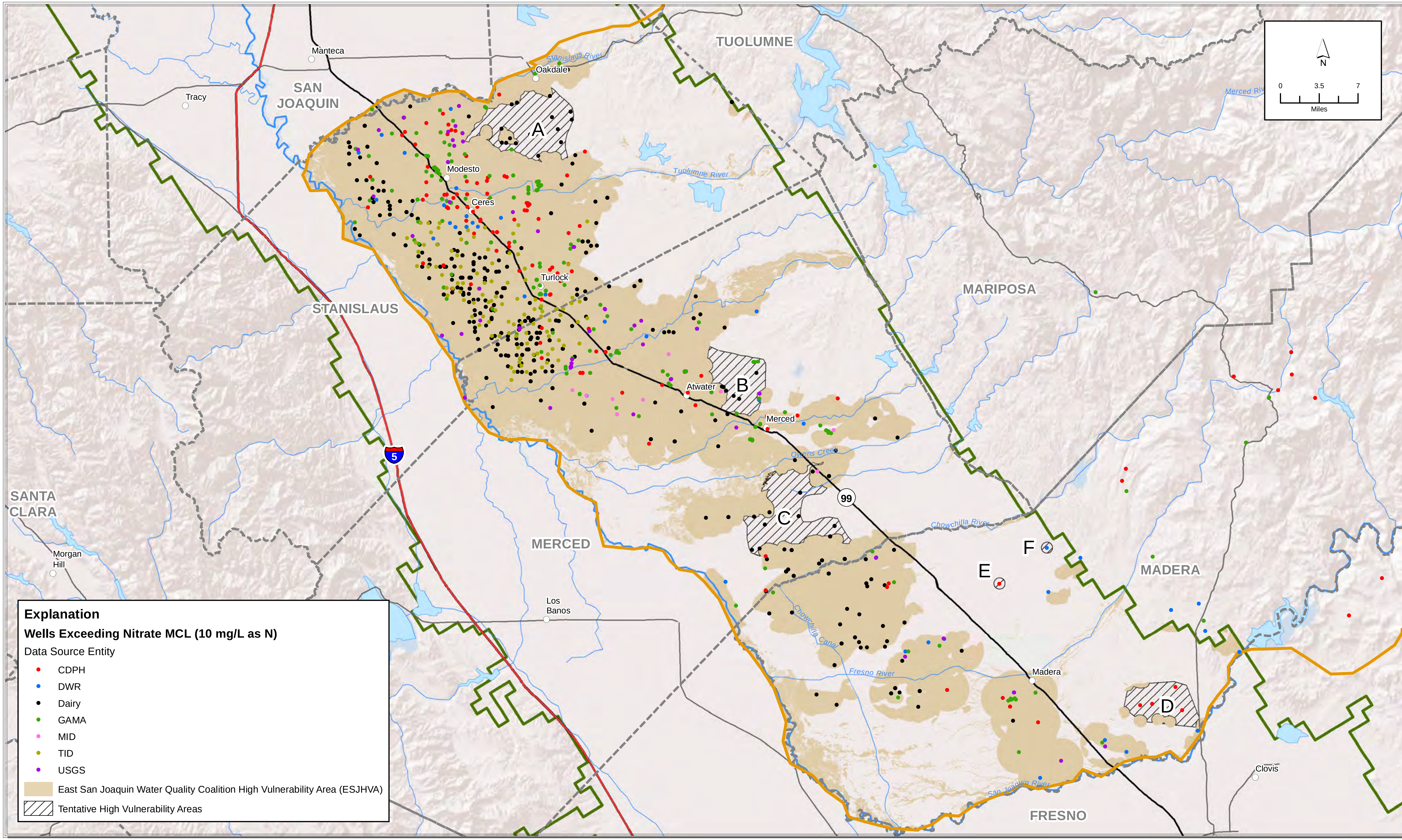

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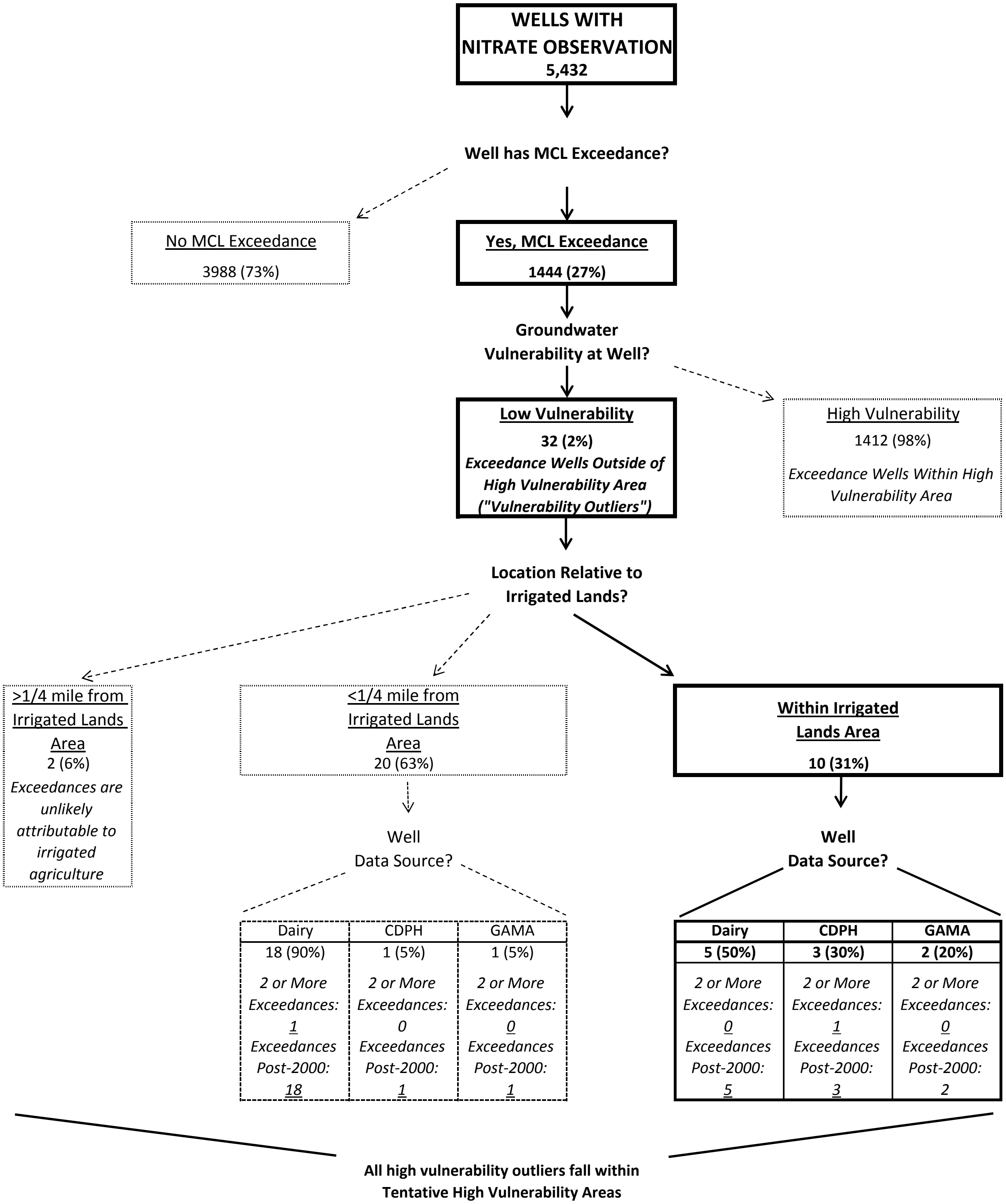
Figure 6-23
High Vulnerability Area for the East San Joaquin Water Quality Coalition

Figure 6-24
Characterization of Wells with Respect to Groundwater Vulnerability Designation



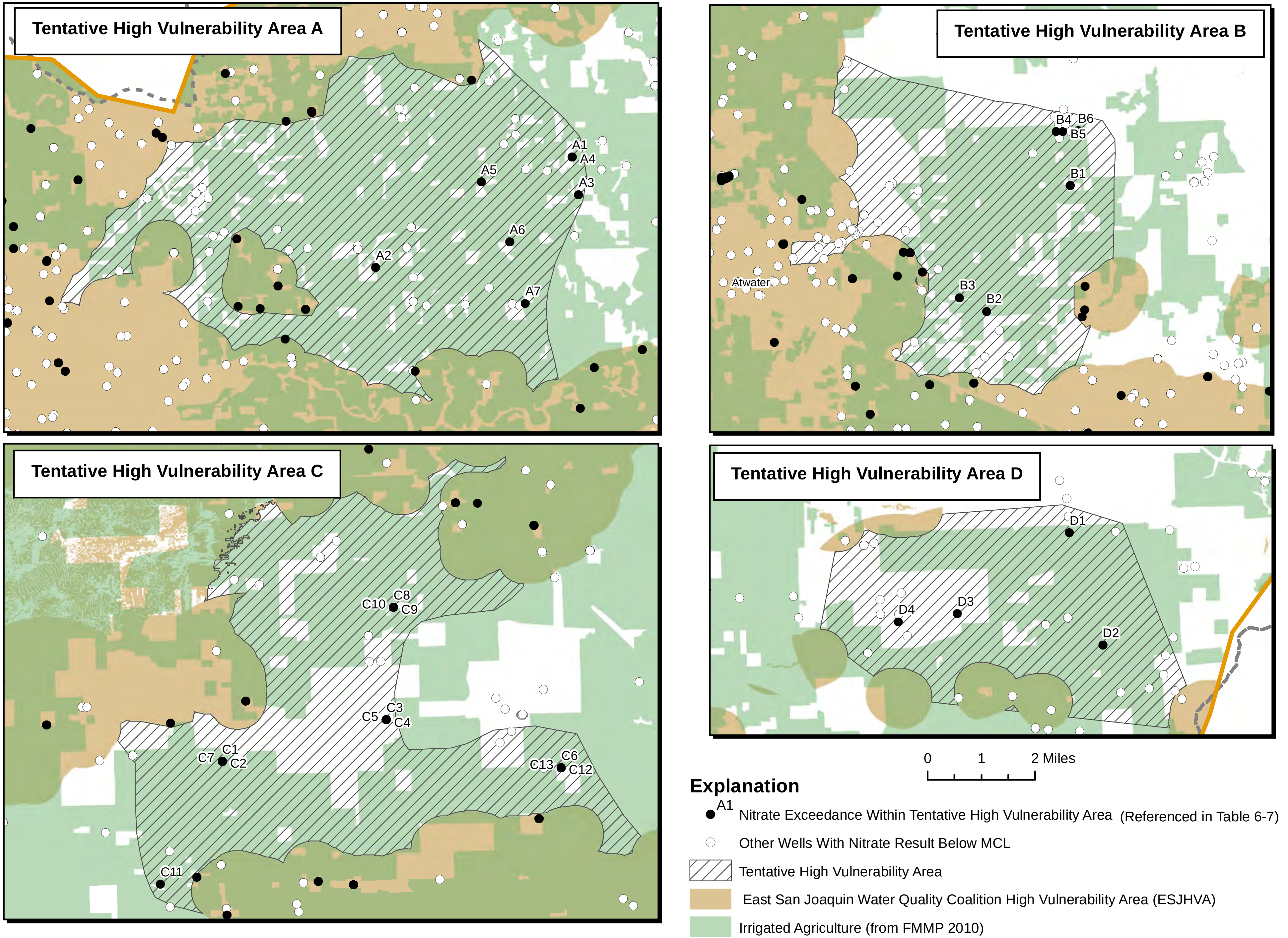


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Figure 6-25
Tentative High Vulnerability Areas

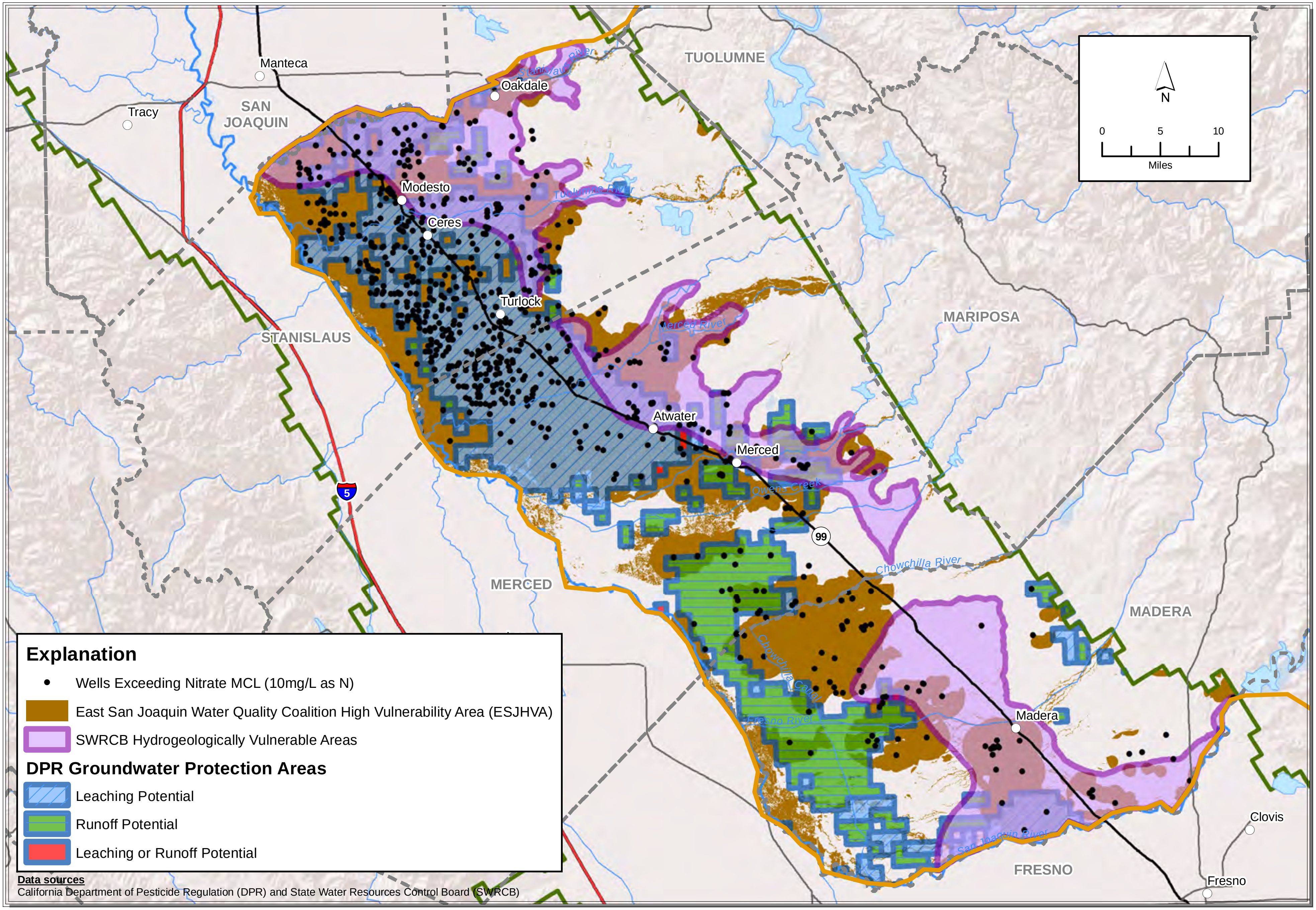

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Figure 6-26
Comparison of High Vulnerability Area Designations and Nitrate Exceedances

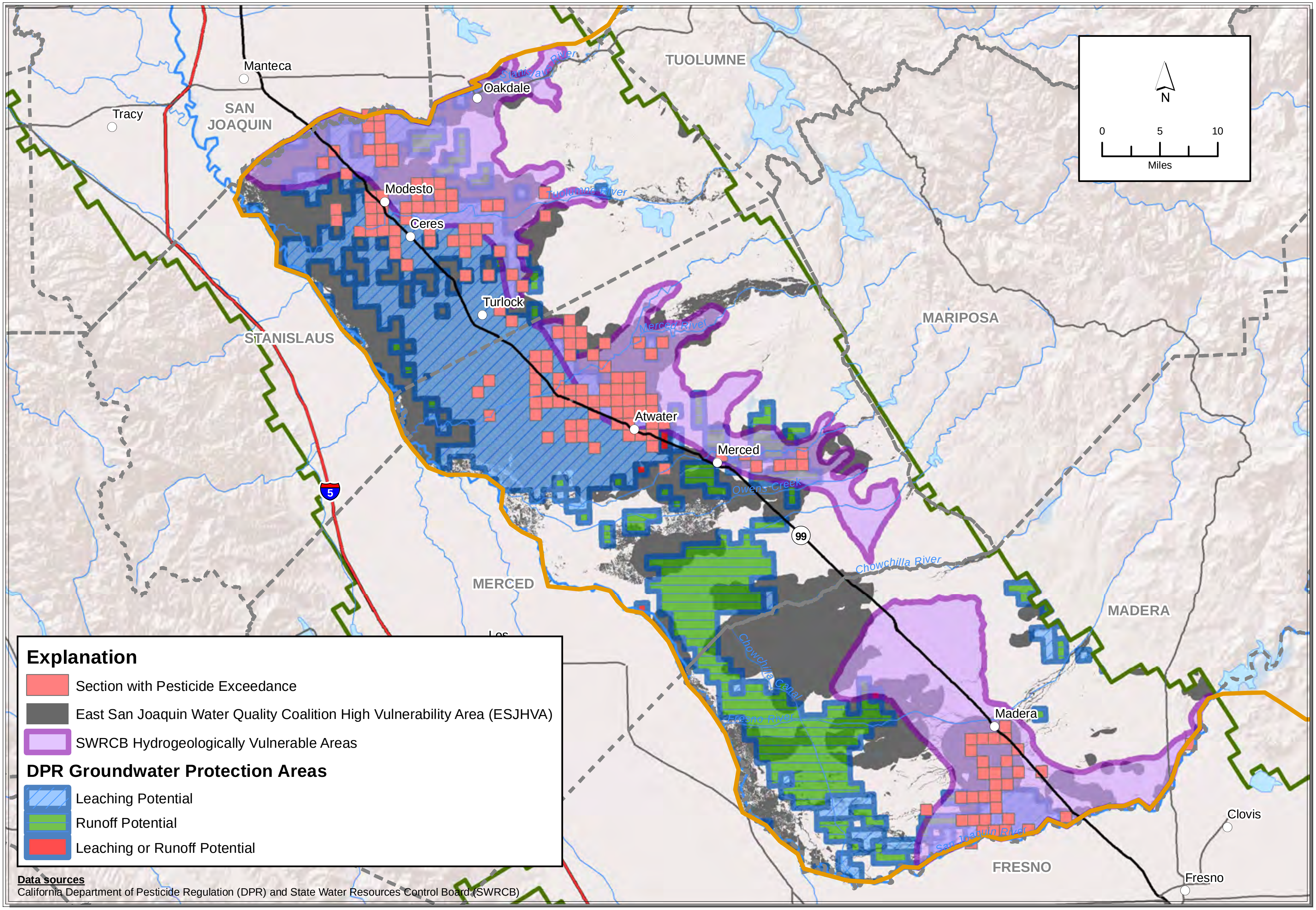

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Figure 6-27
Comparison of High Vulnerability Area Designations and Pesticide Exceedances

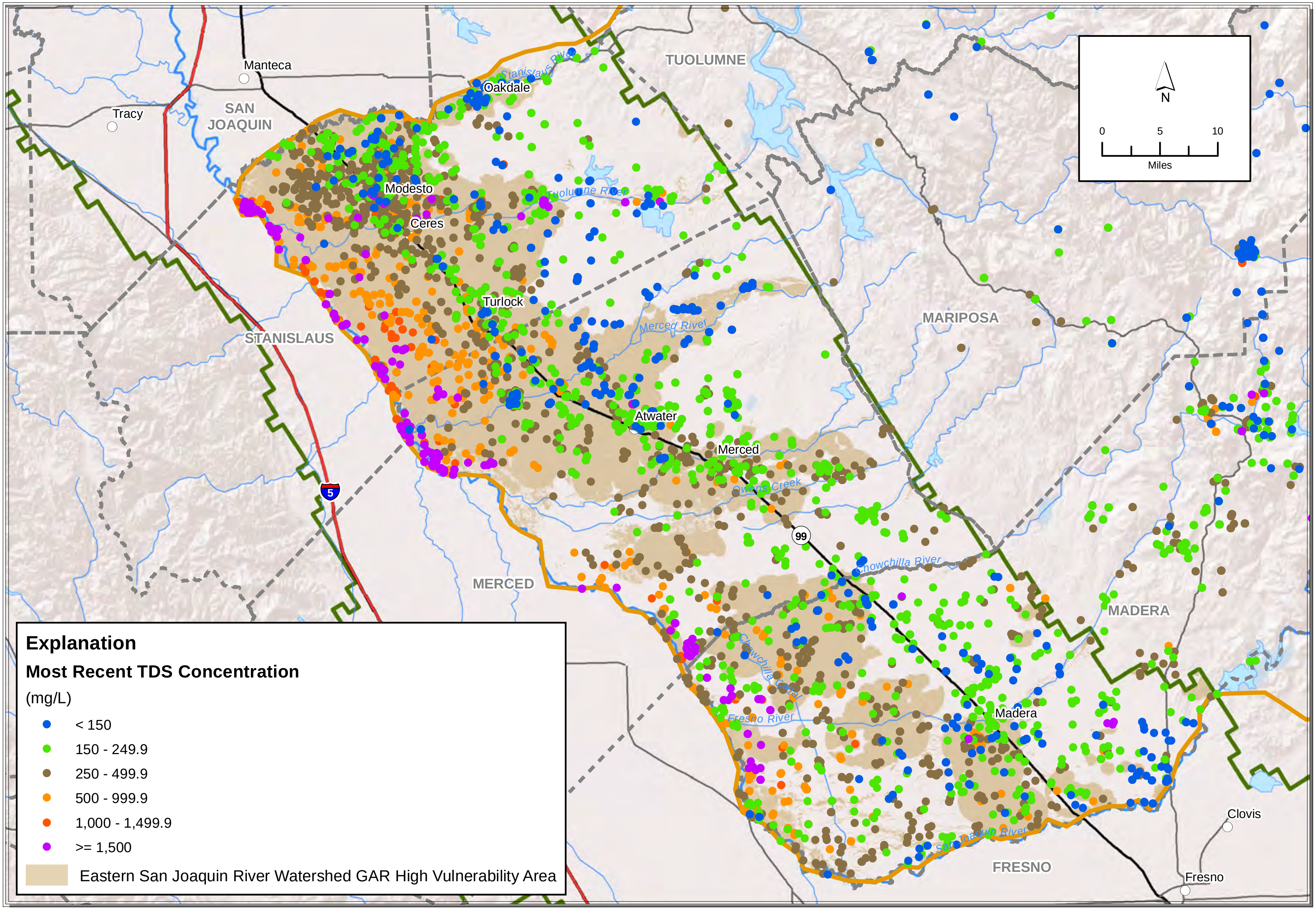

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Figure 6-28
High Vulnerability Area and TDS Concentrations

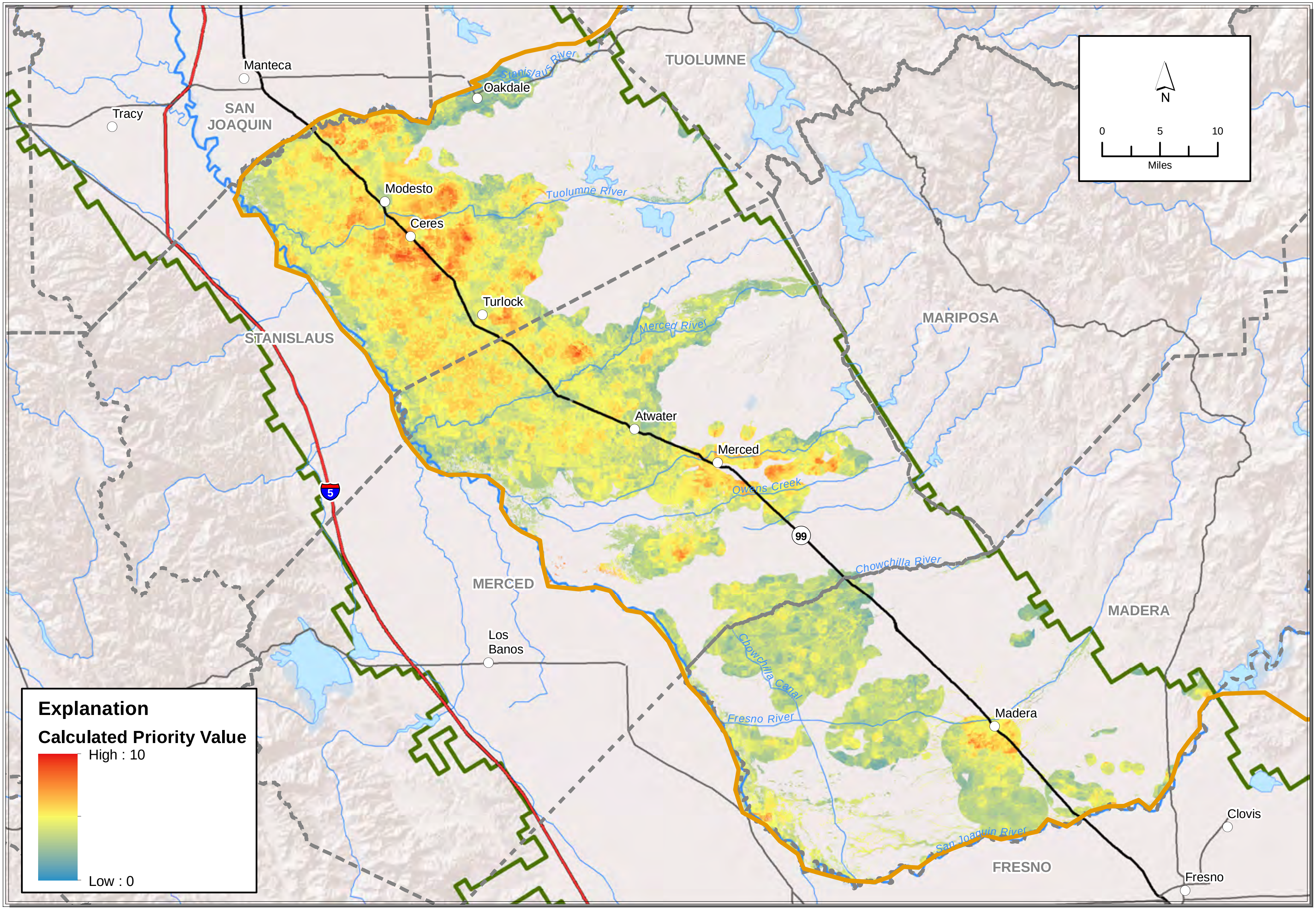

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Figure 6-29
Calculated Priority Values for High Vulnerability Area

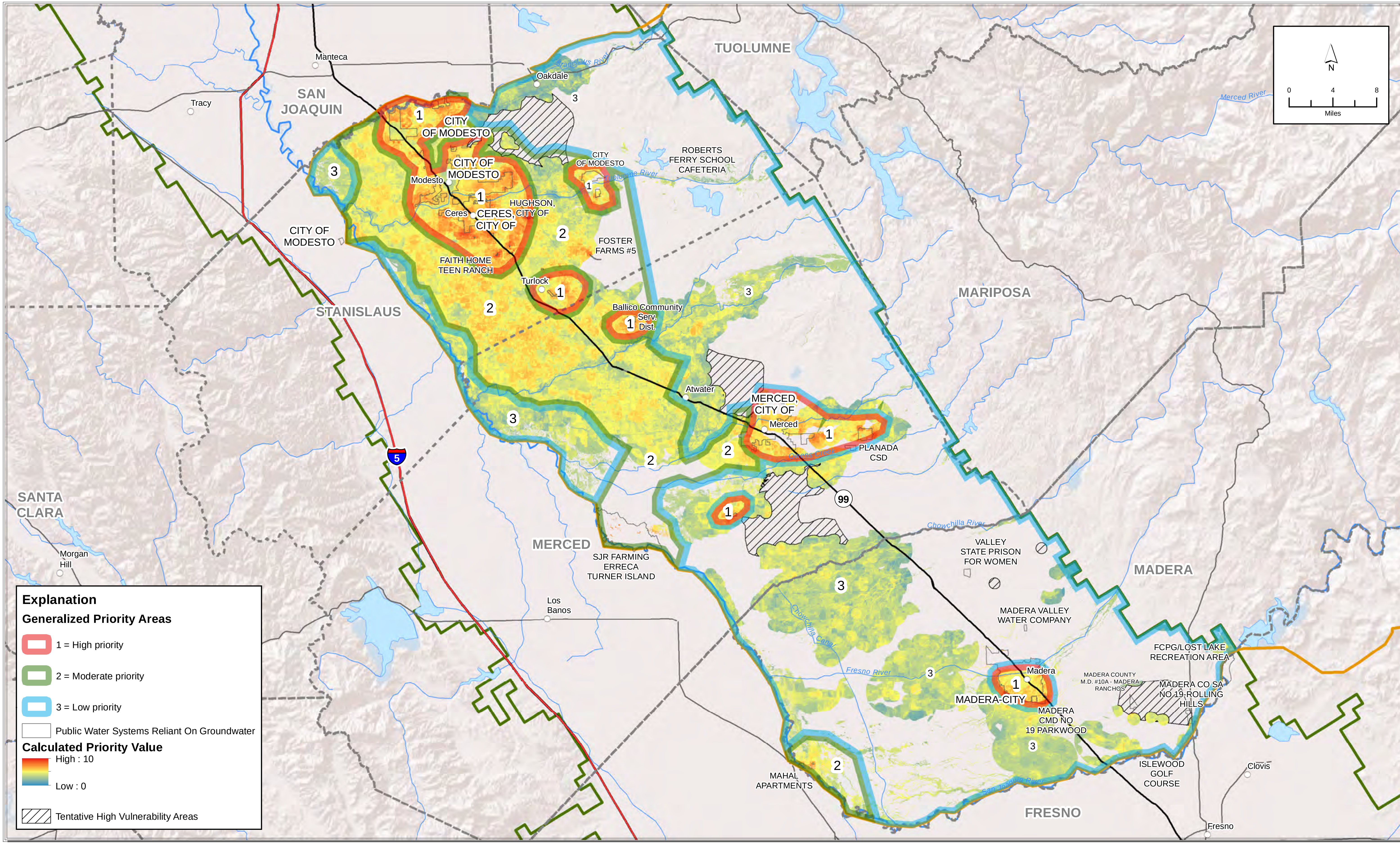

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Figure 6-30
Generalized High Vulnerability Priority Areas

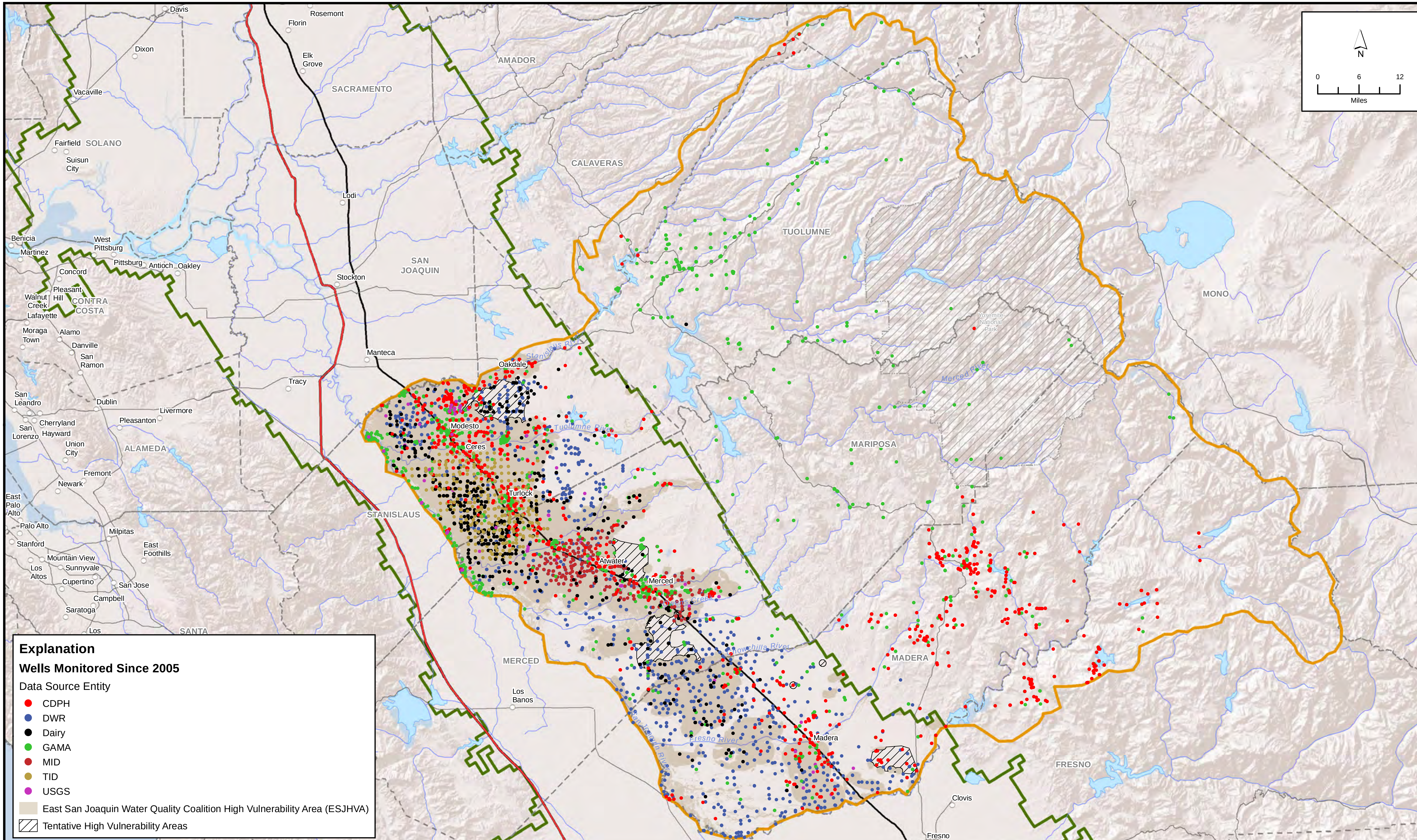

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Figure 7-1
Recently Monitored Wells By Entity

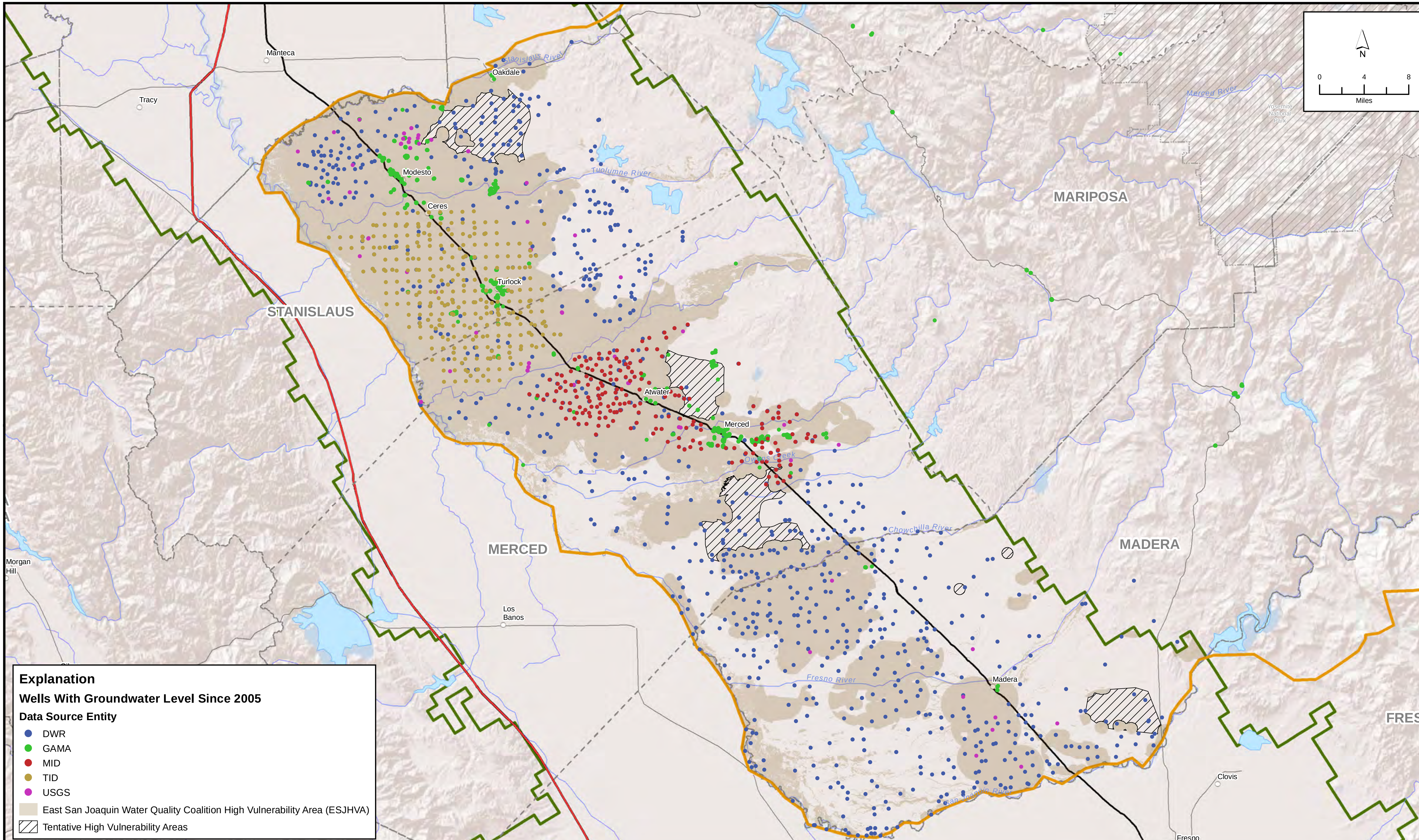

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Figure 7-2
Wells Monitored Recently for Groundwater Levels By Entity

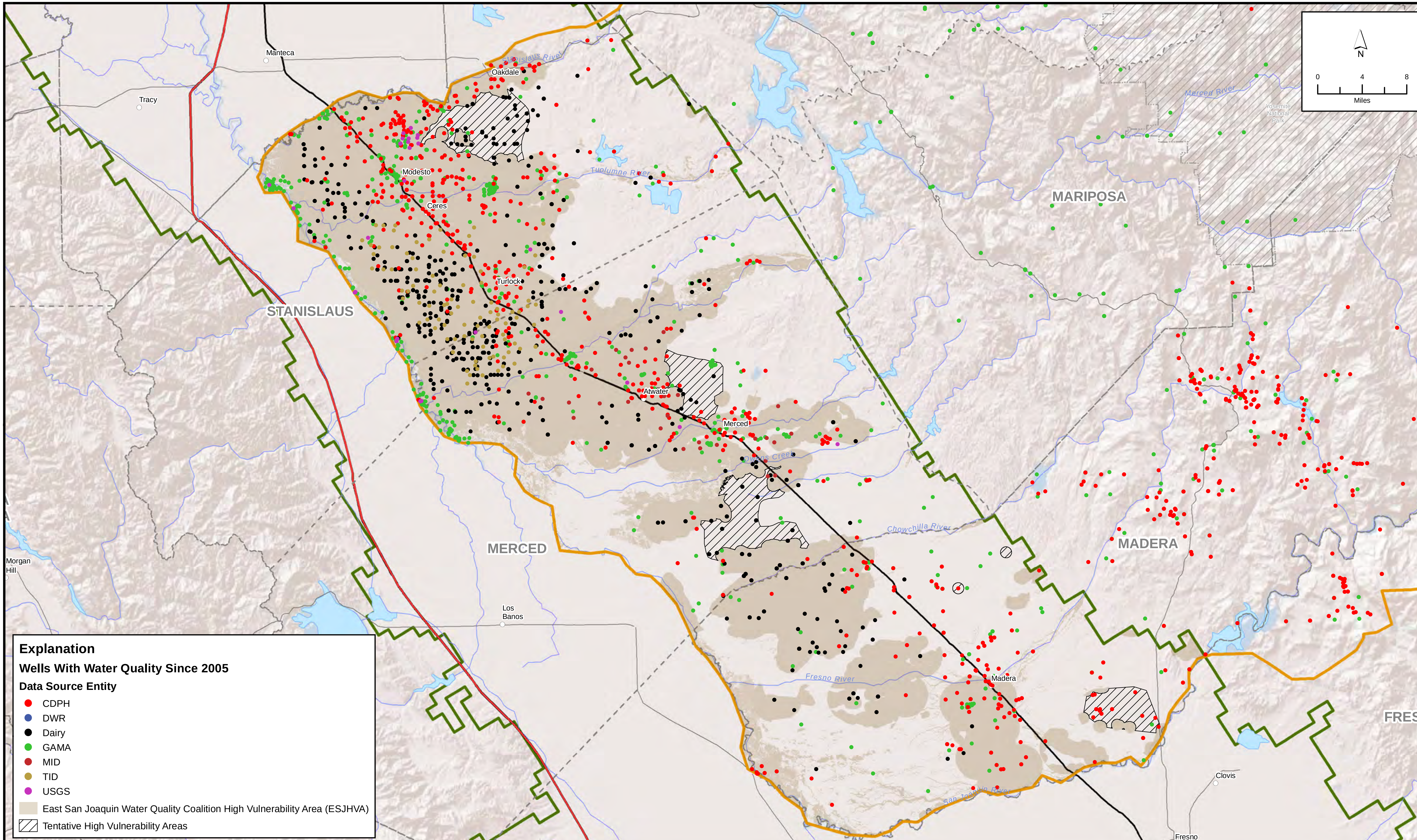

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Figure 7-3
Wells Monitored Recently for Groundwater Quality By Entity

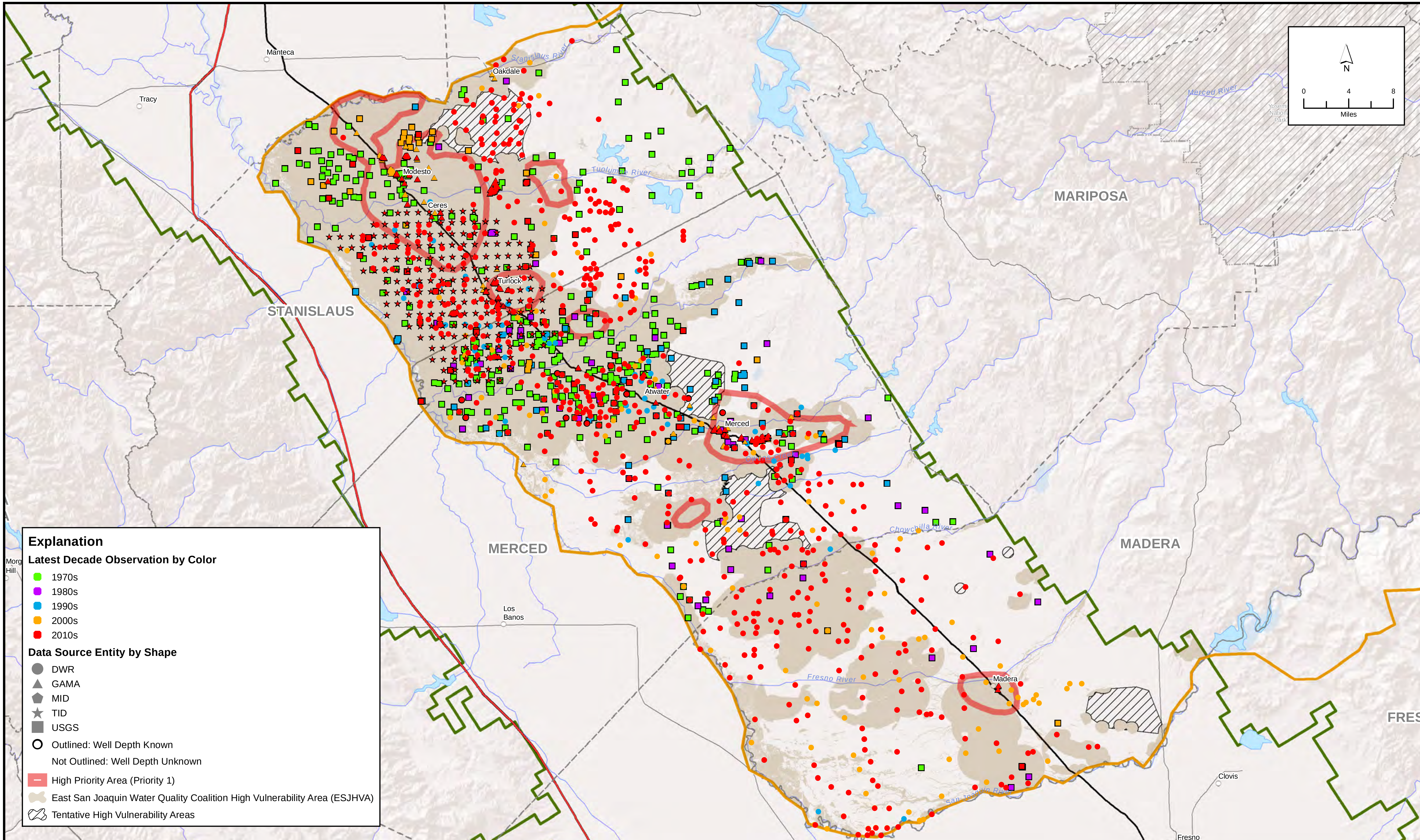

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Figure 7-4
Wells Historically Monitored for Groundwater Levels: Shallow Wells

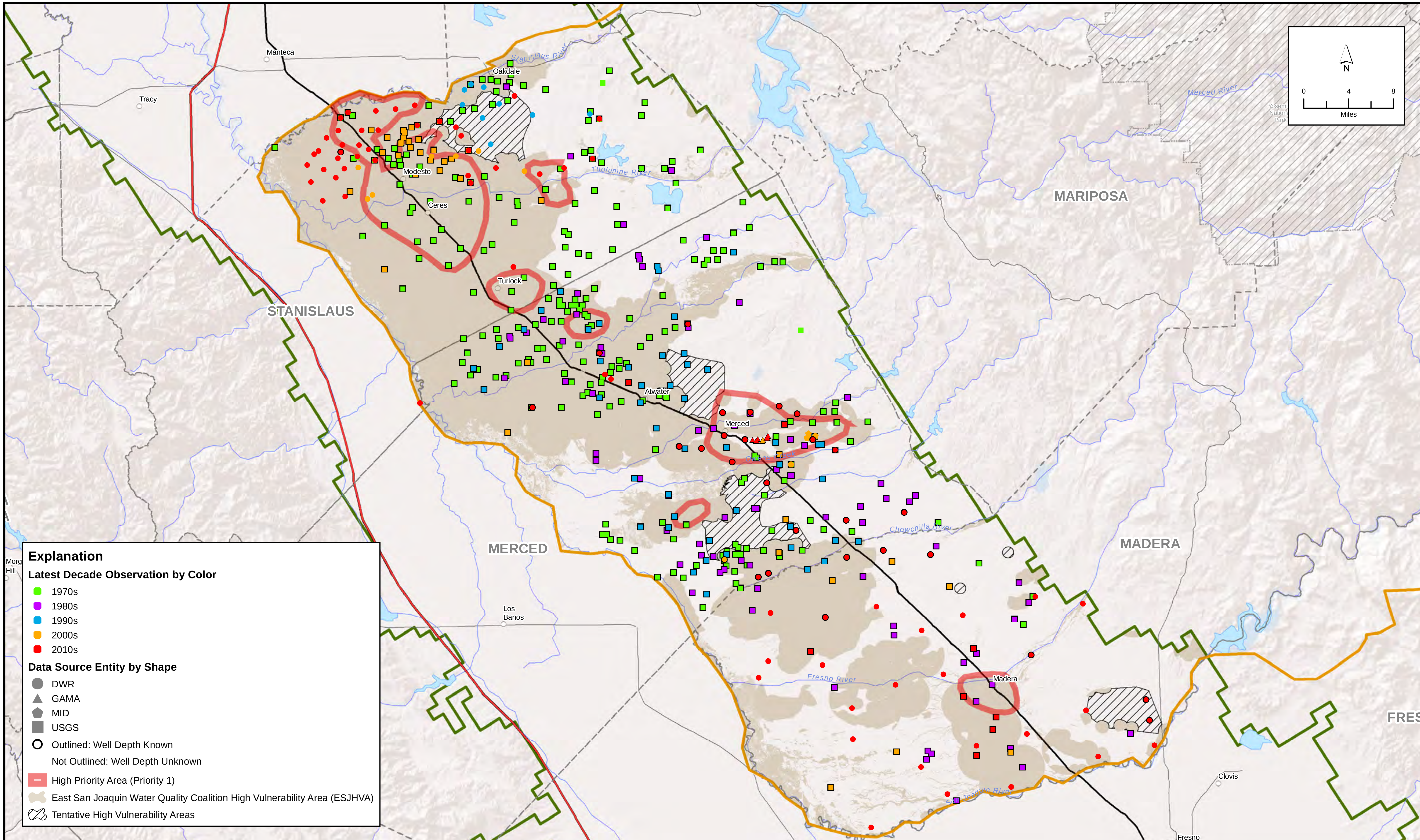

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Figure 7-5
Wells Historically Monitored for Groundwater Levels: Deep Wells

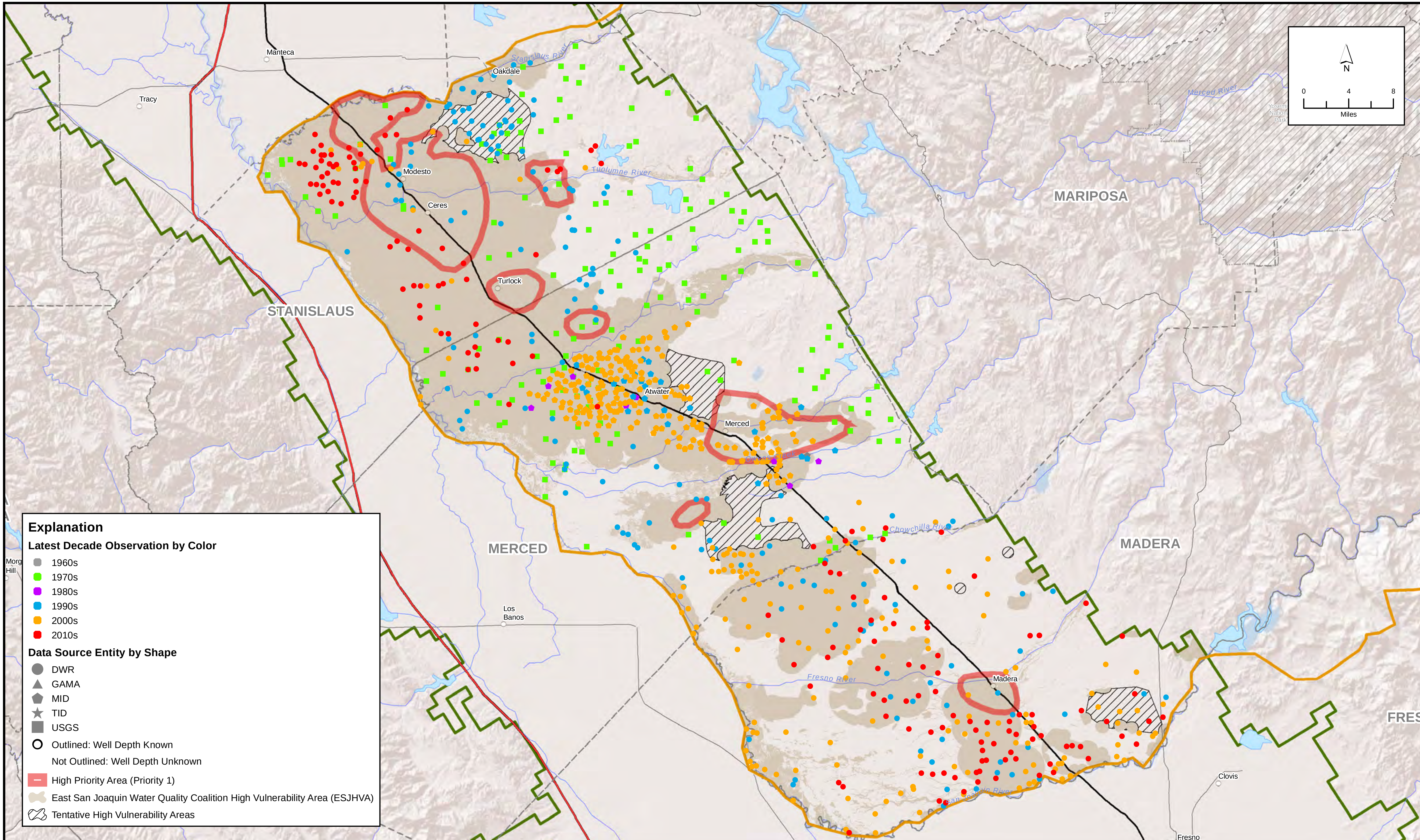

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Figure 7-6

Wells Historically Monitored for Groundwater Levels: Wells of Unknown Depth

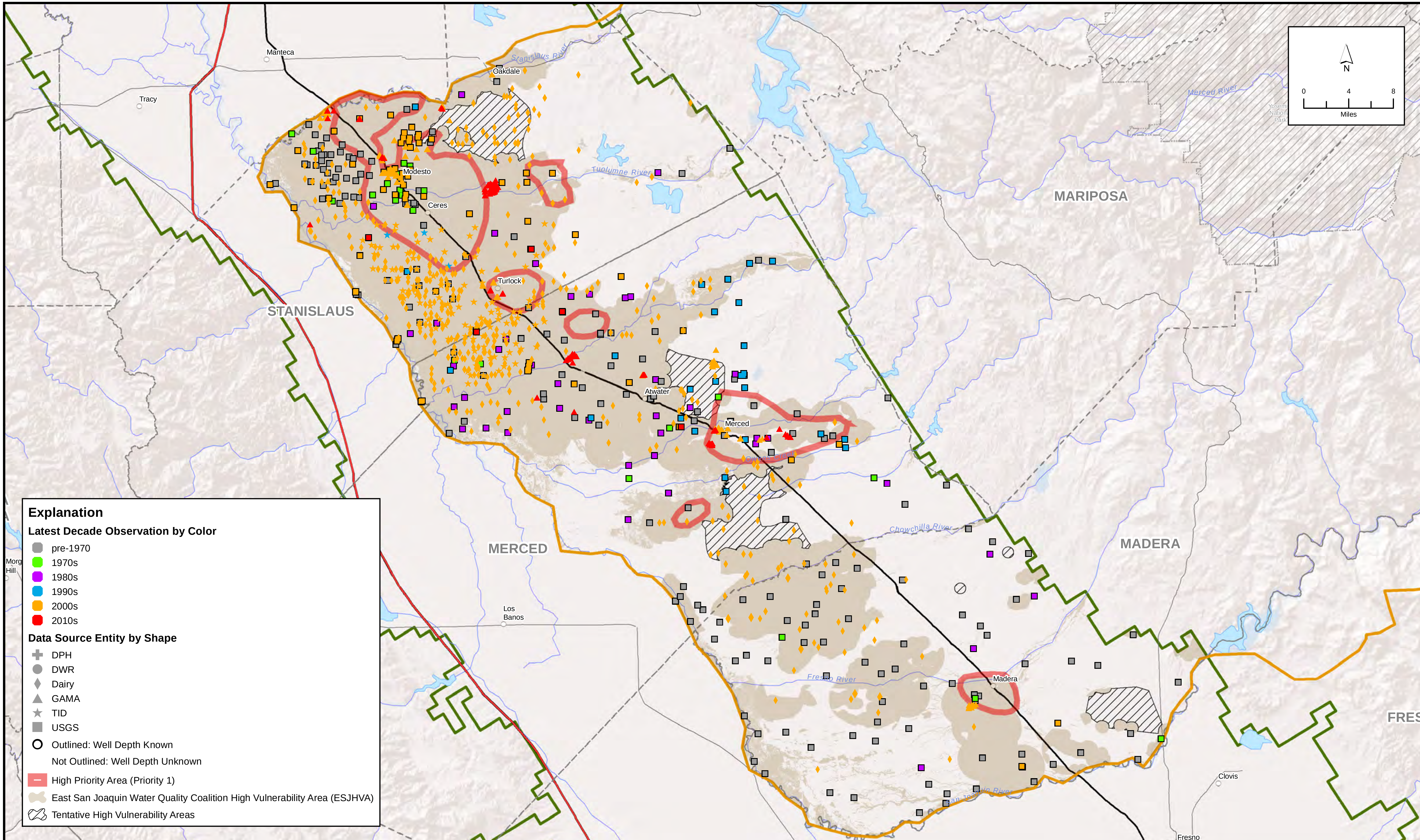

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Figure 7-7

Wells Historically Monitored for Groundwater Quality: Shallow Wells

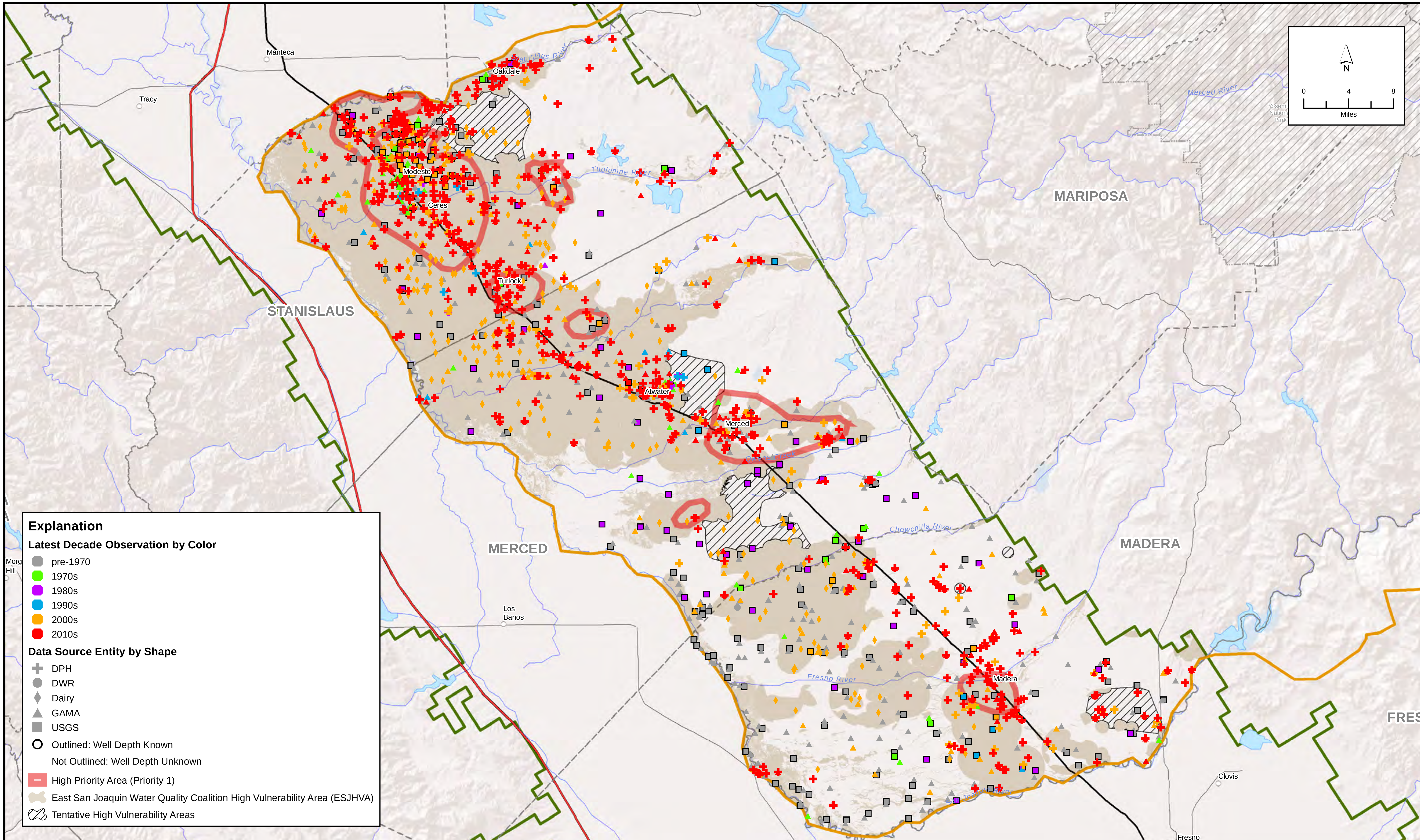

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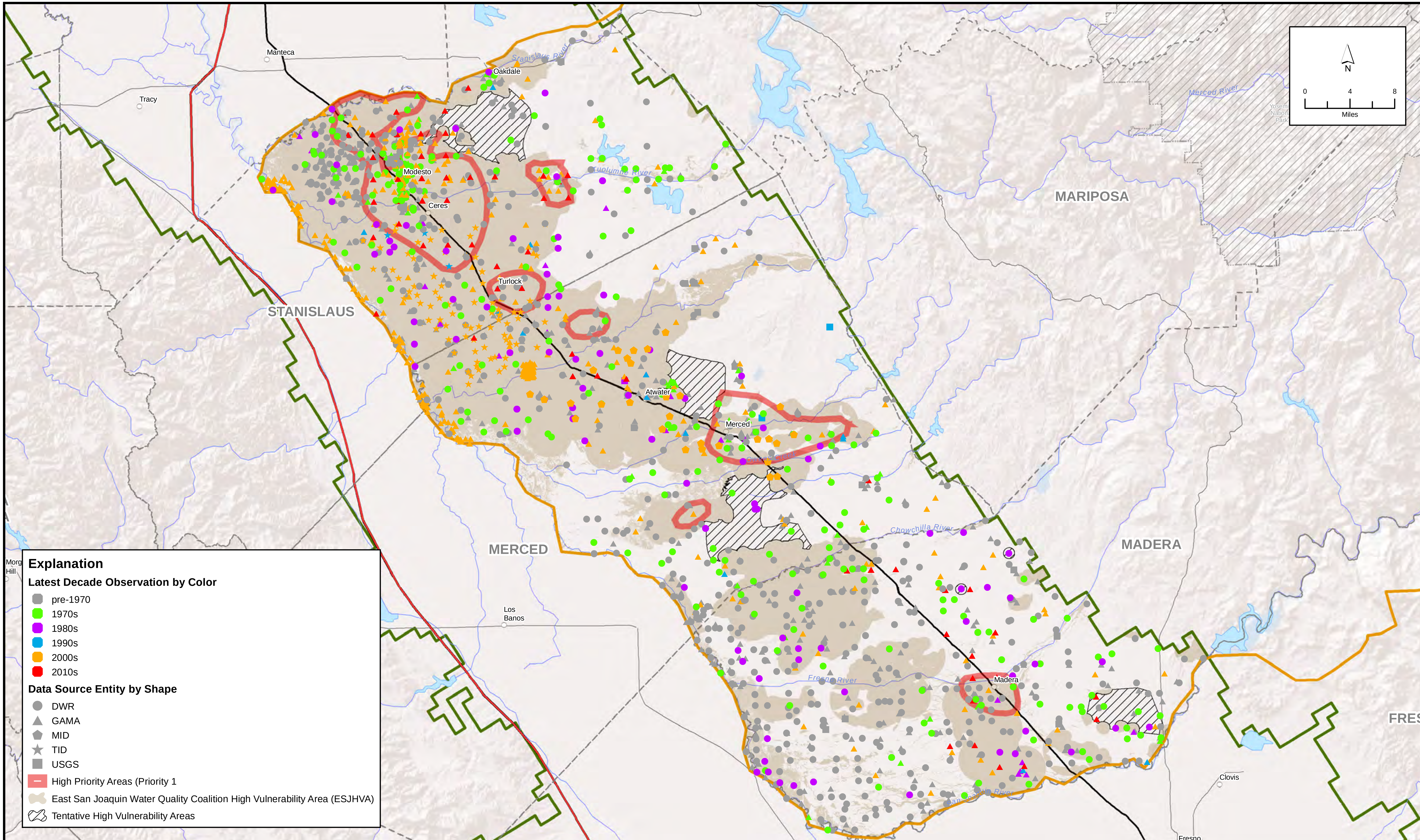
Figure 7-8
Wells Historically Monitored for Groundwater Quality: Deep Wells



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 7-9 Wells Historically Monitored for Water Quality Wells with Unknown Depth.mxd

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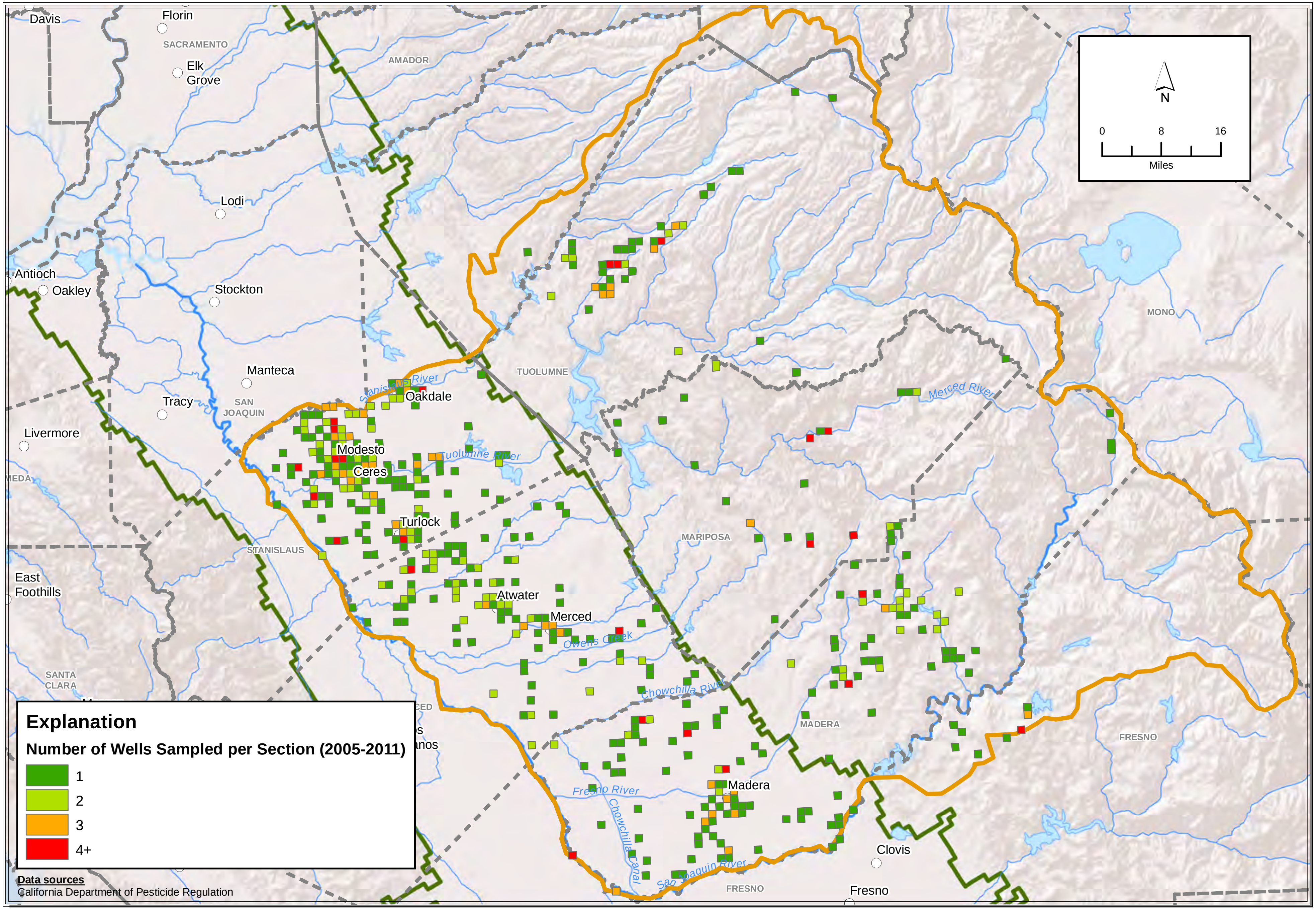
Figure 7-9
Wells Historically Monitored for Groundwater Quality: Wells of Unknown Depth



Path: X:\2012 Job Files\12-118\Report\Figures\Final GIS Map Files\Figure 7-10 Sections Recently Sampled for Pesticides.mxd

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Figure 7-10
Sections Recently Sampled for Pesticides

Figure 7-11
Summary of Recent Pesticide Monitoring
(2005-2011)