Kern River Watershed Coalition Authority

Groundwater Quality Assessment Report

Kern County, California • February 2015

Prepared for:

Kern River Watershed Coalition Authority

Prepared by:

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Kern River Watershed Coalition Authority

Groundwater Quality Assessment Report

Kern County, California
February 2015

Prepared for:
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Kern County, California

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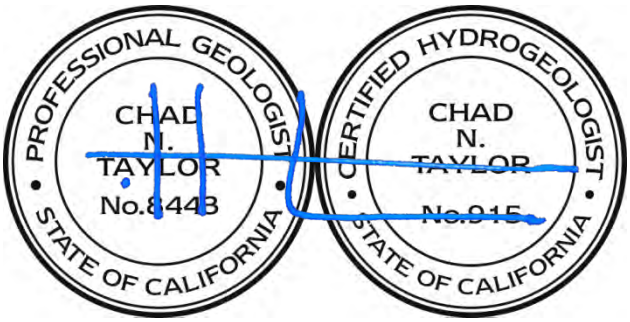

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Abbreviations

AEWSD ..... Arvin-Edison Water Storage District

AC ..... Acre

af ..... acre-foot, acre-feet

AFY ..... Acre-feet per year

AFY/AC ..... Acre-feet per year per acre

A/R Ratio ..... Applied versus removed ratio

BGS ..... Below ground surface

Board ..... Central Valley Regional Water Quality Control Board

BMP(s) ..... Best Management Practice(s)

CASGEM ..... California Statewide Groundwater Elevation Monitoring

CDFA ..... California Department of Food and Agriculture

CDPH ..... California Department of Public Health

CIMIS ..... California Irrigation Management Information System

Coalition ..... Kern River Watershed Coalition Authority

CGQMP ..... Comprehensive Groundwater Quality Management Plan

CVDRMP ..... Central Valley Dairy Representative Monitoring Program

CVHM ..... Central Valley Hydrologic Model

CVC ..... Cross Valley Canal

CVP ..... Central Valley Project

CVRWQCB ..... Central Valley Regional Water Quality Control Board

CV-SALTS ..... Central Valley Salinity Alternatives for Long-Term Sustainability

Dairy General Order ..... CVRWQB General Order for Existing Milk Cow Dairies (Order R5-2013-0122)

DAC(s) ..... Disadvantaged Community(ies)

Delta ..... Sacramento-San Joaquin River Delta

DPR ..... California Department of Pesticides Regulation

DU ..... Distribution Uniformity

DWR ..... California Department of Water Resources

EC ..... Electroconductivity

ET ..... Evapotranspiration

FT^3/day ..... Cubic feet per day

FT/day ..... Feet per day

Ft ..... Foot/Feet

GAMA ..... Groundwater Ambient Monitoring and Assessment

GAR ..... Groundwater Quality Assessment Report

General Order ..... Tulare Lake Basin General Order (Order R5-2013-0120)

GIS ..... Geographic Information Systems

GMP(s) ..... Groundwater Management Plan(s)

GPM ..... Gallons per minute

GTMP ..... Groundwater Quality Trend Monitoring Program

GWMP ..... Groundwater Quality Management Plan

GWPAs ..... Groundwater Protection Areas

HVA(s) ..... High Vulnerability Area(s)

IE ..... Irrigation Efficiency

ILRP ..... Irrigated Lands Regulatory Program

In/Yr ..... Inches per year

IRWM ..... Integrated Regional Water Management

JPA ..... Joint Powers Authority

KCEHS ..... Kern County Environmental Health Services

KCWA ..... Kern County Water Agency

KNWR ..... Kern National Wildlife Refuge

KRWCA ..... Kern River Watershed Coalition Authority

KWB ..... Kern Water Bank

LAFCo ..... Local Agency Formation Commission

LLNL ..... Lawrence Livermore National Laboratory

MCL ..... Maximum contaminant level

MHI ..... Median household income

Mg/L ..... Milligrams per liter

MPER ..... Management Plan Evaluation Report

MPEP ..... Management Practices Evaluation Program

MRP ..... Monitoring and Reporting Program

MSL ..... Mean Sea Level

N ..... Nitrogen

NHI ..... Nitrate Groundwater Pollution Hazard Index

NOA ..... Notice of Applicability

NO_3^- ..... Nitrate

NRCS ..... Natural Resources Conservation Service

NUE ..... Nitrogen Use Efficiency

Nutrient TAC ..... Nutrient Technical Advisory Committee

PAF ..... Pump and Fertilize

PHGs ..... Public health goal(s)

PLS ..... Public Land Survey

SB4 ..... Senate Bill 4 – Oil and Gas Well Stimulation Monitoring

SSURGO ..... Soil Survey Geographic

SSWS ..... State small water system

SWP ..... State Water Project

SWS ..... Small water system

SWRCB ..... California State Water Resources Control Board

SWRCB-AEP ..... State Water Resources Control Board Agricultural Expert Panel

SWRCB-DDW ..... State Water Resources Control Board Division of Drinking Water

TDS ..... Total Dissolved Solids

Third-party ..... Coalition

MHI ..... Median household income

TLB DAC Study ..... Disadvantaged Community Water Study for the Tulare Lake Basin

UCCE ..... University of California Cooperative Extension

USFWS ..... United States Fish and Wildlife Service

USGS ..... United States Geological Survey

UST ..... Underground storage tank

WDR(s) ..... Waste Discharge Requirement(s)

WSR ..... Water Supply Reports

WQO ..... Water quality objective

WRMWSD ..... Wheeler Ridge-Maricopa Water Storage District

WWTP(s) ..... Wastewater treatment plant(s)

Executive Summary

Introduction

This Groundwater Quality Assessment Report (**GAR**) has been prepared on behalf of the Kern River Watershed Coalition Authority (**KRWCA** or **Coalition**) in response to Waste Discharge Requirements (**WDR**) General Order R5-2013-0120 adopted by the Central Valley Regional Water Quality Control Board (**CVRWQCB** or **Board**) on September 19, 2013. The Tulare Lake Basin General Order (Order R5-2013-0120) (**General Order**) requires commercial irrigated land having the potential to discharge to surface water or groundwater to comply with the requirements set forth by the CVRWQCB. Compliance with the General Order requires membership in a coalition (**third-party**) or obtaining coverage through the CVRWQCB under an Individual Order (Order R5-2013-0100).

The KRWCA was established to serve as the coordinator and coalition (third-party) group under the Irrigated Lands Regulatory Program (**ILRP**) for a subarea within the Kern River Watershed portion of Kern County. KRWCA is a Joint Powers Authority (**JPA**), formed on October 1, 2011 between eleven public agencies in the region. The KRWCA boundary generally coincides with the Kern River Watershed boundary, and encompasses approximately 3.5 million gross acres of land, of which approximately 622,200 is irrigated agricultural land. As of February 4, 2015 the KRWCA had 858 growers registered as members, covering approximately 522,833 irrigated acres.

On February 4, 2014 the CVRWQCB issued a Notice of Applicability (**NOA**) to the KRWCA, approving the KRWCA to represent member owners/growers of irrigated agricultural lands within the KRWCA boundary under the ILRP. In accordance with the Section IV.A in Attachment B, Monitoring and Reporting Program (**MRP**), to the General Order, the due date for submittal of the GAR Outline was May 5, 2014. The due date for the complete GAR is one year after the issuance of the NOA to the KRWCA, February 4, 2015. The KRWCA submitted the GAR Outline to the Board on May 5, 2014, and the Board replied on August 18, 2014 with comments, approving the GAR Outline.

Objectives of the Groundwater Quality Assessment Report (GAR)

The KRWCA GAR is an integral part of implementing the ILRP through evaluation of regional groundwater conditions to facilitate long-term protection of groundwater quality. The GAR objectives include an assessment of current and historic groundwater conditions, the relationship between irrigated agriculture and groundwater quality, and a scientifically based approach to determine high and low vulnerability areas. The GAR also provides a basis for establishing workplans as specified in the MRP and identifying priorities for workplan implementation. The goal of the Management Practices Evaluation Program (**MPEP**) is to determine the effect, if any, irrigated agriculture practices have on groundwater quality, and to evaluate the effectiveness of agricultural management practices to protect groundwater quality. The Groundwater Quality Management Plan (**GQMP**) addresses groundwater quality exceedances and high vulnerability areas, as identified in the GAR, through grower outreach and education to implement protective management practices. The Groundwater Quality Trend Monitoring Program (**GTMP**) aims to determine current groundwater quality conditions as related to irrigated agriculture, and to develop long-term groundwater quality trends to assess the regional effects of irrigated agriculture and evaluate the effectiveness of the GQMP workplan.

In Attachment E, Definitions, Acronyms & Abbreviations, to the General Order, high vulnerability areas (**HVAs**) are defined as regions 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…areas (wherein) (1) there is a confirmed exceedance (considering applicable averaging periods) of a water quality objective or applicable water quality trigger limit…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."*

The methodology used to identify high vulnerability of groundwater related to irrigated agricultural practices within this GAR accounts for existing groundwater quality conditions as well as surface activities. Agricultural impacts were evaluated by utilizing the State Water Resource Control Board's (**SWRCB**) Nitrate Groundwater Pollution Hazard Index (**NHI**), an index value that is determined from the crop type, soil type, and irrigation type of a given agricultural management system. Groundwater quality conditions were analyzed from historical and current monitoring data for the primary constituents of concern, nitrate and pesticides. The high vulnerability area (**HVA**) also includes areas designated as Groundwater Protection Areas (**GWPAs**) within the KRWCA primary boundary that are considered vulnerable to pesticide leaching by the California Department of Pesticide Regulation (**DPR**).

The KRWCA HVA was analyzed with three distinct parameters to identify priority regions to facilitate the implementation of the various workplans outlined in the MRP. The prioritization framework utilizes an evaluation of relative hydrogeologic (intrinsic) sensitivity, HVAs upgradient of public groundwater supply wells, and the NHI.

The data compiled in the KRWCA GAR includes publicly available data spanning back in some cases prior to 1968. As more recent and applicable data is gathered through the various workplans as specified in the MRP (e.g. MPEP, GTMP, etc.), and other continuing independent and/or public research, the KRWCA reserves the right to update the GAR as applicable. This is including, but not limited to, groundwater quality results, the NHI, and basin plan amendments.

As also stated elsewhere in the GAR, KRWCA and its members do not waive any of their rights or positions to be advanced in their pending appeal with the SWRCB of General Orders R5-2013-0120 and R5-2013-0100, and the KRWCA reserves the right to revise this GAR consistent with the outcome of those and further proceedings related to the CVRWQCB General Orders for the ILRP.

Kern River Watershed

Section 1 outlines the general characteristics of the KRWCA region. The KRWCA boundary area is separated into the primary boundary, which includes the valley floor, and a secondary boundary that contains very little irrigated acreage (**Figure ES-1**).

The primary boundary is comprised of approximately 1,023,600 gross acres of land that is within the boundary of the Kern groundwater subbasin; of which includes approximately 619,200 irrigated acres on the San Joaquin Valley floor. The Upper Kern River Watershed is located almost exclusively within the KRWCA secondary boundary and encompasses approximately 1.5 million acres in the southeastern

portion of the San Joaquin Valley. Approximately 622,200 acres in the KRWCA primary and secondary boundary is irrigated agricultural land, 18 percent of the total area. Of the non-irrigated acres in the KRWCA primary boundary, approximately 97,600 gross acres are classified as urban, commercial, or industrial areas. The largest population center in the KRWCA is the City of Bakersfield.

Kern County has the second largest economic value of agricultural counties in the state and nation, producing over 250 crops; including 30 types of fruit and nuts, over 40 varieties of vegetables, over 20 field crops, lumber, nursery stock, livestock, poultry and dairy products. Overall, the proportion of permanent crops grown in Kern has increased significantly in the past 20 years and in nearly all cases the permanent crops are irrigated with highly efficient drip and/or micro spray irrigation systems. Current irrigation efficiencies in the Kern Subbasin are, overall, some of the highest in the entire Central Valley.

Surface water supplies utilized in the KRWCA region include the State Water Project (**SWP**) and Federal Central Valley Project (**CVP**) via the California Aqueduct, CVP supplies via the Friant-Kern Canal, and local supplies from the Kern River and Poso Creek. Groundwater from the Kern Subbasin is necessary to maintain a sufficient water supply in the region due to the arid climate and minimal rainfall. It is estimated that groundwater accounts for approximately 39 percent of the total water supply in the region; however, during dry years it can increase to as much as 60 percent.

Soil & Land Use Characteristics

In the KRWCA primary boundary area on the Kern County valley floor, soils have two general origins that are approximately delineated by the trough of the valley. The eastern alluvial fans were deposited primarily by the precipitation and runoff from the Sierra Nevada, Tehachapi, and Transverse Mountain ranges. These soils are of igneous and metamorphic origin; are typically well drained, very low in salinity, and ideal quality for agriculture. The western alluvial fans originated from Coastal Range sedimentary rock formed on the sea bottom. This region tends to have more areas with poorly drained soils of relatively marginal quality. **Section 3** provides a full analysis of regional soil and land surface characteristics.

Soils within the KRWCA primary boundary can generally be categorized into three types according to texture, which are also indicative of other soil characteristics, such as electroconductivity (**EC**) and pH. Fine-textured soils (dominated by clay) are found in the southwest and northwest corners of the area. The northwest corner generally does not include irrigated agricultural land, and the southwest corner is comprised of the historic Buena Vista and Kern lakebeds, and swamp and overflow lands. These soils are also saline and high in pH in some areas, requiring some reclamation before crops can be grown profitably. The remainder of the primary boundary area includes medium to coarse-textured soils which are relatively low in salinity and within the optimal pH range for crop production.

Soil salinity can increase on irrigated land if soils are not properly leached to allow salts to migrate (with water) below the root zone. To manage salts, irrigated water is applied in excess of crop consumption, the leaching fraction, an important management practice in irrigated agriculture. The leaching fraction is considered to be included in required crop water requirements, as it is beneficial to agricultural systems.

Reviewing historical land use data within the KRWCA primary boundary illustrates the change in crops and irrigation systems that has occurred in recent history; specifically, a shift to permanent crops and drip/micro irrigation. See **Section 2** for relevant analysis and mapping. Cotton, field crops, alfalfa, and

truck crops made up almost 80 percent of the cropped irrigated acreage (not including multiple counting of double and triple cropped fields) in 1990; however, almond, grape, and citrus were also significant individual crops at this time. The total cropped commodity acreage within the primary boundary is 806,000 commodity acres (including multiple counting of double and triple cropped fields) in 2013. The total 2013 irrigated acreage (aerial extent) within the KRWCA primary area is 619,241 irrigated acres. Cotton acreage fell to less than 20 percent of its acreage in 1990; while almond and pistachio acreage increased from 62,000 to 162,000 irrigated acres and 3,000 to 44,000 irrigated acres, respectively.

At the field level, agriculture has generally expanded within the KRWCA area in recent history, but has likely reached its peak because of limited land and water resources. Some crop types are concentrated in certain areas, likely because of soil types and microclimates that are suitable for those crops, while others are distributed throughout the KRWCA area.

Surface (gravity) irrigation systems were the first irrigation systems used in agriculture and include furrow, basin, and border strip types. Sprinkler (pressurized) irrigation distributes water over the crop and imitates rainfall; these systems include center pivot and lateral move configurations. Micro-sprinklers include piping networks and distribute water at the soil surface, but in a more targeted and precise manner, relative to the crop root zone. Drip irrigation includes piping networks with direct water delivery points in surface and subsurface systems, delivering low volume irrigation water directly to root zones. Irrigation is currently the single most expensive component of agricultural production in Kern County. The most common irrigation type is drip and/or micro-sprinkler, which is typically the most efficient and uniform irrigation application method. Use of pressurized irrigation systems has increased with the introduction of permanent crops, but use is also increasing on annual crops where studies have shown success; such as tomatoes to save water and increase yield. Surface irrigation is typically the least efficient irrigation method, but it can be relatively efficient and uniform if it is optimally designed and used in conjunction with appropriate soils and/or field slopes. See **Section 4** for additional irrigation management practices.

Growers in the KRWCA generally employ a high level of nutrient management to meet crop needs because fertilizer is a large expense, in addition to the environmental concerns associated with over-application. Accompanying the widespread conversion from gravity irrigation systems to pressurized systems is the increasing use of fertigation, where liquid fertilizer is delivered to the crop in irrigation water.

Groundwater Characteristics

The primary KRWCA area is located mostly within the southern portion of the San Joaquin Valley, which is comprised of up to 10,000 feet of marine and continental sediments. The secondary KRWCA area extends over a large area of varying geologic and hydrogeologic environments, including upland areas of igneous and metamorphic rock and small valleys filled with continental sediments. The primary portion of the KRWCA area is located almost entirely in the areas of recent alluvium deposition, and the contiguous portion of this area is on the floor of the San Joaquin Valley.

The entire KRWCA area is in the Tulare Lake Hydrologic Region (DWR, 2003). The primary portion of the KRWCA area includes parts of four DWR designated basins:

- The Kern County Portion of the San Joaquin Groundwater Basin (Kern County Subbasin);
- The Cummings Valley Groundwater Basin;

- The Tehachapi Valley West Groundwater Basin; and,
- The Brite Valley Groundwater Basin.

There are two separate sources of groundwater in the secondary portion of the KRWCA; groundwater from designated groundwater basins and small alluvial aquifers, and groundwater from fractured bedrock. There are seven designated groundwater basins in relatively small alluvium-filled valleys present in the secondary area. **Section 5** provides additional analysis of the characteristics of the primary and secondary subbasins as well as the subsurface sediments. The assessment focused on the Kern County Subbasin, as the majority of the primary portion of the KRWCA area overlies this aquifer, and there is very little distinct information regarding the other groundwater sources in either the primary or secondary areas. The United States Geologic Survey (**USGS**) Central Valley Hydrologic Model (**CVHM**) estimates of vertical and horizontal aquifer parameters for the entire Central Valley, were used throughout the GAR to represent relative aquifer parameter distribution in the Kern Subbasin. DWR data indicates shallow groundwater areas on the west side of the valley floor, in the historical lake beds, and swamp and overflow land areas, that can be attributed to the presence of thick, shallow, continuous clay layers (DWR, 2014c).

The Corcoran Clay is a regionally extensive low permeability unit located in much of the San Joaquin Valley (Croft, 1972). Pervious assessments of hydrogeologic vulnerability used the absence of the Corcoran Clay to indicate vulnerable areas. However, in Kern County, the Corcoran Clay is not considered to be as low permeability, or function as a continuous aquitard or barrier to vertical flow as it does in the in other portions of the Central Valley. The Corcoran Clay is also present at deeper depths in the KRWCA than in other areas of the Central Valley (Schmidt and Associates, 2006 and Schmidt and Crewdson, personal communication, October 2012).

Groundwater Quality

The constituents of focus cover the most likely constituents to impact groundwater from irrigated agriculture, including nitrate and pesticides. Salinity was also analyzed using total dissolved solids (**TDS**) as a proxy, but there is insufficient understanding of historic and current hydrogeologic processes to perform source evaluations of TDS present in the KRWCA area. As a result, no attempt to distinguish between naturally occurring high salinity areas, such as the marine deposit and lakebed environments of the KRWCA, and anthropogenic sources of TDS has been included in this study. See **Section 6** for mapping and analysis of TDS impacts.

Water quality data available from 1909 through 2014 was analyzed for exceedance of maximum contaminant limits throughout the KRWCA area. A geostatistical analysis of the historical and current data was used to further illustrate areas where groundwater quality has historically been negativity impacted. The maximum concentration for all wells (nitrate, pesticides, and TDS) was calculated within a grid cell, and the resulting value was taken to represent the maximum concentration in that area for the respective constituent. The area discretization for this analysis was the square mile grid for the USGS CVHM.

Nitrate (**NO_3^-**) is a naturally occurring form of nitrogen that can be produced from the atmosphere or decomposing organic matter. Naturally occurring nitrate concentrations generally do not exceed 20 milligrams per liter (**mg/L**) nitrate as nitrate in groundwater (Todd, 1980 and Hounslow, 1995). Nitrate can also be found in groundwater as a result of excess application of nitrogen fertilizers in irrigated agricultural and landscaped areas, runoff from feedlots or dairies, wastewater and food processing

waste percolation, and leachate from septic system drainfields (Harter, T. et al., 2012). For this study, the maximum contaminant limit (**MCL**) of 45 mg/L nitrate as nitrate has been used to identify nitrate impacted groundwater. The distribution of maximum concentrations of nitrate illustrated the highest nitrate concentrations are located on the edges of the primary area, specifically in the eastern portion, the very southern portion and a small group located outside the primary area boundary in the upper elevations to the east. The geostatistical analysis conducted using the groundwater quality data resulted in the existing nitrate impacted area shown on **Figure ES-2**.

DWR completed a nitrate evaluation of the San Joaquin Valley in 1970, which plotted maximum nitrate concentrations found by public land survey (**PLS**) sections in Kern County from records for 1950 through 1969 (DWR, 1970). Spatial analysis of the nitrate impacts indicates that much of the nitrate exceedance area defined in **Section 6** was already above the MCL in 1970. This correlation is particularly evident throughout the eastern rim and southwestern portion of the KRWCA primary region. **Figure ES-3** provides an overlay of the nitrate impacted area identified in the GAR and the historical DWR findings. As irrigated agriculture began in the late 19th century and regional travel times range from decades to centuries, it is plausible to deduce that the impacts recorded in the 1970 DWR report may be the result of early, inefficient, agricultural practices and/or natural sources.

Sources of pesticides in the environment include applications to agricultural and lawn and garden areas, golf courses, and road or railway weed control. Concentrations in most water bodies are low, generally ranging from 10^{-5} to 10^{-3} mg/L (Chapman and Kimstach, 1992 and Montgomery, 1993). There are at least 146 individual chemical compounds that indicate pesticides in water quality samples. Pesticide impacted groundwater in the KRWCA area was identified by an exceedance of the respective MCL for detected constituents. Pesticides or pesticide-related products have been detected in more than 1,000 of the over 5,000 wells with pesticide sampling results in the KRWCA area. The detections and exceedances are located in different parts of the primary portion of the KRWCA area, and do not appear to have a spatial trend. The pesticide impacted area, developed using the CVHM grid methodology, is shown in **Figure ES-4**.

For this analysis, it is assumed that all groundwater quality results represent first encountered groundwater; however, construction information is available for very few wells with groundwater quality sampling. Future monitoring programs should include the collection of well construction data to provide additional information on the vertical distribution of these constituents over time.

Groundwater Hydrology

The groundwater hydrology of the KRWCA area is considered notable within the Tulare Lake Hydrologic Region (**TLHR**) due to the regional groundwater basin configuration, hydrologic stresses, and depth to first-encountered groundwater. As noted in the expert report submitted to the CVRWQCB, these unique aspects represent spatial and temporal disconnects throughout the KRWCA area which may potentially complicate the groundwater monitoring required by the General Order (Gailey 2013). There is very little information regarding groundwater conditions in the secondary portion of the KRWCA, especially groundwater level information.

Based on annual spring groundwater elevation contours prepared by KCWA for 2000 through 2013 (KCWA 2014), the highest groundwater elevations in the period were in the spring of 2007 and the lowest occurred in the spring of 2013. The wet period (spring 2007) unconfined aquifer depth to groundwater ranges from less than 50 feet below ground surface (**bgs**) to over 700 feet bgs. The

deepest groundwater depths occur in the southern portion of the KRWCA primary area. The dry period (spring 2013) unconfined aquifer depth to water contours are similar but show that groundwater is generally 30 to 80 feet lower. The dominant groundwater elevation trends in the area are the large variations near the Kern River on the Kern Fan, produced by the high volumes of managed groundwater recharge and extractions associated with groundwater banking projects. These effects dissipate away from the Kern Fan, where groundwater elevation patterns are more muted and show seasonal effects, short term responses to wet and dry periods, and long term groundwater declines.

Given the significant variations in groundwater elevations that occur throughout the Subbasin in response to variations in hydrologic conditions, no single groundwater elevation surface should be taken to be representative of groundwater flow directions. Therefore, a combined groundwater elevation surface was generated to represent trends in groundwater elevation and flow directions throughout the Subbasin. These flow directions show that average groundwater flow north of the Kern River is generally towards the north and center of the Subbasin, focused on low average elevations in the north. South of the Kern River, groundwater flow is less uniform; flowing from local highs associated with high volumes of recharge towards localized pumping centers (**Figure 7-10**).

Groundwater recharge is the sum of the hydrogeologic processes by which water percolates into a groundwater aquifer, and is a function of available water and permeable materials at the ground surface. Recharge areas are a "primary" net benefit to water quantity, and high source water quality may provide a "secondary" net benefit by diluting the concentrations of groundwater constituents. Estimates and descriptions of natural recharge, agricultural return flows, municipal return flows, industrial discharges, and enhanced recharge can be found in **Section 8**.

Natural recharge, a function of precipitation, evapotranspiration (**ET**), and soil moisture holding capacity, is limited in the primary area and cannot be estimated for the secondary area. Agricultural return flow is the water that runs off crop land and/or percolates past the root zone in excess of the crop needs, or root zone water holding capacity. KCWA estimates the total agricultural return flow in Water Supply Reports (**WSR**) ranges from 378,000 acre-feet per year (**AFY**) to 753,000 AFY. Municipal return flow results from precipitation and water applied to the ground surface in municipal settings or percolation from stormwater detention basins. In Bakersfield, the estimated return flow from 2006 through 2010 was 9,100 AFY over a combined service area of 65,587 acres, or 0.14 AFY/ac.

Treated wastewater is regulated by the CVRWQCB under specific individual waste discharge requirements (**WDRs**). Recharge from septic systems is significant in the KRWCA, but is not measured or estimated. Recharge from wastewater generated by food processing, confined animal facilities, and other industries are also significant, but are generally also regulated under individual WDRs.

Enhanced recharge and banking is performed in the area through various mechanisms, including canal seepage as water is conveyed, recharge ponds, and seepage from reservoirs. In-lieu recharge activities that displace groundwater use with surface water were not evaluated in this assessment. There are a number of enhanced groundwater recharge projects in the KRWCA area.

To identify areas upgradient of public groundwater supply wells a well capture zone analysis was utilized. Capture zones for all defined public groundwater supply wells were estimated using uniform flow equations (Todd and Mays, 2005). The uniform flow equations are a means of approximating the area of an aquifer that contributes flow to a well operating in a sloping groundwater surface. This methodology was employed in the HVA prioritization framework, described in detail in **Section 11**.

Data Review & Analysis

Section 9 outlines the conclusions drawn from review of available data, and the limitations thereof, for land use and crop types, soil characteristics, irrigation and agricultural management practices, hydrogeology, groundwater hydrology, groundwater quality, and recharge to groundwater. Some notable limitations include the lack of direct measurement of aquifer parameters in the primary and secondary area of the KRWCA. While the CVHM provides estimates of these parameters, the actual hydraulic conductivity values may vary from this interpretation.

Additionally, groundwater levels are collected from wells that were generally not designed for groundwater monitoring purposes. Accurate locations and well construction data associated with available groundwater quality data are not available for all sources, limiting the spatial groundwater quality analysis precision and accuracy. The groundwater quality data could also contain biases as wells may be more frequently monitored if they have high concentrations on constituents of concern, or if they are in areas that may be impacted by a high concentration source.

Groundwater Vulnerability Areas

High vulnerability lands were defined as areas which are designated as GWPAs for pesticide leaching by the DPR, are determined by the NHI to have a high nitrate leaching risk from the land surface, or have underlying groundwater quality exceedances for nitrates and pesticides. KRWCA identified HVAs are presented on Figure ES-5. The KRWCA HVA identifies 211,040 irrigated acres within the primary boundary (34 percent of total irrigated acres) as high vulnerability. The relationship between the three main designation scenarios and respective acreages is presented on Figure ES-6. Of the identified 211,040 KRWCA HVA irrigated acreage, 185,127 irrigated acres (88 percent) is currently enrolled under members in the KRWCA.

Groundwater quality data and analysis in the KRWCA area was presented and discussed in Section 6. The noted geostatistical analysis using CVHM grid cells to identify impacted groundwater quality areas is a conservative approach, accounting for spatial imprecision when identifying groundwater well locations and correlating spatial groundwater quality results. 132,232 irrigated acres are identified as being within CVHM grids impacted by nitrate and pesticides. The irrigated acreage impacted by nitrates, pesticides, or both nitrate and pesticide exceedances is shown comparatively in Figure ES-7.

The NHI focuses on the main contributors to nitrate leaching potential related to agricultural land use at the ground-surface: soil type, crop type, and irrigation type. These three aspects are respectively assigned hazard values based on their potential to leach nitrogen and considered additively to determine the overall nitrate leaching hazard. The NHI results for the area under evaluation, found in Section 10, indicate that 83 percent of irrigated lands within the KRWCA fall into the lower nitrogen leaching risk category. This is largely because of the efficient and/or uniform irrigation systems used on permanent crops, or irrigation systems with typically lower efficiency and/or uniformity used on fine-textured soils. Areas with NHI scores over 20 are areas where modified management or farming methods could decrease the vulnerability potential. The threshold of 20 was developed in the original version of the NHI and applied by researchers that have since validated this methodology in California (Wu et al., 2005; Pettigrove, 2012; Dzurella, 2012). The value of 20 in the NHI is not an arbitrary threshold, but was chosen to reflect the major influences on nitrate leaching. As demonstrated by previous studies in the San Joaquin Valley, the threshold of 20 can be used successfully to distinguish

between relative lower and higher nitrate leaching risk. See **Section 10** for a discussion of the relevancy and utility of employing the NHI in the KRWCA vulnerability analysis.

The HVA decision matrix flowchart presented in **Figure ES-8** illustrates the process for identifying high vulnerability fields in the KRWCA area. For a field to be identified as being high vulnerability based on a groundwater quality exceedance (nitrate or pesticide) or a DPR GWPA leaching risk designation, the majority of the field had to be within the respective grid cell. For a field to be identified as having relatively higher nitrate leaching risk based on the NHI, the field must have a NHI score greater than 20. Fields identified as high vulnerability by water quality exceedances but with an NHI less than 20 may be a result of historical agricultural management practices, or legacy conditions. It is the KRWCA's position that areas identified as having agricultural management practices with a higher potential to leach nitrate (NHI scores greater than 20) should be the only land identified as high vulnerability.

To facilitate and focus the planning of future groundwater quality monitoring and agricultural management efforts, all identified KRWCA HVAs were prioritized. An additive overlay and index approach was used to calculate priority values for the identified HVA, which were grouped in a three tier system of high (Tier I), medium (Tier II), and low (Tier III) priorities. The KRWCA HVA prioritization framework evaluates factors identified in the MRP as appropriate metrics, including:

- Relative hydrogeologic (intrinsic) sensitivity;
- HVAs upgradient of public groundwater supply wells; and,
- The NHI.

Relative hydrogeologic (intrinsic) sensitivity incorporated unsaturated zone thickness, horizontal hydraulic conductivity, and vertical hydraulic conductivity in a multiplicative overlay and index method applied to the KRWCA area. These sensitivity values do not indicate relative vulnerability, and no determination of absolute sensitivity has been made or implied for this data. To identify HVAs upgradient of public groundwater supply wells, including those within disadvantaged communities, the well capture zone analysis, described above, was utilized. Incorporating the NHI allows resources to be focused on areas where agricultural management practices have a relatively higher potential to leach nitrate in the area. **Section 11** defines the prioritization matrix and methodologies further.

Figure ES-9 provides the various prioritization parameters, the scenarios for each parameter, and the points applied to each respective scenario. For each identified HVA field, the respective scenario points were added together to arrive at an HVA field prioritization score. The resulting prioritized high vulnerability lands are provided on **Figure ES-10**.

Existing Groundwater Monitoring Programs Assessment

There are many local agencies/entities that historically and currently conduct groundwater monitoring in the KRWCA area, including groundwater quality and groundwater elevation data collection. The General Order specifies that within one year from the approval of the GAR, the KRWCA shall develop a workplan for conducting groundwater quality trend monitoring to determine current groundwater quality conditions and develop long-term groundwater quality information that can be used to evaluate the regional effect of irrigated agriculture, if any. KRWCA reserves the right to withhold judgment on the validity of groundwater quality trend monitoring due to the spatial and temporal disconnects

inherent in the KRWCA area. Existing state and local groundwater quality and elevation monitoring programs and the associated data available are summarized in **Section 6**, **Section 9**, and **Section 12**.

Summary and Recommendations

As specified in the General Order, the purpose of the MPEP is to determine the effects that irrigated agricultural practices may have on first encountered groundwater under different surface conditions. It is extremely difficult to establish a direct relationship between the nitrogen mass balance, nitrate discharge below the root zone, and groundwater quality monitoring as related to specific representative agricultural management practices and physical conditions. Monitoring groundwater quality in field scale studies may not be representative of the impacts of current practices, due to the spatial and temporal disconnects inherent to KRWCA hydrogeology (Gailey, 2012). Additionally, individual practices may contribute to overall good irrigation and nutrient management, but the interaction of the practices with one another is what influences nitrate leaching.

As such, it is the position of the KRWCA that practices which are protective of groundwater quality are a function of overall irrigation and nutrient management, rather than the intrinsic effectiveness of individual practices. Technically and economically feasible agricultural management practices should be prioritized by cropping scenarios defined as having a high nitrate leaching potential, with relevant practices evaluated in field scale studies. The KRWCA will attempt to unify formerly conducted research, best practices, and current knowledge to determine realistic time frames for implementation, decipher where data gaps truly exist, and assess the barriers to implementation of irrigation and nutrient management.

Overall, it is recommended that the evaluation of practices, and ultimately success of implementation, be based upon metrics such as the nitrogen applied versus removed ratio (**A/R ratio**). The timeline of implementation of MPEP objectives may also be influenced by the cost of implementation and available funding, potentially resulting in phased workplans.

The intent of the GTMP is to determine current groundwater quality conditions, and to develop long-term groundwater quality information that can be used to evaluate the regional effects relevant to irrigated agriculture. Due to the hydrologic characteristics of the KRWCA region, collected monitoring well data will include a great deal of variability, requiring multi-year long-term evaluations to define trends. Long-term monitoring wells will be located in each PLS township within the KRWCA, with an average of one to three per township. Additional short-term groundwater quality monitoring wells will be located in PLS sections of the KRWCA which do not currently have groundwater quality data to obtain a full coverage of groundwater quality for the primary area.

A number of the regions which lack data are in locations in which there is no usable groundwater or groundwater wells, including but not limited to, the Buena Vista Lake area. The representative long-term monitoring wells chosen per township will be proportional to the percent of high vulnerability land within the respective township, and related to the local data gaps and HVA prioritization tiers within the township. The long-term monitoring periods should also be reflected in member implementation and compliance schedules.

The focus of the KRWCA Comprehensive Groundwater Quality Management Plan (**CGQMP**) will rely on the understanding that surface level activities can drive nitrate leaching beneath the root zone. Management plan implementation will focus efforts on addressing irrigation and nutrient management

practices through extensive outreach and education for all irrigated lands included in the scope of the CGQMP. The KRWCA intends to conduct a thorough literature review of current knowledge pertaining to efficient irrigation and nutrient management practices, particularly as they relate to priority crops and scenarios, to develop outreach resources. Feedback on compliance will be from member data provided by Nitrogen Plan Summary Reports and Farm Evaluations. Outreach and education resources will be developed alongside partners to improve the available data and provide relevant training in irrigation and nutrient management, as well as efforts such as pump and fertilize (**PAF**).

Recommended GAR five year updates include potential enhancements to the NHI. Validating soil hazard values, improving the quality of spatial irrigation data for the KRWCA region, and incorporating layers such as the A/R ratio to the NHI are some examples that will serve to produce a more robust evaluation tool for future assessments.

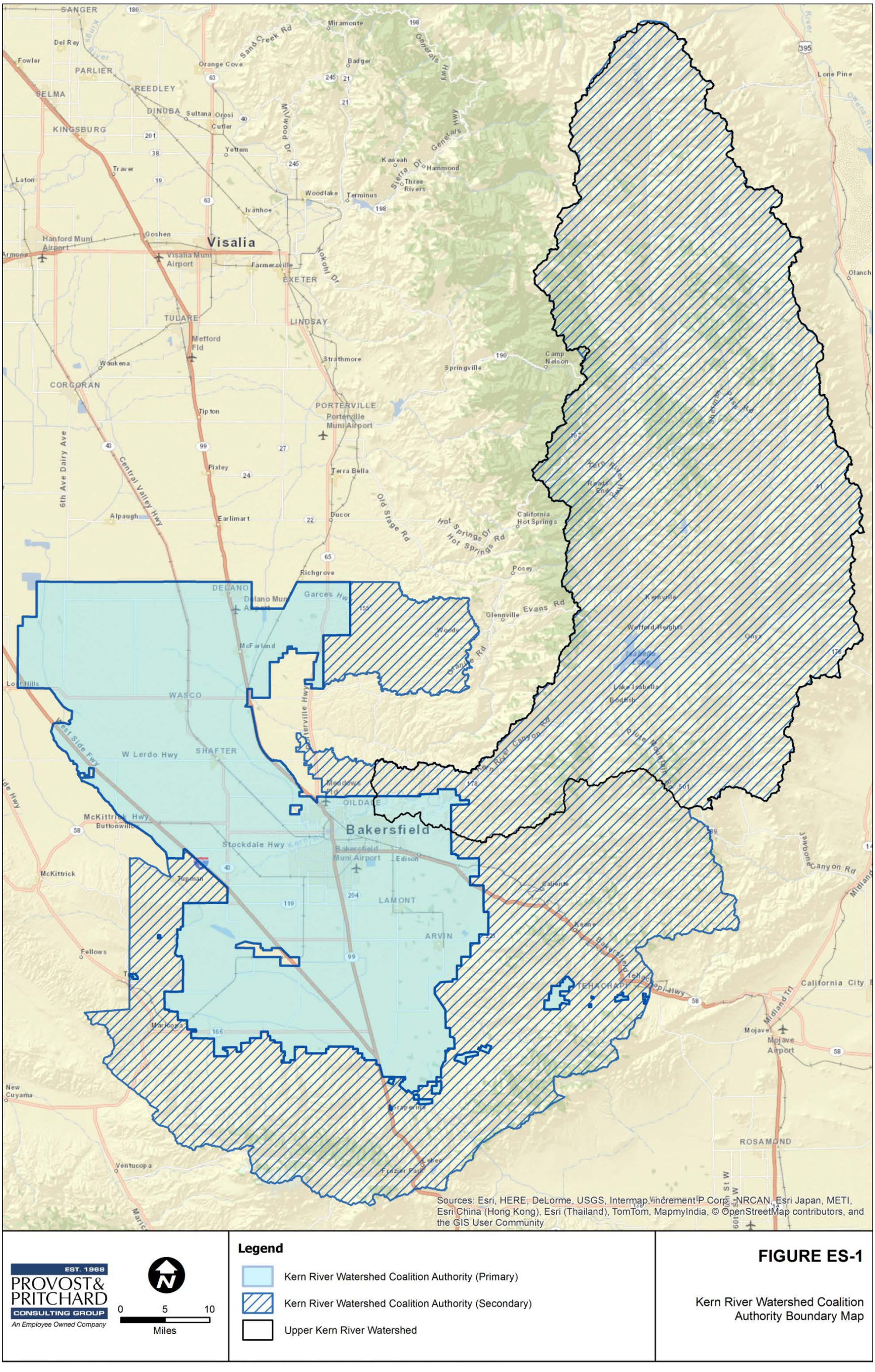


Figure ES-1. Kern River Watershed Coalition Authority Boundary

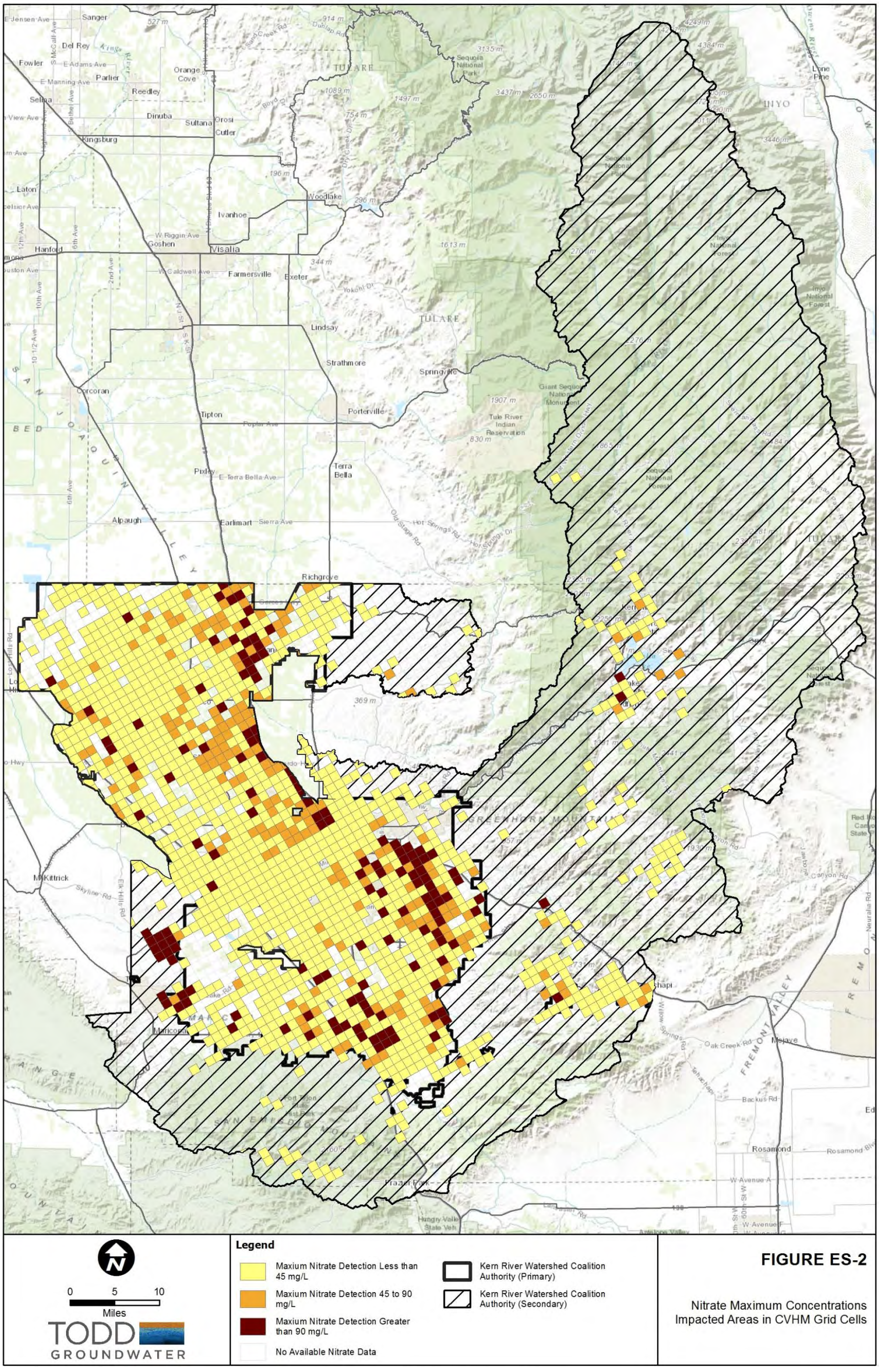


Figure ES-2. Nitrate Maximum Concentrations, Impacted Area in CVHM Grid Cells

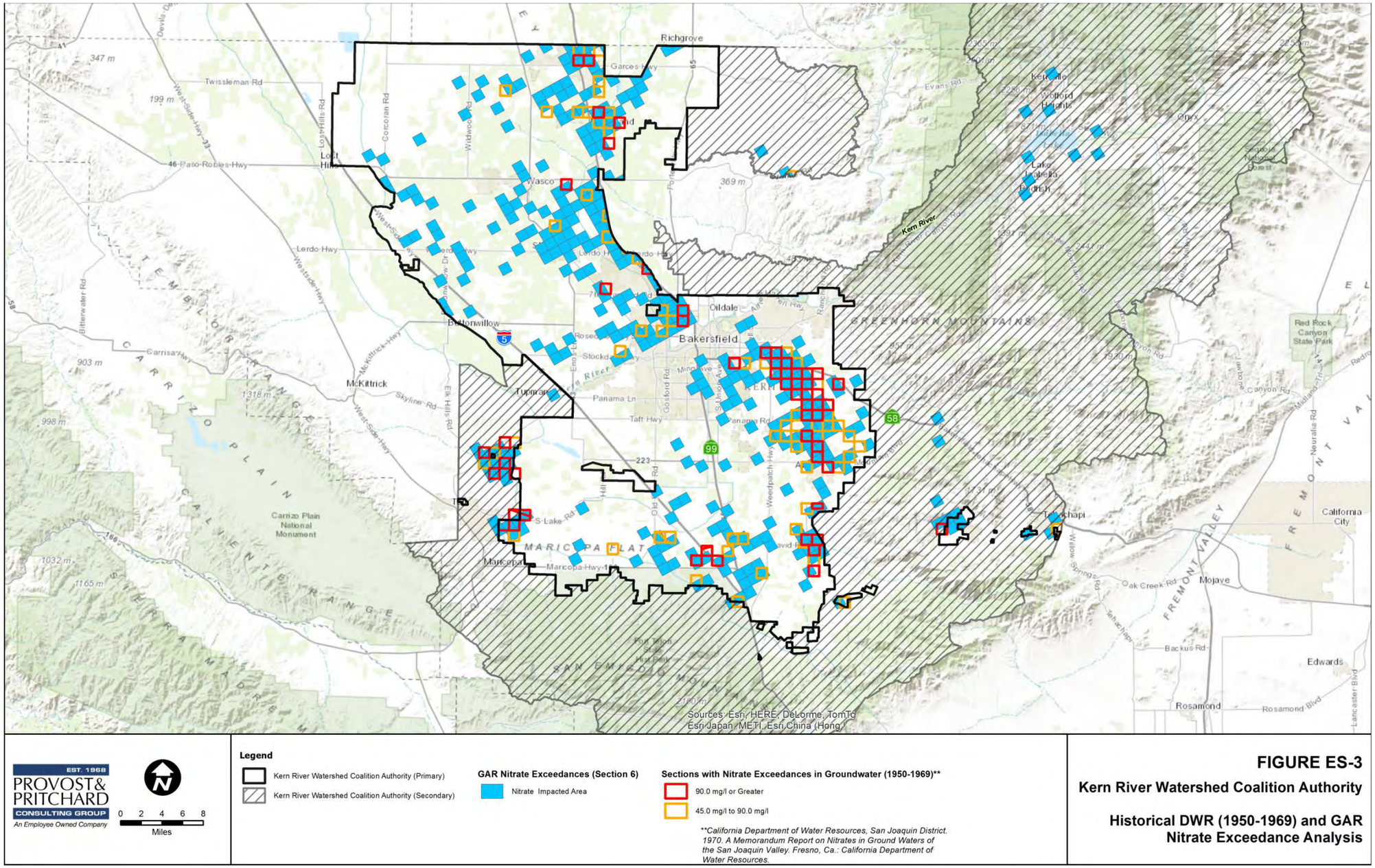


Figure ES-3. Historical DWR (1950-1969) and GAR Nitrate Exceedance Analysis Overlay

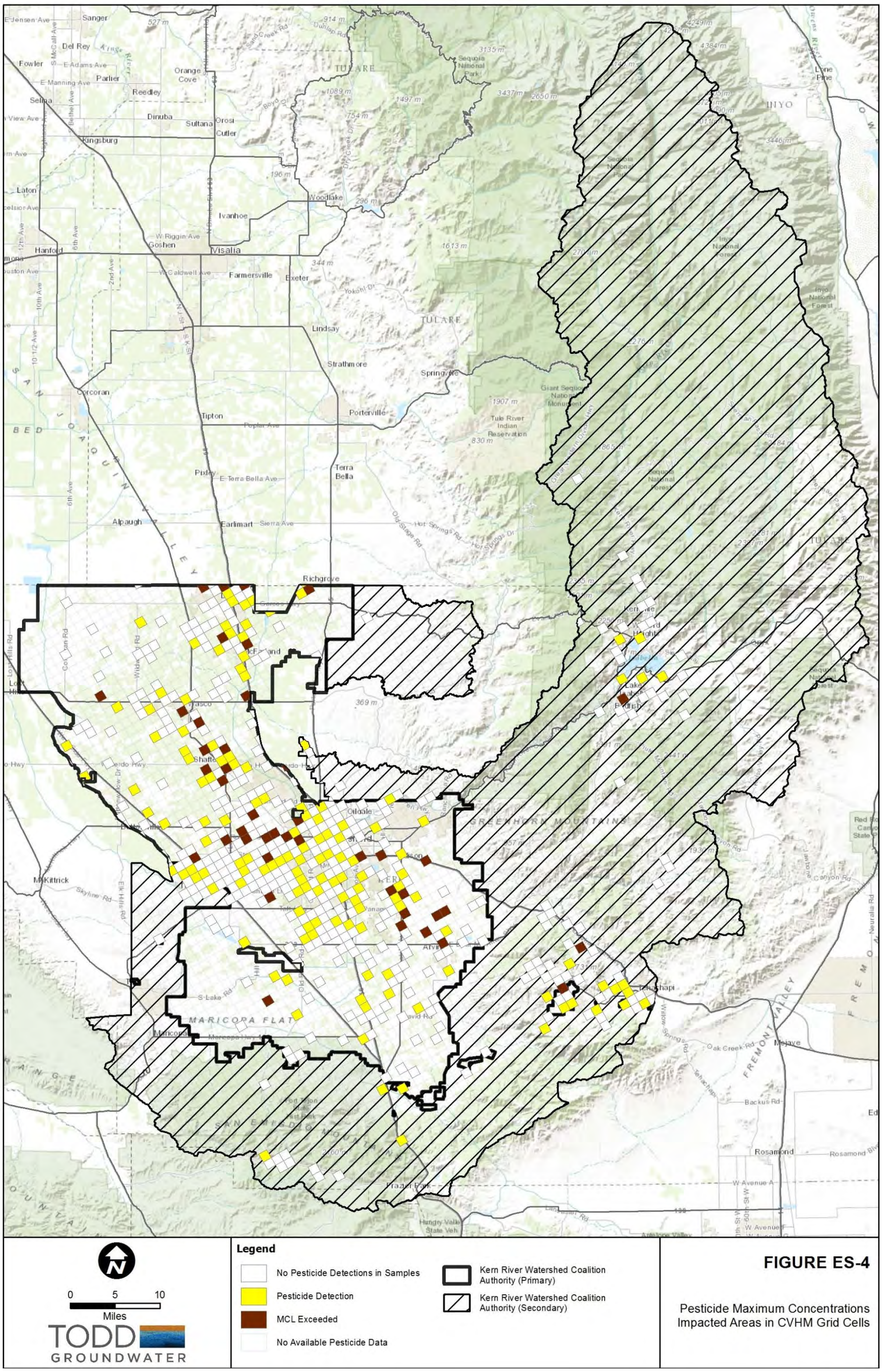
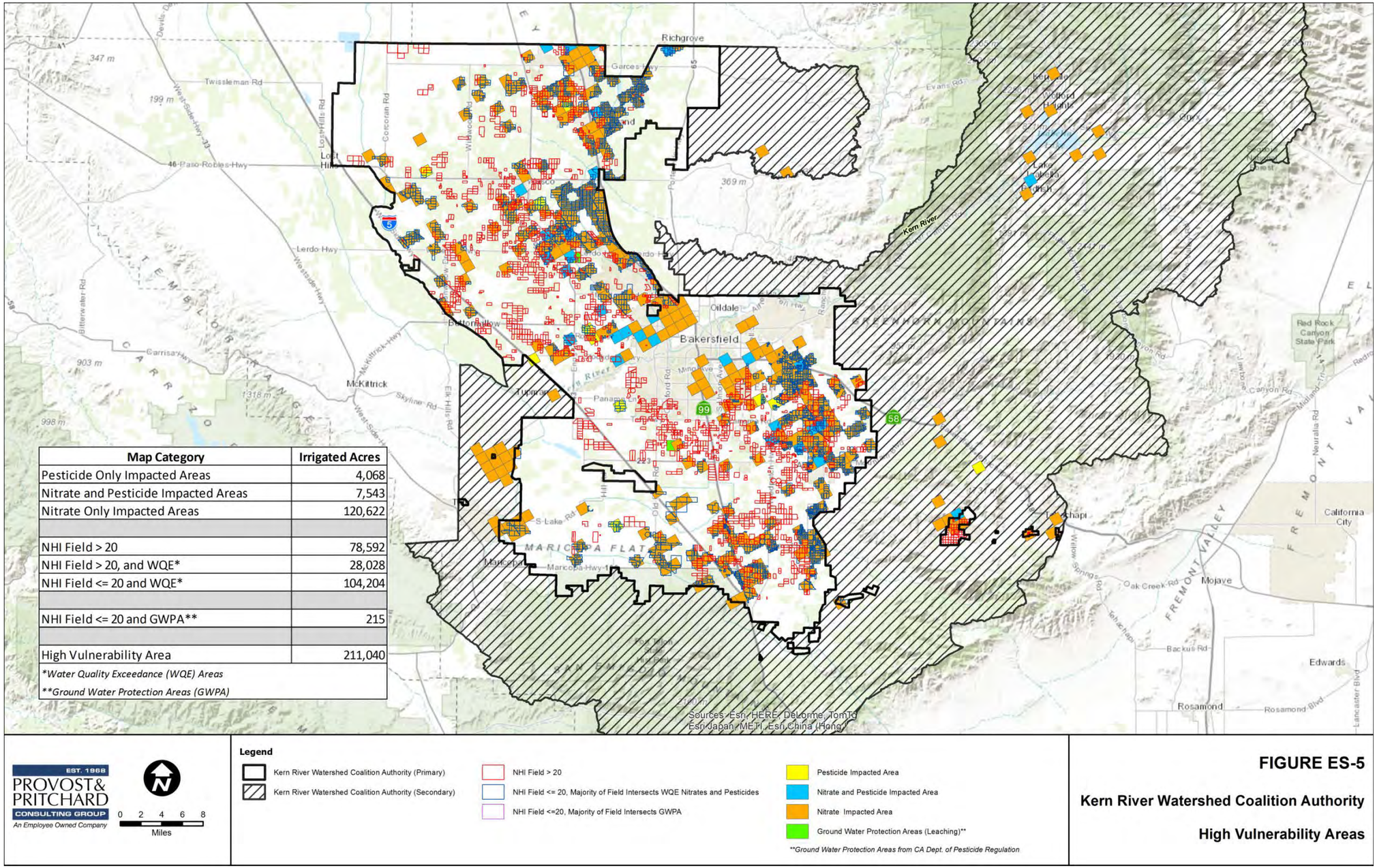


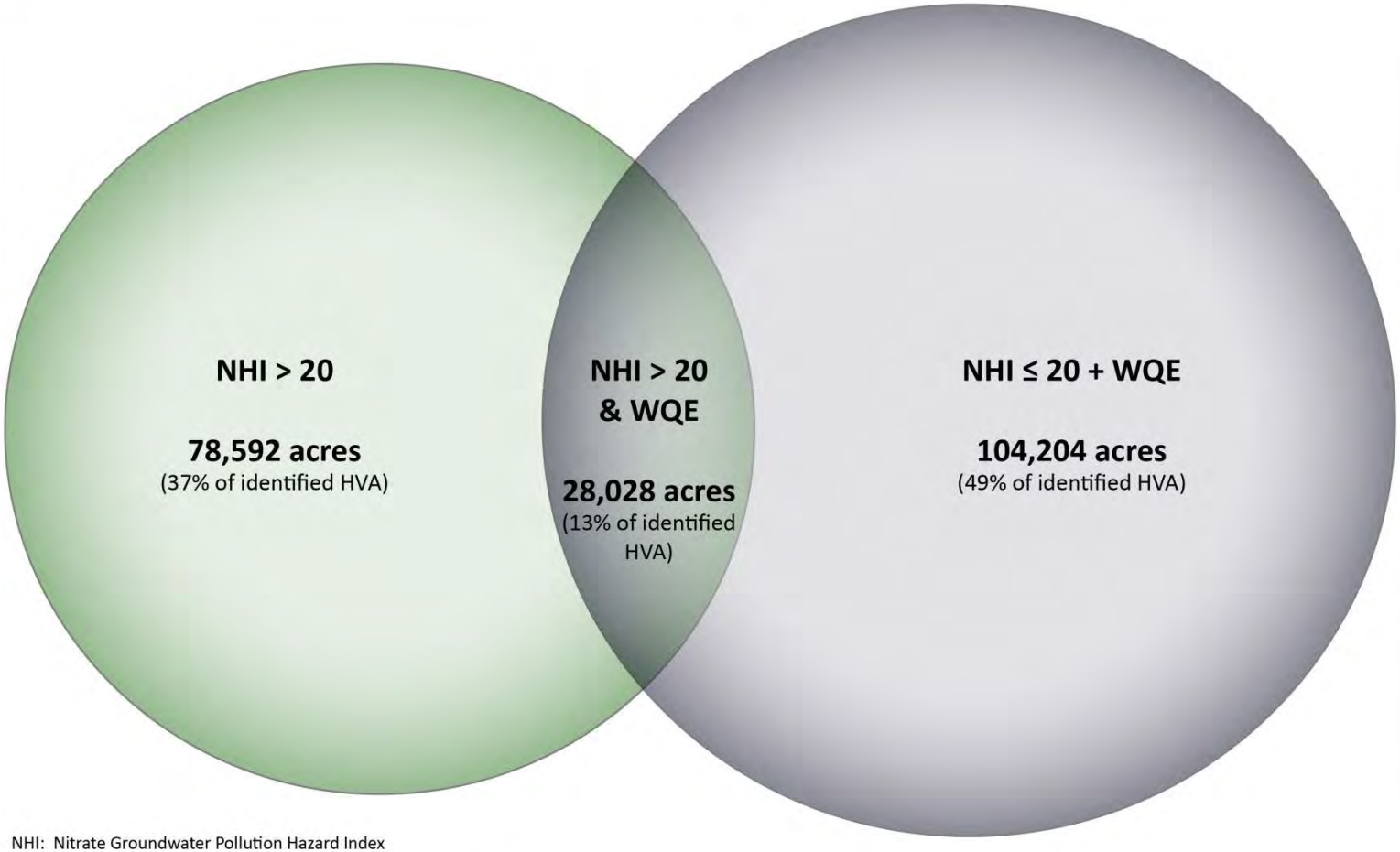
Figure ES-4. Pesticide Maximum Concentrations, Impacted Area in CVHM Grid Cells



Map Category	Irrigated Acres
Pesticide Only Impacted Areas	4,068
Nitrate and Pesticide Impacted Areas	7,543
Nitrate Only Impacted Areas	120,622
NHI Field > 20	78,592
NHI Field > 20, and WQE*	28,028
NHI Field <= 20 and WQE*	104,204
NHI Field <= 20 and GWPA**	215
High Vulnerability Area	211,040

**Water Quality Exceedance (WQE) Areas*
***Ground Water Protection Areas (GWPA)*

Figure ES-5. KRWCA High Vulnerability Area



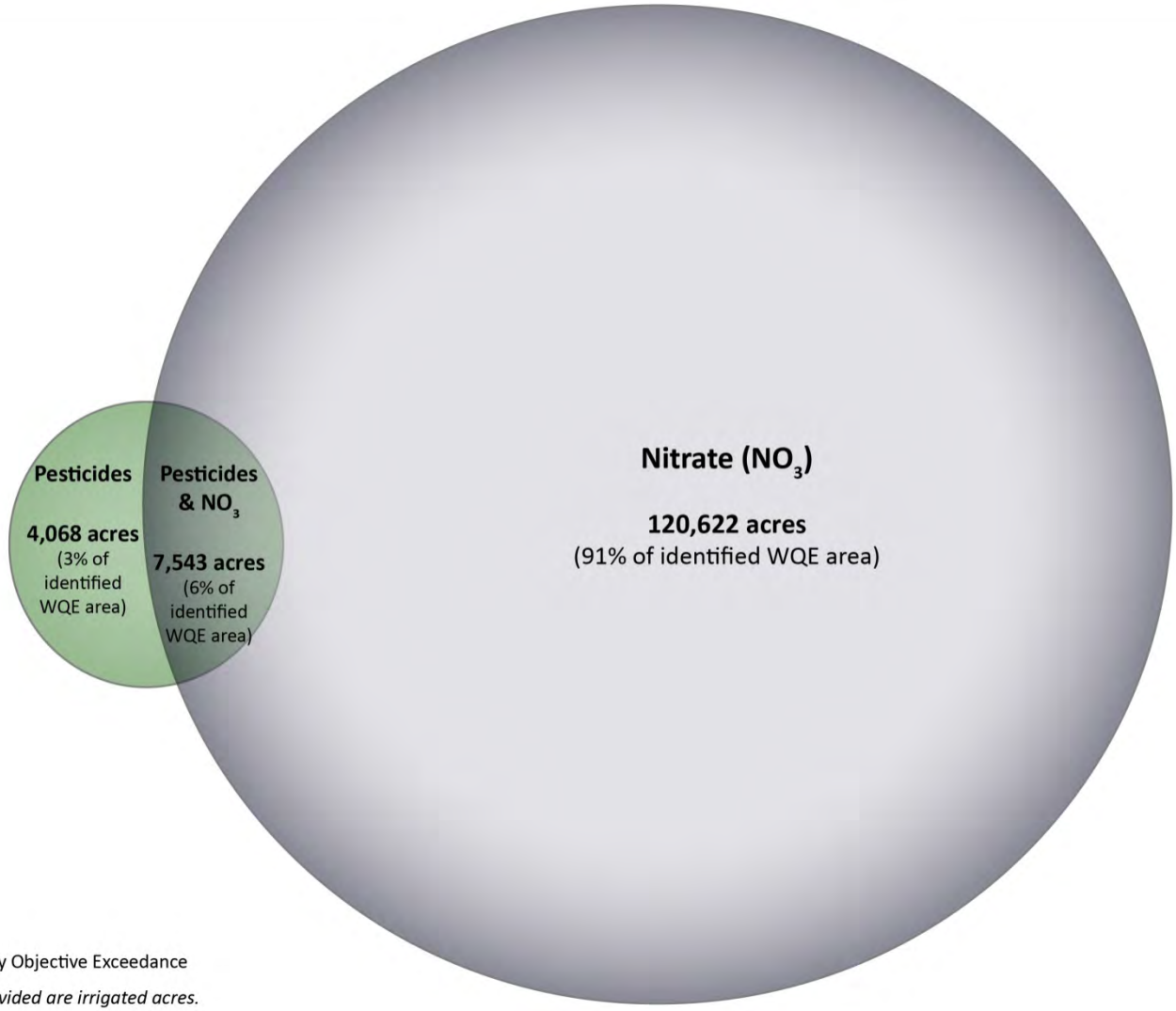
NHI: Nitrate Groundwater Pollution Hazard Index

WQE: Water Quality Objective Exceedance (Nitrate and/or Pesticides)

HVA: High Vulnerability Area

Note: Acreages provided are irrigated acres.

Figure ES-6. KRWCA NHI and Water Quality Exceedance HVA Venn Diagram



WQE: Water Quality Objective Exceedance

Note: Acreages provided are irrigated acres.

Figure ES-7. KRWCA Pesticides and Nitrates Water Quality Exceedance Venn Diagram

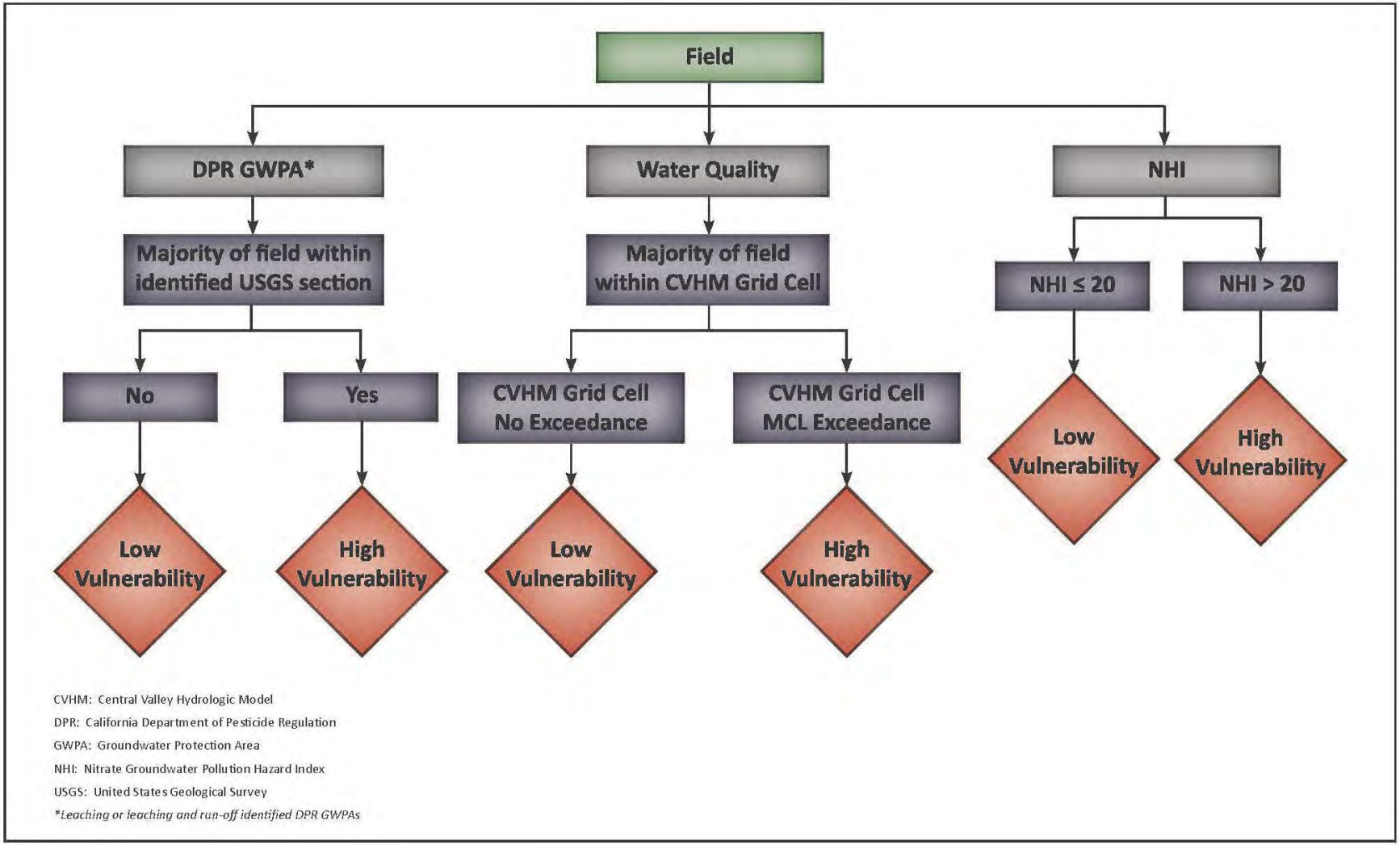


Figure ES-8. KRWCA High Vulnerability Decision Matrix Flow Chart

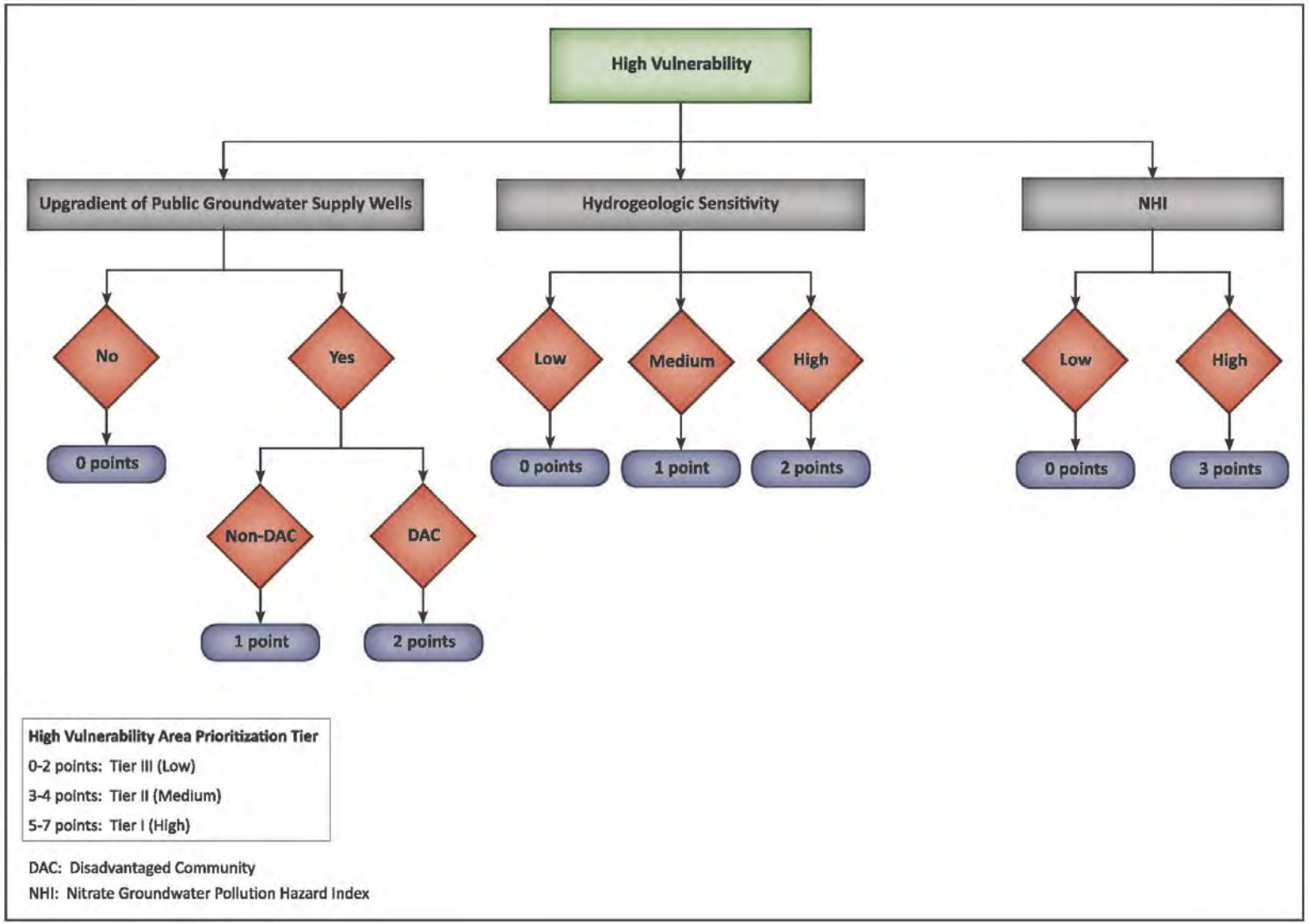


Figure ES-9. KRWCA Prioritization Framework Flowchart

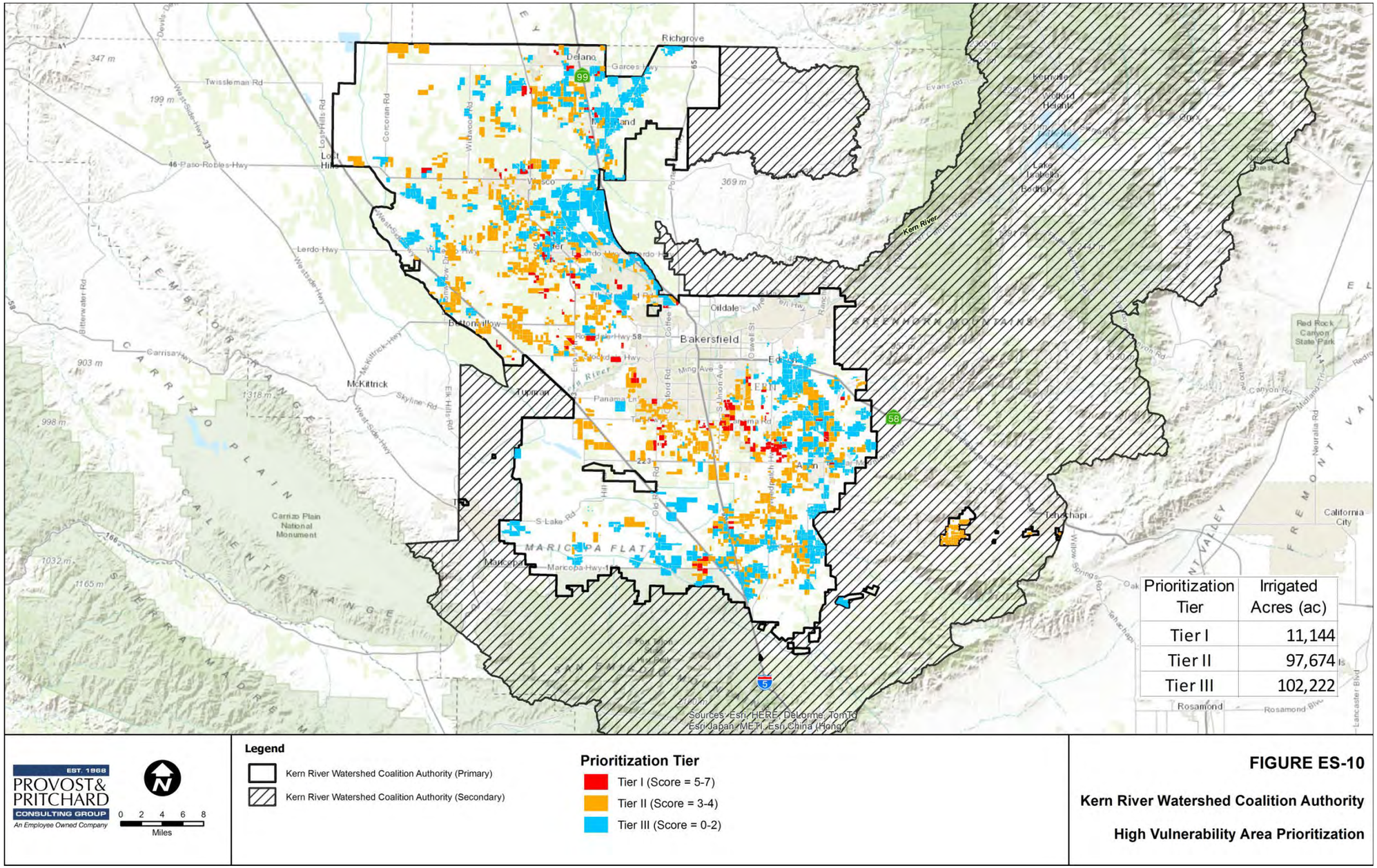


Figure ES-10. KRWCA High Vulnerability Area Prioritization

1 Introduction

This Groundwater Quality Assessment Report (**GAR**) has been prepared on behalf of the Kern River Watershed Coalition Authority (**KRWCA** or **Coalition**), in response to Waste Discharge Requirements (**WDR**) General Order R5-2013-0120, adopted by the Central Valley Regional Water Quality Control Board (**CVRWQCB** or **Board**) on September 19, 2013. The WDR applies to growers in the Tulare Lake Basin, **Figure 1-1**. The Kern River Watershed boundary generally coincides with the KRWCA boundary (**Figure 1-2**).

1.1 Background

The Tulare Lake Basin General Order (Order R5-2013-0120) (**General Order**) requires any commercial irrigated land having the potential to discharge to surface water or groundwater to comply with the requirements set forth by the CVRWQCB. The CVRWQCB defines irrigated land as "land irrigated to produce crops or pasture used for commercial purposes including lands that are planted to commercial crops that are not yet marketable (e.g. vineyards and tree crops). Irrigated lands also include nurseries, and privately and publicly managed wetlands". Compliance with the General Order requires membership in a coalition (**third-party**) or by obtaining coverage through the CVRWQCB under an Individual Order (Order R5-2013-0100).

The third-party option allows growers to work together as a group and share resources, minimizing redundant efforts and reducing overall costs. Investigations and evaluations necessary to fulfill the General Order may require extensive expertise and funding, making it difficult for the average grower to complete them independently.

1.1.1 Kern River Watershed Coalition Authority (KRWCA)

The KRWCA was established to serve as the coordinator and coalition (third-party) group under the Irrigated Lands Regulatory Program (**ILRP**) for a specific subarea within the Kern River watershed portion of Kern County. There are multiple third-party groups located within Kern County. KRWCA is a joint powers authority (**JPA**), formed on October 1, 2011 between the following public agencies in the region:

i. Arvin-Edison Water Storage District (**AEWSD**);
ii. Henry Miller Water District;
iii. Kern Delta Water District;
iv. Kern-Tulare Water District;
v. North Kern Water Storage District;
vi. Olcese Water District;
vii. Rosedale-Rio Bravo Water Storage District;
viii. Semitropic Water Storage District;
ix. Shafter-Wasco Irrigation District;
x. Southern San Joaquin Municipal Utilities District; and,

xi. Wheeler Ridge-Maricopa Water Storage District (**WRMWSD**).

On February 4, 2014 the CVRWQCB issued a Notice of Applicability (**NOA**) to the KRWCA, approving the KRWCA to represent member owners/growers of irrigated agricultural lands within the KRWCA boundary under the ILRP.

The KRWCA boundary (**Figure 1-2**) encompasses approximately 3.5 million gross acres of land, of which approximately 622,200 is irrigated. Approximately 39,200 irrigated acres of this area falls under the regulatory coverage of the CVRWQCB WDR General Order for Existing Milk Cow Dairies (Order R5-2013-0122) (**Dairy General Order**). It is unknown how many acres within the KRWCA boundary are under the regulatory jurisdiction of other WDR's or conditional waivers of WDR's (i.e. effluent wastewater, food processing, recycled water, etc). As of February 4, 2015 the KRWCA has 858 growers registered as members, covering approximately 522,833 irrigated acres.

Peripheral to the primary KRWCA boundary are the "secondary" regions that contain very little irrigated acreage. The Sierra Nevada Mountain Range is located to the east of the primary region and contains the Upper Kern River watershed, which extends approximately 60 miles north into Tulare County. The secondary region to the south of the KRWCA boundary is composed of the Tehachapi Mountains and Transverse Ranges, which form the southern end of the San Joaquin Valley, and the San Emigdio Range, which forms the southwestern end of the San Joaquin Valley.

1.1.2 Waste Discharge Requirements (WDR)

The NOA approval date (February 4, 2014) starts the timeline for several requirements outlined in the WDR, including Section IV.A in Attachment B, Monitoring and Reporting Program (**MRP**), to the General Order. 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 data sources and references that will be considered in developing the GAR." In accordance with the MRP, the due date for submittal of the GAR Outline was May 5, 2014. The due date for the complete GAR is one year after the issuance of the NOA to the KRWCA, February 4, 2015.

The KRWCA submitted the GAR Outline to the Board on May 5, 2014, and the Board replied on August 18, 2014 with comments, approving the GAR Outline.

1.2 Objectives of the Groundwater Quality Assessment Report (GAR)

Adequate groundwater resources within the KRWCA are crucial to the economic well being of agriculture and the protection of public health. The KRWCA GAR is an integral part of implementing the ILRP by evaluating the groundwater conditions of the area to facilitate long-term protection of groundwater quality. The GAR objectives include an assessment of current and historic groundwater conditions, the relationship between irrigated agriculture and groundwater quality, and a scientifically based approach to determine high and low vulnerability areas. High and low vulnerability areas will be identified by utilizing the State Water Resource Control Board's (**SWRCB**) Nitrate Groundwater Pollution Hazard Index (**NHI**) methodology. The NHI will also be utilized to determine priority areas within the High Vulnerability Area (**HVA**). **Table 1-1** lists the major requirements of the GAR and their corresponding location in the document.

The methodology used to identify the vulnerability of groundwater to irrigated agricultural practices accounts for existing groundwater quality conditions and the NHI. The NHI is an index value that is

determined by crop type, soil type, and irrigation type at the ground surface. HVA prioritization will incorporate an evaluation of the proximity of high vulnerability land to urban communities, rural communities, and disadvantaged communities (**DACs**) that rely on groundwater, as well as other parameters as detailed in the GAR.

Objectives of the GAR as per the WDR are as follows:

- 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;
- Establish priorities for implementation of monitoring and studies within high vulnerability areas;
- Provide a basis for establishing work plans to assess groundwater quality trends;
- Provide a basis for establishing work plans and priorities to evaluate the effectiveness of agricultural management practices to protect groundwater quality; and,
- Provide a basis for establishing groundwater quality management plans in high vulnerability areas and priorities for implementation of those plans.

1.3 Kern River Watershed

1.3.1 Location Map

The Upper Kern River Watershed encompasses approximately 1.5 million acres in the southeastern portion of the San Joaquin Valley (**Figure 1-2**). The Upper Kern River Watershed, with the exception of the Kern River canyon portion, is located almost exclusively within the KRWCA secondary boundary. There is a limited amount of irrigated agricultural land in the Upper Kern River watershed. The KRWCA primary boundary includes the Lower Kern River Watershed, which is located on the San Joaquin Valley floor. The Lower Kern River Watershed receives runoff from the Upper Kern River Watershed as well as discharge from multiple smaller watersheds. It is important to note that although the entire KRWCA boundary covers approximately 3.5 million gross acres, only approximately 622,200 acres in the KRWCA boundary is irrigated agricultural land (18 percent). This irrigated agricultural land is located primarily on the valley floor. The major body of water in the region is the Kern River, which is regulated by Isabella Dam and Reservoir. Minor streams in the watershed include, but are not limited to, Poso Creek (covered by a separate third-party in Kern County), Caliente Creek, El Paso Creek, and Chanac Creek.

1.3.2 General Characteristics

The focus area of the GAR is the San Joaquin Valley floor portion of Kern County within the KRWCA primary boundary area (**Figure 1-2**). The primary boundary area is comprised of approximately 1,023,600 gross acres of land that are within the boundary of the Kern groundwater subbasin. Of the KRWCA primary boundary, approximately 619,200 acres are irrigated agricultural lands and approximately 404,400 gross acres are non-irrigated. Of the non-irrigated acres, approximately 97,600 acres are classified as urban, commercial, or industrial. The largest population center in the KRWCA is

the City of Bakersfield and there are multiple DACs in the KRWCA region. **Figure 1-4** depicts the major cities and communities located within the KRWCA boundary, and identifies DACs in the region; **Table 1-2** lists the DACs and respective median household incomes in the region. DAC identification and boundaries were obtained from the California Department of Water Resources (**DWR**) for United States Census cities and designated places (DWR, 2014). DAC identification and boundaries were obtained from the Disadvantaged Community Water Study for the Tulare Lake Basin (**TLB DAC Study**) for unincorporated communities that were not United States Census cities or designated places (Provost & Pritchard, 2014).

Kern County has the second largest economic value of agricultural counties in the state and nation, producing over 250 crops; including 30 types of fruit and nuts, over 40 varieties of vegetables, over 20 field crops, lumber, nursery stock, livestock, poultry and dairy products (USDA, 2014). Mineral and petroleum resources are also fundamental parts of Kern County's economy.

1.3.3 Climate

The climate of the Coalition area varies greatly between Mediterranean on the San Joaquin Valley floor to alpine in the upper reaches of the Kern River watershed. The valley floor and foothill areas are characterized by hot, dry summers and mild, foggy winters. Precipitation usually falls during the winter, in November through March.

The mean annual temperature for the area is 64.7 °F; the mean for July, the hottest month, is 83.9 °F; and the mean for January, the coldest month, is 46.8 °F. Summertime high temperatures can approach 120 °F and wintertime lows are rarely below 30 °F. The south end of the San Joaquin Valley lies in the rain shadow of the Coastal and San Emigdio Mountains. When air masses pass over the western side of the valley and descend to the valley floor, they contain less moisture. Average rainfall is between 5 to 6 inches per year for the valley floor and foothill areas. Precipitation increases as storms move up the western face of the Sierra Nevada Mountains and snow depth can exceed 60 inches at the higher elevations. Snow levels rarely extend below 4,000 feet in elevation. (Wood and Dale, 1964)

See **Table 1-3** for Kern County valley floor and foothill temperature and rainfall characteristics.

Potential evapotranspiration (**ET**), the amount of water evaporated and transpired from healthy grass in a normal year, is 57.9 inches in the southern San Joaquin Valley (Jones, 1999). Potential ET from May to August varies little, less than 5 percent, from year to year (Sanden, 2014a).

Effective precipitation is the portion of precipitation that can be beneficially used by crops. This varies from 1.2 inches in a dry year to 4.9 inches in a wet year, averaging 3.4 inches in a normal year (Kern County Water Agency, 2005).

1.3.4 KRWCA Agriculture

Agriculture has been practiced in Kern County since livestock was brought into the area in the 1860's. Irrigated agriculture began soon after this occurred (1870s). Because the climate is arid, with an average of less than six inches of annual precipitation, almost all crops must be irrigated. Kern County has a large agricultural base; the market value of agricultural products sold is about $6 billion (Kern County Census of Agriculture, 2012). Kern County agriculture is characterized by a wide variety of crops and livestock, but it is mostly known for its top crops – almonds, grapes, pistachios, carrots, potatoes, other

vegetables – and cattle. Kern County is the second largest producer of fruits, tree nuts, and berries in the state of California and in the United States.

The year-round growing season allows successful cultivation of numerous crops as well as double and triple cropping, where two or three crops are grown within one calendar year.

Irrigation is the single most expensive component of agricultural production in Kern County. Water costs range from $40 to $190 per ac/ft depending on irrigation district and elevation in a normal (non-drought) year (Sanden, 2014b)**.** Current irrigation efficiencies in the Kern Subbasin are, overall, some of the highest in the entire Central Valley. This is partly the result of on-farm and irrigation district conservation methods and system improvements. More notably, the high irrigation efficiency can be attributed to a county wide conversion from gravity-based irrigation systems to pressurized drip/micro systems that has occurred alongside the shift in regional crop type distribution from annual to permanent crops.

Overall, the proportion of permanent crops grown in the Subbasin has increased significantly in the past 20 years and in nearly all cases the permanent crops are irrigated with highly efficient drip and/or micro spray irrigation systems. This change in crop type distribution is likely to continue considering the increasing global market for fresh nuts and fruits (Equilibrium Capital, 2013). The long-term return potential of permanent crops provides a lucrative opportunity for the regions growers while simultaneously increasing water use efficiency. Additional water use improvements are seen as pressurized systems are increasingly used on annual crops, such as tomatoes, due to the opportunity for increased yield and decreased water use (Water Association of Kern County).

1.3.5 Water Supply

Water supplies utilized in the KRWCA region include the State Water Project (**SWP**) and Federal Central Valley Project (**CVP**) surface water supplies via the California Aqueduct, CVP surface water supplies via the Friant-Kern Canal, local surface water supplies from the Kern River, as well as groundwater from the Kern Subbasin. Other groundwater basins located in the KRWCA boundary include the Kern River Valley, Walker Valley Creek, Tehachapi Valley West and East, and Cummings Valley.

1.3.5.1 Surface Water Supply

Figure 1-5 provides an overview of the SWP major facilities and conveyances. The SWP was authorized by the California State Legislature in 1959, with construction of most initial facilities completed by 1973. Today, the SWP utilizes 28 dams and reservoirs, 26 pumping and generating plants, and approximately 660 miles of conveyances managed by DWR. The primary SWP source is the Feather River, a tributary of the Sacramento River, downstream of Oroville Dam. Releases from Oroville Dam flow down natural river channels to the Sacramento-San Joaquin River Delta (**Delta**). A vast majority of SWP supplies, used for both agriculture and municipal uses, are pumped from the southern Delta into the California Aqueduct (with a minor portion of supplies pumped from the northern Delta to supply the North Bay Aqueduct, although this facility does not deliver water to the KRWCA region). Many areas in the region receive SWP water from turnouts located directly on the California Aqueduct or on the bidirectional east-west conveyance facility, Cross Valley Canal (**CVC**). Recent regulatory and judicial decisions related to endangered species and water quality in the Delta have impacted the reliability and conveyance capability of the SWP due to increased restrictions on pumping from the south Delta. (Kennedy/Jenks Consultants, 2011)

Figure 1-6 provides an overview of the major CVP facilities and conveyances. The CVP is a collection of federally owned conveyance facilities that extend generally from north of Redding to areas near Bakersfield, including the South Bay area. The Westside CVP, or Shasta Division, is supplied by the Sacramento River, which flows south towards the Delta, and the San Joaquin River, which flows north towards the Delta. The Westside CVP system jointly shares facilities with SWP and California Aqueduct from the Delta to the south. In addition, the CVP also has an eastside system, or commonly referenced as the Friant Division, which includes Friant Dam, storing San Joaquin River flows in Millerton Lake, and regulating flows southward into the Friant-Kern Canal. Friant Dam also regulates flows northward into the Madera Canal, which does not deliver water to the KRWCA region. The Friant-Kern Canal is 151.8 miles long and conveys water southward for both agriculture and municipal uses from Millerton Lake to its terminus in the Kern River. Friant CVP water deliveries are anticipated to be reduced significantly due to implementation of the San Joaquin River Restoration Program. (Kennedy/Jenks Consultants, 2011)

Figure 1-7 provides an overview of the Kern River, Isabella Reservoir, as well as downstream conveyances that divert Kern River supplies. The Kern River is the most utilized source of naturally occurring surface water in the region. The Kern River is regulated by the Isabella Dam and Reservoir, operated by the U.S. Army Corps of Engineers. The Kern River is approximately 164 miles long and is fed by the annual snowmelt in the Southern Sierra Nevada mountain range, including Mt. Whitney. The Kern River drains approximately 2,100 square miles (**mi^2**) of watershed upstream of the Isabella Dam and Reservoir, approximately 300 mi^2 in the foothills downstream of Isabella Dam and Reservoir, and approximately 600 mi^2 of alluvial fan. The main branch of the Kern River (North Fork Kern River) connects to the South Fork Kern River just upstream of the Isabella Dam and Reservoir. Isabella Dam and Reservoir was constructed in 1954 to serve as flood control for the San Joaquin Valley floor region in Kern County. Isabella Reservoir was designed to store approximately 570,000 AF of water; however, since 2006 the reservoir has been limited to about 60 percent capacity due to various structural integrity issues (340,860 AF). (Kennedy/Jenks Consultants, 2011)

1.3.5.2 Groundwater

Groundwater is necessary in the region to maintain a sufficient water supply due to the arid climate and minimal rainfall. It is estimated that groundwater accounts for approximately 39 percent of total water supply in the region; however, during dry years it can increase to as much as 60 percent. Groundwater aquifer recharge in the region occurs through the, Kern River, SWP, CVP, and the above mentioned surface water supplies. Additionally, major water recharge and conjunctive use projects, including in-lieu recharge, contribute large amounts of recharge to the groundwater aquifer. The main groundwater basin in the region is the San Joaquin Valley groundwater basin (Kern Subbasin). Other groundwater basins in the region include small, sporadic basins located throughout the foothills in the region (Kennedy/Jenks Consultants, 2011).

1.3.6 Focus Area: Central Valley Floor (extent of DWR Bulletin 118 Groundwater Basin)

As previously mentioned, **Figure 1-2** delineates the KRWCA boundary into the primary and secondary boundary. The primary boundary, however, will be the focus area for the KRWCA GAR. The primary boundary includes a majority of the irrigated agriculture in the KRWCA region and includes what is hydrogeologically referred to as the Central Valley Floor. The KRWCA primary boundary includes

approximately 619,200 acres of irrigated agricultural lands, or 99.5 percent of the total irrigated agricultural land within the KRWCA boundary. The primary boundary covers the Kern groundwater subbasin (DWR, 2006c). The hydrogeology and groundwater hydrology of this area will be addressed in detail in subsequent sections of the GAR.

1.3.7 Reconnaissance Area: Peripheral Area to the Central Valley Floor

The peripheral areas to the Central Valley Floor, or KRWCA's secondary boundary (**Figure 1-2**), will be addressed through a reconnaissance assessment of existing groundwater data. The assessment for this area will evaluate groundwater hydrology data and groundwater quality data (to the extent readily available). Data for this region is sporadic and limited in comparison to the data available for the Central Valley Floor; therefore, the hydrogeology and groundwater hydrology in these areas will not be addressed in detail in the GAR. For the purpose of providing a brief description of the geology and general characteristics of the secondary area, the KRWCA area was divided into sub-watershed boundaries from the valley floor to the crest of each major watershed (**Figure 1-8**). A brief overview of the geology and general characteristics of the sub-watersheds within the secondary boundary is provided below.

1.3.7.1 Upper Kern River Watershed

The Upper Kern River Watershed is the largest watershed of the secondary area, covering an area of approximately 2,420 square miles. The Upper Kern River Watershed also has the highest relief of watersheds in the peripheral area (14,128 feet), from the top of Mount Whitney at 14,413 feet mean sea level (**msl**) to the valley floor north of Bakersfield at 285 feet msl. This watershed is drained from the north by the Little Kern River, the main stem of the Kern River and the South Fork of the Kern River. The Kern River traverses north to south in the north portion of the watershed, following the Kern Canyon Fault; a major geologic feature in the area. Smaller watersheds of numerous tributaries to the Kern River drain the southern portion of the watershed. These drainages include Pinyon Creek/Dry Meadow Creek, Erskine Creek, Bodfish Creek, Clear Creek, Mill Creek, Lucas Creek, Cow Flat Creek, and Stark Creek. Most of these small southerly watersheds are tributary to the Kern River below Lake Isabella. The main stem of the Kern River and the South Fork Kern River, along with Canebrake Creek and Chimney Creek, drain into the Kern River Valley where they are impounded behind Isabella Dam and form Lake Isabella. Downstream of Lake Isabella, the Kern River drops through the Kern River gorge before discharging onto the floor of the San Joaquin Valley north of Bakersfield. Immediately adjacent to the distal margin of the Upper Kern River Watershed is a small portion of the Goose Lake Slough-Jerry Slough Watershed. The generalized geologic description for the Upper Kern River Watershed includes the Goose Lake Slough-Jerry Slough Watershed; as the geologic materials in this area are a continuation of the geology found in the lower elevations of the peripheral Kern River Watershed areas.

The vast majority of the rocks in the Upper Kern River Watershed are Mesozoic granites, quartz monzonite, granodiorite, or quartz diorite (**Figure 1-8**). There is a fairly significant amount of alluvial material associated with the Kern River Valley (DWR groundwater basin 5-25); however, few alluvial deposits exist outside of this area. This indicates that the majority of groundwater developed and used in the Upper Kern River Watershed is from the area's fractured bedrock aquifer. Other major rock types include pre-Cenozoic metasedimentary and metavolcanic "of great variety", as well as some chiefly Mesozoic dioritic and gabbro rocks. At high elevations there are also some deposits of glacial till.

1.3.7.2 Walker Basin Watershed

The Walker Basin Watershed is adjacent to and south of the Kern River Watershed covering an area of about 120 square miles. The Walker Basin Watershed has a relief of about 7,377 feet, from a high point of 8,225 feet msl along the crest of the Sierra to 848 feet msl in the foothills east of Bakersfield. The upper reaches of the watershed are drained by Rancheria Creek, Thompson Creek, and the North Fork of Walker Basin Creek. In the lower portions of the watershed, Paceritos Creek is tributary to the main branch of Walker Basin Creek. The major rock types in Walker Basin Watershed are the Mesozoic granites, quartz monzonite, granodiorite, or quartz diorite (**Figure 1-8**). There is a significant amount of alluvium near the confluence of Rancheria Creek and the North Fork Walker Creek. This is an area of relatively low relief and constitutes the Walker Basin Creek Valley (DWR groundwater basin 5-26). In the lower part of the watershed, near the valley floor, there is an area composed mostly of sandstone, shale, fanglomerates, and loosely consolidated deposits of shale, sandstone, and gravel. The eastern edge of Walker Basin also has a fairly significant outcropping of pre-Cenozoic metasedimentary and metavolcanic rocks.

1.3.7.3 Tehachapi and Caliente Creek Watersheds

This watershed is a combination of the Caliente Creek and Tehachapi Creek Watersheds. These watersheds are combined in this report because Tehachapi Creek is a tributary to Caliente Creek before it flows onto the valley floor, thus the water quality impacts to the agricultural lands on the valley floor are a combination of water quality from both sub-watersheds. Together these two watersheds cover an area of about 342 square miles. Elevation ranges from 6,913 feet msl to 791 feet msl, for a total relief of 6,122 feet. The main creeks in the combined watershed are Brite Creek, Tehachapi Creek, Caliente Creek, Indian Creek, Weaver Creek, and Tweedy Creek. This combined watershed is comprised predominantly of the Mesozoic granites, quartz monzonite, granodiorite, or quartz diorite (**Figure 1-8**). There is a significant amount of relatively young, Tertiary aged, intrusive volcanic rocks as plugs and dikes in the Caliente Creek area, as well as some volcanic flow rocks. In the upper reaches of the Tehachapi drainage there is some alluvium in the Tehachapi Valley (DWR groundwater basin 5-28). Some of these lands are actively farmed and are enrolled in the KRWCA. These areas will be addressed in detail in subsequent sections of the GAR. There are also some areas mapped as limestone and metasedimentary/metavolcanic rocks in the middle portions of both sub-watersheds.

1.3.7.4 Lake Paulina

The Lake Paulina Watershed covers an area of about 107 square miles. It is bordered by Tehachapi Creek Watershed to the northeast and the Tejon Creek Watershed to the east and south. This watershed has about 6,487 feet of relief from its highest point at 6,913 feet msl to 426 feet msl near the valley floor. The watershed is drained near its southern boundary by Comanche Creek (**Figure 1-8**). Similar to the surrounding watersheds the major rock type in the watershed is the Mesozoic granites, quartz monzonite, granodiorite, or quartz diorite (**Figure 1-8**). There are alluvial deposits of various ages at the bottom of the watershed near the valley floor and some alluvium is mapped on the eastern side of the watershed. In the southwest part of the watershed, moderately consolidated shale, sandstone, siltstone, conglomerate and breccia are found along with some small pockets of metasedimentary and metavolcanic rocks.

1.3.7.5 Southern Watersheds of Kern Lake Bed

Several small watersheds drain into the Kern Lake bed from the south. These small watersheds include the Tejon Creek, El Paso Creek, Pastoria Creek, Grapevine Creek and the upper portions of the Kern Lake Bed watershed. Combined, these watersheds cover an area of about 499 square miles and vary in elevation from 7,962 feet msl at the top of the Tejon Creek Watershed to 476 feet msl near the valley floor in the Kern Lake Bed Watershed. Numerous other creeks traverse this area including Plietito Creek, Salt Creek, Colorful Creek, Tecuya Creek, Cattle Creek and Tunis Creek. These watersheds have a significant amount of the Mesozoic granites, quartz monzonite, granodiorite, or quartz diorite (**Figure 1-8**). The relative amount of granites decreases westward across the area and comprises only about 40 percent of the Kern Lake Bed Watershed. A significant portion of the upper central part of El Paso Creek Watershed is composed of metasedimentary/metavolcanic rocks. Lower regions in these watersheds and the western part of the combined area has a wide variety of geologic materials in various stages of consolidation including sandstones, breccias, siltstones, conglomerates, and volcanic flow rocks. A large landslide deposit mapped in the lower part of the Kern Lake Bed Watershed is also notable. Several significant deposits of alluvium mapped in this area are recognized DWR groundwater basins. These pockets of alluvium are DWR basin 5-27 (Cummings Valley), DWR basin 5-80 (Brite Valley), and in the Grapevine Creek area; DWR basin 5-29 (Castaic Lake Valley), and 5-82, 5-83, and 5-84, respectively, Cuddy Canyon Valley, Cuddy Ranch Area, and Cuddy Valley.

1.3.7.6 Southwestern Watersheds of Buena Vista Lake Bed

Several watersheds in the southwestern part of the peripheral area drain to the Buena Vista Lake Bed. The main drainage in this area is the upper portion of the Buena Vista Lake Bed Watershed. This area covers about 310 square miles. North of the Buena Vista Lake Bed Watershed, the Upper Kern River Flood Canal and parts of the West Side Canal drain to the Kern River; however the generalized geology is included in this discussion. This area has a relief of 8,367 feet from 8,655 feet msl to 288 feet msl at the valley floor. Several creeks drain this area including but not limited to San Emigdio Creek, Los Lobos Creek, Muddy Creek, Santiago Creek, Bitter Creek, Bitter Water Creek, Cienaga Creek, Sandy Creek, Buena Vista Creek, and the Outlet Canal. Unlike the watersheds to the north and east, only small amounts of the Buena Vista Lake Bed Watershed contain the Mesozoic granites, quartz monzonite, granodiorite, or quartz diorite (**Figure 1-8**). Geologic materials over the majority of the area are chiefly moderately to well consolidated sandstone, shale, siltstone, conglomerate and breccias. Lower in the watersheds, there are significant amounts of unconsolidated to loosely consolidated Quaternary deposits of alluvium, lake bed, playa, and terrace deposits, as well as loosely consolidated deposits of sandstone, shale and gravel. Part of the San Andreas Fault traverses the upper part of the Buena Vista Lake Bed Watershed and the Grapevine Creek Watersheds. In this area a wide variety of rock types outcrop including schist of various types, gneiss, hornfels, sandstone, limestone, shale, marble, and conglomerates. In the upper part of the Buena Vista Lake Bed Watershed there is a DWR recognized groundwater basin (DWR basin 5-85, Mil Potrero Area) associated with a significant deposit of alluvium along the San Andreas Fault.

1.3.7.7 Rag Gulch Watershed

Disconnected from and north of the remainder of the peripheral lands is an area within the peripheral lands that is dominated by Rag Gulch Watershed. There are also portions of the Lower White River and Dry Creek-Lake Woollomes Watersheds in this area. Combined, the area is about 159 square miles. Compared to the other watersheds, this is an area of relatively low elevation from a high of 4,553 feet

msl to 657 feet msl. The major creeks that drain this area include Dead Ox Creek, Willow Spring Creek, and Five Dog Creek. The upper part of this watershed is composed of the Mesozoic granite, quartz monzonite, granodiorite, and quartz diorite (**Figure 1-8**). Valleyward, the granitoid rocks give way to sandstones, shale, conglomerate, breccia, siltstone and gravel deposits. At lower elevations, these deposits are loosely consolidated and are moderately to well consolidated at higher elevations. The eastern extent of DWR groundwater basin 5-22.14, Kern County basin, in the Rag Gulch Watershed area, is roughly delineated by the area mapped as alluvium or mostly loosely consolidated sandstone, shale and gravel deposits.

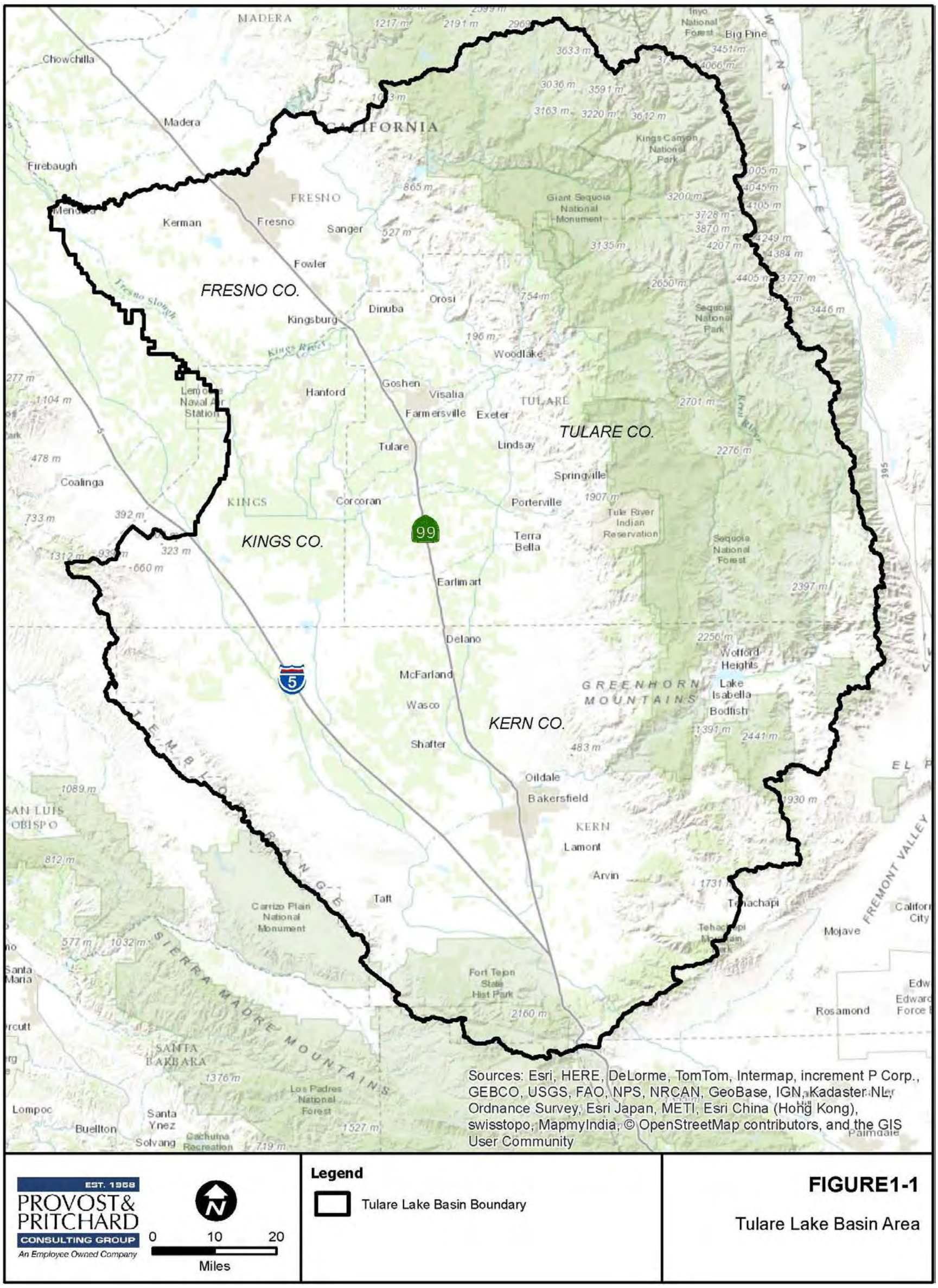


Figure 1-1. Map of the Tulare Lake Basin Area

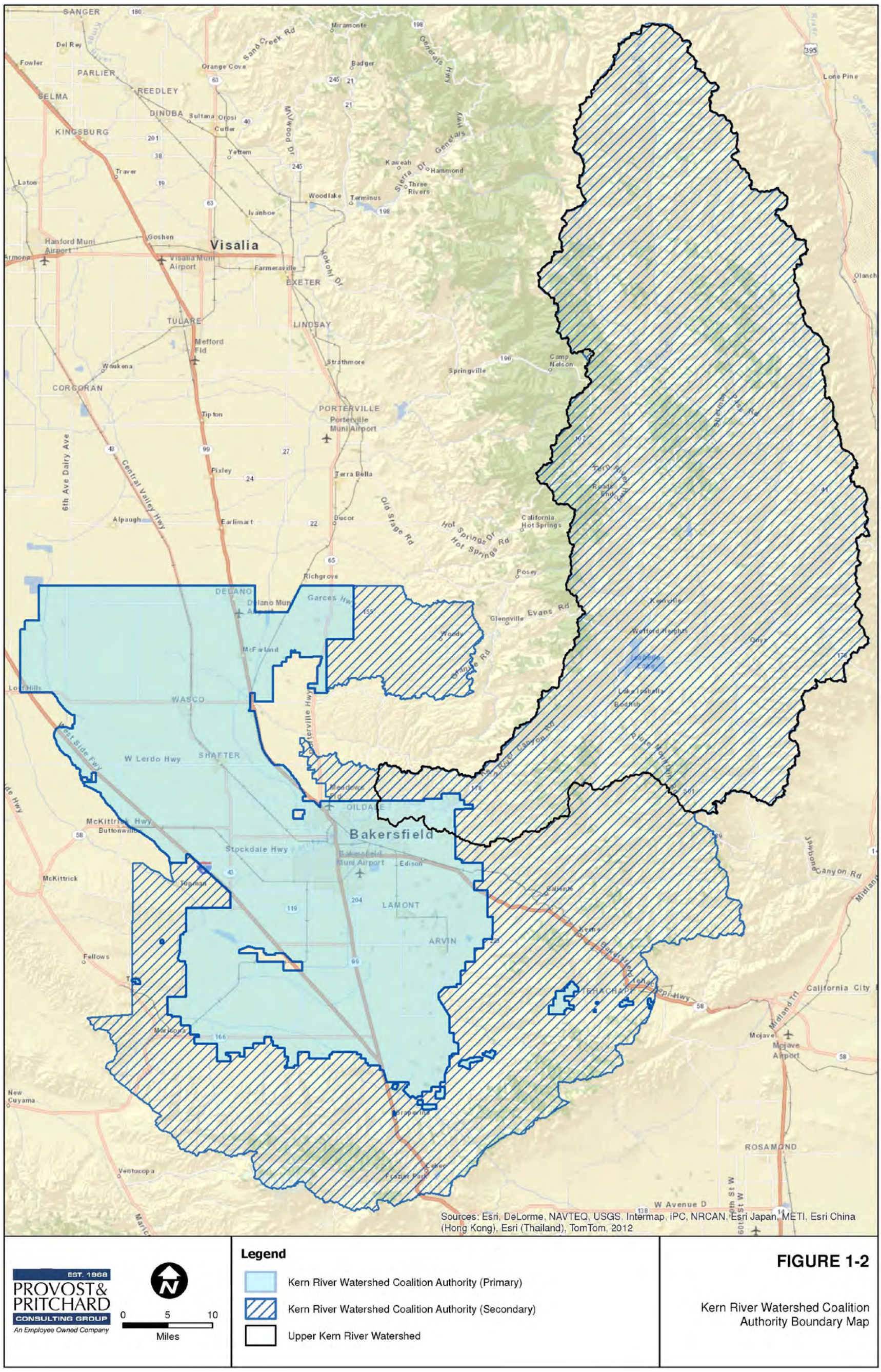


Figure 1-2. Kern River Watershed Coalition Authority Boundary

Table 1-1. Components of the GAR and Report Section

GAR Component Name (WDR Reference)	GAR Section
Data Compilation – Relevant existing federal, state, county, and local databases and documents (Attachment B.IV.A.2.p.13)	
Pertinent geologic and hydrogeologic information (AttB.IV.A.3.p12)	Section 5, 7, 9.4, 9.5
Detailed land use information	Section 2, 9.1
Contour maps (groundwater depth, elevation, elevation change)	Section 7, 9.5
Groundwater recharge	Section 8, 9.7
Soil survey information	Section 3, 9.2
Irrigation and agricultural management practices	Section 4, 9.3
Shallow groundwater constituent concentrations; potential constituents of concern identified	Section 6, 9.6
Existing groundwater data collection and analysis efforts	Section 6, 7, 9, 12
Data Review and Analysis (Attachment B.IV.A.3.p.13)	
Known groundwater quality impacts	Section 6, 9.6, 10
Merit and feasibility of incorporating existing data collection and monitoring well systems	Section 9.5, 9.6, 12
Designate high and low vulnerability areas for groundwater (AttB.IV.4.p.13-14)	Section 10.4
a. Rationale for vulnerability determinations (AttB.IV.A.4.p.14)	Section 10
b. Ranking of high vulnerability areas, basis for prioritization of workplans (AttB.IV.A.5.p.14)	Section 11
Foundational Information for Groundwater Monitoring (VII.1.p.29 and Attachment B.IV.1.p.12)	
Recommendations for Management Practice Evaluation Program design (AttB.IV.B and D, p. 14-18)	Section 13
Recommendations for Groundwater Quality Trend Monitoring Program design (AttB.IV.C and E, p. 16-19)	Section 13
Recommendations for establishing Groundwater Quality Management Plans and priorities for implementation (AppMRP-1.l.B.3.p.3-4)	Section 13
References (Attachment B.IV.A.p. 12)	
Data Sources	Section 14
Bibliography	Section 14

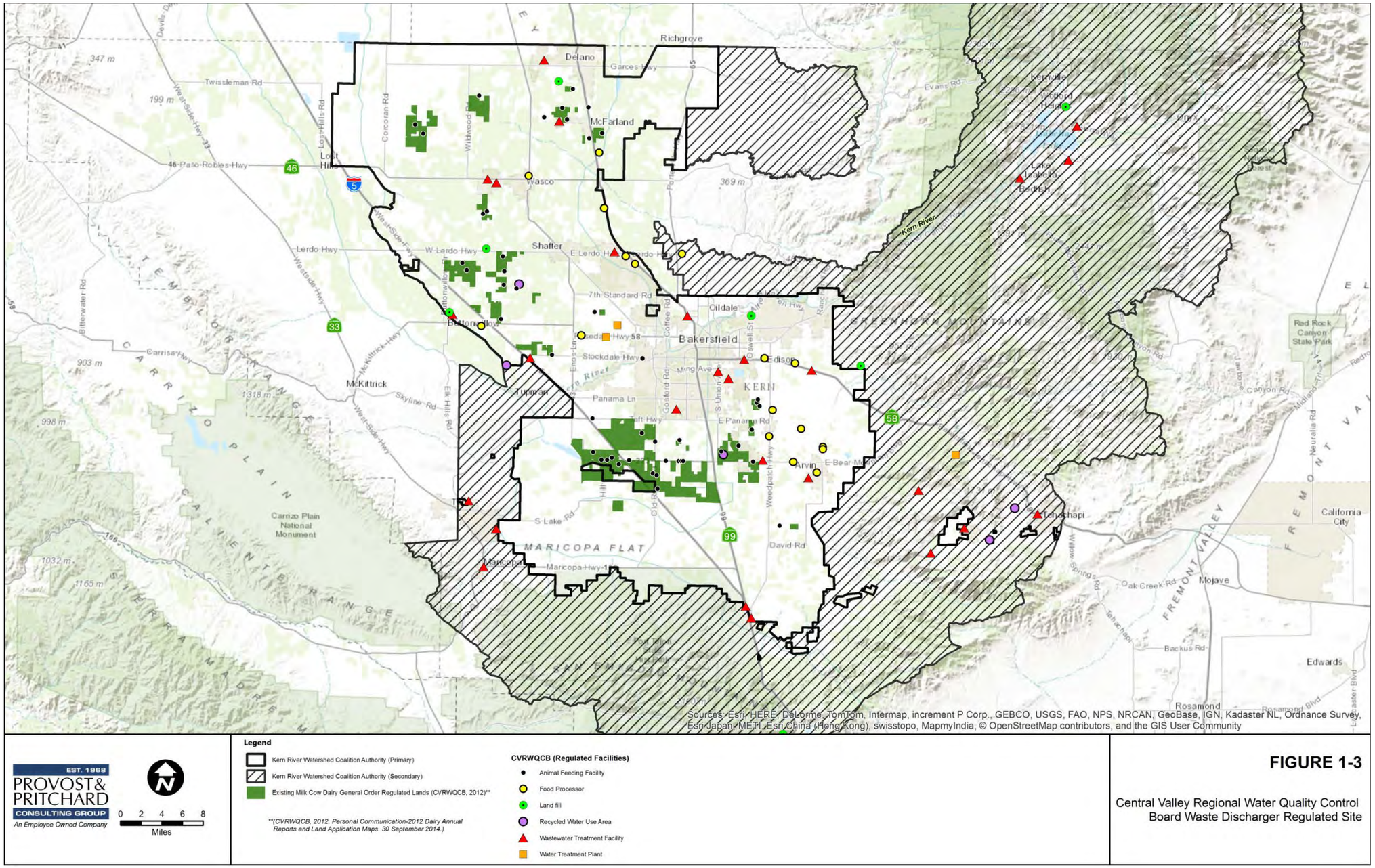


Figure 1-3. Map of CVRWQCB Waste Discharger Regulated Site

Table 1-2. KRWCA Disadvantaged Communities and Median Household Income

City/Community	Median Household Income (MHI)
Alta Sierra	$24,714
Arvin	$32,949
Bodfish	$32,667
Bonanza Farms	$35,278
Calders Corner	$38,900
Cherokee Strip	$45,903
Community 421	$29,646
Community 427	$38,900
Delano	$35,673
Dustin Acres	$39,712
East Niles	$47,663
Edmundson Acres	$36,944
El Adobe Property Owners Association	$32,620
Fuller Acres	$31,551
Glennville	$40,941
Greenfield	$45,851
Havilah	$29,646
Kernville	$47,308
Lake Isabella	$19,627
Lamont	$33,799
Maricopa	$39,464
McFarland	$35,656
Mettler	$28,889
Mexican Colony	$32,321
Mountain Mesa	$48,431
Oildale	$35,538
Onyx	$36,250
Opal Fry and Son	$35,278
Panama Road Property Owners Association	$33,457
Pine Mountain Club	$44,375
Pond	$41,948
Poplar Ave Community	$37,403
Shafter	$35,915
Smith Corner	$25,573
Tehachapi	$46,067
Tupman	$23,750
Wasco	$40,054
Weedpatch	$24,324
Weldon	$32,690
Wofford Heights	$25,224
Woody	$40,941

Table 1-3. KRWCA Temperature and Rainfall Characteristics

Temperature and Rainfall Characteristics – Kern County Valley Floor													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Avg. Rainfall (in) /1	1.40	1.17	0.79	0.76	0.17	0.00	0.01	0.01	0.08	0.35	0.40	0.66	5.80
Avg. Max Temp (°F) /2	56.6	63.2	68.8	73.7	84.2	91.8	97.8	95.8	90.7	79.2	65.6	58.8	77.2
Avg. Min Temp (°F) /2	36.4	38.8	43.0	47.2	54.8	61.2	67.9	65.9	60.7	52.0	42.6	36.8	50.6
NOTES: /1 - CIMIS Data for Arvin-Edison Station 125. /2 - Western Regional Climate Center, Bakersfield 5 NW 354 Station for the Years 1999 to 2007.													
Temperature and Rainfall Characteristics - Kern County Foothills													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Avg. Rainfall (in) /1	2.79	2.39	1.93	0.87	0.28	0.10	0.12	0.18	0.29	0.38	1.35	1.84	12.52
Avg. Max Temp (°F) /1	59.1	62.7	66.4	72.8	81.0	90.3	97.6	96.7	91.1	80.1	67.3	60.0	77.1
Avg. Min Temp (°F) /1	32.2	35.0	38.0	43.1	50.5	58.0	64.3	62.7	57.3	47.4	37.5	32.3	46.5
NOTES: /1 - National Weather Service. Average Temperature by Month 1946 to 2008, Kern River PH3 Weather Station.													

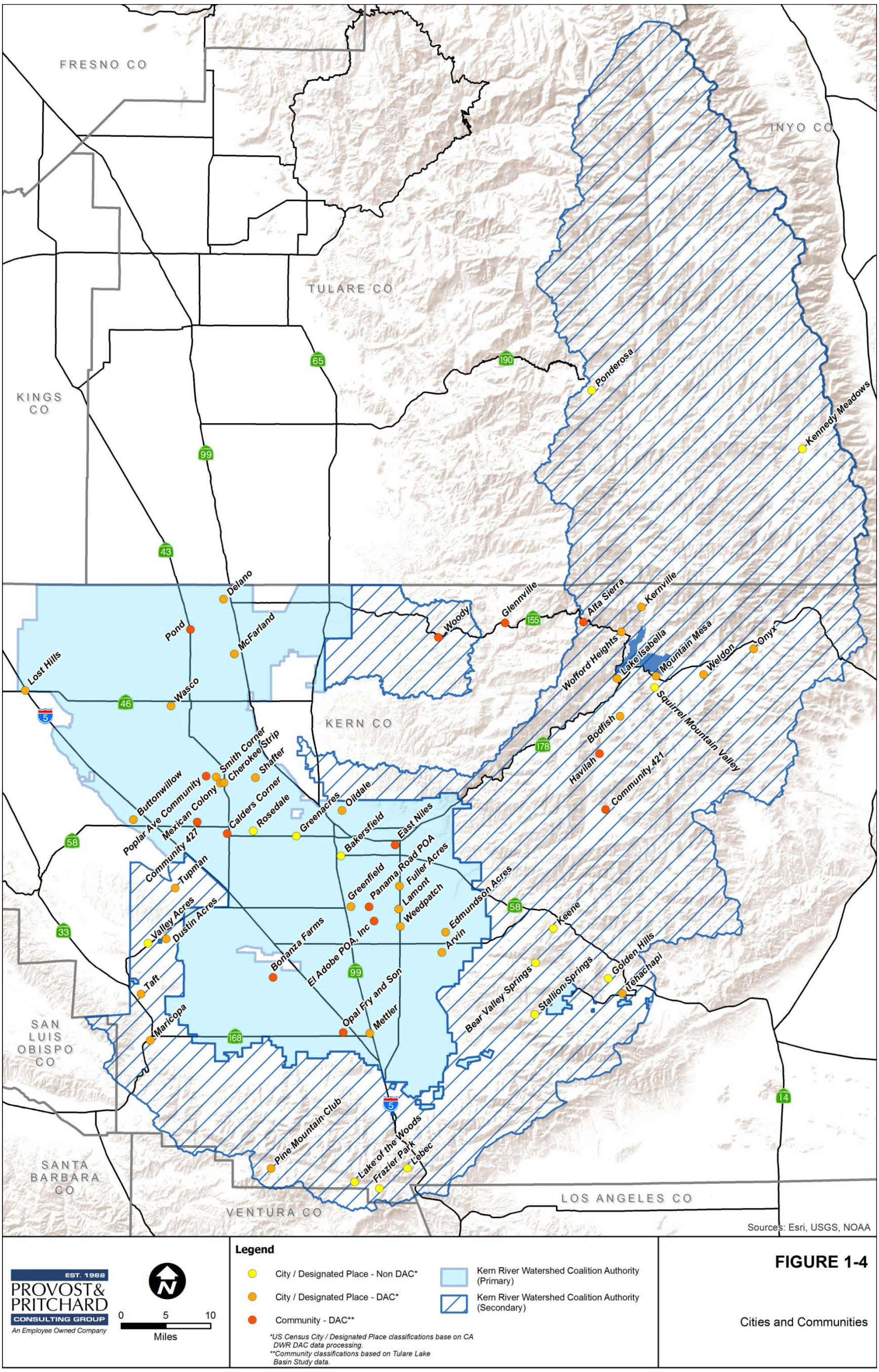


Figure 1-4. Cities and Communities

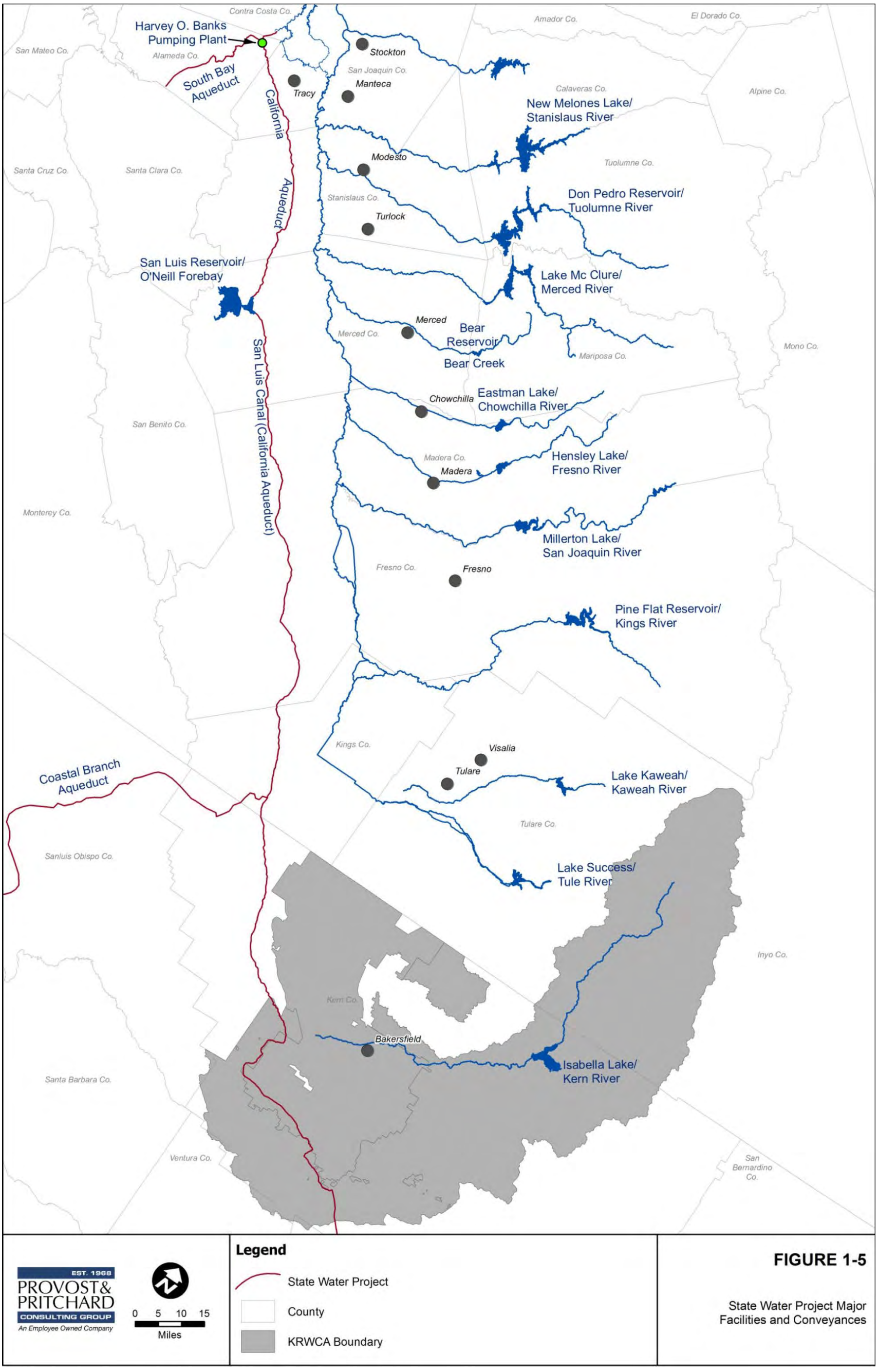


Figure 1-5. State Water Project Major Facilities and Conveyances

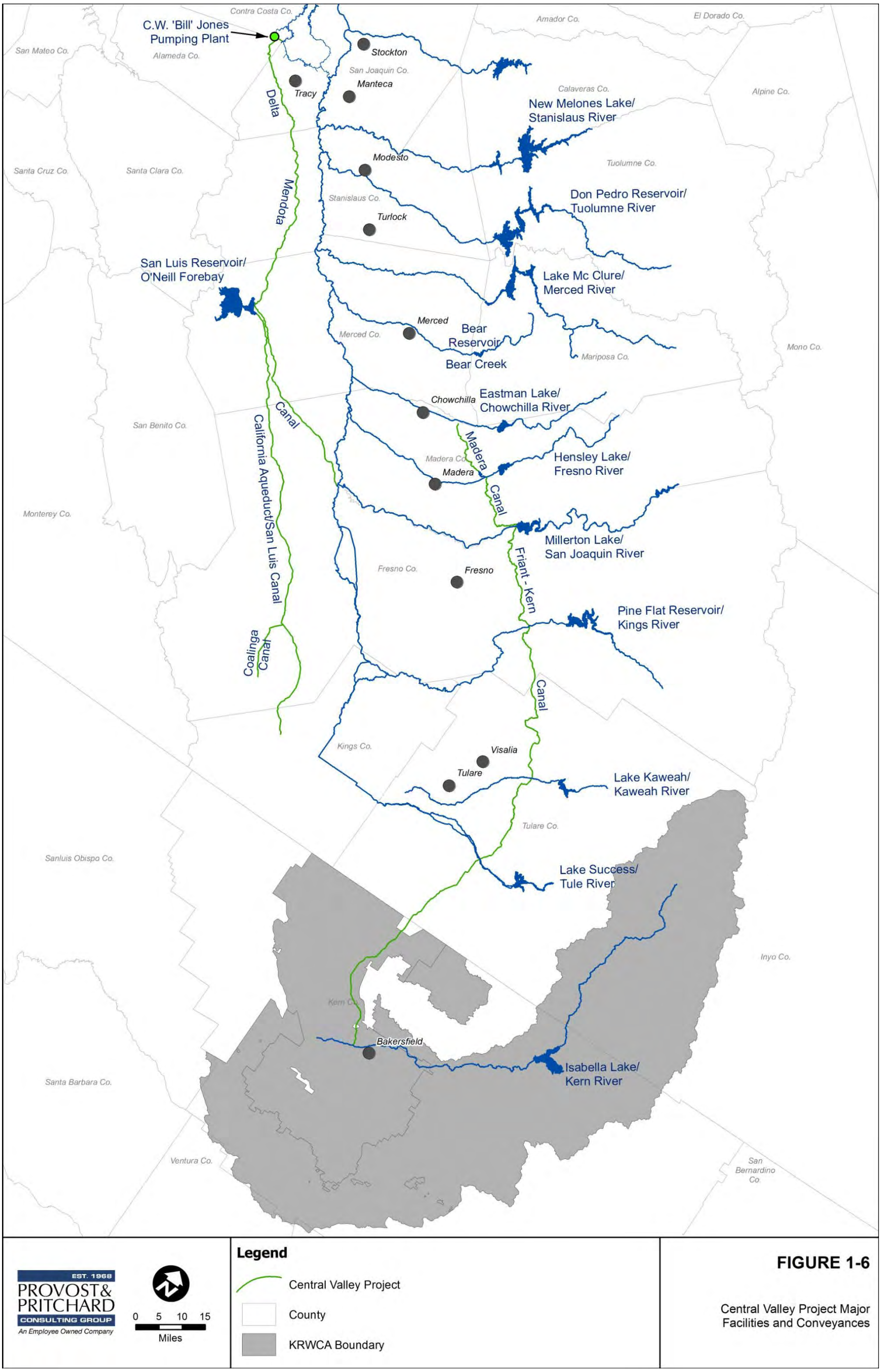


Figure 1-6. Central Valley Project Major Facilities and Conveyances

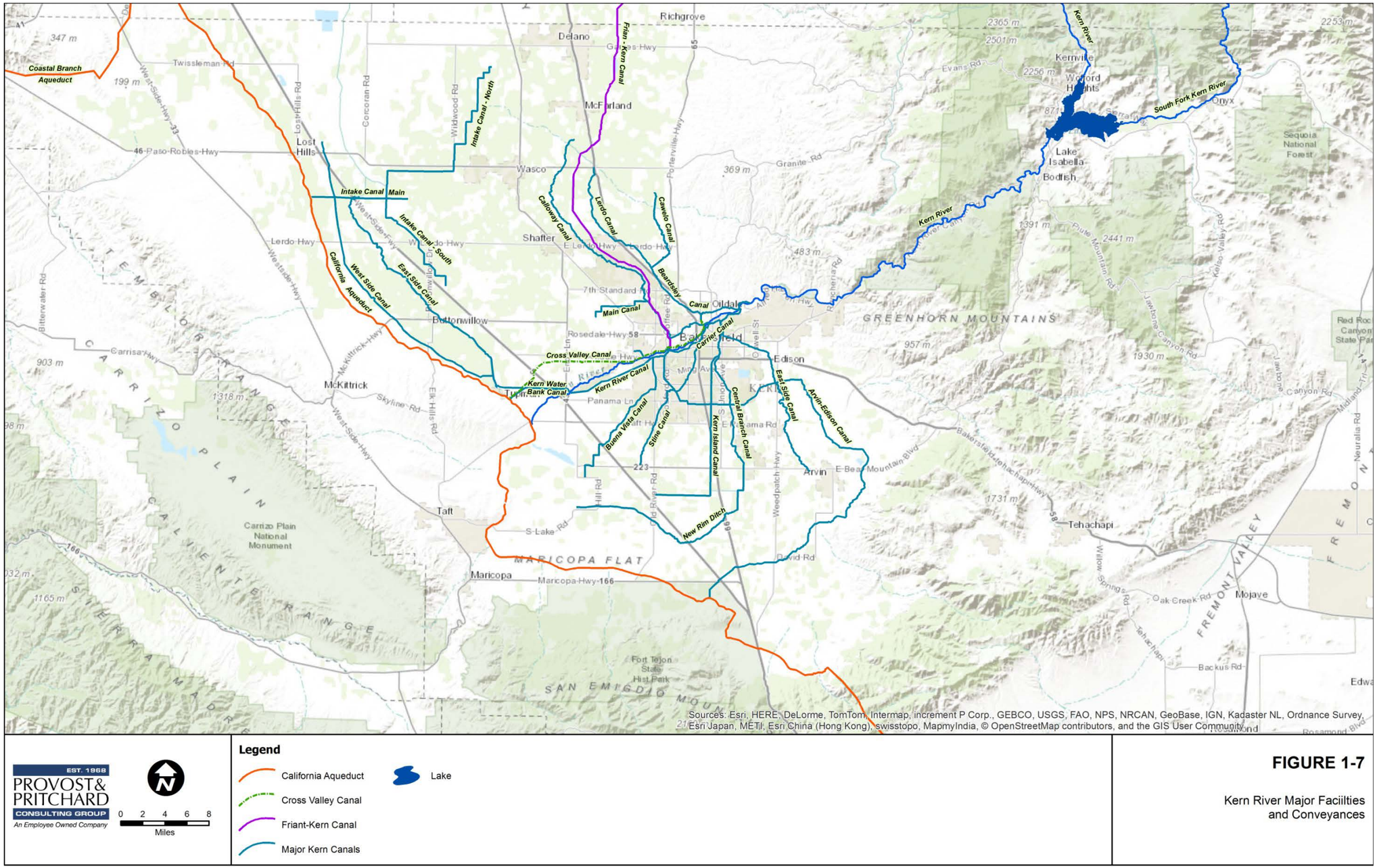


Figure 1-7. Kern River Major Facilities and Conveyances

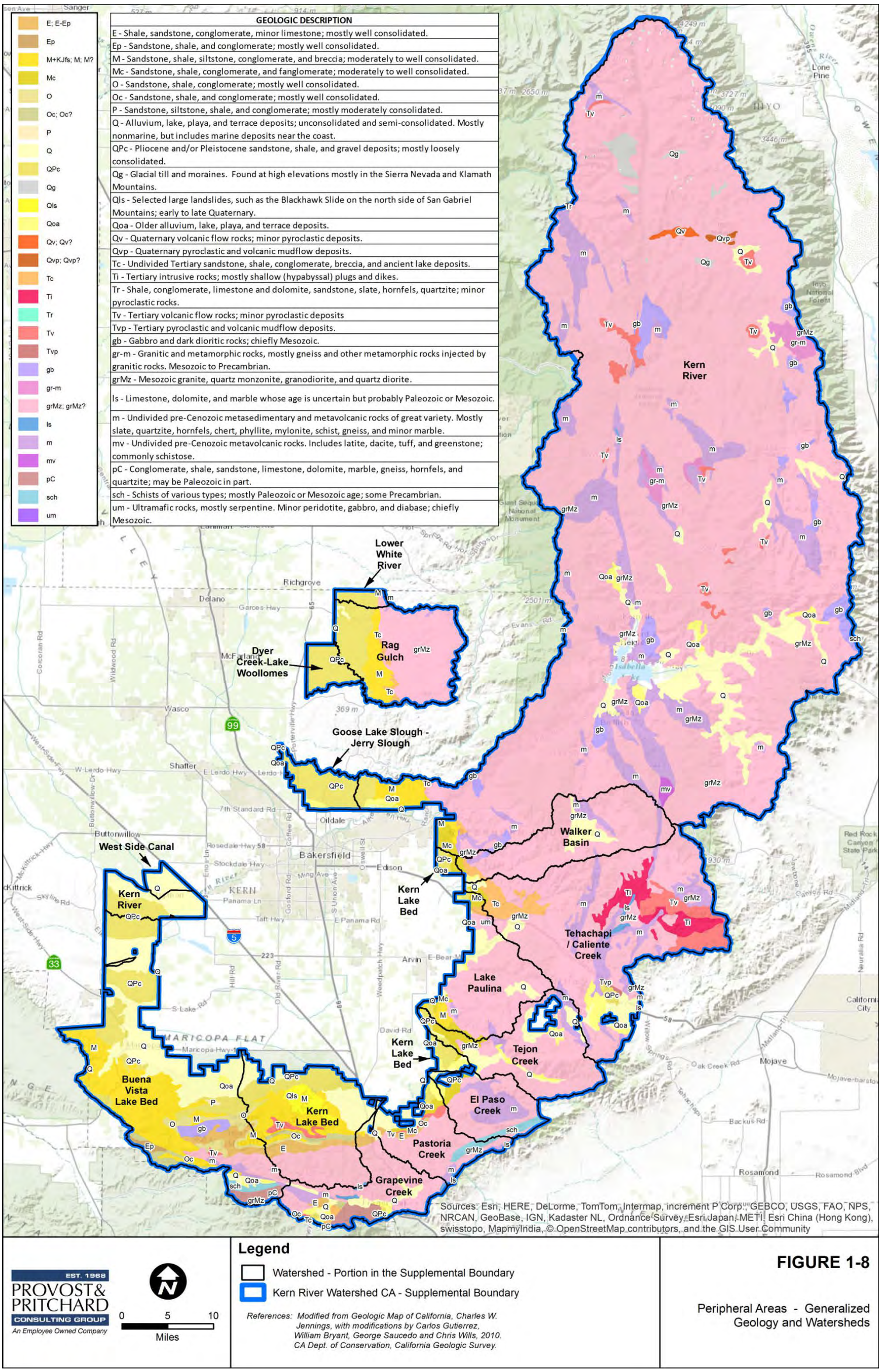


Figure 1-8. Peripheral Areas – Generalized Geology and Watersheds

2 Land Use Determinations

2.1 Historical Identification of Land Cover

The purpose of collecting and reviewing historical land use data within the Kern River Watershed Coalition Authority's (**KRWCA**) primary boundary is to illustrate the change in crops and irrigation systems that has occurred in recent history. Data from 1990 was used because it is the oldest accurate spatial crop data. It also marks the beginning of a major shift in irrigation systems from surface types to micro-sprinkler and drip irrigation. The California Department of Water Resources (**DWR**) crop database is an accurate source of spatial crop type information that is available to the public (DWR, 2014). It is completed by field survey, meaning that DWR field staff and/or local district staff makes observations on the crop and irrigation type for every field in each county. Because the crop database is produced by field observations, this database only includes the irrigated acreage, or aerial extent, of crops in Kern County. This geospatial data is of medium resolution and dates back to 1990 for Kern County. Historical dairy facilities were determined by reviewing the Kern County Planning Department Dairy List (Kern County Planning Department, 2005) and cross checking the facilities to historical 1995 aerial photography.

The summary of information presented below resulted from analysis using this geospatial database.

2.1.1 Predominant Commodities

Figure 2-1 shows the distribution of crop types within the KRWCA primary boundary in 1990. At this time, there were approximately 683,000 irrigated acres. The predominant 1990 crop was cotton, accounting for about 236,000 acres (over one third of irrigated acres). Cotton acreage peaked in 1990, according to DWR crop surveys, and has since declined. Cotton, field crops (small grains, hay and forage), alfalfa, and truck crops (vegetables, melons and berries) made up almost 80 percent of the cropped irrigated acreage; however, almond, grape, and citrus were also significant individual crops at this time. **Table 2-1** lists the various KRWCA crops in 1990 and respective percent of total irrigated acreage.

2.2 Current Identification of Land Cover

The 2013 spatial crop database was acquired from the Kern County Agricultural Commissioner (County of Kern Agriculture and Measurement Standards, 2014). It is an accurate, annually updated database that is available to the public. This database includes crop type as well as double and triple cropping of fields, but no irrigation system information. Therefore, one field may be planted with more than one crop in a particular year, and these fields are labeled with a "mixed-veg" label on **Figure 2-2**. The total cropped commodity acreage within the primary boundary, including multiple counting of double and triple cropped lands was 806,000 commodity acres in 2013. Therefore, the cropped commodity acres are not equivalent to the acres of irrigated land or the cropped aerial extent. Currently, 466,347 irrigated acres are single-cropped while 152,894 irrigated acres (not commodity acres) are multi-cropped. The 2013 KRWCA total irrigated acres, not including double or triple cropping (aerial extent), is 619,241 acres. The total irrigated acreage within the primary boundary decreased by approximately

63,759 acres (9 percent) compared to the DWR 1990 dataset. Current dairy facilities were determined by the Central Valley Regional Water Quality Control Board (**CVRWQCB**) Waste Discharge Requirements General Order for Existing Milk Cow Dairies (Order R5-2013-0122) (**Dairy General Order**). The CVRWQCB provided a spatial dataset based on 2012 program monitoring of all reported dairy facility and associated crop acreage (CVRWQCB, 2012). The CVRWQCB dairy spatial dataset was crosschecked to 2012 aerial photography to ensure dairy facility and dairy crop accuracy.

2.2.1 Predominant Commodities

Table 2-2 lists the commodity acreage and percentage of total cropped area in 2013. **Figure 2-2** shows the crop distribution in 2013, and **Figure 2-3** shows the change in main commodities from 1990 to 2013 in the KRWCA primary boundary. Several changes in crop type distribution are worth noting. Cotton acreage fell to approximately 38,000 acres in 2013 (less than 20% of its acreage in 1990). In contrast, almond and pistachio acreage increased from 62,000 to 162,000 acres and 3,000 to 44,000 acres, respectively. Corn also increased from 6,000 acres to 40,000 acres; replacing some of the alfalfa acreage, and much of the range and pasture acreage, which fell from 4,000 to 400 acres. This change was likely the result of the corresponding increase in dairies (**Figure 2-4**), as corn is a higher energy feed source. Dairy facilities within the KRWCA primary boundary in 1995 compared to 2012 are also shown on **Figure 2-4**; associated dairy crop lands are only available in 2012, as it is reported as part of the Dairy General Order. Dairy facilities in Kern County increased approximately 4,200 acres from 1995 to 2012 (231 percent). Approximately 39,200 irrigated acres in the 2013 crop database are associated with dairies from the 2012 Dairy General Order reporting. It is important to note, that approximately 45,800 gross acres are enrolled in the Dairy General Order as associated crop acreage, the difference between the irrigated acres and enrolled acres can be attributed to fallow lands. Carrot acreage increased from 7,000 to 38,000 acres, and truck crop (vegetables, melons and berries) acreage more than doubled from 50,000 to 116,000 acres.

2.2.2 Distribution Relative to Soil Type

Some generalizations may be made on the types of soils that are used to grow different crop types. Within the KRWCA primary boundary, most citrus is grown along the eastern side, or Foothills region, where soils are medium-textured. The Foothills regional topography also creates microclimates with fewer incidences of freezing temperatures, which is more conducive to citrus. Mountain and foothill areas in the northeastern part of the KRWCA boundary are used as rangeland for cattle or sheep and are primarily non-irrigated. Crops such as dryland wheat may be grown in this area. Grapes are also typically grown on coarse or medium textured soils found in the northeastern portion of the KRWCA primary area and in the southern area corresponding to the Kern Fan. In contrast, the heavy soils of the Clay Rim region are dominated by crops such as cotton, wheat, corn and tomatoes. In general, permanent crops have expanded onto various types of soils that were previously not used to grow trees and vines. Corn and silage has also expanded on various soil types in response to livestock feed demand, primarily in proximity to dairy developments.

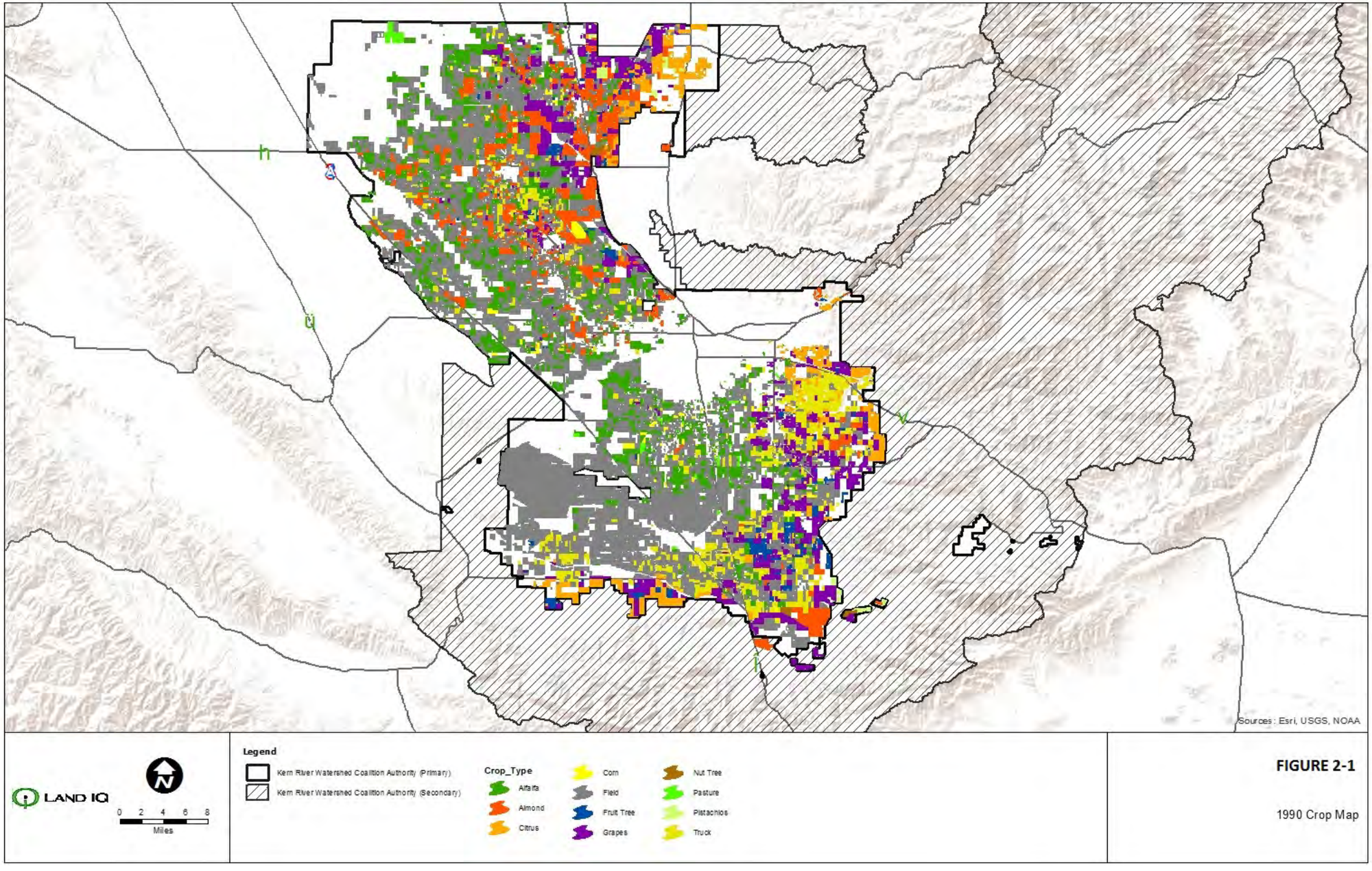


Figure 2-1. 1990 Distribution of Crop Types in KRWCA

Table 2-1. 1990 KRWCA Irrigated Acres and Percent of Total

Crop	1990 Irrigated Acres	% of Total
Alfalfa	96,302	14.09%
Almond	62,254	9.11%
Carrots	7,304	1.07%
Citrus	32,292	4.72%
Corn	6,125	0.90%
Cotton	236,853	34.66%
Field Crop	102,334	14.97%
Fruit Tree	11,604	1.70%
Grapes - Table and Wine	66,681	9.76%
Nut Tree	2,198	0.32%
Pistachios	3,111	0.46%
Range/Pasture	4,199	0.61%
Silage/Forage	2,520	0.37%
Truck Crop	49,675	7.27%
Total:	**683,451**	**100%**

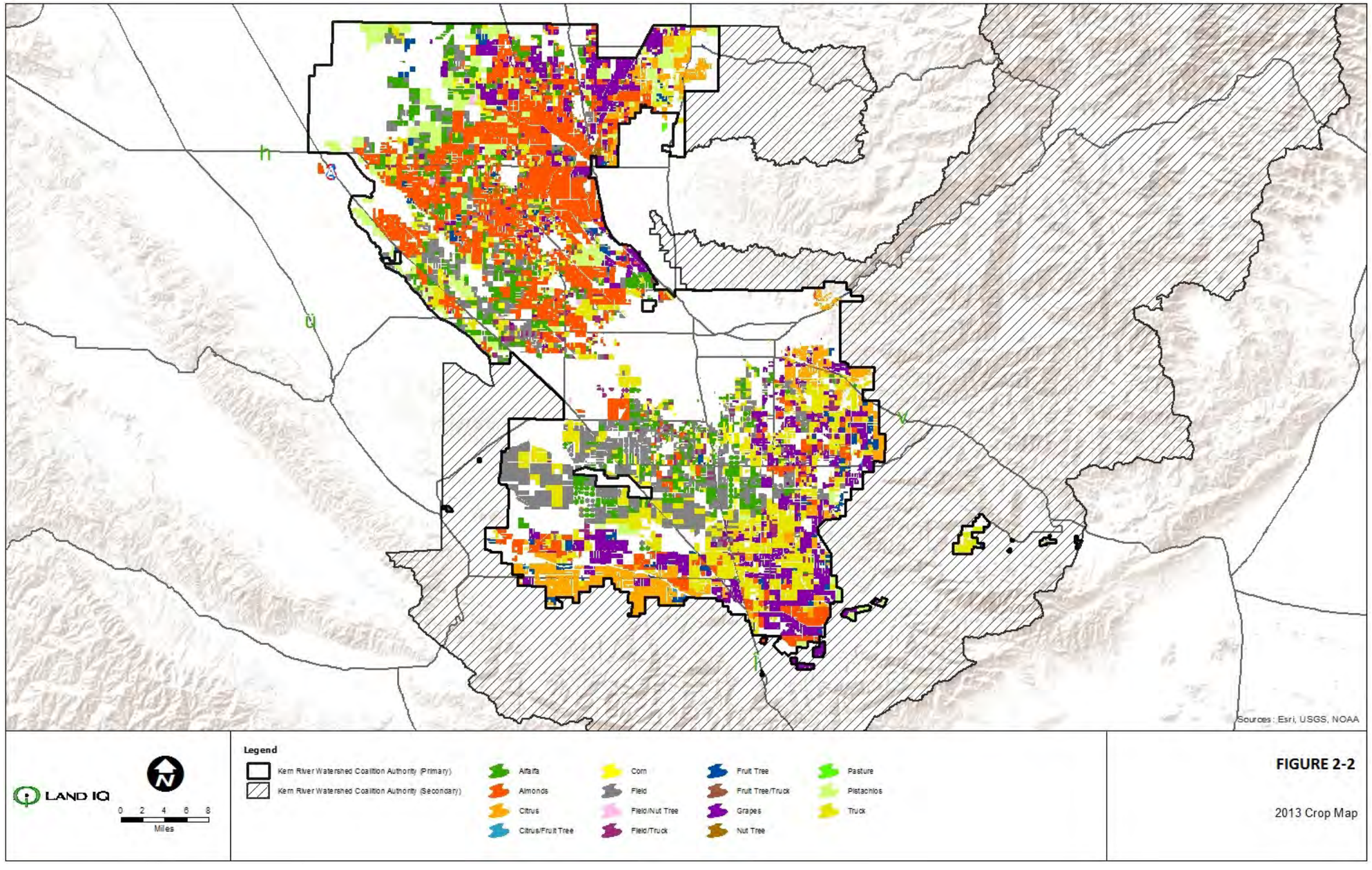


Figure 2-2. 2013 Distribution of Crop Types in KRWCA

Table 2-2. 2013 KRWCA Commodity Acres and Percent of Total

Crop	2013 Commodity Acres	% of Total
Alfalfa	76,220	9.45%
Almond	162,813	20.20%
Carrots	37,654	4.67%
Citrus	56,732	7.04%
Corn	39,496	4.90%
Cotton	38,033	4.72%
Field Crop	130,554	16.19%
Fruit Tree	15,140	1.88%
Grapes - Table and Wine	87,359	10.84%
Nut Tree	1,535	0.19%
Pistachios	43,565	5.40%
Range/Pasture	375	0.05%
Silage/Forage	667	0.08%
Truck Crop	116,010	14.39%
Total:	**806,153**	**100%**

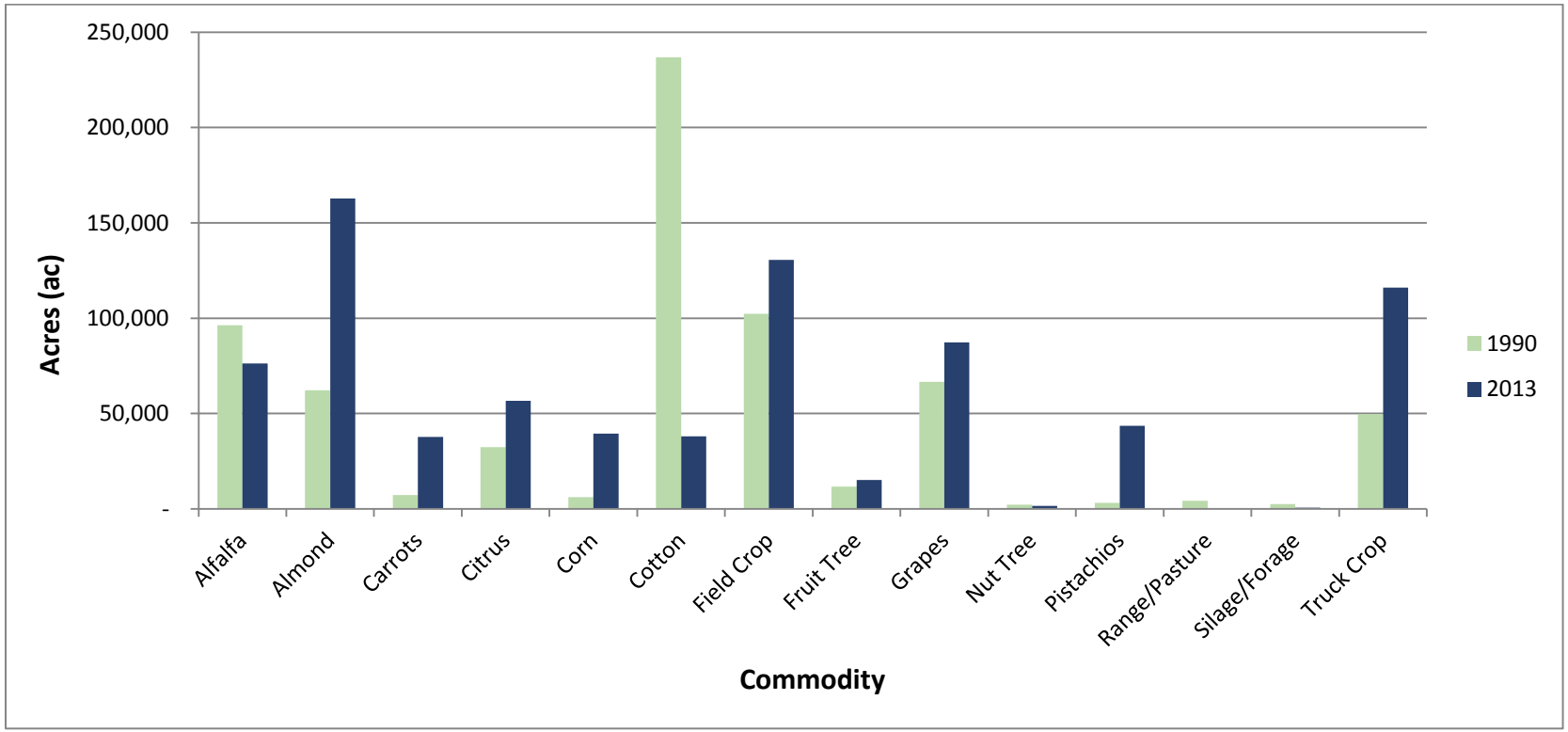
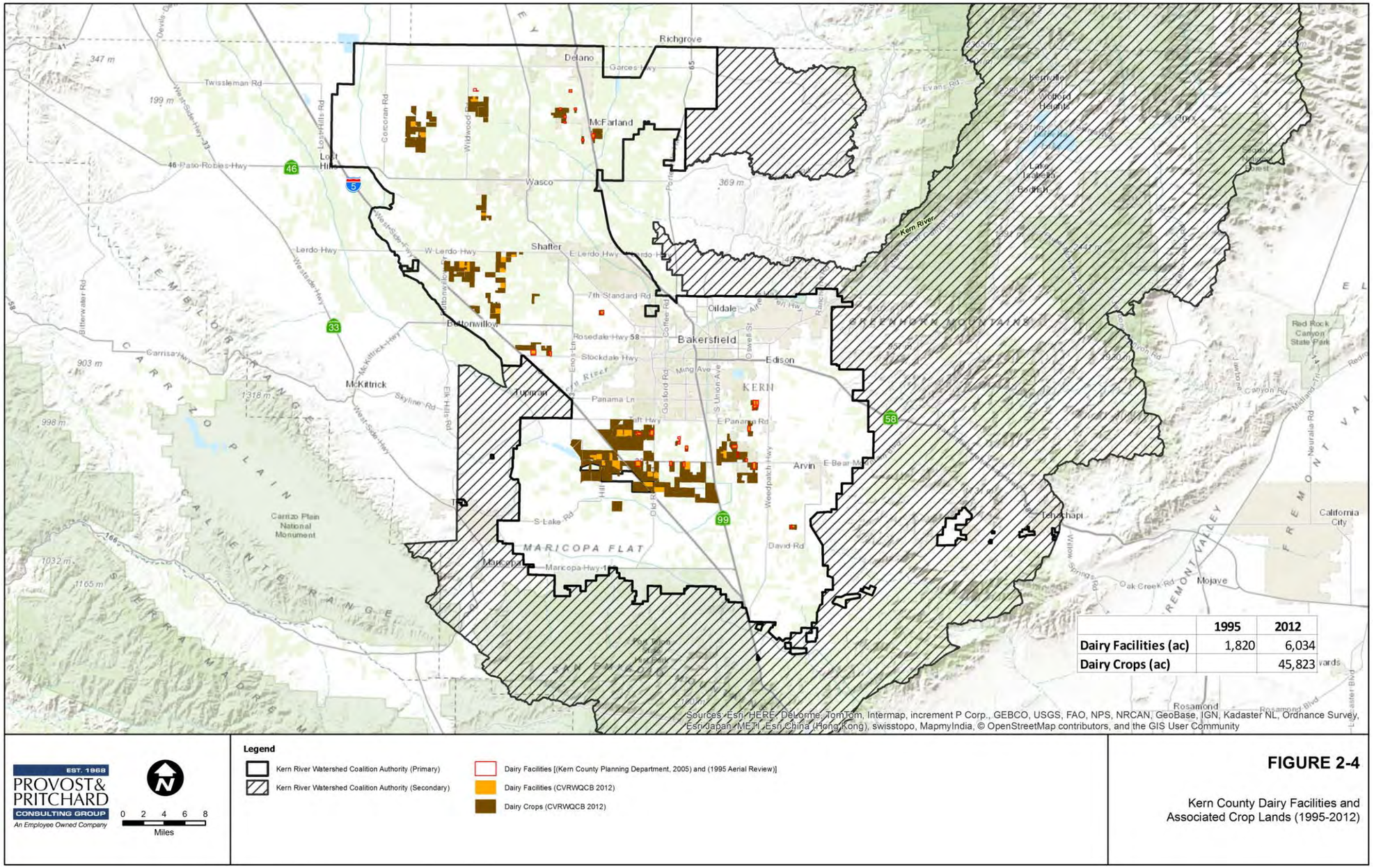


Figure 2-3. KRWCA Change in Main Commodities from 1990 to 2013



	1995	2012
Dairy Facilities (ac)	1,820	6,034
Dairy Crops (ac)		45,823

Figure 2-4. Kern County Dairy Facilities and Associated Crop Lands (1995 – 2012)

3 Soil and Land Surface Characteristics

3.1 Summary of KRWCA Soils

In the focus area on the Kern County valley floor, soils have two general origins that are approximately delineated by the trough of the valley. The eastern alluvial fans were deposited primarily through alluvial deposition generated by the precipitation and runoff from the Sierra Nevada, Tehachapi, and Transverse Mountain ranges. These soils are mostly of igneous and metamorphic origin, well drained, very low in salinity, ideal quality for agriculture, and have large well developed groundwater basins. The western alluvial fans originated mostly from coastal range sedimentary rock formed on the sea bottom. This region tends to have more areas with poorly drained soils of relatively marginal quality. Many of the soils on the west side of the valley required some reclamation before crops could be grown profitably.

For the purpose of broad characterization, the primary area can be divided up into five main areas relative to soil texture (**Figure 3-1**):

i. Clay Rim;
ii. Foothills;
iii. Kern Fan;
iv. Northern Areas; and,
v. Wheeler Ridge/Arvin-Edison Region.

The Clay Rim region accounts for approximately 154,000 gross acres in the Kern River Water Coalition Authority's (**KRWCA**) primary boundary, and consists of heavy (fine-textured) soils extending from the mid-northern western boundary of the focus area southerly to the southern tip. It includes the historic Buena Vista Lake Bed and historic Kern Lake Bed, derived from lacustrine deposits, and lands in historic swamp and overflow lands at the margins of alluvial fans and historic lake beds.

The Foothills region represents about 63,000 gross acres, and consists of medium-textured soils extending along the eastern edge of the focus area.

The Kern Fan region, representing approximately 225,000 gross acres, includes soil derived from river deposition. Because of their alluvial origins soil texture varies with the distance from the mouth of the historic drainage coming from the foothills, but can generally be characterized as coarse-textured.

The Northern Areas region, representing approximately 331,000 gross acres, consists of some alluvium from Poso Creek and other sources, but is generally comprised of soils that are less easily characterized and divergent in texture.

The Wheeler Ridge/Arvin-Edison region encompasses approximately 198,000 gross acres and generally has coarse-textured soils. The region boundary generally follows the Arvin-Edison Water Storage District (**AEWSD**) and Wheeler Ridge-Maricopa Water Storage District (**WRMWSD**) borders, with some exceptions. A portion of northeastern AEWSD has been included in the Foothills region, as it is more consistent with that area in terms of cropping and soils. Similarly, because of differences in soil texture and crop type in the northern part of WRMWSD, the northern portion is included in the Clay Rim region.

3.2 Soil Types in Survey Areas

The description of soils in the focus area is summarized from the following soil surveys:

- Soil Survey of Kern County, Northeastern Part, and Southeastern Part of Tulare County, California (2007);
- Soil Survey of Kern County, California, Southwest Part (2009, currently updated online); and,
- Soil Survey of Kern County, California, Northwestern Part (1988, currently updated online).

The soil survey of the northeastern part of Kern County includes the mountains and foothills of the southern Sierra Nevada Range, and small portions of the Central Valley. This area is dominated by the Sierra Nevada and the areas immediately to the west. The KRWCA boundary includes the San Joaquin Valley floor, a small part of this survey area. Soils in the northeastern part of Kern County that are included within the KRWCA boundary range from flood plains, alluvial fans, stream terraces, and fan remnants, to hillslopes and mountain slopes.

The northern part of the KRWCA is broadly divided into two areas: 1) the margins of alluvial fans and plains on the west side of the valley and the Clay Rim associated with historic swamp and overflow lands; and, 2) alluvial fans and plains on the east side. The nearly level to gently sloping landscape on the west side often consists of poorly drained alluvial material deposited by run-off from the Coast Range and periodic high flows of Kern River and Poso Creek. Alluvial fans and plains on the east side, however, contain soils that are well-drained because of the areas westerly slope and the deposition of alluvial material derived entirely from the Sierra Nevada Range.

The southwestern part of Kern County includes the historic Kern and Buena Vista Lake Beds, swamp and overflow lands, and the western slope of the southern San Joaquin Valley. The valley floor consists of a nearly level basin floor and fan skirts, and sharply sloping alluvial fans and fan remnants. Because historic lake bed soil and hydrology are unique features of the KRWCA, they are discussed in more detail below.

3.2.1 Historic Lake Bed Areas

Historic lake beds, swamps, and overflow lands consist of slightly acidic lacustrine and alluvial fan margin soils that are formed when fine particles settle out from lake and swamp water. The Kern and Buena Vista historic lake beds are comprised of clay soils with little variation. In particular, the Buena Vista lakebed, though it has silty clay soils at the surface, is underlain by a very thick horizon of clay soil with very low permeability. Surface soils typically have a relatively high saturation percentage (60 percent to 80 percent), meaning that they hold relatively large amounts of water compared to coarser-textured soils with large pores that drain water more readily. **Figure 3-2** shows the unique soil features of the Buena Vista Lake Basin. These unique soil and hydrologic features influence agricultural practices on the lake bed, and these unique practices are discussed in detail in **Section 4**.

3.2.2 Influence of Agriculture on Soils

Agricultural practices have modified surface soils and soil hydrology. Addition of soil amendments and leaching has been used on lake beds and other areas to partially reclaim saline-sodic and saline soils. In

some areas, perched water tables resulted from poor drainage and the introduction of irrigation water. In general, most of the area water tables were historically closer to the surface than they are now.

Increased water application by irrigation increased the downward movement of carbonates, gypsum, fertilizers, salts, and various amendments through the soil profile. Gypsum applied to reclaim sodic soils results in changes in soil structure and sodium-rich layers below the surface that can become dense clay layers. Acidification can be caused by some fertilizer amendments.

3.3 Soil pH and Salinity

Spatial pH and salinity data for the KRWCA primary area was collected from the Natural Resources Conservation Service (**NRCS**) Soil Survey Geographic (**SSURGO)** Database (Natural Resources Conservation Service).

The spatial distribution of soil pH is shown in **Figure 3-3**. Soil pH is commonly referred to as alkalinity or acidity, and is a prime chemical control on soil quality. Neutral soils have a pH of 7 or near 7 (6.5 to 7.5), acidic soils have a pH below 7, and alkaline soils have a pH above 7. pH is a logarithmic scale, which means that each decrease in pH by 1 whole number equates to a 10-fold increase in acidity. Generally, agricultural crops thrive in soils that are neutral or slightly acidic (in the range between 6 and 7). At very high and very low pH levels, nutrients become less available, and elements that are potentially toxic become more available.

Soil pH is generally higher in the southern and north-western areas of the primary KRWCA area. These areas roughly correspond to alluvium from the San Emigdio Mountains and fringes of alluvial fans. Low pH is typical of lakebed soils and upper portions of eastside alluvial fans. The eastern side of the primary KRWCA area is generally within the range of 5 to 8, while the west and south portions have many areas with 8 to 10. Some low pH areas are found near the north-eastern part of the area as well as within the Kern Fan, and correspond to coarser-textured soils.

Soil salinity is measured using electrical conductivity (**EC**) tests. Crops differ in their ability to tolerate salinity, but most crops are negatively impacted when the soil EC is above 4 deciseimens per meter (**dS/m**). Salinity decreases a plant's ability to take up water from the soil, and some salts are specifically toxic to plants. Soil salinity can increase on irrigated land if soils are not properly leached to move the salts down (with water) below the root zone. Therefore, applying irrigation water in excess of crop consumption is an important management practice in irrigated agriculture.

The spatial distribution of soil salinity in the KRWCA primary boundary is shown in **Figure 3-4**, which shows similar patterns to soil texture and pH. The finer-textured soils in the Clay Rim regions are generally higher in salinity, whereas the coarser, alluvial soils on the eastern side of the KRWCA primary area are generally lower in salinity. High salinity is also typical of historic lakebed, swamp and overflow, and alluvial fan margin soils; the combination of high pH and high salinity is found in many of those areas.

3.4 Tile Drain Systems

The presence of shallow or perched groundwater in parts of the west side, historical lake beds, and the swamp and overflow areas has led towards the installation of tile drains in some areas to allow for crop production. Readily available data sources were researched in an attempt to identify locations of known

tile drain systems within the KRWCA region. **Figure 3-5** identifies subsurface drain monitoring locations based on California Department of Water Resources (**DWR**) Agricultural Drainage data (DWR, 2014c). The DWR data indicates shallow groundwater areas on the west side of the valley floor, in the historical lake beds, and swamp and overflow land areas, that can be attributed to the presence of thick, shallow, continuous clay layers. Tile drains may be installed in actively farmed locations with shallow groundwater locations depicted in **Figure 3-5**; however, the exact locations and number of facilities are unknown. **Table 3-1** presents the gross acreage of shallow groundwater (by depth) in the primary KRWCA area as identified by DWR Agricultural Drainage data (**Figure 3-5**).

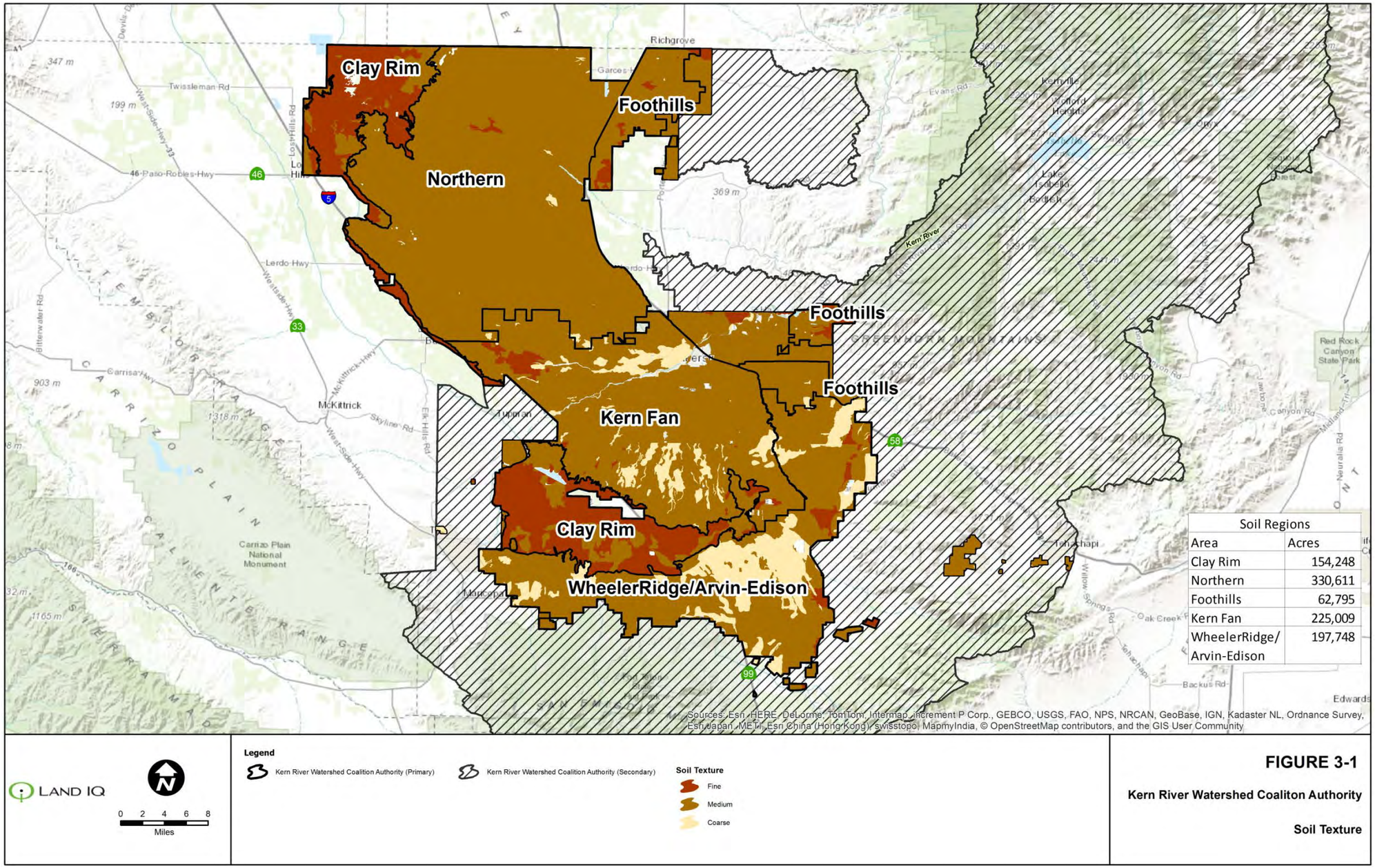


Figure 3-1. KRWCA Primary Boundary Generalized Soil Texture Map

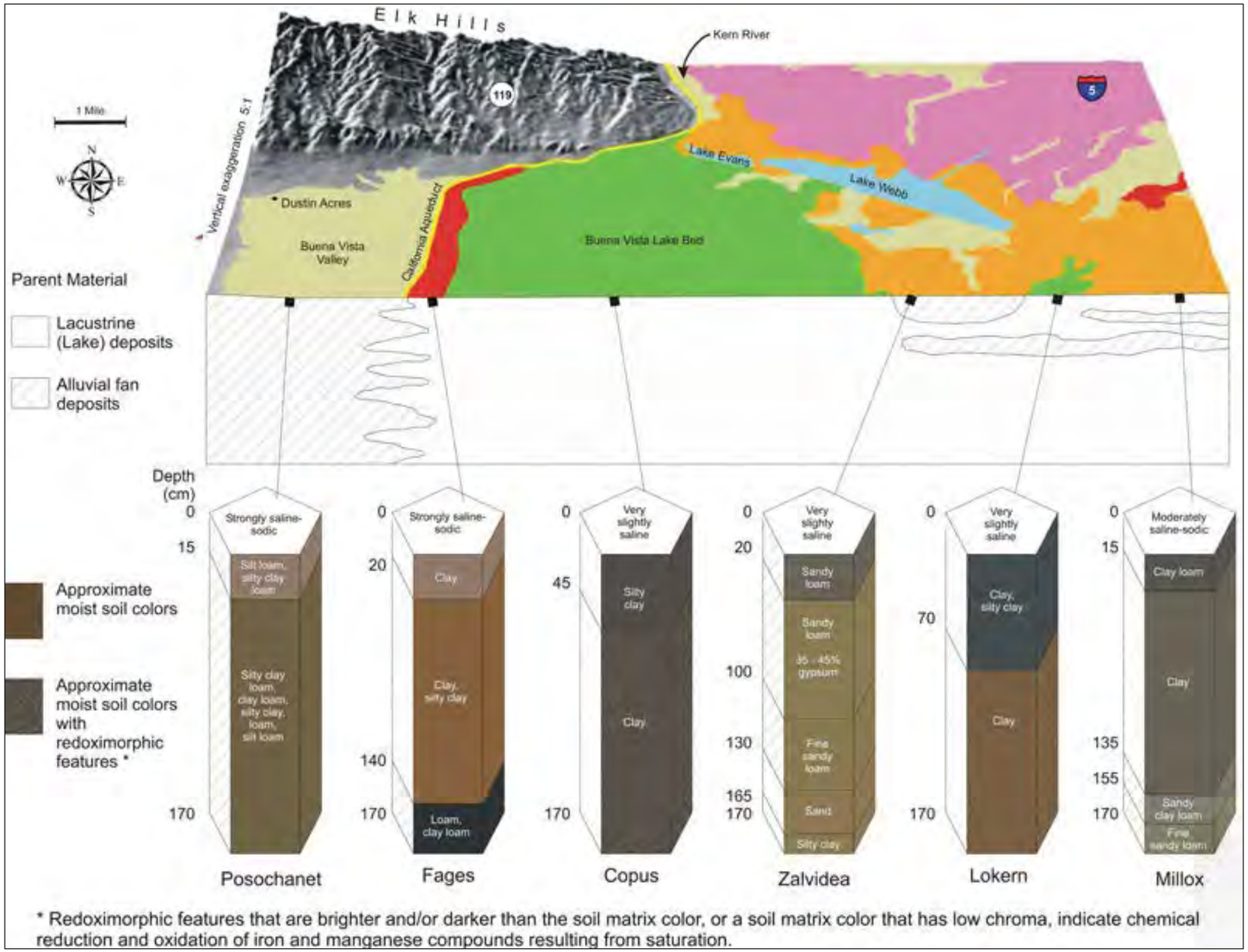


Figure 3-2. Soil, landscape, and stratigraphy model of the Buena Vista Lake Basin

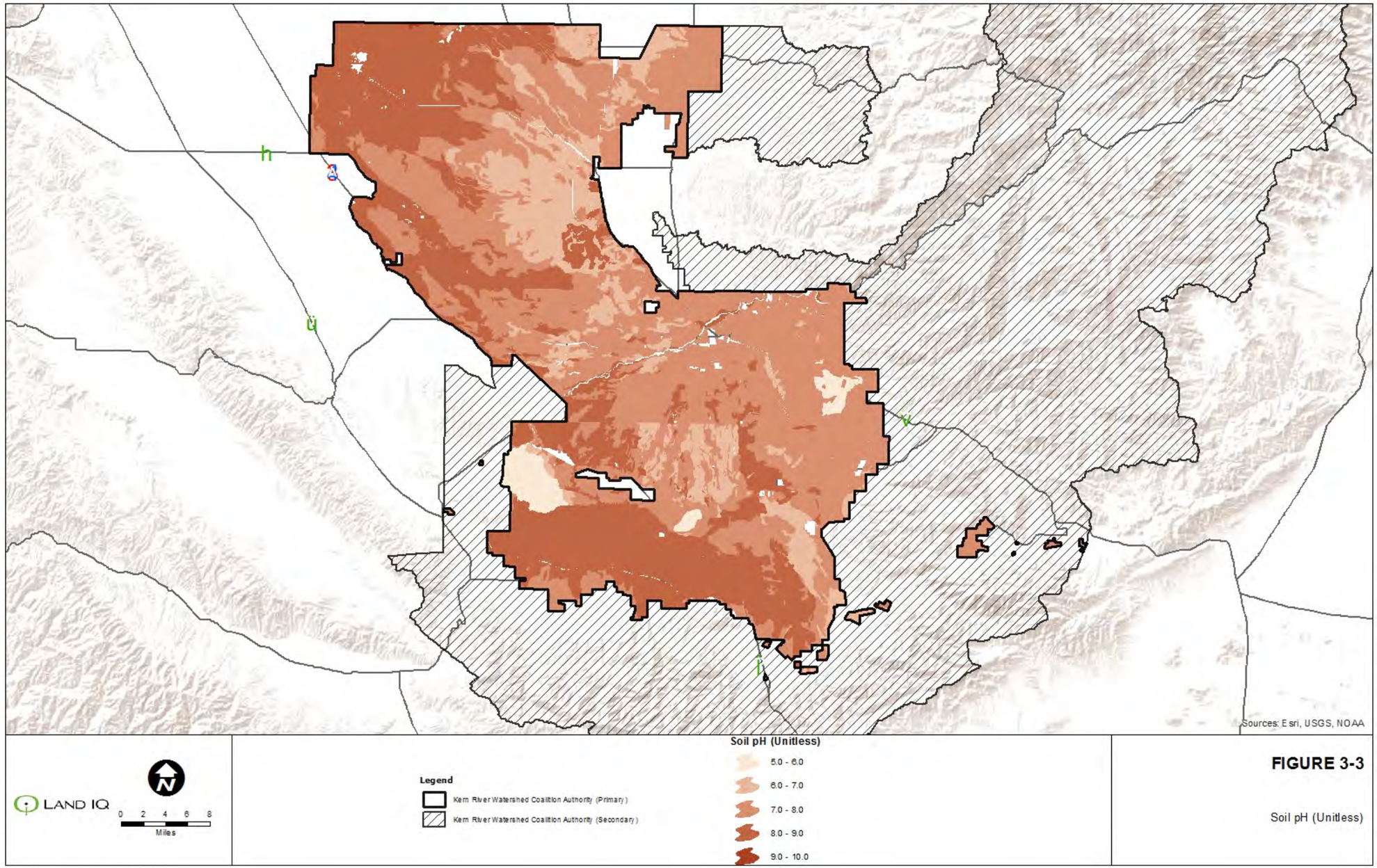


Figure 3-3. KRWCA Soil pH

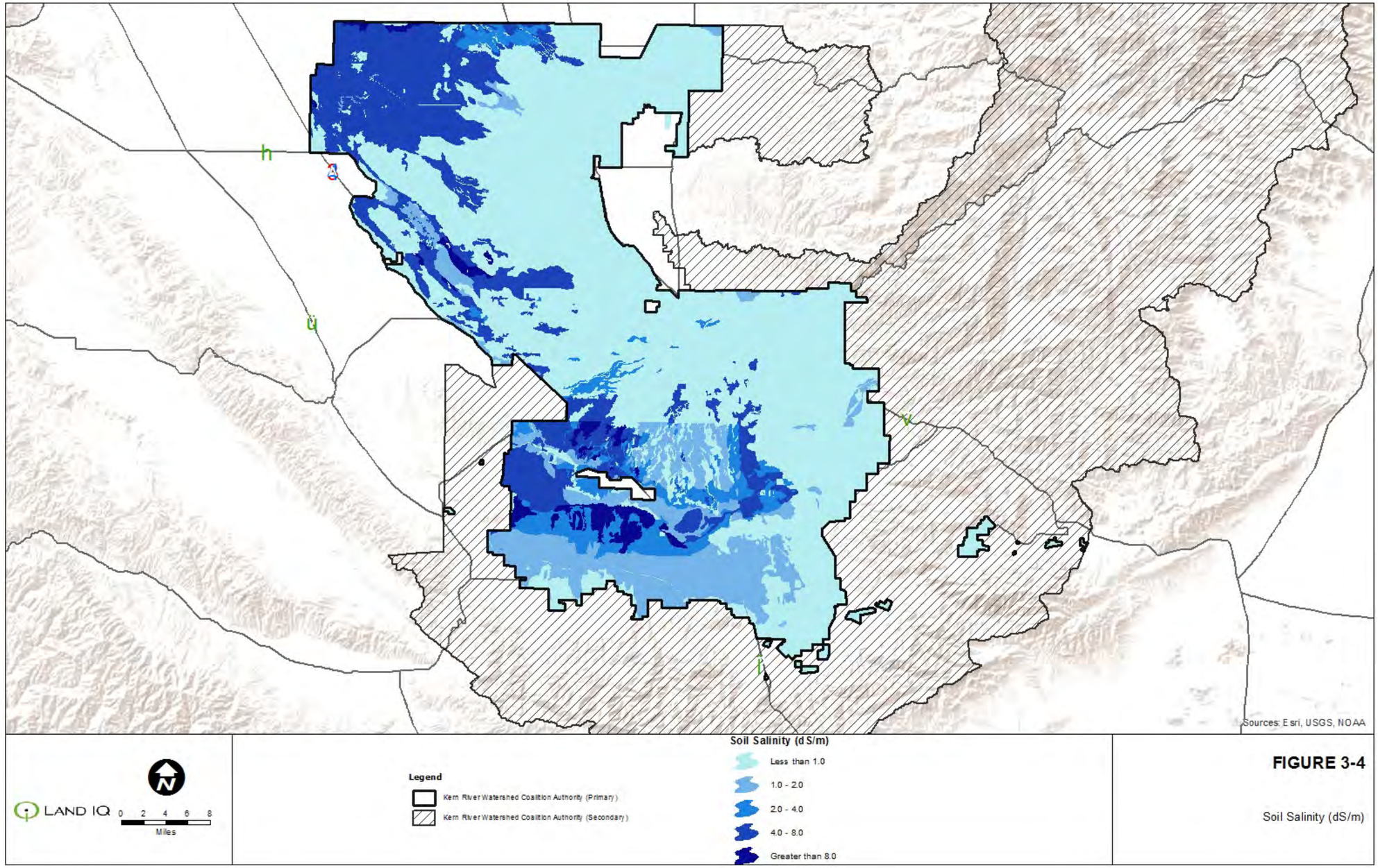


Figure 3-4. KRWCA Soil Salinity

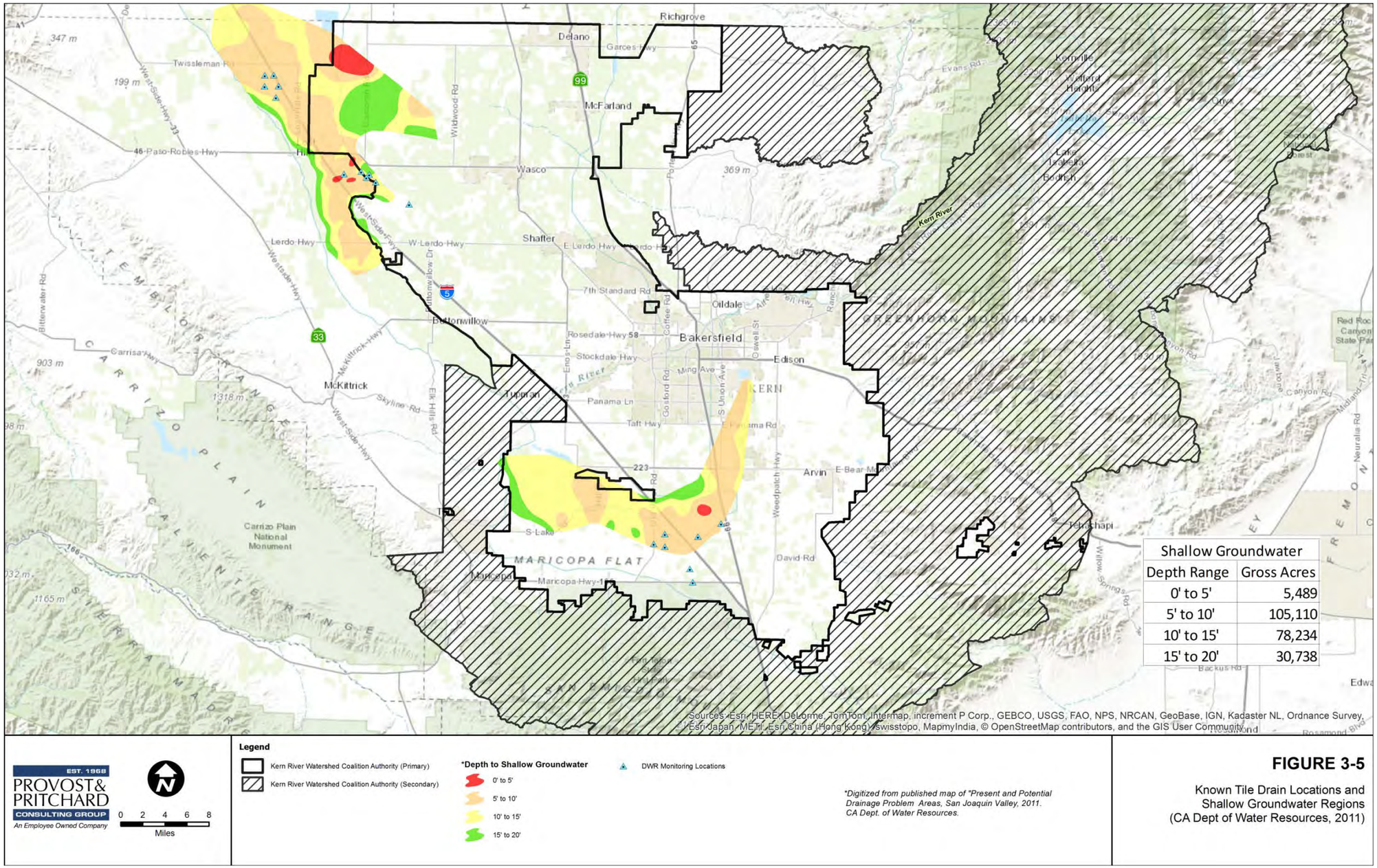


Figure 3-5. Known Tile Drain Locations and Shallow Groundwater Regions

Table 3-1. Shallow Groundwater in Primary Coalition Boundary

Shallow Groundwater in KRWCA Primary Boundary (DWR 2014c)	
Depth	**Gross Acres**
0' to 5'	5,318
5' to 10'	51,370
10' to 15'	50,421
15' to 20'	24,773
Grand Total:	**131,881**

4 Irrigation and Agricultural Management Practices

4.1 Sources of Information

Kern River Watershed Coalition Authority (**KRWCA**) irrigation districts (see **Section 1** for a complete list of districts) supplied current KRWCA members/water users irrigation method information to the extent they were available. In some cases, this information was provided in a geospatial database. In other cases, non-spatial information was supplied. Historical irrigation information was collected from various sources but some data gaps remained. In the instances where no irrigation information was available, field evaluations of irrigation system type were conducted.

University of California Cooperative Extension (**UCCE**) provided guidance on agricultural management practices pertinent to the vulnerability analysis, such as deep ripping practices, and the use of fertigation and their respective influences on irrigation management. This guidance is referenced throughout this section and **Section 9**.

4.2 Irrigation Management

4.2.1 Historical

Agriculture has been practiced in Kern County since about 1860, when livestock was brought into the area, and Irrigated agriculture began soon after in the 1870s (Kern County Soil Surveys). Because the climate is arid, with an average of less than six inches of annual precipitation, almost all crops must be irrigated. Irrigation systems used historically and currently, and their assumed efficiencies, are briefly reviewed below. Distribution Uniformity (**DU**) is a measure of how evenly water is applied across a field, and is generally a function of the irrigation system and/or its design. DU contributes to the overall Irrigation Efficiency (**IE**), which is a ratio of beneficially used water to total applied water. IE is also influenced by other management decisions including leaching requirements, tilling practices, travel times, tailwater return, etc. The Groundwater Quality Assessment Report (**GAR**) will generally focus on IE.

Surface (gravity) irrigation systems were the first irrigation systems used. These systems are gravity-fed and include furrow, basin, and border strip types. These systems are typically considered less efficient than more recently developed pressurized systems, but that is not always the case. In some basins, the over-application of water or deep percolation leads to beneficial groundwater recharge. The average efficiency of surface irrigation systems generally ranges from 65 percent to 85 percent. Sprinkler irrigation distributes water over the crop and imitates rainfall. This type of irrigation was developed during the 1950s and 1960s. Sprinkler irrigation average efficiency ranges from 65 percent to 90 percent, with center pivot and lateral or linear move types on the upper end of this range (80 percent to 90 percent). Micro-sprinkler and drip (surface and sub-surface) became commonly used during the last 20 to 30 years, and typically achieve average efficiencies of 85 percent to 90 percent (Howell, 2003).

In general, the following trends have occurred throughout California during the last 25 years: I) the use of drip and micro-sprinkler irrigation increased (from about 2 percent to 20 percent); II) sprinkler

irrigation use stayed the same (30 percent of all crops); and, III) surface irrigation decreased from approximately 70 percent to 50 percent of all crops (Hanson, undated). These trends are descriptive of overall averages for California. Trends in the KRWCA area have been even more dramatic and much higher than State averages, particularly for certain crops, and will be discussed below.

4.2.2 Current

Irrigation is currently the single most expensive component of agricultural production in Kern County. Water costs have ranged from $40 to $190 per acre foot (**AF**), depending on irrigation district and elevation, in relatively "normal" water years (Sanden, 2014a). However, during the drought conditions of the past year, the price of irrigation water reached $1,200 per AF in some areas (Fisher, personal comm.). In addition to the per acre-foot water tolls, growers also pay assessment fees to most water districts on a per acre basis that pay for a portion of the cost to import surface water and for overhead, and therefore the total cost of irrigation water is much higher in the area. It is important to note, that growers pay these assessment fees to most water districts annually, whether surface water is delivered or not. Water use for crops varies from 1.5 acre foot per acre (**AF/ac**) for winter grain to approximately 4 AF/ac for alfalfa. Growers have an incentive to conserve water because of the high cost of water, and the proportion of input costs for growing a crop that are dedicated to water (40 percent to 60 percent). Drip and micro-sprinkler irrigation systems can cost up to $2,000/acre, so it is important to determine which irrigation system is best suited for the required application (Water Association of Kern County).

For these reasons, irrigation is generally carefully planned, extensively monitored, and efficiently applied in Kern. Soil infiltration rates, water holding capacity, and desired DU are considered when planning an irrigation system. Improvements in IE realized in the KRWCA area are a result of the following practices:

- Adoption of pressurized irrigation systems with higher DU and the ability to apply smaller amounts of water to more closely match evapotranspiration (**ET**);
- Laser-guided grading, to precisely grade and increase slope across surface irrigated fields. Increased slope decreases the time for water to advance across the field, helping to minimize differences in infiltration opportunity time, increasing DU. Shorter runs, accomplished by splitting fields, also contribute to better DU;
- Use of weather stations and computerized irrigation scheduling;
- Automated irrigation, to more accurately follow irrigation schedules, delivering precise amounts of water as prescribed;
- Monitoring of soil and water salinity with leaching requirement calculations; and,
- Soil and plant moisture monitoring, contributing to better irrigation management. Many technologies and practices, including tensiometers, neutron probes, soil sampling, capacitance probes, infrared thermo-meters, and pressure-bombs help to refine irrigation schedules by monitoring soil moisture and/or plant water stress.

4.3 Irrigation Systems

Irrigation system information was collected from each of the irrigation districts within KRWCA. In some cases, this data was available by field and year in a geospatial format. In other cases, less spatially and

temporally refined data was available. A summary of irrigation system information is presented in **Table 4-1**. This information was supplemented by information from UCCE staff and local growers (Nunez, personal communication, 2014; M. Mendes, personal communication, 2014) to make the following assumptions about irrigation system and fertigation use:

- Drip irrigated vegetable crops are fertigated (Nunez, 2014);
- Sprinkler irrigated vegetable crops are fertigated (Nunez, 2014); and,
- Permanent crops on drip are fertigated (Analysis of crop and irrigation data from district showed that most permanent crops are drip irrigated; therefore, where no spatial irrigation information was available for permanent crops they were assumed to be drip irrigated).

Spatial irrigation data is presented in **Figure 4-1**. Overall, permanent crops are increasing significantly in the region and in nearly all cases are developed with highly efficient drip and/or micro-spray irrigation systems. This corresponding increase in highly efficient irrigation systems on permanent crops (e.g. almonds, pistachios, grapes, etc.) is somewhat similar in other counties, however not to the degree it has developed in Kern County. For example, by 2012, 91 percent of almonds were irrigated with drip or micro-sprinkler irrigation systems in Kern County, compared to 82 percent and 83 percent of almonds in Tulare and Fresno counties, respectively. Similar trends occurred in citrus and grapes; for example, in 2012, 91 percent of grapes were on drip or micro-sprinkler systems in Kern County, compared to 63 percent in Fresno County and 77 percent in Tulare County. (Kimmelshue and Tillman, 2013) This is likely due to the scarcity and expense of water, as well as a more dynamic and recent change to permanent crops in Kern County. Pressurized irrigation systems are also increasing on annual crops such as tomatoes because they can save water and increase yield due to their ability to closely match ET, minimizing plant water stress, and deliver nutrients through fertigation more efficiently.

While there has been significant conversion from gravity irrigation systems to pressurized systems, especially during the last 25 years, one unique exception is the historical lake-bottom farming. The historic Buena Vista and Kern Lake Beds, and swamp and overflow lands constitute a Closed Recirculating System, managed uniquely with a combination of surface irrigation systems utilizing tail water recovery and return, pressurized subsurface drip systems used on tomatoes, pressurized sprinklers sometimes used for pre-irrigation, and in limited cases, subsurface tile drains. In those areas, heavy clay soils, shallow ground water, and flooding potential limit crop choice to annual crops such as wheat, cotton, corn, and tomatoes. While the top soil is rich, it is underlain by a thick layer of clay which hinders water from reaching deeper aquifers. In this scenario, surface irrigation systems are not only necessary, but highly efficient because leached irrigation water's movement downward is restricted by the clay layer. Clayey soil infiltration rates facilitate a relatively quick advance across the field, equalizing infiltration opportunity time. Also, infiltration rates tend to slow as soil water holding capacity is reached. Further, surface irrigation systems avoid salinization problems, which can occur in these soil types when drip irrigation is used, while achieving comparable water use efficiency levels. This unique situation is largely the result of soils with a saturation percentage between 60 percent and 80 percent, which is very high compared to most agricultural soils.

4.4 Fertilizer Management

Growers in KRWCA generally employ a high level of management to match fertilizer application to crop needs because fertilizer represents a large expense in addition to the environmental concerns

associated with over-application. Practices vary from grower to grower, and there are differences associated with each crop. But the following practices are common in KRWCA:

- Consulting with Kern County Farm Advisors, UCCE, and National Resources Conservation Service (**NRCS**) specialists regarding best management practices;
- Use of soil, water, and plant tissue tests to help guide fertilizer recommendations; and,
- Employing agronomists, soil scientists, plant scientists, and professional crop advisors to help guide fertilizer practices.

UCCE specialists were consulted for general information on fertigation practices in the focus area.

Accompanying the widespread conversion from gravity irrigation systems to pressurized systems is the increasing use of fertigation, where liquid fertilizer is delivered to the crop in irrigation water. Pressurized systems allow for accurate fertilizer delivery, whereas surface irrigation is less suited to this practice, although fertigation is used in some surface irrigation systems as well. The advantage of fertigation is that it allows fertilizer to be delivered in small amounts at specific times during the growing season when the crop is most likely to take it up. In this practice, fertilizer uptake and use are more efficient.

Fertigation is common in drip, micro-sprinkler, and sprinkler irrigation systems. For example, most vegetables on drip and sprinkler systems are fertigated (Nunez, 2014). It is also used in surface irrigation systems, such as on the Buena Vista Lake Bed where some, but not all, fertilizer may be injected into the irrigation water. In this case, the fertilizer source is close to the field so that fertilizer travel time in the irrigation water is reduced. Because excess water in these systems is either captured in tile drains or collected in tail water, and returned to the irrigation system, excess fertilizer contained in this water is also recycled to the irrigation system.

Fertilizer use data for Kern County (Gronberg and Spahr, 2012) is summarized in **Figure 4-2**. The data spans the years of 1987 to 2006, and are estimations of applied synthetic fertilizer and livestock manure. This data is compiled from several sources and are based on county fertilizer sales. They indicate that total fertilizer sales for Kern County generally increased during this period of record. However, because crop commodity acreage also increased during this time, nitrogen (**N**) fertilizer application rates (N fertilizer applied per acre) did not increase, and remained at approximately 68 lb per acre.

Fertilizer rates typically applied to KRWCA crops in 2005 (Rosenstock et al. 2013) are shown in **Table 4-2**. This data is calculated from a simple average of expert recommendations (UC Davis) and grower accounts, which the authors call the “representative rate”. As **Table 4-2** shows, not all crops are represented because of lack of data. Leguminous crops, such as alfalfa, do not have a representative rate because they fix nitrogen from the atmosphere, and typically require no or very little nitrogen application.

4.5 Other Farm Management Practices Pertinent to Nitrogen Leaching Potential

4.5.1 Deep Ripping and Chiseling

Deep ripping occurs on most fields where permanent crops (trees, bushes and vines) will be planted (Sanden, B., personal communication, June 2014; Kallsen, C., personal communication, June 2014; Fisher, M., personal communication, June 2014). Fields are usually deep-ripped to a depth of 2 to 5 feet. The purpose of deep ripping is to break up compacted soil to improve root development. Adjustments to the Nitrate Groundwater Pollution Hazard Index (**NHI**) hazard values for deep ripping of permanent crops are discussed in **Section 10**.

For annual/field crops, in some instances field chiseling is required to prepare the field for crops (Tristao, D., personal communication, January 2015). This is not an annual operation, and depends on various field properties. Because annual/field crops generally have a shallower root zone than permanent crops, fields are usually chiseled to a maximum depth of 22 inches; the average chiseling depth is 18 inches. As with deep ripping, the purpose of field chiseling is to break up compacted soil to improve root development in the upper 18 inches of the soil pedon. The above chiseling practices describe operations in the historical Buena Vista and Kern Lake regions. Areas with medium and coarse-textured soils could also utilize field chiseling, but the extent of implementation would be less as the soil pedon is not as prone to compaction. Because field chiseling is not an annual operation, and the average disturbance of soil profile is 18 inches, no adjustments were made to the NHI hazard values for chiseling of fields for annual/field crops.

4.5.2 Frost Protection

Citrus production in Kern County is some of the most advanced and efficient in the State. County-wide, the vast majority is irrigated with micro sprinklers, drip, and impact head sprinklers. The Kern County Agricultural Commissioner Office (Kern County, 2013) creates an annual crop survey of the entire county including irrigation method. In 2013 there were 48,150 irrigated acres of citrus within the county. Of that total acreage, records indicated that 87 irrigated acres were irrigated with non-pressurized, surface irrigation methods. Therefore, any risk of nitrate leaching due to non-pressurized, surface irrigation methods is nearly non-existent relative to the remaining citrus acreage and associated irrigation methods.

When frost conditions occur, most growers will use their pressurized irrigation systems to mitigate frost damage. According to Craig Kallsen, growers do not experience frost risk every year (Kallsen, C., personal communication, January 2015. Bakersfield, Cal.: University of California, Kern County Farm Advisor for Citrus and Subtropical Horticulture). Also, the duration the irrigation system is operative during frost protection is usually less than a normal irrigation event during the demand-based months. Further, while demands are less during winter months, citrus requires water for evapotranspiration during every month of the year. Therefore, it should be expected that the leaching risk is actually less during a frost protection event as compared to a demand-based event. In addition, timing of nitrogen (**N**) application for citrus production should be recognized and considered. It is recommended by the University of California, and known to growers, that no N should be applied after the middle to late summer months (Kallsen, 2014). This is because N promotes vegetative growth and not necessarily fruit

development and maturation. Therefore, it is counter-productive to have excess N available for crop uptake (or possible leaching) in the late fall and winter when citrus is ripening. If excess N were available, it would promote late summer/early fall vegetative growth, which would be the first damaged part of the tree during a frost event and may impact future yield. Growers are cognizant of timing of N application for these reasons. Therefore, it should be expected that N available for leaching during frost protection events is minimal.

Considering all of the above factors, no adjustments were made to the NHI hazard values for irrigation to account for frost protection. This approach is supported by previous NHI studies (Dzurella et al., 2012), which also did not include adjustments to irrigation hazard values for frost protection.

Table 4-1. Data and Information Included in Water District Irrigation System Surveys

Water District	Source of Data	Year of Irrigation System Survey	Format
Arvin-Edison Water Storage District	District staff survey	2013	Spatial (GIS)
Henry Miller Water District	Henry Miller Water District	2014	Spatial (AutoCAD)
Kern Delta Water District	District staff knowledge of area	No formal irrigation surveys conducted	Narrative/non-spatial
Kern-Tulare Water District	District staff knowledge of area	No formal irrigation surveys conducted	Narrative/spatial – all on drip since 2006
North Kern Water Storage District	North Kern Water Storage District	2014	Non-spatial for most recent data
Olcese Water District	Olcese Water District	2014	Spatial (manual)
Rosedale-Rio Bravo Water Storage District	Rosedale-Rio Bravo Water Storage District	2014	Spatial (manual)
Semitropic Water Storage District	Semitropic Water Storage District	2013	Spatial (GIS)
Shafter-Wasco Irrigation District	DWR	2006	Non-spatial
Southern San Joaquin Municipal Utility District	Southern San Joaquin Municipal Utility District	2014 (SSJMUD)/2006 (DWR)	Non-spatial
Wheeler Ridge-Maricopa Water Storage District	Wheeler Ridge-Maricopa Water Storage District	2012	Spatial (GIS)

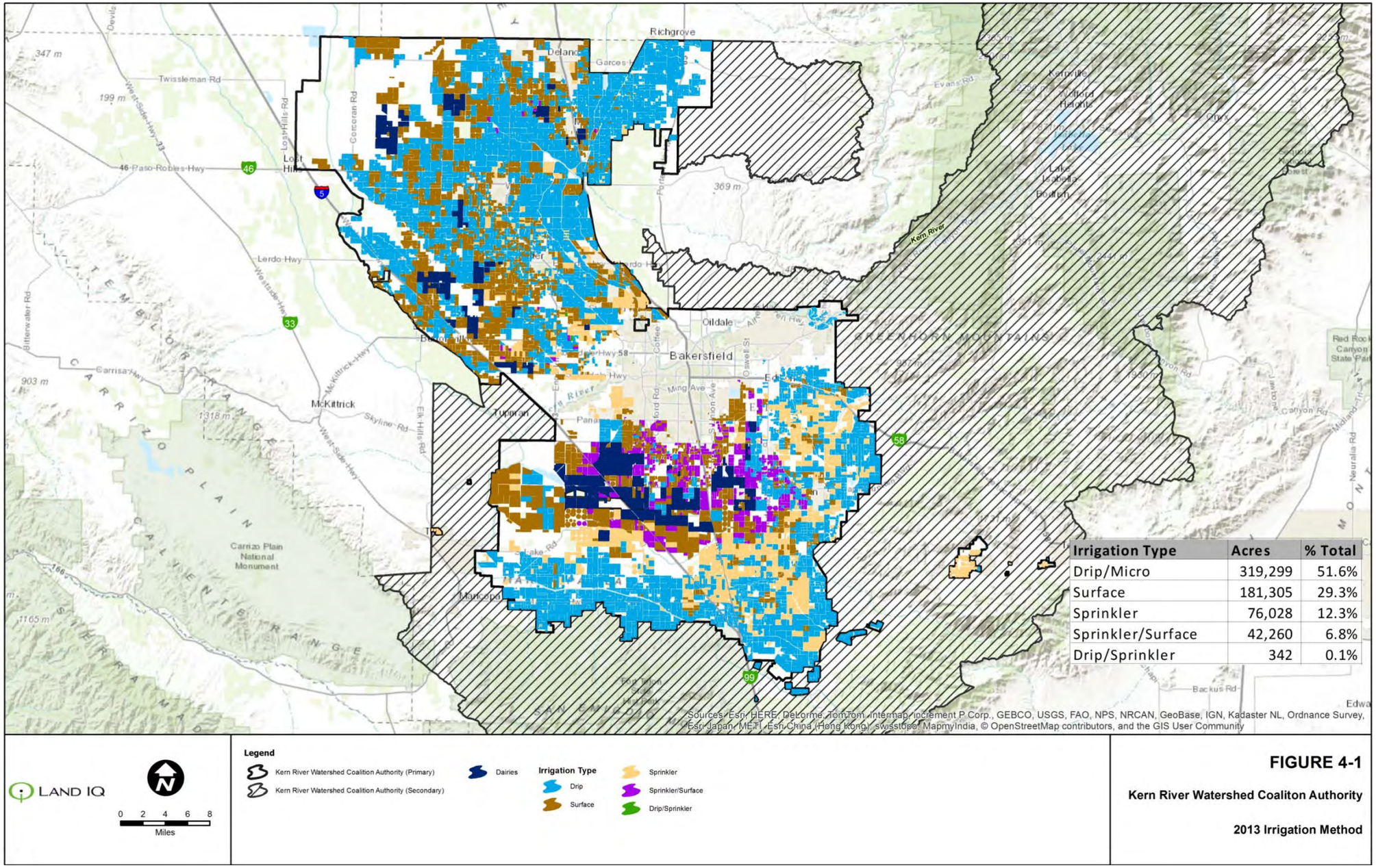


Figure 4-1. KRWCA Irrigation Systems

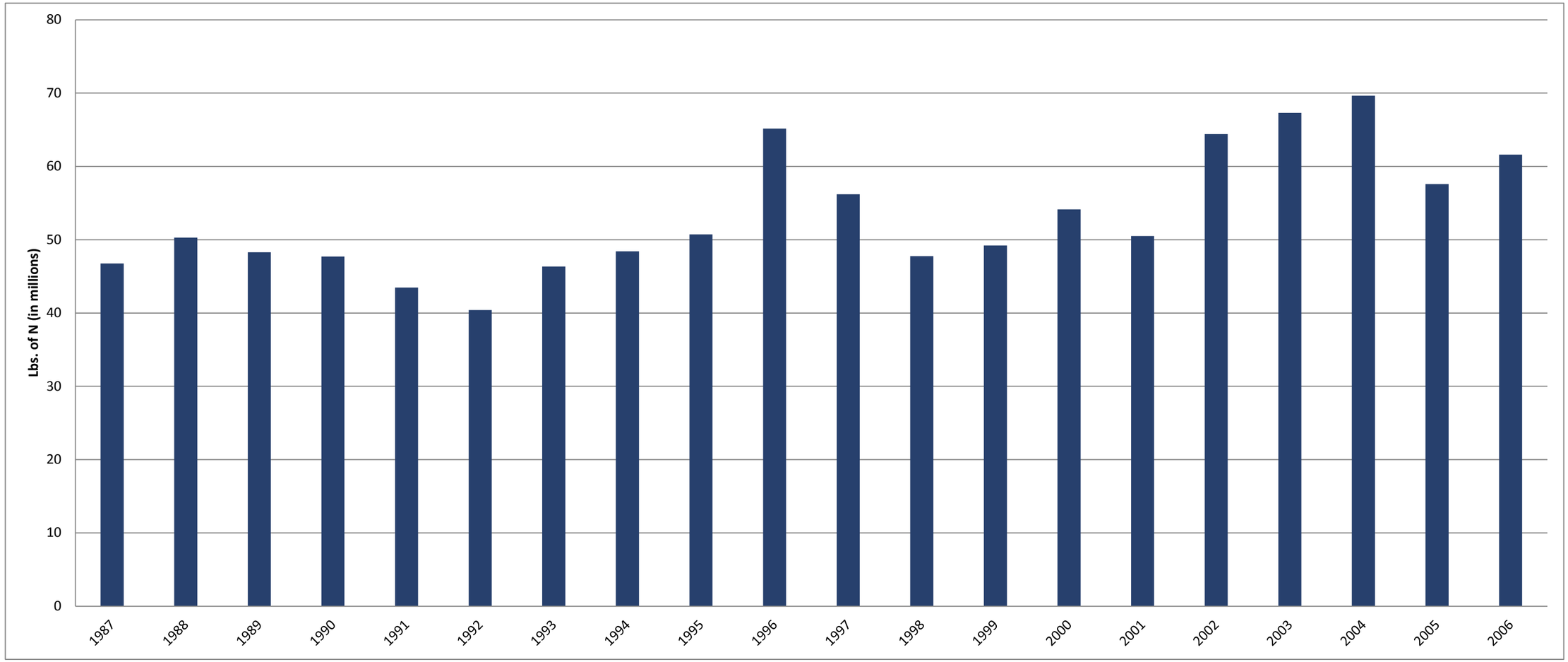


Figure 4-2. Kern County Nitrogen Fertilizer Use

Table 4-2. Nitrogen Fertilizer Rates for KRWCA Crops

Crop	2013 Acreage	N fertilizer Application Rate (lb/acre) in 2005	*Notes*
Almond	162,813	179	
Field Crop	130,554	177	Wheat
Truck Crop	116,010	217	Various vegetables and melons
Grapes	87,359	38	Average of table, raisin, and wine varieties
Alfalfa	76,220	no data	
Citrus	56,732	109	Average of lemons and oranges
Pistachios	43,565	159	
Corn	39,496	213	Sweet
Cotton	38,033	174	
Carrots	37,654	216	
Fruit Tree	15,140	110	Peaches, plums, nectarines
Nut Tree	1,535	138	Walnuts
Silage/Forage	667	no data	
Range/Pasture	375	no data	

Source: Rosenstock et al. 2013

5 Hydrogeology

5.1 Regional Geologic Setting

The primary Kern River Watershed Coalition Authority (**KRWCA**) area is located mostly within the southern portion of the San Joaquin Valley, a long structural trough filled with up to 10,000 feet of marine and continental sediments. The continental sediments represent a variety of depositional environments including fluvial, deltaic, lacustrine, and alluvial fan sequences, and form an alluvial wedge that thickens to the west across the valley. The secondary KRWCA area extends over a large area of varying geologic and hydrogeologic environments, including upland areas of igneous and metamorphic rock and small valleys filled with continental sediments.

Numerous investigators have described and mapped geologic units and water-bearing sediments throughout the valley for more than 100 years. That work has been presented and summarized in hundreds of publications and is not repeated here. Surficial regional geology is shown on **Figure 5-1** (USGS, 2014) and key elements of the geologic and hydrogeologic setting are summarized below.

The primary portion of the KRWCA area is located almost entirely in the areas mapped as very recent or recent alluvium, and the entire contiguous portion of this area is on the floor of the San Joaquin Valley. A geologic map showing recent deposits (Page 1986) is presented on **Figure 5-2** showing more detail of the Neogene and Holocene (late Tertiary and younger) basin sediments that comprise the majority of the contiguous primary portion of the KRWCA area. These basin sediments are rimmed by Tertiary and pre-Tertiary bedrock to the east, south, and west. The Kern River bisects the area and it is underlain by recent channel deposits. The morphology of the recent alluvial fan is indicated by the trajectory of the canal systems south of the river. The terminus of the ancestral river occurred at inland lakes including the Kern Lake and Buena Vista Lake beds, shown on the map. During long periods of large flows, the river drained north to the Tulare Lake Bed. These paleo-drainages are associated with the deposition of fine-grained sediments, shown on the map as flood-basin deposits and older lacustrine deposits. There are small areas east of the San Joaquin Valley near Stallion Springs and Tehachapi that are also included in the KRWCA primary area. The geology of these areas is not shown on the recent detailed map on **Figure 5-2**; the regional geologic map shown on **Figure 5-1** identifies these areas as very recent alluvium.

The mapped geology in the secondary portion of the KRWCA area indicates a wide range of materials and depositional environments. Nearly 80 percent of this area is mapped as igneous and metamorphic materials that likely have no primary porosity. The remaining 20 percent of the secondary area is approximately half older lithified sedimentary material and half recent alluvial, glacial, or landslide deposits.

5.2 Aquifer Delineation

There are several delineated groundwater aquifers in the KRWCA primary and secondary areas. The primary source for defined aquifer delineation is the Department of Water Resources (**DWR**) through Bulletin 118 (DWR, 2003), which defines the extents and describes the recognized alluvial aquifers in California. The entire KRWCA area is in the Tulare Lake Hydrologic Region (DWR, 2003).

5.2.1 Aquifers in the Primary KRWCA Area

The primary portion of the KRWCA area includes parts of four DWR designated basins:

- The Kern County Portion of the San Joaquin Groundwater Basin (Kern County Subbasin, No. 5-22.14);
- The Cummings Valley Groundwater Basin (No. 5-27);
- The Tehachapi Valley West Groundwater Basin (No. 5-28); and,
- The Brite Valley Groundwater Basin (No. 5-80).

The locations of these groundwater basins are shown on **Figure 5-3**.

5.2.1.1 Kern County Subbasin of the San Joaquin Groundwater Basin (No. 5-22.14)

The majority of the primary portion of the KRWCA area is within the Kern County Subbasin, which is the southern-most portion of the San Joaquin Valley Groundwater Basin, as defined by DWR. The Kern County Subbasin is bounded on the north by the Kern County line and the Tulare Groundwater Subbasin, on the east and southeast by granitic bedrock of the Sierra Nevada foothills and Tehachapi mountains, and on the southwest and west by the marine sediments of the San Emigdio Mountains and Coast Ranges. Principal rivers and streams include the Kern River and Poso Creek, and there are numerous small intermittent and ephemeral streams originating in the mountains to the west and south that contribute some seasonal flow into the Subbasin. There are active faults in the Subbasin including the Edison, Pond-Poso, and White Wolf faults. Average precipitation in the Subbasin ranges from 5 inches per year (**in/yr**) in the interior of the valley floor to as high as 13 in/yr in the margins of the Subbasin.

The Subbasin is the southern terminus of the San Joaquin Valley structural trough that is 200 miles long and up to 70 miles wide. This trough is up to 10,000 feet deep and filled with marine and continental sediments deposited during periodic inundation by the Pacific Ocean and by erosion of the surrounding mountains, respectively. Continental deposits shed from the surrounding mountains forming an alluvial wedge that thickens from the valley margins toward the axis of the structural trough (Page, 1986).

In total, the Subbasin covers approximately 3,040 square miles and has been estimated to contain approximately 40,000,000 acre-feet (**AF**) of groundwater in storage with another 10,000,000 AF of storage capacity, including areas where water levels have declined (DWR, 2006a). There are not any recent comprehensive comparisons of total inflows and outflows (i.e. water balances) available for the Subbasin. However, the Kern County Water Agency (**KCWA**) compiles hydrologic accounting information in Water Supply Reports (KWCA, 2011). These reports include estimates of groundwater use in the Subbasin, which indicate that total groundwater use varies widely from year to year. Between 2000 and 2011 total estimated groundwater production in the Subbasin was as low as 230,000 acre-feet per year (**AFY**) and as high as 2,300,000 AFY (KWCA, 2011). The KCWA Water Supply Reports do not include all water balance components, so estimates of the relationship between total inflow and outflow are not available.

The Kern County Subbasin is included in the Central Valley Hydrologic Model (**CVHM**), developed by the United States Geological Survey (**USGS**) as part of an assessment of water availability in California's Central Valley (Faunt, 2009). The USGS generally used the DWR delineations of groundwater basins in the Central Valley in the development of the active area of the CVHM. Additional discussion of the CVHM is included below.

5.2.1.2 Cummings Valley Groundwater Basin (No. 5-27)

The Cummings Valley Groundwater Basin is bounded on the north by the Sierra Nevada and on the south by the Tehachapi Mountains, with low-lying ridges connecting the two ranges on its east and west sides. The valley drains to the southwest via Chanac Creek, a small ephemeral creek that flows from Brite Valley. Average precipitation in the basin ranges from 10 to 14 in/yr (DWR, 2006b).

The basin is surrounded to the north and east by Pre-Tertiary granitic rocks and Paleozoic sediments of the Sierra Nevada, and to the west and south by pre-Tertiary granitic rocks of the Tehachapi Mountains (Smith, 1964). This bedrock material forms the bottom of the basin over which recent alluvium has been deposited (DWR, 2006b).

5.2.1.3 Tehachapi Valley West Groundwater Basin (No. 5-28)

The Tehachapi Valley West Groundwater Basin encompasses the western half of Tehachapi Valley, and is bounded on the north by the Sierra Nevada, and on the south by the Tehachapi Mountains. A low-lying ridge connecting these two ranges forms the western boundary; a similar ridge with a narrow gap separates Brite Valley from Tehachapi Valley. An alluvial high between this basin and the adjacent Tehachapi Valley East basin forms the eastern boundary of this basin. Brite Creek drains southern Brite Valley and joins Tehachapi Creek, which drains the western Tehachapi Valley, before the combined flows exit the basin toward the San Joaquin Valley. The average annual precipitation in the basin ranges from 10 to 14 in/yr (DWR, 2004a).

The basin is surrounded on the north and west by Paleozoic sediments, pre-Tertiary granitic rocks, and Tertiary sediments of the Sierra Nevada and by Paleozoic sediments, and pre- Tertiary granitic rocks of the Tehachapi Mountains to the south (Smith, 1964 and DWR, 2004a).

5.2.1.4 Brite Valley Groundwater Basin (No. 5-80)

Brite Valley Groundwater Basin is a northwest to southeast trending valley bounded on the north by the Sierra Nevada, and on the south by the Tehachapi Mountains, with low-lying ridges connecting the two ranges on its east and west sides. This is a high elevation basin, ranging from 4,200 to 5,000 feet above mean sea level (**msl**). The southeast portion of the basin is drained by Brite Creek, which flows into Tehachapi Valley and joins with Tehachapi Creek. The northwest portion of the basin is drained by an unnamed ephemeral stream which flows into Cummings Valley. Average precipitation in the basin ranges from 10 to 14 in/yr (DWR, 2004b). The basin is generally surrounded by Pre-Cretaceous metamorphic rocks, including limestone and dolomite units. There are also some limited Pre-Cenozoic and Mesozoic granitic rocks north and east of the basin (Smith 1964). This bedrock material also forms the bottom of the basin over which recent alluvial material has been deposited (DWR, 2004b).

5.2.2 Aquifers in the Secondary KRWCA Area

There are two separate sources of groundwater in the secondary portion of the KRWCA; groundwater from designated groundwater basins and small alluvial aquifers, and groundwater from fractured bedrock. There is a significant difference in the water storage and transmission capacities of these two groundwater aquifer types, and this difference combined with the geographic separation between them means that they behave as distinct groundwater bodies with limited connectivity.

5.2.2.1 Designated Basins and Alluvial Aquifers in the Secondary KRWCA Area

There are seven designated groundwater basins in relatively small alluvium-filled valleys present in the secondary area. These designated basins are:

- Kern River Valley Groundwater Basin (5-25);
- Walker Basin Creek Valley Groundwater Basin (5-26);
- Castaic Lake Valley Groundwater Basin (5-29);
- Cuddy Canyon Valley Groundwater Basin (5-82);
- Cuddy Ranch Area Groundwater Basin (5-83);
- Cuddy Valley Groundwater Basin (5-84); and,
- Mil Potrero Area Groundwater Basin (5-85).

The locations and extents of these groundwater basins are shown on **Figure 5-3**. There are also thin aquifers of limited storage capacity in some of the other valleys in the secondary area. These small valley sediment aquifers have restricted extents and are assumed not to be used extensively for groundwater supply. Given the small size and limited use, no studies of the hydrology or hydrogeology of these aquifers have been completed.

The designated groundwater basins and the small valley fill aquifers in the secondary area are generally bordered by bedrock units of the Sierra Nevada or Tehachapi mountain ranges, and underlain by the same bedrock units. These basins and valley fill aquifers are composed of recent alluvial material of continental origin (DWR, 2003).

As noted above, the secondary portion of the KRWCA area mostly consists of consolidated rocks with little to no primary porosity. These materials do not generally have high capacity for water storage or transmission, and most groundwater production from these areas is from relatively shallow fractured bedrock (secondary porosity) wells. There is some use of fractured bedrock groundwater in small domestic and agricultural water supply systems. No information regarding the hydrogeology of these fractured bedrock aquifers or extensive groundwater evaluations exist for this groundwater source.

5.3 Subsurface Sediments

The assessment of subsurface sediments has focused on the Kern County Subbasin, as the majority of the primary portion of the KRWCA area overlies this aquifer, and there is very little distinct information regarding the other groundwater sources in either the primary or secondary areas. The information presented in this section pertains only to the Kern County Subbasin within the primary portion of the KRWCA area.

The majority of the water bearing material in the Kern County Subbasin is relatively young (Pliocene to Holocene) continentally derived unconsolidated alluvium, with marine derived unconsolidated alluvium of similar age present in the western and southern portions of the Subbasin (Wood and Davis 1959; Davis et al., 1959; Hilton et al., 1963; Wood and Dale, 1964; Dale et al. 1966; Croft, 1972; Page, 1973; Bartow and McDougall, 1984; Page, 1986; Williamson et al., 1989; Bertoldi et al., 1991 and DWR, 2006a,). The hydrogeology and hydraulic properties of these materials have been studied and described by multiple parties. When these studies included large areas of the Subbasin, or the Subbasin in total, they have generally focused on describing groundwater availability and flow in basic terms without identifying variations in aquifer parameters over the entire area.

The purpose of the KRWCA Groundwater Quality Assessment Report (**GAR**) includes providing a basis for establishing workplans to assess groundwater quality trends and to evaluate the effectiveness of agricultural management practices. Assessment of hydrogeology relating to these objectives includes consideration of relative differences in travel time from ground surface to first encountered groundwater through the unsaturated (vadose) zone. The mechanics involved in the movement of water through the unsaturated zone are a complicated mixture of multi-phase and porous media flow conditions. The movement of chemical constituents through the unsaturated zone adds additional complexity, as they do not always behave in the same way that water does. This complex system is rarely studied over large areas in enough detail to allow for accurate calculations of water or chemical constituent travel time to first encountered groundwater. No Subbasin-wide studies of unsaturated zone flow have been completed for the Kern County Subbasin. However, the numerical groundwater flow model developed as part of the CVHM does include estimates of hydraulic conductivity for the unsaturated zone throughout the Kern County Subbasin. These estimates were not specifically developed to represent unsaturated zone flow, but are based in part on geologic and hydrogeologic observations for the Subbasin, and they can be used to evaluate the relative distribution of hydraulic properties.

5.3.1 Corcoran Clay

The Corcoran Clay is a regionally extensive low permeability unit located in much of the San Joaquin Valley (Croft, 1972). In many places the Corcoran Clay is a confining unit separating deeper groundwater from surface recharge and shallow groundwater. However, in the Kern County portion of the San Joaquin Groundwater Basin the material correlating to the Corcoran Clay is not considered to be as low permeability as it is further north, and it does not function as a continuous aquitard or barrier to vertical flow (Schmidt and Associates, 2006; Schmidt and Crewdson, personal communication, October 2012). In addition, where the Corcoran Clay occurs in the Kern County portion of the San Joaquin Groundwater Basin it is deeper than in other areas of the Central Valley. Comparing the depth to the top of the Corcoran Clay to first encountered groundwater shows that the clay is below first encountered groundwater in over 90 percent of its extents in the KRWCA area. The Corcoran Clay is included in the CVHM groundwater model in the KRWCA area, as shown in **Figure 5-4**. The extent and thickness of the Corcoran Clay in the CVHM shown on **Figure 5-4** was modified from previous studies (Page, 1986 and Burow et al., 2004). The extent, thickness, and permeability of the Corcoran Clay is included in the evaluation of hydraulic conductivity below.

5.3.2 Central Valley Hydrologic Model (CVHM)

The CVHM encompasses the alluvial deposits of the entire Central Valley extending from the Cascade Ranges in the north to the Tehachapi Mountains on the south, and bounded on the east by the Sierra Nevada and on the west by the Coast Ranges. The only outlet for this entire area is through Carquinez Strait, a narrow tidal strait that is part of the tidal estuary of the Delta of the Sacramento and San Joaquin Rivers. To create enough detail to be practical for water-management decisions, the aquifer was divided spatially into 20,000 model cells with a uniform horizontal discretization of one square mile oriented parallel to the valley axis at 34 degrees west of north (Faunt, 2009). The active model domain within the KRWCA area is shown on **Figure 5-5**.

The vertical discretization of the model into layers and the distribution of aquifer parameters throughout the model domain were informed by a textural analysis of subsurface sediments throughout

the aquifer. The textural analysis was completed by evaluating lithologic drillers logs from wells to identify the coarse-grained fraction in depth increments of 50 feet. The resulting texture values were then interpolated to the mile-square model cells using a 3-D variogram model (Faunt, 2009). The texture data was interpolated to the model grid in two stages. In the first stage, the texture was estimated for each of the 50-ft thick layers. In the second stage, the resulting estimates were aggregated vertically into 10 model layers. Although the lateral spacing stayed the same throughout the model, the thickness of each model layer was increased with depth. Where the Corcoran Clay was mapped, the layers above the clay were modified so that the clay was explicitly represented by layers 4 and 5. Hydraulic conductivity parameters were distributed to the CVHM using the texture data and geographically specific multipliers for hydraulic conductivity of the coarse and fine-grained fractions. These aquifer parameter values were then modified during model calibration to better match local groundwater elevation observations. The calibrated CVHM includes horizontal and vertical hydraulic conductivity values for every cell in the model (i.e. every active mile-square cell in every layer). Post-calibration aquifer parameters are effectively model outputs, and are not perfect representations of aquifer conditions in all areas of the model. However, this information is the best available interpretation of aquifer parameters covering the KRWCA primary area. The post-calibration horizontal and vertical hydraulic conductivities from the CVHM have been evaluated to identify unsaturated zone conditions, as described below.

5.4 Identification of the Unsaturated Zone

As noted above, the intent of the hydrogeologic analysis for the KRWCA GAR is to assess the unsaturated zone. In order to assess the representation of the unsaturated zone from the CVHM it was first necessary to define its thickness (or depth).

The thickness of the unsaturated zone varies over time and space in the Kern County Subbasin. KCWA collects groundwater elevation data throughout the Kern County Subbasin and prepares annual spring contour maps of groundwater elevation, depth to groundwater, and depth to shallow groundwater for this entire area (KCWA, unpublished contour maps-Spring 2000 through Spring 2014. 2014). These contour datasets are available in electronic format for 2000 through 2013. The combined depth to groundwater and depth to shallow groundwater contour data show the variation in depth to groundwater over time and space, which is the same as unsaturated zone thickness. These changes in unsaturated zone thickness occur in response to temporal and geographic variation in recharge and groundwater use.

5.4.1 Representative Groundwater Elevation Conditions

Variations in unsaturated zone thickness were assessed by comparing groundwater elevation contour maps from multiple years to one another. This analysis involved the conversion of contour datasets into surfaces representing groundwater elevation using geographic information system (**GIS**) tools. Individual groundwater elevation surface datasets were generated for the spring of every year from 2000 through 2013. Each spring annual groundwater elevation surface was compared to each other annual surface using raster math tools in GIS to identify the highest groundwater elevation in the period. This analysis indicated that groundwater elevations were highest overall in spring 2007, as compared to the other years between 2000 and 2013. The spring 2007 groundwater elevation contours are shown on **Figure 5-6**.

The depth to groundwater and depth to shallow groundwater contour data prepared by KCWA was used to define the thickness of the unsaturated zone based on the results of the comparison of groundwater elevations described above. Since the spring 2007 depth to water data corresponds to the highest groundwater elevations in the period of study, it also corresponds to the shallowest depth to groundwater and thinnest unsaturated zone. This condition was chosen to characterize the unsaturated zone for the hydrogeologic evaluation because it is conservative with regard to travel time from ground surface to first encountered groundwater.

As noted above, KCWA prepares two annual depth to groundwater maps. There is one annual spring map showing depth to groundwater in the unconfined aquifer throughout the Kern County Subbasin (**Figure 5-7**), and another showing depth to water in shallow groundwater areas (**Figure 5-8**) where water is present at less than 20 feet below ground surface.

Additional information regarding groundwater elevation, flow directions, and responses to wet and dry conditions is included in **Section 7**.

5.4.2 Shallow Groundwater Areas

The shallow groundwater areas identified and mapped by KCWA roughly correlate to areas of low permeability soils in and around the Buena Vista and Kern Lake beds in the southern portion of the Subbasin, and with the western portion of the Semitropic Water Storage District, Lost Hills Water District, and Buena Vista Water Storage District in the northern portion of the Subbasin. KCWA has been tracking the presence of these shallow groundwater areas since 1976, and the extent of the area has generally increased over that period (KCWA, 2011).

While the shallow groundwater areas are contoured separately from the unconfined aquifer, there is no indication that shallow groundwater is actually a completely separate and distinct water body. There are actually areas on the periphery of the shallow groundwater contours where shallow groundwater is commonly contoured at depths similar to the unconfined aquifer, especially when groundwater elevations are high. These high groundwater areas are likely the result of low permeability materials near the ground surface that hold on to percolated water from rainfall and irrigation return flows longer than areas of high permeability. While these areas have grown slightly since KCWA began tracking them, they do not appear to generally get much larger than they were in the spring of 2007. In addition, these areas become smaller during periods of reduced rainfall and imported water availability. This short term contraction and the relatively consistent maximum extents of these areas likely indicates that there is flow from them to the more widespread unconfined aquifer in the Subbasin.

5.4.3 Combined Depth to Groundwater/Unsaturated Thickness

Since the shallow groundwater areas do not appear to be separate and distinct from the rest of the Subbasin, the two spring 2007 depth to groundwater contour datasets were combined for the assessment of unsaturated zone thickness. The contours for each spring 2007 depth to water condition were converted to surfaces using GIS tools and then combined. Where the two surfaces overlapped, the shallower depth to water value was used. This resulted in a single dataset representing depth to first encountered groundwater in the entire Subbasin.

5.5 Unsaturated Zone Hydraulic Conductivities

Noting the above qualifications about accuracy, hydraulic conductivity parameters from the CVHM groundwater model were extracted for the unsaturated zone throughout the primary KRWCA area. The combined depth to groundwater surface described above was interpolated to the CVHM grid to identify the depth of the unsaturated zone in every cell. These depths were then compared to the cell specific depth of each layer to develop a dataset of thickness for each unsaturated layer in each cell. In circumstances where the unsaturated zone included a portion of the thickness of a layer but not the entire thickness, the unsaturated fraction of the layer was used. Thickness data were then used as weights in calculating arithmetic means (averages) of horizontal and vertical hydraulic conductivities for the entire unsaturated zone in each cell. The arithmetic mean was used for both averages because it produces an average that biases towards the higher values in a dataset, which results in hydraulic conductivity estimates that are conservative. These averages were calculated using the following:

- Unsaturated horizontal hydraulic conductivity, K_{HU}:

$$K_{HU} = \frac{T_{l1} \cdot K_{Hl1} + T_{l2} \cdot K_{Hl2} + \cdots + T_{ln} \cdot K_{Hln}}{T_{l1} + T_{l2} + \cdots + T_{ln}}$$

- Unsaturated vertical hydraulic conductivity, K_{VU}:

$$K_{VU} = \frac{T_{l1} \cdot K_{Vl1} + T_{l2} \cdot K_{Vl2} + \cdots + T_{ln} \cdot K_{Vln}}{T_{l1} + T_{l2} + \cdots + T_{ln}}$$

Where:

K_{HU} = Unsaturated zone horizontal hydraulic conductivity,

K_{VU} = Unsaturated zone vertical hydraulic conductivity,

$T_{l1\text{-}ln}$ = Unsaturated thickness of each layer in the unsaturated zone (specific to each cell),

$K_{Hl1\text{-}ln}$ = Horizontal hydraulic conductivity by layer in the unsaturated zone (cell specific),

$K_{Vl1\text{-}ln}$ = Vertical hydraulic conductivity by layer in the unsaturated zone (cell specific),

The distribution of these hydraulic conductivity values is shown on **Figure 5-9** and **Figure 5-10**. These unsaturated hydraulic conductivity values represent the best available information regarding relative permeability of the unsaturated zone throughout the Kern County Subbasin portion of the KRWCA primary area.

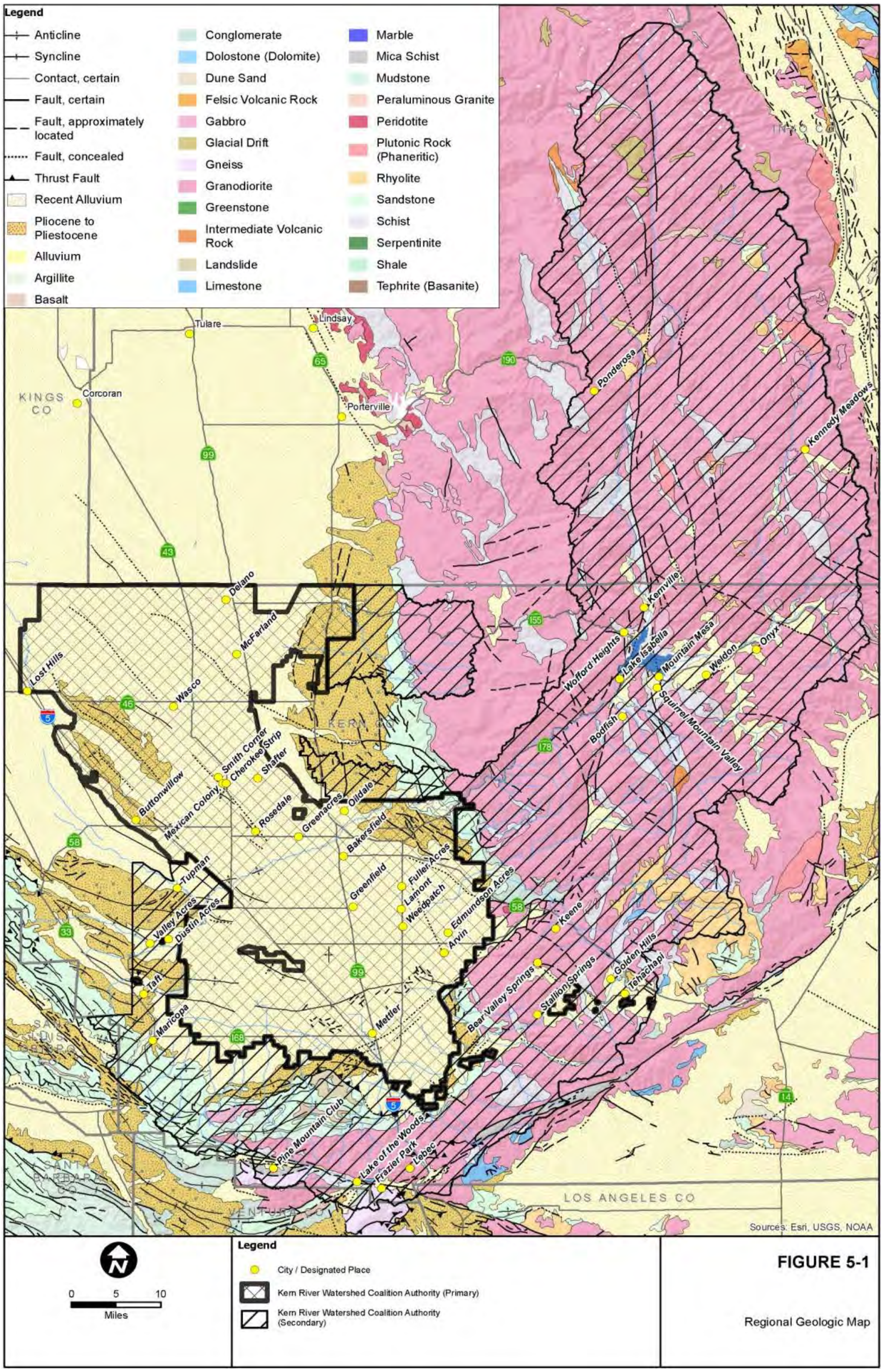


Figure 5-1. Regional Geologic Map

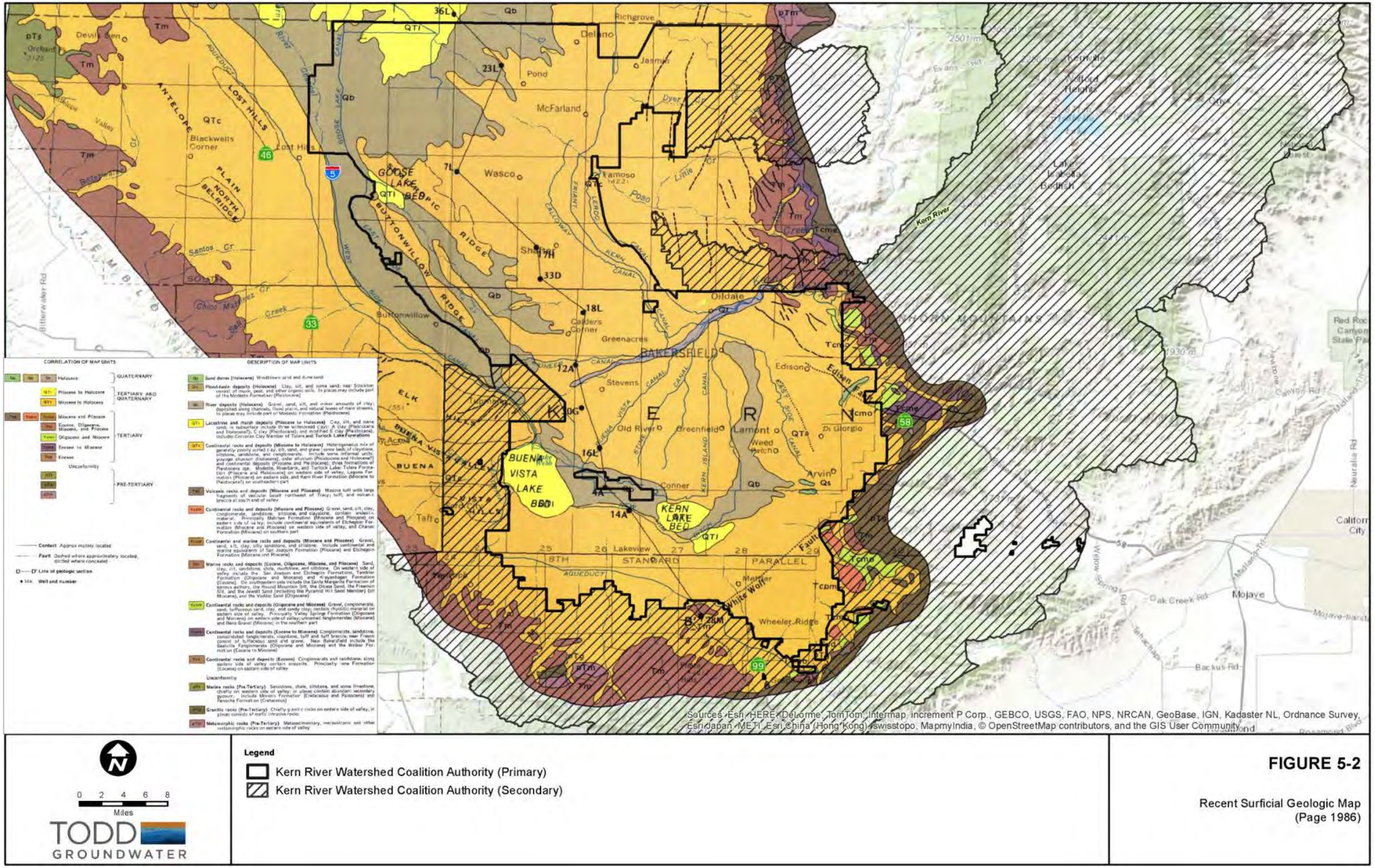


Figure 5-2. Recent Surficial Geologic Map (Page 1986)

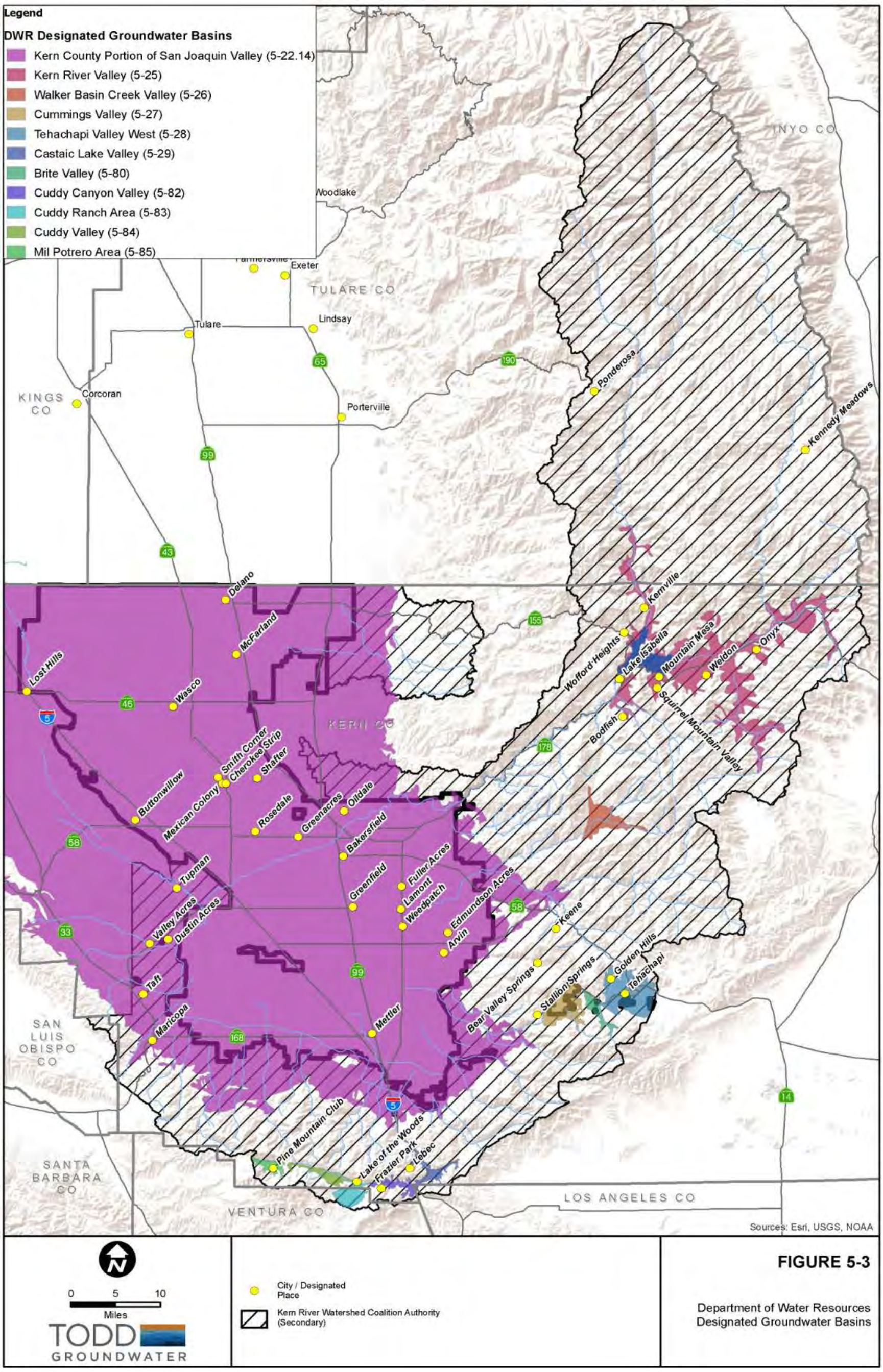


Figure 5-3. Department of Water Resources Designated Groundwater Basins

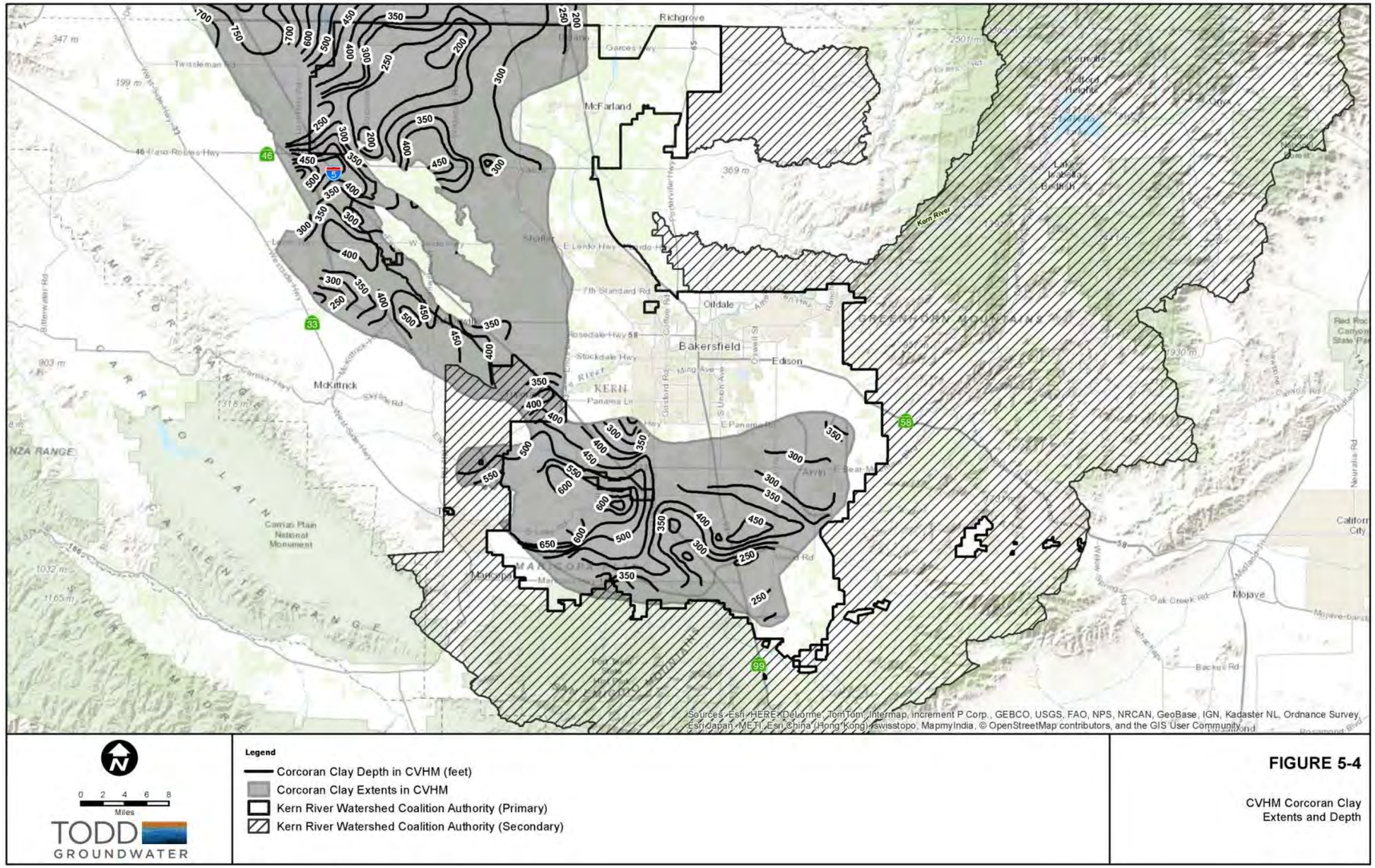


Figure 5-4. CVHM Corcoran Clay Extents and Depth

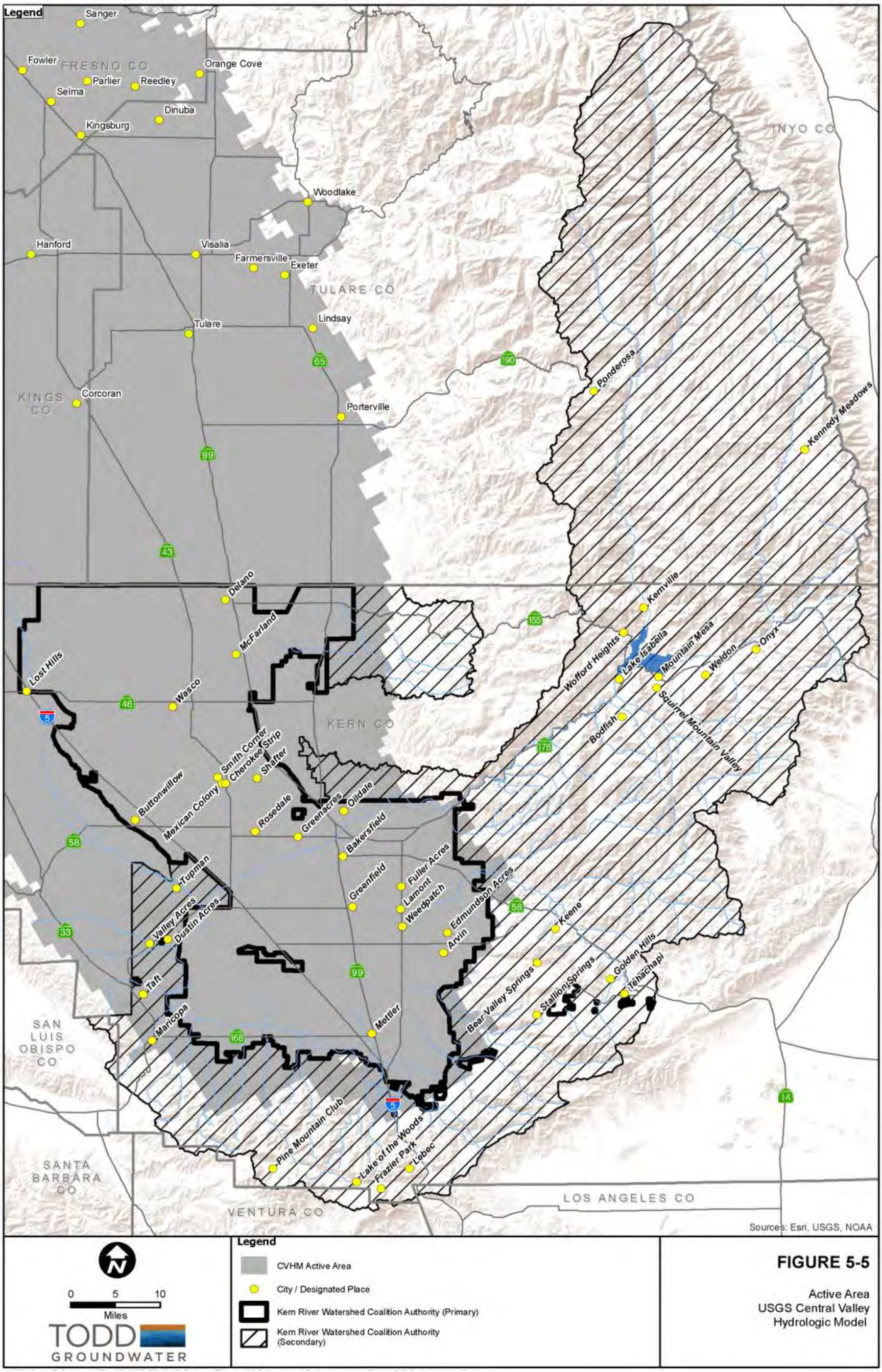


Figure 5-5. Active Area, USGS Central Valley Hydrologic Model

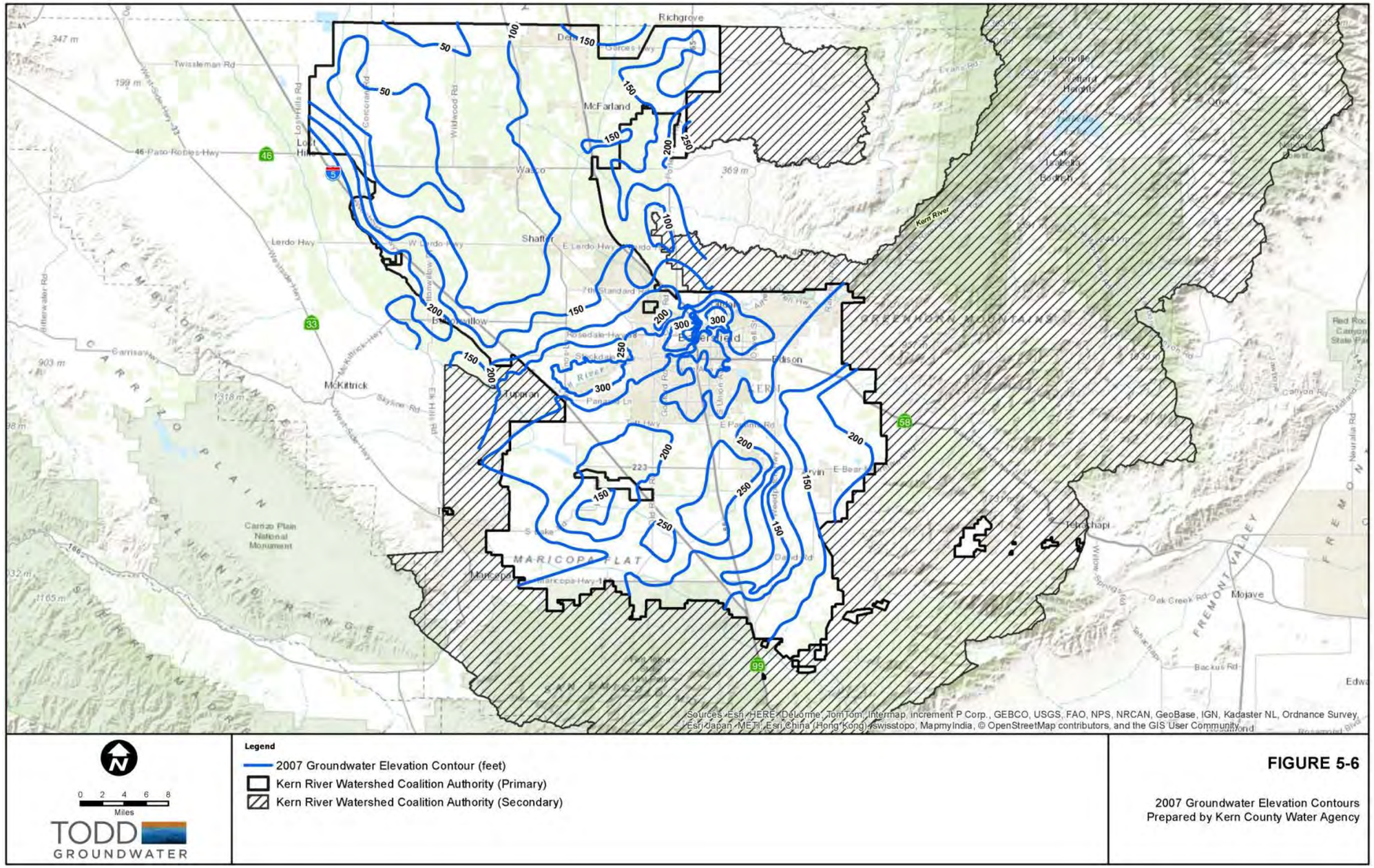


Figure 5-6. 2007 Groundwater Elevation Contours, Prepared by Kern County Water Agency

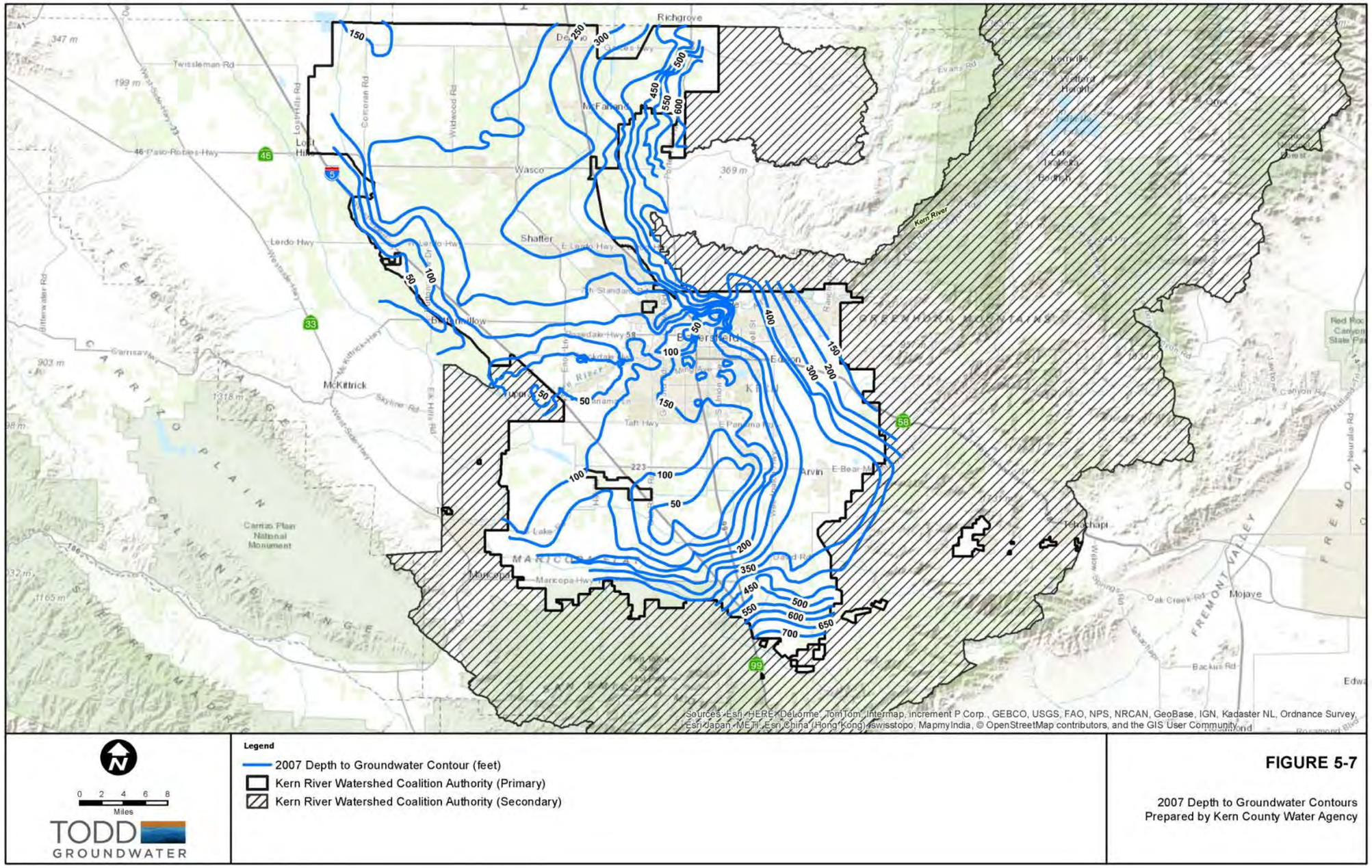


Figure 5-7. 2007 Depth to Groundwater Contours, Prepared by Kern County Water Agency

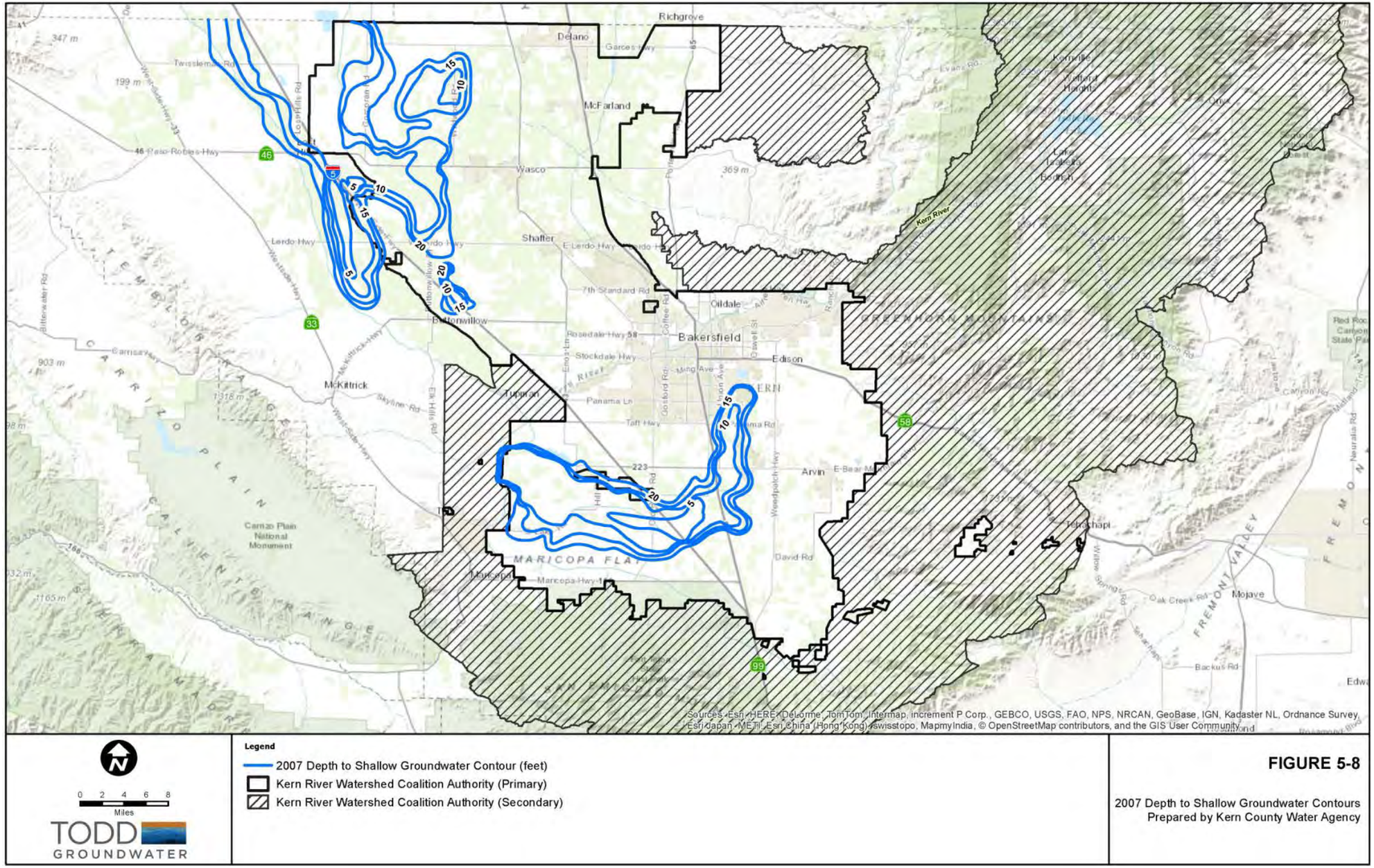


Figure 5-8. 2007 Depth to Shallow Groundwater Contours, Prepared by Kern County Water Agency

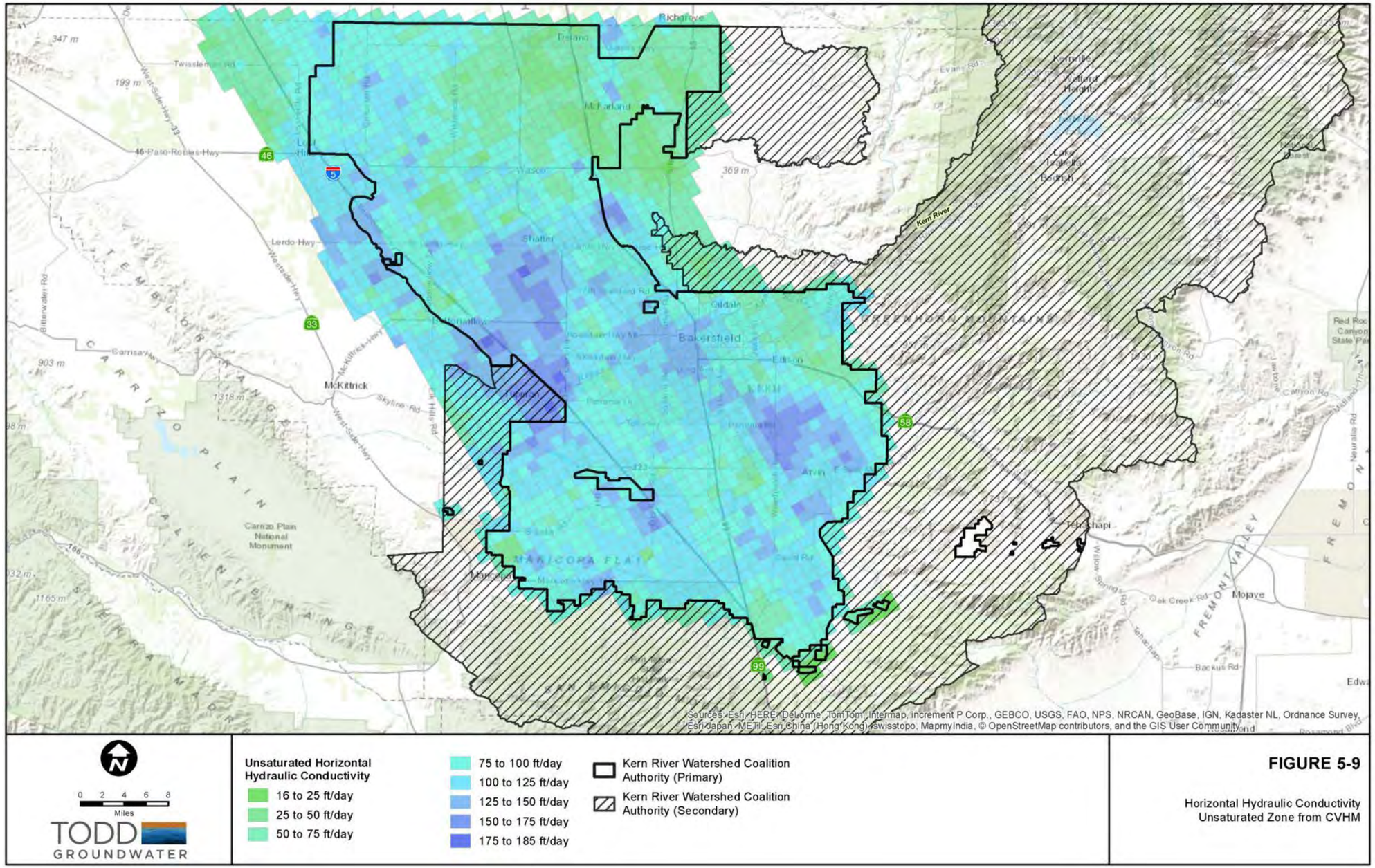


Figure 5-9. Horizontal Hydraulic Conductivity, Unsaturated Zone from CVHM

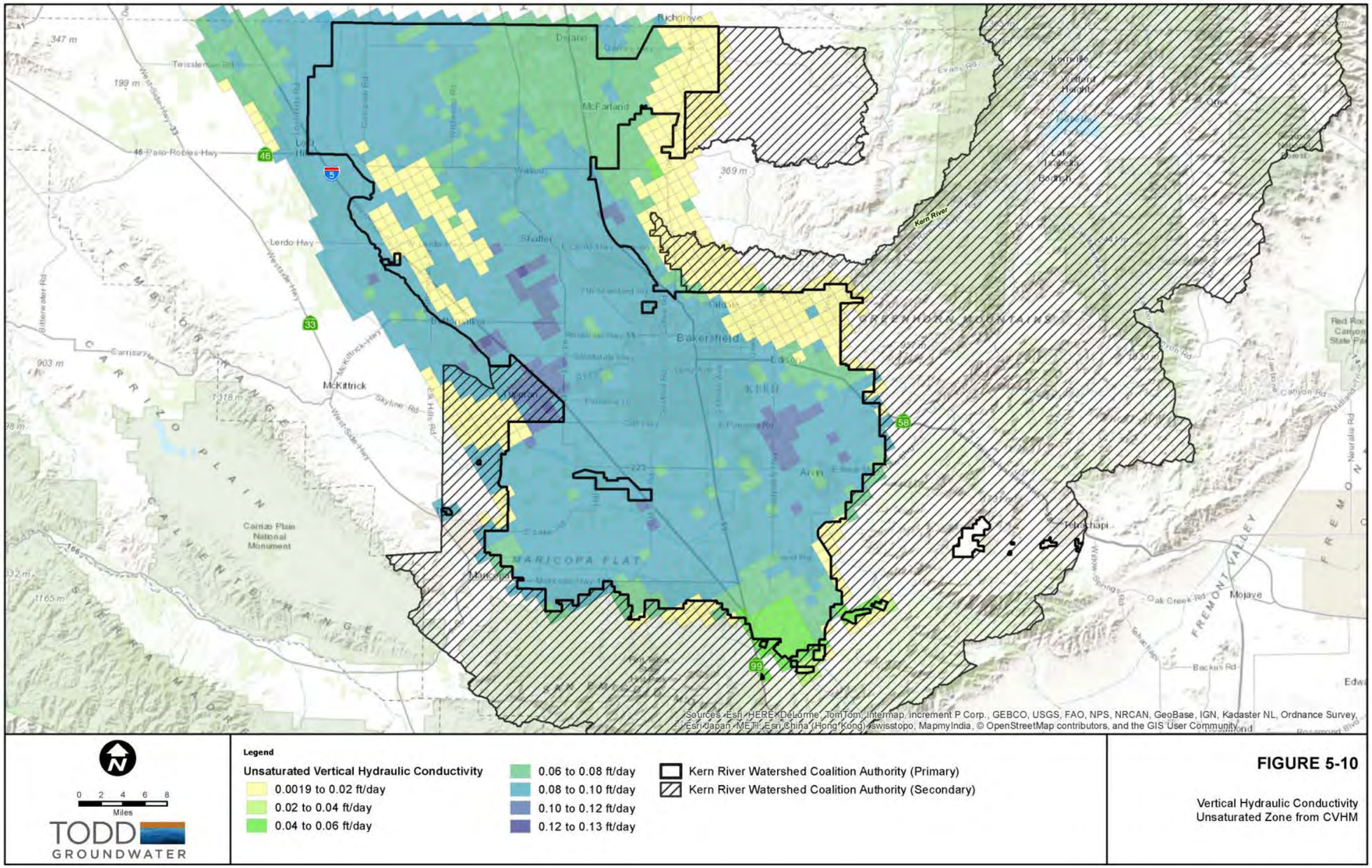


Figure 5-10. Vertical Hydraulic Conductivity, Unsaturated Zone from CVHM

6 Water Quality

The purpose of this section is to describe the historic and current groundwater quality in the Kern River Watershed Coalition Authority (**KRWCA**) area.

6.1 Constituents of Focus

Three categories of constituents were selected to focus the groundwater quality assessment. The constituents of focus for this assessment are nitrate, salinity, and pesticides. These three parameters are commonly used to identify areas that may have been impacted by irrigated agriculture. However, higher nitrates and salinity in groundwater may also be present from natural sources.

6.1.1 Nitrate

Nitrate (**NO_3^-**) is a naturally occurring form of nitrogen that can be sourced from the atmosphere or decomposing organic matter. Naturally occurring nitrate concentrations are generally less than 10 milligrams per liter (**mg/L**) nitrate as nitrate, and generally do not exceed 20 mg/L in groundwater (Todd, 2005 and Hounslow, 1995). Nitrate can also be found in groundwater as a result of excess application of nitrogen fertilizers in irrigated agricultural and landscaped areas, runoff from feedlots or dairies, wastewater and food processing waste percolation, and leachate from septic system drainfields (Harter T., et al. 2012).

There are two maximum contaminant levels (**MCL**) for nitrate in drinking water based on reporting type; 10 mg/L for nitrate as nitrogen, and 45 mg/L for nitrate as nitrate (CCR, 2014). The MCL for nitrate as nitrogen is based on an approximate relationship whereby 10 mg/L nitrate as nitrogen is equivalent to 45 mg/L nitrate as nitrate. This equivalency relationship is not absolute, so evaluation of nitrate as nitrate is preferred. For this study the 45 mg/L nitrate as nitrate MCL has been used as the basis for identifying areas of existing nitrate impacted groundwater.

6.1.2 Salinity

Total Dissolved Solids (**TDS**) was selected as the primary measurement to determine salinity in groundwater. TDS is commonly analyzed during initial groundwater quality assessments and routine water quality sampling events, and it is defined as the total quantity of inorganic salts and small amounts of organic matter that remain when a water sample is evaporated (WHO, 2003). Because numerous individual constituents contribute to the TDS value, waters of similar TDS concentrations may not be similar water types. However, TDS can be used as a general indicator of salinity, with concentrations below 1,000 mg/L typically defined as fresh water.

TDS in water supplies can originate from natural sources, sewage, runoff and deep percolation from urban and agricultural areas, industrial wastewater, and oilfield produced water. Complex hydrogeologic processes often dissolve, transport, dilute, concentrate, and/or precipitate salts. As noted in **Section 5**, the primary portion of the KRWCA area includes the majority of the Kern County Subbasin of the San Joaquin Groundwater Basin, which is an inland groundwater basin with no significant outflow. Because of this, salts generally tend to increase in concentration over time in groundwater, which contributes to increasing salinity and TDS concentrations (KCWA 2012). Variations

in surface water availability affect groundwater recharge with higher quality surface water, which may lead to dilution of salts, and TDS.

6.1.3 Pesticides

Pesticides are chemicals used to control bacteria, fungi, weeds, insects, and other vectors in agriculture, and generally do not occur naturally in the environment. Sources of pesticides in the environment include applications to agricultural and lawn and garden areas, golf courses, and roadside weed control. Some of these chemical compounds are readily soluble in water, but highly sorptive to soil, and historically degrade very slowly tending to persist in soils for many years. Some pesticide chemicals have low chemical stability and rapidly decay in the environment (Chapman and Kimstach, 1992). Concentrations in most water bodies are rather low, generally ranging from 10^{-5} to 10^{-3} mg/L (Chapman and Kimstach, 1992 and Montgomery, 1993). There are at least 146 individual chemical compounds that indicate pesticides in water quality samples. **Figure 6-1** lists pesticides detected in the KRWCA area.

Pesticide impacted groundwater in the KRWCA area was identified by exceedance of respective MCLs for those detected constituents with established MCL values. The relevant MCLs for evaluating exceedances were identified from the California State Water Resources Control Board (**SWRCB**) Water Quality Goals database (SWRCB 2014a), an online searchable database that provides State and national established primary MCLs, secondary MCLs, State public health goals (**PHGs**), and State notification levels (**NLs**), among other water quality numeric standards for numerous constituents. The State or national MCL was used to determine thresholds for each detected pesticide constituent. Some constituents do not have established State or national MCLs. In such cases, no evaluation of exceedances was completed. A summary of the pesticides that were detected in the available data along with the respective thresholds is included in **Table 6-1**.

6.2 Data Sources

Data from multiple sources was collected and compiled into a comprehensive groundwater quality database for the KRWCA area. The sources of groundwater quality data available for this study are:

- State Water Resources Control Board Division of Drinking Water [**SWRCB-DDW**, formerly California Department of Public Health (**CDPH**)] [through the Groundwater Ambient Monitoring & Assessment Program (**GAMA**)];
- CDPH Archived Data;
- California Department of Water Resources (**DWR**);
- Cleanup Sites (EDF) (through the GAMA program);
- Kern County Water Agency (**KCWA**);
- California Department of Pesticide Regulation (**DPR**) CDPH (through the GAMA program);
- United States Geological Survey (**USGS**) (through the GAMA program); and,
- Central Valley Regional Water Quality Control Board (**CVRWQCB**) Waste Discharge Requirements General Order for Existing Milk Cow Dairies (Order R5-2013-0122) Monitoring Data.

The resulting database included over 145,000 records for the three constituents of focus from over 6,700 locations. These water quality data represent available results from 1909 through 2014. Well construction information is not generally available for the wells for which groundwater quality data are available. As a result, the analyses presented in this section do not include any evaluation of depth or aquifer material associated with water quality results. It is assumed for the sake of this evaluation that all groundwater quality results represent first encountered groundwater. Accurate locations for wells associated with available water quality data are not available for all sources. Location information for wells associated with the SWRCB-DDW, KCWA, DWR, and DPR water quality data are available only as approximations based on rectangular grids as a means of protecting public water supply systems. As a result, there may be some inaccuracy associated with well locations used for the analyses presented below. Some of the available groundwater quality data was associated with wells for which location information was not available; these data were not included in the analyses presented below.

The monitoring programs associated with the data used in this assessment are detailed in **Section 12** and summarized in **Table 6-3.**

6.3 Spatial Distribution

6.3.1 Nitrate

The distribution of maximum concentrations of nitrate in groundwater wells from 1920 to 2014 is shown on **Figure 6-1**. The yellow circles indicate where nitrate has been sampled, but concentrations have not exceeded the MCL of 45 mg/L. The orange circles indicate the MCL was exceeded (45 mg/L), but maximum concentrations remain below 90 mg/L, and the red circles represent the samples greater than or equal to 90 mg/L. As shown on **Figure 6-1**, the highest nitrate concentrations are located on the edges of the primary area, specifically in the eastern portion, the very southern portion, the south western portion, and a small group located outside the primary area boundary in the upper elevations to the east.

Recent maximum nitrate concentrations in groundwater between 2000 and 2014 are shown on **Figure 6-2**. While less data is available, the recent spatial trends remain similar; higher nitrate concentrations on the eastern and southern edge of the primary study area.

A geostatistical analysis was used to further illustrate areas where groundwater quality is already negativity impacted. This analysis used the concentrations from wells to represent the concentrations of an area. The area discretization for this analysis was the grid for the USGS Central Valley Hydrologic Model (**CVHM**). The input data and grid discretization from the CVHM has also been used in other portions of the KRWCA groundwater assessment, and using the same grid creates consistency between variables. The maximum nitrate concentration was calculated for all the wells within a square mile CVHM grid cell. The highest resulting maximum concentration value within a cell was taken to represent the maximum nitrate concentration in that area. This analysis was conducted using all the data from the entire period of record. The resulting existing nitrate impacted area is shown on **Figure 1-3**. For the purpose of this study, the areas shown as having maximum nitrate concentrations above 45 mg/L are considered to already be impacted. Grid cells with no color applied indicate areas where no nitrate data is available. The actual extent of the high nitrate areas vary based on the local geology, the volume and timing of the nitrate source, and groundwater flow.

6.3.2 Salinity

The distribution of maximum concentrations of TDS in groundwater wells from 1909 to 2014 is shown on **Figure 6-4**. The yellow circles indicate locations where TDS has been detected, but concentrations have not exceeded the secondary MCL of 500 mg/L. The orange circles indicate the secondary MCL was exceeded (500 mg/L), but the maximum concentration remains below the 1,000 mg/L threshold, and the red circles represent the wells where the maximum historical concentration detected is above 1,000 mg/L. Higher concentrations are generally found to the west of the primary boundary area. This is consistent with the KCWA Water Supply Reports (KCWA, 2012), which illustrate historical salinity concentrations in the western Central Valley portion of Kern County. In the western edge of the basin, the alluvial fan may thin and wells located here may be screened in bedrock formations rather than the alluvium. As with nitrate, there are higher TDS concentrations in the eastern and southern portions of the primary boundary, as well. Recent maximum concentrations from wells with results between 2000 and 2014 are shown on **Figure 6-5**. The recent data show that the highest concentrations remain persistent along the western edge.

The maximum and grid approach to represent existing groundwater quality impacted areas described for nitrate was also used for TDS. The maximum TDS results for the CVHM grid cells are shown on **Figure 6-6**. The western and southern edges of the primary study area show high concentrations of TDS. This may represent naturally occurring high salinity resulting from local geologic conditions associated with more potent material of marine origin being involved in processes that form aquifers and overlying soils through which water moves. However, there is not sufficient water quality data available or understanding of historic and current hydrogeologic processes to perform a complete evaluation of the source of TDS present in these areas. As a result, no attempt to distinguish between naturally occurring and anthropogenic sources of TDS has been included in this study. Grid cells with no color applied indicate areas where no TDS data is available.

6.3.3 Pesticides

The distribution of sampling for any pesticide in groundwater wells from 1984 to 2014 is shown on **Figure 6-7**. There are many separate constituents that could be considered a pesticide, and not all those constituents are regularly monitored. The water quality threshold for each individual detected constituent was compiled from various sources as discussed above and shown in **Table 6-2**. If the sampled concentration was greater than the respective MCL, the location was mapped as an exceedance. In addition, several of the chemicals assumed to be pesticides for the purposes of this analysis (e.g., naphthalene) have other non-agricultural uses and may originate from activities other than agriculture. Pesticides or pesticide-related products have been detected in more than 1,000 of the over 5,000 wells with pesticide sampling results in the KRWCA area. **Figure 6-8** shows the maximum recent pesticide detections from between 2000 and 2014. The detections and exceedances are located in different parts of the primary portion of the KRWCA area and do not appear to have a spatial trend. Pesticide concentrations appear to have a higher frequency in the center of the primary study area, but the frequency of monitoring is also greatest in this location. There are no detections in the southern portion of the study area, but there is also little to no sampling in this area.

The pesticide impacted area is shown on **Figure 6-9**. This area was developed using the CVHM grid methodology used to develop the nitrate and salinity impacted areas. The pesticide impacted area on **Figure 6-9** includes any grid cell that has an exceedance of MCLs for a specific pesticide. Grid cells where

sampling has occurred without any detectable pesticides and those where detectable concentrations have been reported are also shown on **Figure 6-9**.

6.4 Additional Groundwater Quality Characteristics

The constituents of focus cover the most likely constituents to impact groundwater from irrigated agriculture. There are constituents that are used at a smaller scale, including hydrocarbons (fuel), volatile organic compounds (solvents), and other minerals (soil amendments). These constituents are not monitored frequently, if at all, and agriculture is not the only or most likely source. Therefore, no additional analyses to evaluate these constituents have been completed as part of this study.

Other methods of analyzing water quality data include trend analysis. Data was not sufficiently available to perform statistical trend analysis. As the data used for this study was from a variety of sources, there were few locations with regular and frequent monitoring of the same constituent.

6.5 Shallow Groundwater Quality

For this analysis, it is assumed that all groundwater quality results represent first encountered groundwater. This assumption may not be correct, as many wells are likely screened only in deeper aquifer units or screened at multiple depths, which would mean that the results are more representative of deeper groundwater quality. However, construction information is only available for a handful of wells (**Table 6-3**), so no attempt to correlate water quality with construction information was made.

In general, impacts to shallow groundwater likely originate from natural sources and processes plus anthropogenic sources. Thus, wells screened at shallower depths would most likely result in higher concentrations. Throughout this analysis, statistics (such as maximum well concentrations and arithmetic mean) are used to represent water quality concentrations. Future monitoring programs should include the collection of well construction data to provide additional information on the vertical distribution of these constituents over time.

Table 6-1. Pesticides Detected in KRWCA Area

Pesticides Detected in KRWCA Area	
1,2 Dibromoethane (Edb)	Dinoseb
1,2 Dichlorobenzene (1,2-Dcb)	Diuron
1,2 Dichloropropane (1,2 Dcp)	Endothall
1,2-Dibromo-3-Chloropropane (Dbcp)	Endrin
1,3 Dichloropropene	Eptc
2,4,5-Tp (Silvex)	Glyphosate (Round-Up)
2,4-Dichlorophenoxyacetic Acid (2,4 D)	Heptachlor
Acenaphthene	Heptachlor Epoxide
Acetone	Hexachlorobutadiene
Alachlor	Hexazinone
Aldicarb	Lindane (Gamma-Bhc)
Aldicarb Sulfone	Methiocarb
Atrazine (Aatrex)	Methoxychlor
Bentazon	Methyl Bromide (Bromomethane)
Bromacil	Metolachlor
Butachlor	Metribuzin
Carbofuran	Molinate
Carbon Disulfide	Naphthalene
Carbon Tetrachloride	Norflurazon
Chlordane	Oxamyl
Cyanazine	Paraquat
Deethylatrazine	Penoxalin
Diazinon	Picloram
Dicamba (Banvel)	Prometon
Dichlorprop	Prometryn
Dieldrin	Propachlor (2-Chloro-N-Isopropylacetanilide)
Dimethoate	Simazine
Dimethoate	Thiobencarb
Dimethyl Phthalate	Xylenes (Total)
Di-N-Butylphthalate	

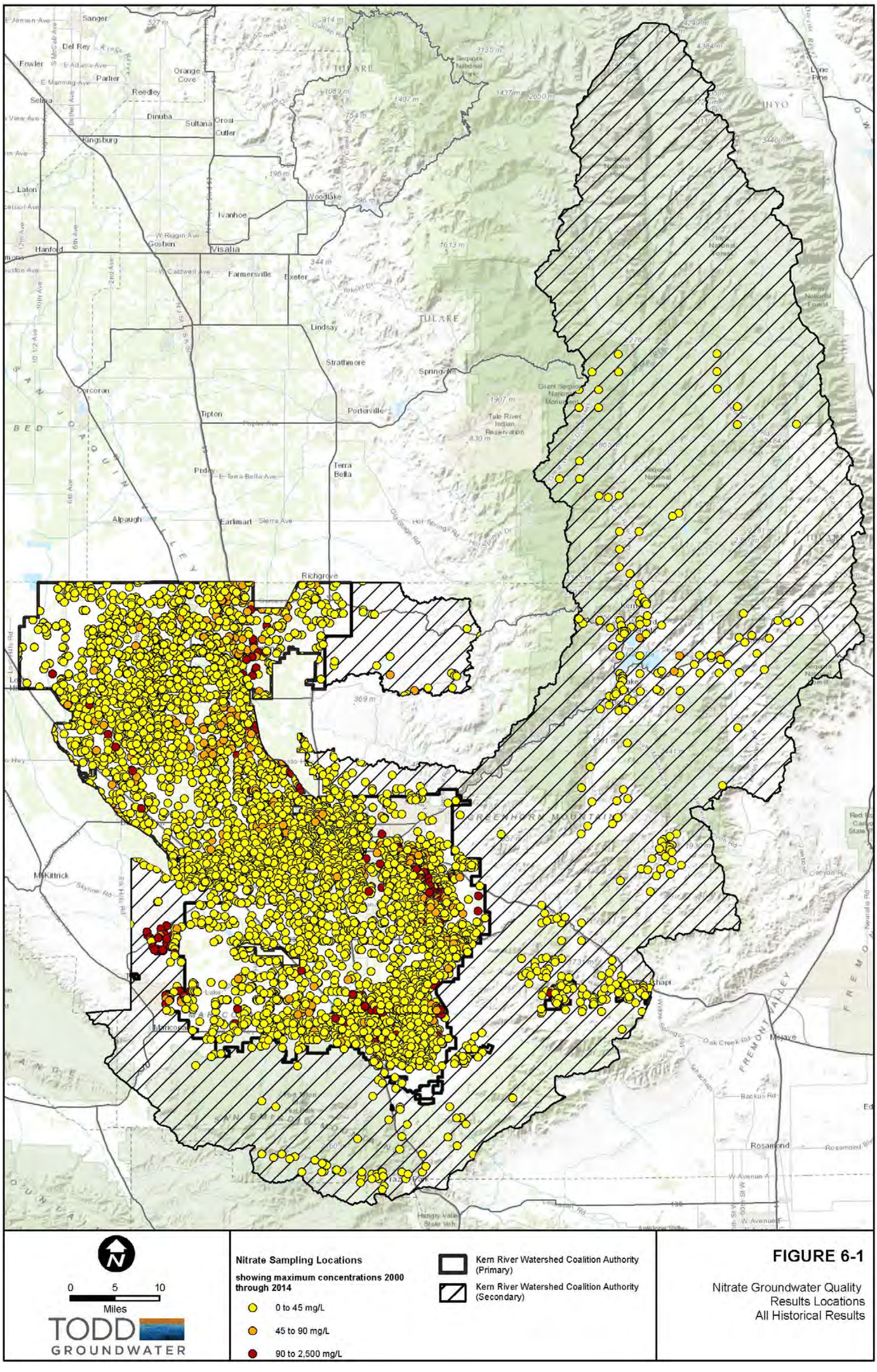


Figure 6-1. Nitrate Groundwater Quality Results Locations, All Historical Results

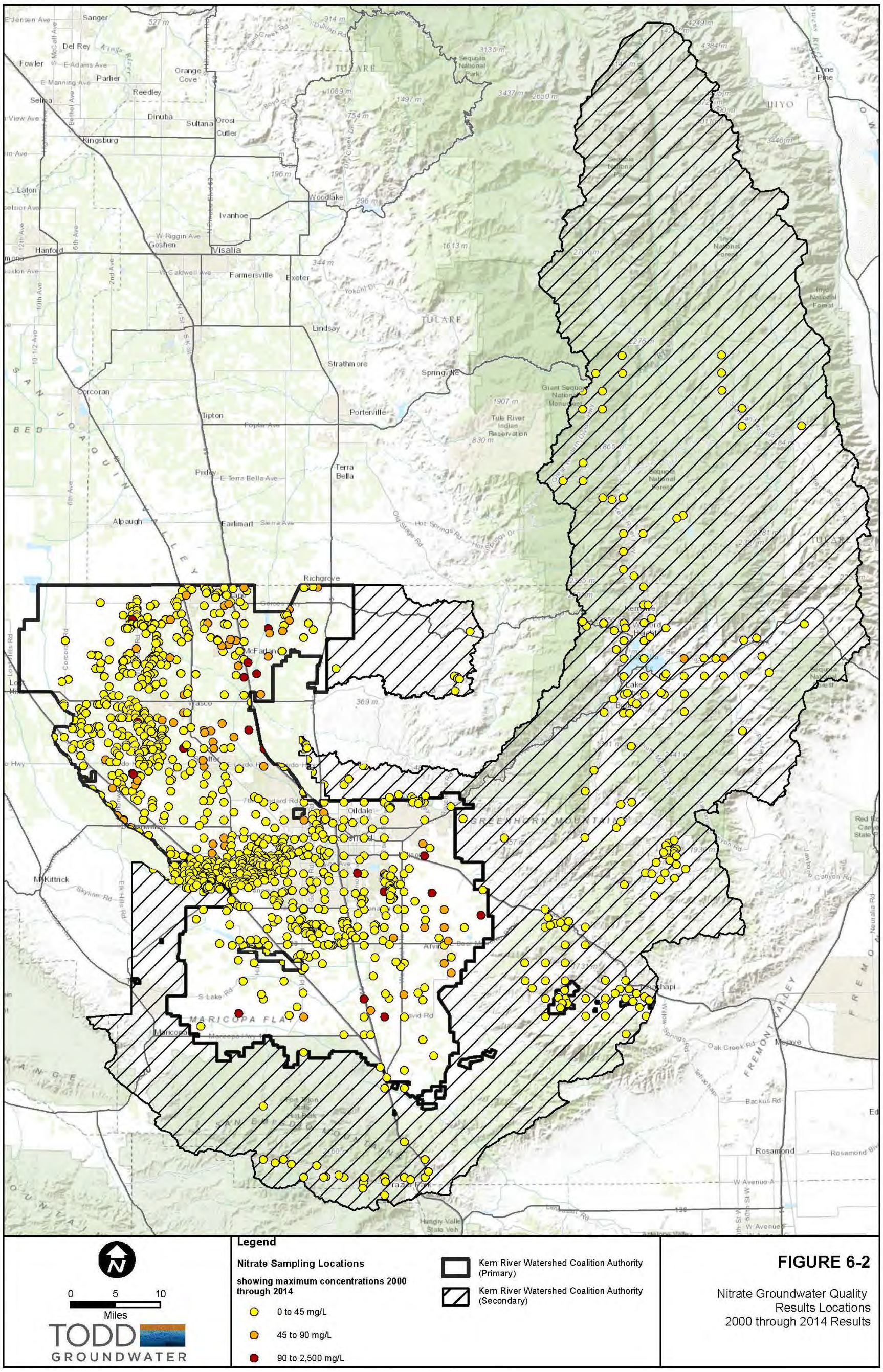


Figure 6-2. Nitrate Groundwater Quality Results Locations, 2000 through 2014 Results

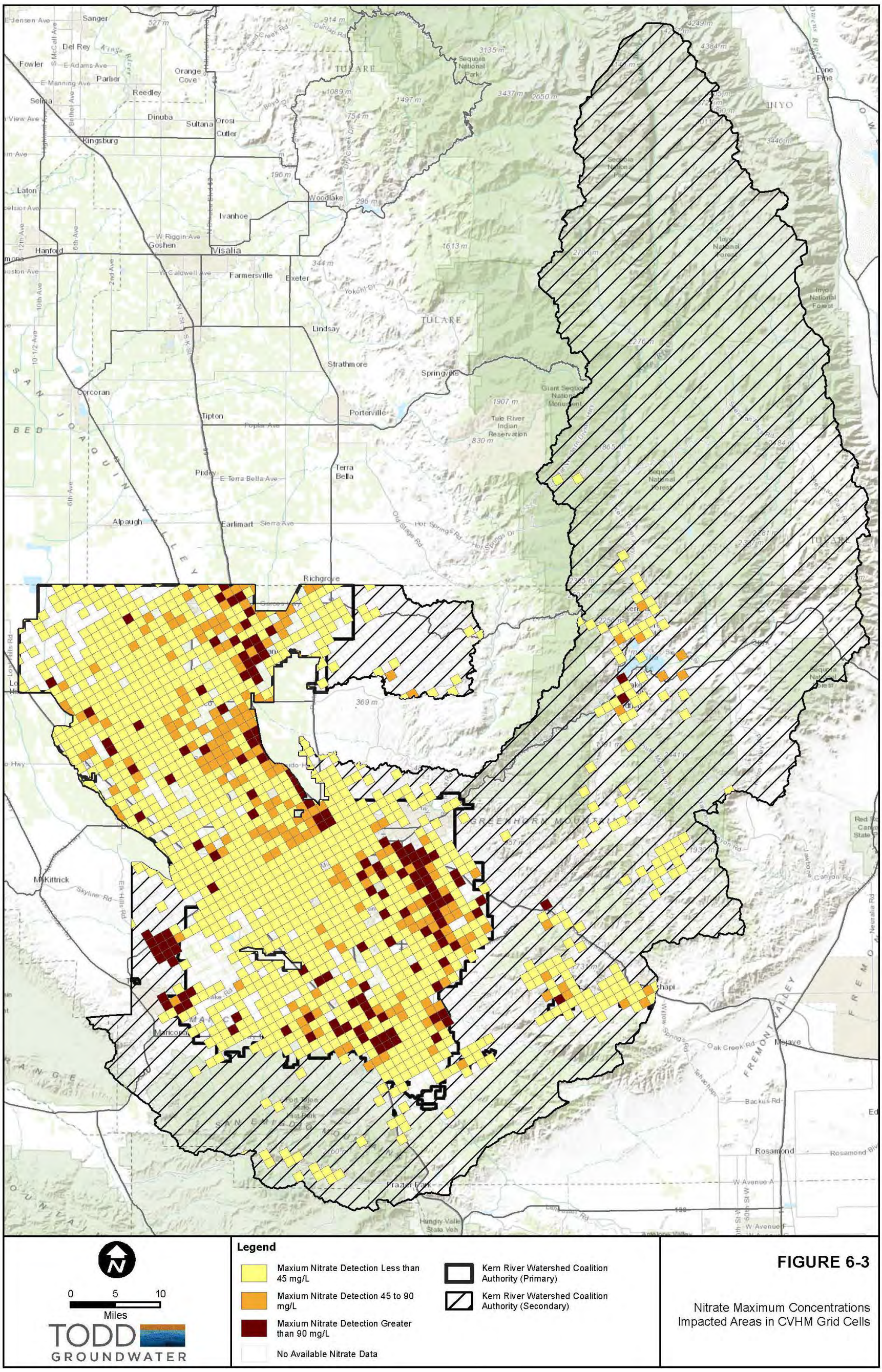


Figure 6-3. Nitrate Maximum Concentrations, Impacted Area in CVHM Grid Cells

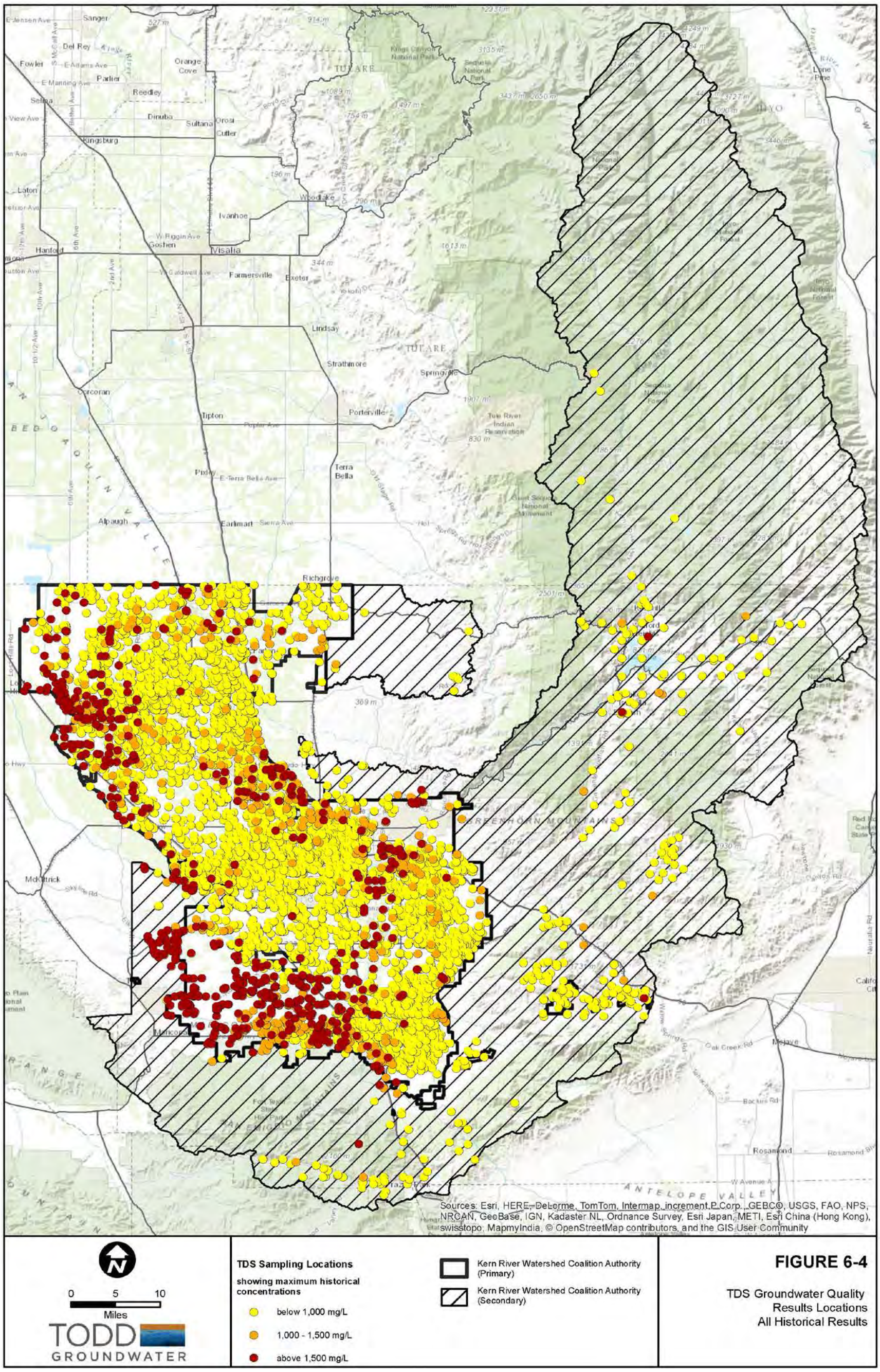


Figure 6-4. TDS Groundwater Quality Results Locations, All Historical Results

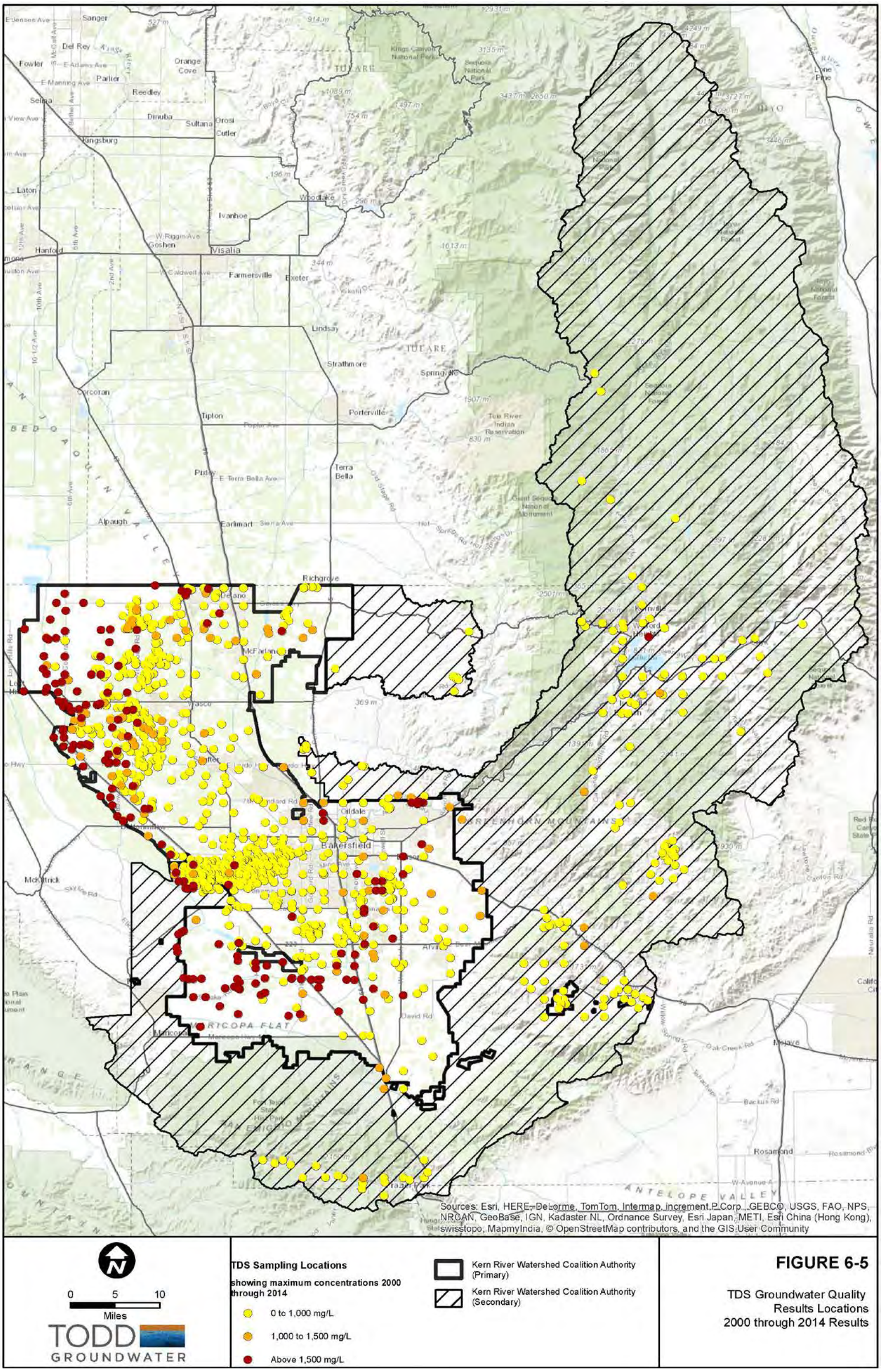


Figure 6-5. TDS Groundwater Quality Results Locations, 2000 through 2014 Results

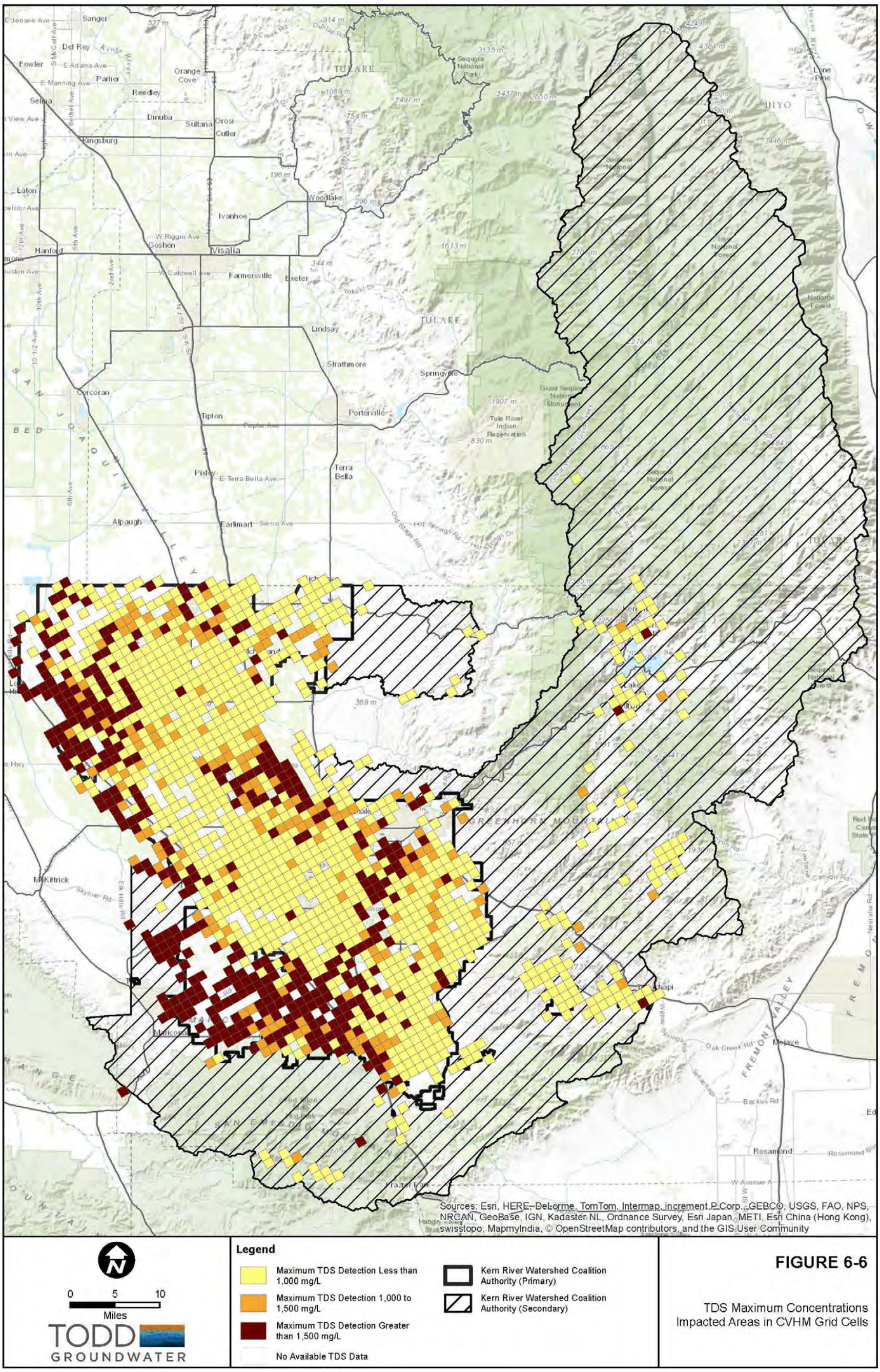


Figure 6-6. TDS Maximum Concentrations, Impacted Area in CVHM Grid Cells

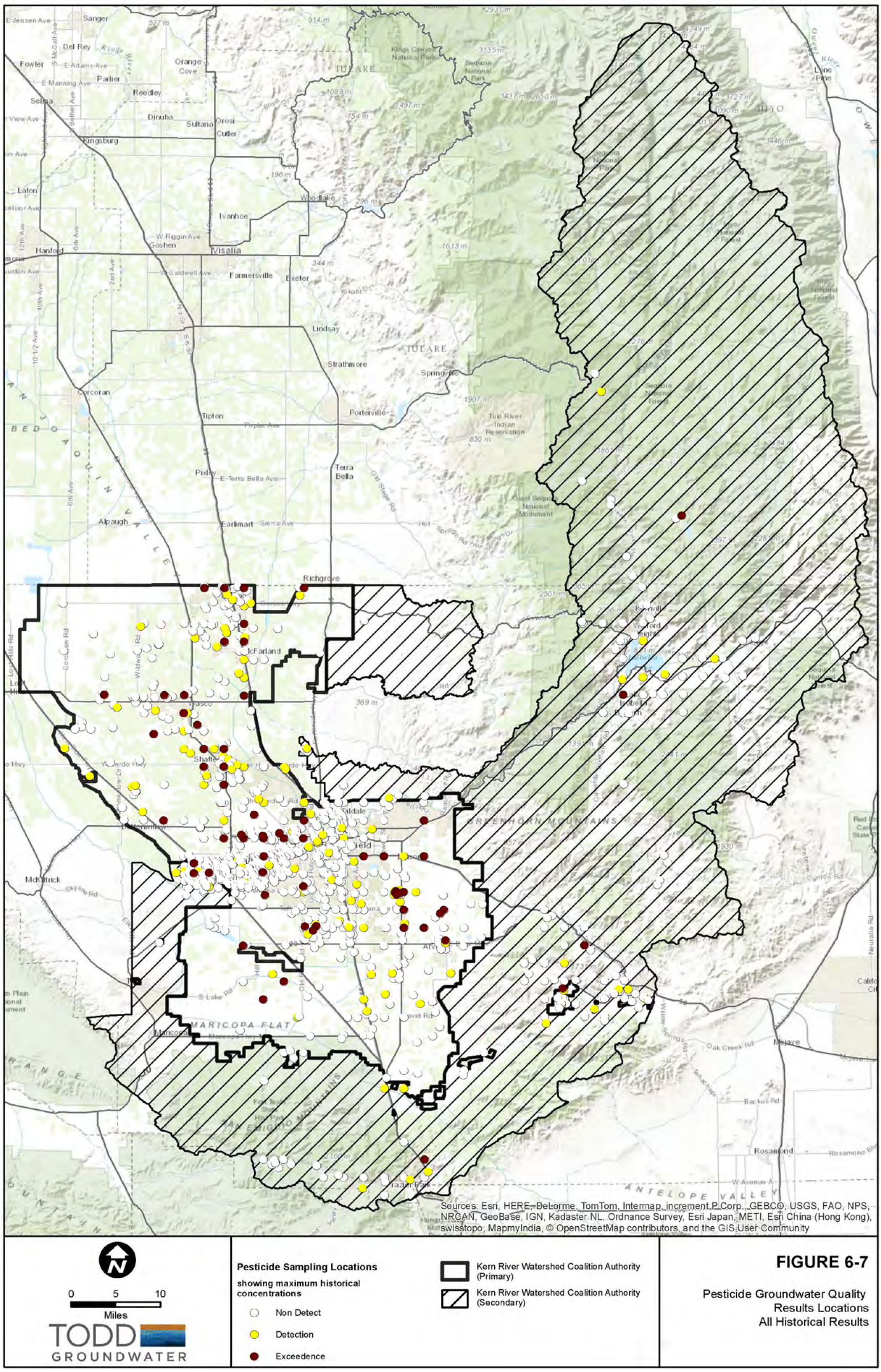


Figure 6-7. Pesticide Groundwater Quality Results Locations, All Historical Results

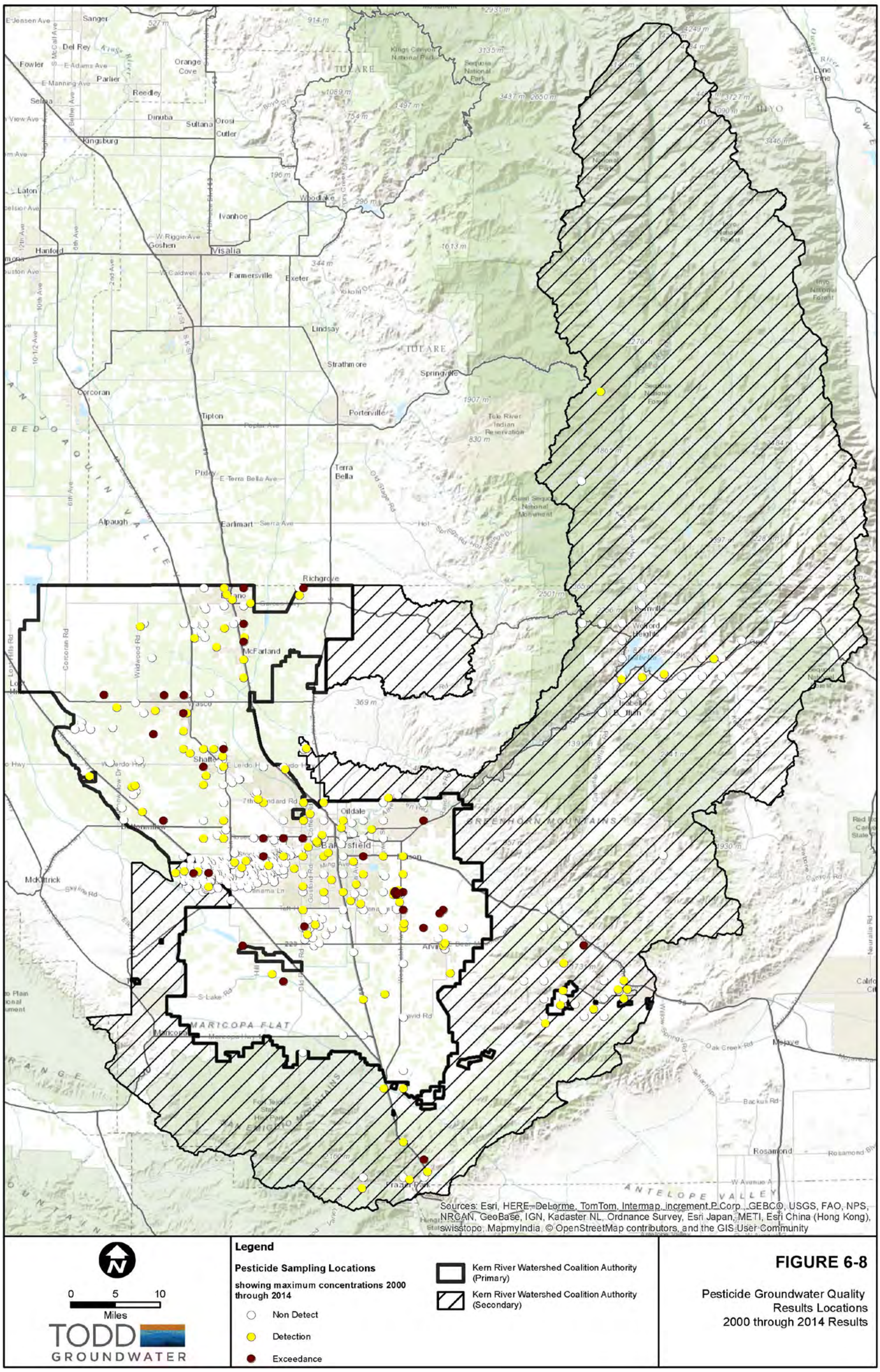


Figure 6-8. Pesticide Groundwater Quality Results Locations, 2000 through 2014 Results

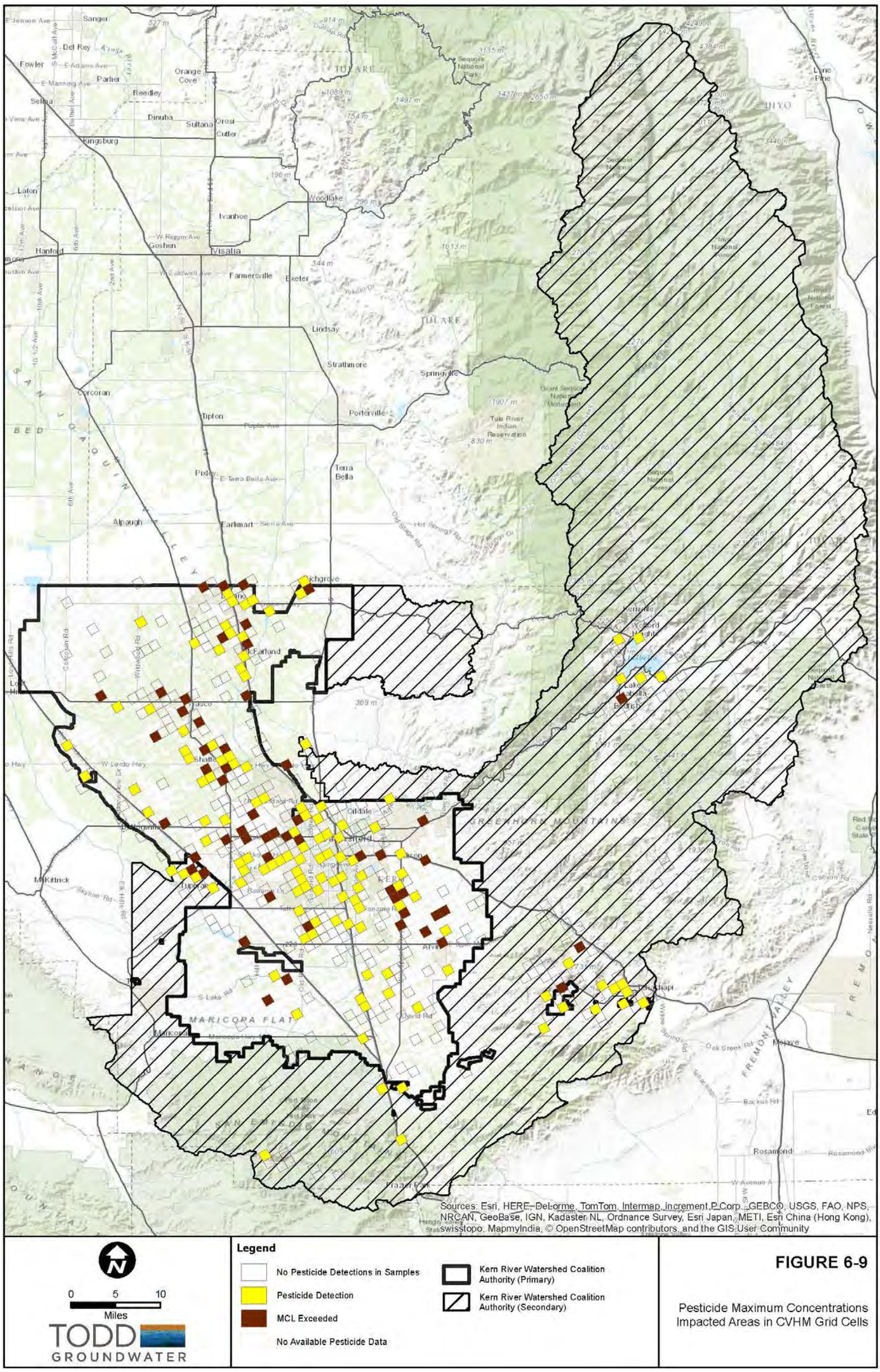


Figure 6-9. Pesticide Maximum Concentrations, Impacted Area in CVHM Grid Cells

Table 6-2. Maximum Contaminant Levels for Detected Pesticides

Maximum Contaminant Levels for Detected Pesticides								
Pesticide	Maximum Contaminant Level (MCL, µg/L)	Total Number of Samples	Minimum Concentration (µg/L)	Maximum Concentration (µg/L)	Date of First Sample	Date of Most Recent Sample	Number of Wells with Exceedances	Number of Samples Exceeding Threshold
1,2 Dibromoethane (EDB)	0.05	16,145	ND (<10)	0.63	7/28/1983	6/25/2014	34	171
1,2 Dichlorobenzene (1,2-DCB)	600	15,986	ND (<15)	7	1/4/1984	6/25/2014		
1,2 Dichloropropane (1,2 DCP)	5	15,890	ND (<10)	7	7/28/1983	6/25/2014	2	2
1,2-Dibromo-3-chloropropane (DBCP)	0.2	17,593	ND (<100)	74	10/19/1980	6/25/2014	156	1,443
1,3 Dichloropropene	0.5	14,174	ND (<1)	7	8/8/1984	6/25/2014	1	1
2,4,5-TP (Silvex)	50	1,454	ND (<10)	1	10/15/1984	7/10/2013		
2,4-Dichlorophenoxyacetic acid (2,4 D)	70	3,598	ND (<100)	65	7/6/1984	6/1/2796		
Acenaphthene	N/A	268	ND (<10)	8	6/10/2792	4/1/2013		
Acetone	N/A	11	ND (<1)	42	9/3/1987	1/26/2011		
Alachlor	2.0	6,011	ND (<4)	5.9	1/7/1985	6/12/2014	1	1
Aldicarb	N/A	2,413	ND (<5)	88	11/27/1979	6/1/2796		
Aldicarb Sulfone	N/A	1,633	ND (<5)	97	3/1/1989	5/19/2014		
Atrazine	1.0	9,894	ND (<2.4)	8.5	5/3/1985	6/12/2014	4	9
Bentazon	18	3,941	ND (<20)	48	2/10/1989	6/3/2014	2	2
Bromacil	N/A	7,437	ND (<20)	23	8/30/1984	5/15/2014		
Butachlor	N/A	782	ND (<1)	1	2/22/1993	9/20/2012		
Carbofuran	18	3,226	ND (<50)	8	8/30/1984	5/19/2014		
Carbon Disulfide	160	642	ND (<1,000)	0.5	9/26/2001	2/6/2014		
Carbon Tetrachloride	0.5	6,938	ND (<12)	9.7	1/4/1984	12/30/1999	7	26
Chlordane	0.1	3,442	ND (<40)	35	7/10/1984	5/5/2014	4	4
Cyanazine	N/A	820	ND (<150)	0.023	5/3/1985	9/20/2012		
Deethylatrazine	N/A	639	ND (0)	0.52	3/2/1993	4/27/2011		
Diazinon	N/A	5,251	ND (<4)	2	8/30/1984	5/15/2014		
Dicamba	N/A	1,697	ND (<15)	0.08	2/14/1985	5/5/2014		
Dichlorprop	N/A	14	ND (<1)	0.5	6/30/1989	7/7/2004		
Dieldrin	N/A	660	ND (<2.5)	0.2	7/10/1984	9/20/2012		
Dimethoate	N/A	5,574	ND (<100)	2	8/30/1984	5/15/2014		
Dimethyly Phthalate	N/A	144	ND (<10)	0.8	7/10/1984	4/1/2013		
Di-N-Butylphthalate	N/A	187	ND (<10)	9.5	7/10/1984	7/19/1999		
Dinoseb	7	1,069	ND (<100)	0.18	8/30/1984	6/1/2796		
Diuron	N/A	3,709	ND (<50)	6.5	8/30/1984	9/20/2012		
Endothall	100	2,135	ND (<100)	64	8/30/1984	5/19/2014		
Endrin	2.0	1,430	ND (<10)	0.2	7/10/1984	7/10/2013		
EPTC	N/A	879	ND (<50)	170	8/30/1984	7/29/2011		
Glyphosate (Round-up)	700	1,710	ND (<25)	19	7/25/1986	9/16/2013		
Heptachlor	0.01	3,363	ND (<1.9)	0.005	7/10/1984	3/28/2014		
Heptachlor Epoxide	0.01	3,386	ND (<2.2)	0.021	7/10/1984	3/28/2014	2	2
Hexachlorobutadiene	N/A	5,008	ND (<10)	7	7/10/1984	12/29/1999		
Hexazinone	N/A	1,046	ND (<0.9)	0.24	9/29/1992	8/29/2012		
Lindane (Gamma-BHC)	0.2	3,826	ND (<5)	0.22	7/6/1984	3/28/2014	1	1
Methiocarb	N/A	145	ND (<10)	4	5/9/1989	12/14/2009		
Methoxychlor	30	4,140	ND (<100)	0.77	7/6/1984	3/28/2014		
Methyl Bromide (Bromomethane)	N/A	12,407	ND (<118)	7	1/17/1984	6/25/2014		
Metolachlor	N/A	4,340	ND (<1)	1	7/10/1987	5/15/2014		
Metribuzin	N/A	4,641	ND (<2.4)	0.5	7/10/1987	5/15/2014		
Molinate	20	6,383	ND (<4)	2	9/9/1985	5/15/2014		
Naphthalene	N/A	17,743	ND (<1,000)	358	7/10/1984	6/25/2014		
Norflurazon	N/A	571	ND (<0.04)	2.48	3/29/1995	4/27/2011		
Oxamyl	50	2,430	ND (<50)	9	8/30/1984	5/19/2014		
Paraquat	N/A	237	ND (<100)	1.7	8/30/1984	12/14/2009		
Penoxalin	N/A	56	ND (<10)	0.5	8/31/1986	11/22/1999		
Picloram	500	980	ND (<1)	0.1	1/30/1991	7/10/2013		
Prometon	N/A	2,352	ND (<1.3)	1.12	3/18/1986	3/28/2014		
Prometryn	N/A	5,843	ND (<2.8)	2	5/3/1985	5/15/2014		
Propachlor (2-Chloro-N-isopropylacetanilide)	N/A	673	ND (<1)	1	2/22/1993	11/9/2012		
Simazine	4	10,252	ND (<10.1)	3.5	6/1/1982	6/12/2014		
Thiobencarb	70	6,088	ND (<4)	1	9/9/1985	5/15/2014		
Xylenes (total)	1,750	16,720	ND (<100)	38000	1/4/1984	6/25/2014		

Table 6-3. Water Quality Data Availability Summary

Water Quality Data Availability Summary																			
Source	All Historical Results						Recent Results (2000 through 2014)						Wells with Construction Information			General Well Type			
	Number of Wells			Number of Sampling Events			Number of Wells			Number of Sampling Events						Drinking Water	Irrigation	Monitoring	Mixed
	Nitrate	Pesticides	TDS	Nitrate	Pesticides	TDS	Nitrate	Pesticides	TDS	Nitrate	Pesticides	TDS	Nitrate	Pesticides	TDS				
State Water Resources Control Board Division of Drinking Water (SWRCB-DDW, formerly CDPH) (through the GAMA program)	1,898	1,781	1,543	39,095	31,502	9,047	1,640	1,299	1,177	30,263	18,276	4,955	0	0	0	X			
CDPH Archived Data	1,306	1,467	1,243	8,741	8,567	4,061	0	0	0	0	0	0	0	0	0	X			
California Department of Water Resources (DWR)	3,905	0	3,216	7,488	0	6,020	0	0	0	0	0	0	550	0	485				X
Cleanup Sites (EDF) (through the GAMA program)	1	37	1	3	608	13	1	37	1	3	608	13	0	0	0			X	
Kern County Water Agency (KCWA)	2,253	409	2,633	7,292	1,399	12,663	1,001	224	1,205	2,419	588	5,525	718	240	736				X
California Department of Pesticide Regulation (DPR) CDPH (through the GAMA program)	0	1,143	0	0	1,515	0	0	177	0	0	451	0	0	0	0		X		
Groundwater Ambient Monitoring and Assessment (GAMA)	181	181	181	181	181	181	181	181	181	181	181	181	0	0	0	X			
United States Geological Survey (USGS) (through the GAMA program)	1,417	310	1,562	2,190	1,868	2,893	153	231	153	209	263	210	0	0	0	X			
Central Valley Regional Water Quality Control Board (CVRWQCB) Waste Discharge Requirements General Order for Existing Milk Cow Dairies (R5-2013-0122) Monitoring Data	376	0	0	1,359	0	0	376	0	0	1,359	0	0	0	0	0				X

7 Groundwater Hydrology

The groundwater hydrology of the Kern River Watershed Coalition Authority (**KRWCA**) area can generally be summarized with information about groundwater levels, groundwater level trends, and the groundwater flow directions. Groundwater levels are influenced by local geology, recharge flows and utilization demands, which can vary significantly in wet and dry periods. The KRWCA is characterized by a large range in groundwater depths which are significantly influenced by managed recharge and storage operations; however, the groundwater storage capacity of the KRWCA area allows for a large range in operations. Local groundwater level trends indicate the variability that the water management programs introduce throughout the region during both wet and dry periods. Groundwater flow directions are also influenced by these demands and operations, as well as local geology.

The groundwater hydrology of the KRWCA area is considered notable within the Tulare Lake Hydrologic Region (**TLHR**) due to the regional groundwater basin configuration, hydrologic stresses, and depth to first-encountered groundwater. As noted in the expert report submitted to the Central Valley Regional Water Quality Control Board (**CVRWQCB**), these unique aspects represent temporal and spatial disconnects throughout the KRWCA area which may potentially complicate the groundwater monitoring required to fulfill the General Order (Gailey, 2013).

7.1 Groundwater Levels

Groundwater is present in both the primary and secondary portions of the KRWCA area, as discussed in **Section 5**. Groundwater level measurements have been collected in the primary portion of the KRWCA area for many decades by multiple parties, including the large scale long term monitoring programs of the California Department of Water Resources (**DWR**), United States Geological Survey (**USGS**), and Kern County Water Agency (**KCWA**). These monitoring programs have not included groundwater level data collection in the secondary area, so information regarding groundwater elevations and flow directions in the secondary portion of the KRWCA area is not available.

7.1.1 Primary Portion of the KRWCA Area: the Central Valley Floor

The primary portion of the KRWCA area comprises a portion of the DWR designated Kern County Portion of the San Joaquin Groundwater Basin (Kern County Subbasin), as well as portions of the Cummings Valley, Tehachapi Valley West, and Brite Valley Groundwater Basins (DWR 2003), as discussed in **Section 5**. Groundwater level data is only available for the Kern County Subbasin part of the KRWCA primary area. The primary source of regionally extensive groundwater level information within the Kern County Subbasin is the KCWA. The KCWA has long collected and compiled groundwater level data from throughout the Subbasin, including data from other agencies, and prepares annual depth to groundwater and groundwater elevation contour maps from these data (KCWA, 2014, Unpublished Electronic Water Level Contour Maps, Spring 2000 through Spring 2013. Bakersfield, Cal.: Kern County Water Agency). The existing data presents a good functional representation of the groundwater level conditions and trends, if any, within the primary portion of the KRWCA.

As discussed in **Section 5**, groundwater levels in the Kern County Subbasin fluctuate from year to year as a result of hydrologic conditions, among other variables. As a result, no single year is completely representative of groundwater level conditions in any area. To show the range of groundwater level

conditions that can occur as a result of varying hydrologic conditions this assessment presents information from a period of high groundwater levels and a period of low groundwater levels. As discussed in **Section 5**, the annual spring groundwater elevation contours prepared by KCWA for 2000 through 2013 (KCWA, 2014) were compared to one another. This comparison showed that the highest groundwater elevations in the period were in the spring of 2007, and that the lowest occurred in the spring of 2013. Groundwater level information for these two time periods are discussed below.

7.1.1.1 Depth to Groundwater

Depth to groundwater in the KRWCA primary area is represented by contour maps prepared by KCWA. These maps are prepared for both the unconfined aquifer and for shallow groundwater areas (KCWA, 2014). As noted above, wet period and dry period depth to groundwater is represented by spring 2007 and spring 2013, respectively.

The wet period unconfined aquifer depth to groundwater contours represented by spring 2007 are shown on **Figure 7-1**. These contours indicate that the unconfined aquifer depth to groundwater in the KRWCA primary area ranges from less than 50 feet below ground surface (**bgs**) to over 700 feet bgs. The shallowest depths to groundwater occur below the Kern River, on the west side of the Subbasin, and in the southern portion of the Kern Delta Water District. The deepest groundwater depths occur in the southern portion of the KRWCA primary area, at the eastern end of the Wheeler Ridge-Maricopa Water Storage District. The spring 2007 depth to shallow groundwater contours are shown on **Figure 7-2**. As noted in **Section 5**, the shallow groundwater areas are mapped in the areas of low permeability soils in and around the historic swamp and overflow lands, Buena Vista and Kern Lake beds, and margins of alluvial fans in the southern portion of the Subbasin, and in the western portion of the Semitropic Water Storage District, Lost Hills Water District, and Buena Vista Water Storage District in the northern portion of the Subbasin. The shallow depth to groundwater contours show that groundwater in these areas occurs at depths as low as 5 feet bgs and extending to 20 feet bgs.

The 2013 dry period depth to groundwater contours in the unconfined aquifer are shown on **Figure 7-3**. As expected, these dry period depth to water contours generally show that groundwater is deeper than in the wet period. There are still areas where groundwater is present within 40 ft bgs, but the locations where groundwater was within 50 feet bgs in 2007 show depths in excess of 100 feet bgs in 2013. These generally deeper groundwater conditions are a result from decreased recharge and increased groundwater use when surface water sources are less available. In addition, during dry periods the groundwater banking activities in the Subbasin change from storage/recharge to recovery/extraction operations. The depth to shallow groundwater contours in the dry period of 2013 are shown on **Figure 7-4**. These contours are very similar in extent and distribution to those from 2007. The similarity in these contour datasets in different hydrologic conditions may indicate that the shallow groundwater in these areas is influenced more by local geology and irrigation practices versus surface water availability and recharge/banking operations.

7.1.1.2 Groundwater Elevations

As noted above, the KCWA prepares annual spring groundwater elevation contour maps for the unconfined aquifer in the Kern County Subbasin (KCWA, 2014). The representative spring 2007 wet period and 2013 dry period groundwater elevation contours are shown on **Figure 7-5** and **Figure 7-6**, respectively. These two groundwater elevation contour datasets show the range of groundwater

conditions that occur in the unconfined aquifer in the KRWCA area in typical wet and dry hydrologic conditions.

As expected from the information presented in the depth to groundwater discussion above**,** **Figure 7-5** shows groundwater elevations in 2007 were highest near the Kern River and the associated groundwater banking operations. The lowest groundwater elevations during this period are in the northeast portion of the Subbasin. There are also local groundwater elevation lows in the southern portion of the KRWCA primary area. The groundwater elevations in the dry period represented by spring 2013 conditions shown on **Figure 7-6** are similar to those from 2007, although generally 30 to 80 feet lower. The highest groundwater elevations in 2013 were not coincident with the Kern River, but with the eastern edge of the Subbasin.

7.1.2 Secondary Portion of the KRWCA Area

As noted previously in this section and in previous sections of this GAR, there is very little information regarding groundwater conditions in the secondary portion of the KRWCA. This is especially true of groundwater level information. Since groundwater in most of the secondary area occurs in fractured bedrock, as discussed in **Section 5**, there is not a consistent groundwater surface between geographically separate portions of the secondary area. In addition, there are very few groundwater level measurements available for the secondary area and no previously completed assessment of regional groundwater patterns has been completed.

7.2 Groundwater Level Trends

Groundwater level trends within the KRWCA primary area occur on regional and local scales. Regional scale trends can be shown by evaluating changes in groundwater elevations over the entire area. Local groundwater level conditions vary more widely than regional conditions, but in the Kern County Subbasin the trends in these conditions generally fall into one of a few categories. These categories can be illustrated through representative hydrographs of groundwater elevations over time.

7.2.1 Most Recent KCWA One Year Change in Groundwater Elevation Map

The two most recent KCWA produced groundwater elevation contour datasets were compared to one another to produce a change in groundwater elevation dataset. This comparison was completed by constructing groundwater elevation surfaces from each of the contour datasets using geographic information system (**GIS**) tools. The spring 2012 groundwater elevation surface was then subtracted from the spring 2013 surface. The resulting surface and the contours of groundwater elevation change are shown on **Figure 7-7**. As the 2013 period represents a drought period, this change in groundwater elevations presented on **Figure 7-7** represents changes resulting from drought conditions. This is clearly illustrated on **Figure 7-7**, which shows groundwater elevations decreasing by as much as 350 feet between 2012 and 2013. On average, groundwater elevations within the KRWCA primary area decreased over 34 feet between spring 2012 and spring of 2013. The highest magnitude reductions in groundwater elevations during this period occurred along the eastern edge of the Subbasin. However, large areas of reduced groundwater elevation were also present in the Kern Fan area around the Kern River, in the central southwestern portion of the KRWCA area, and in the southern portion of the Semitropic Water Storage District.

7.2.2 Groundwater Elevation Change Representative of Wet Period

A wet period change in groundwater elevations in the Kern County Subbasin was identified by comparing the KCWA prepared groundwater elevation contour datasets from 2000 through 2013 to one another, as described previously. This comparison indicated that the largest average change in groundwater elevations in the period occurred between the spring of 2005 and the spring of 2006. This wet period change in groundwater elevations is shown on **Figure 7-8**. While the changes in groundwater elevations presented on **Figure 7-8** are not all increases, there is an obvious difference when compared to the information shown on **Figure 7-7**. Between 2005 and 2006 groundwater elevation changes ranged between increases of over 120 feet to decreases of nearly 140 feet. The average change in groundwater elevations within the KRWCA primary area between spring 2005 and spring 2006 was an increase of over 13 feet. The increases in groundwater elevations shown for this wet period largely occurred around the Kern River and the Kern Fan. There were also significant increases in groundwater elevations in the northern portion of the Subbasin that appear to correlate to North Kern Water Storage District and Semitropic Water Storage District managed groundwater recharge operations. There are areas of both positive and negative groundwater elevation change in the southern portion of the Subbasin within the Kern Delta Water District and Wheeler Ridge-Maricopa Water Storage District.

7.2.3 Illustrative Hydrographs in Focus Area

Selected illustrative hydrographs showing a range of local groundwater elevation trends throughout the KRWCA primary area are shown in **Figure 7-9**. These hydrographs show that the dominant groundwater elevation trends in the area are the large variations near the Kern River on the Kern Fan. Groundwater elevations in this area show the pattern of wet and dry hydrologic cycles and the high volumes of managed recharge and recovery associated with groundwater banking projects. These effects dissipate away from the Kern Fan and the active banking projects, where groundwater elevation patterns are more muted and show seasonal effects, short term responses to wet and dry periods, and long term groundwater declines over the 14 year study period.

7.3 Groundwater Flow Directions

Given the significant variations in groundwater elevations that occur throughout the Subbasin in response to variations in hydrologic conditions, no one groundwater elevation surface should be taken to be representative of groundwater flow directions. Therefore, a combined typical groundwater elevation surface was generated to represent general trends in groundwater elevation and flow directions throughout the Subbasin during the 14 year period. This combined surface was produced by averaging the surfaces represented by all of the KCWA produced groundwater elevation contour datasets for the period from 2000 through 2013 (KCWA, 2014). The resulting averaged groundwater elevation contour data are shown on **Figure 7-10**. The groundwater elevations shown on **Figure 7-10** do not necessarily represent average groundwater elevations, but rather general trends in groundwater flow patterns within the unconfined aquifer. Groundwater flow directions indicated by these average contours are included on **Figure 7-10**. These flow directions show that average groundwater flow north of the Kern River is generally towards the north and center of the Subbasin, focused on low average elevations in the north. This flow pattern also shows flow from the western and eastern edges of the Subbasin towards the center. South of the Kern River, groundwater flow is less uniform. In this region

groundwater flows from local highs associated with high volumes of recharge from various sources (i.e. managed recharge, canal losses, and irrigation return flows) towards areas with weaker surface water supplies and less managed recharge.

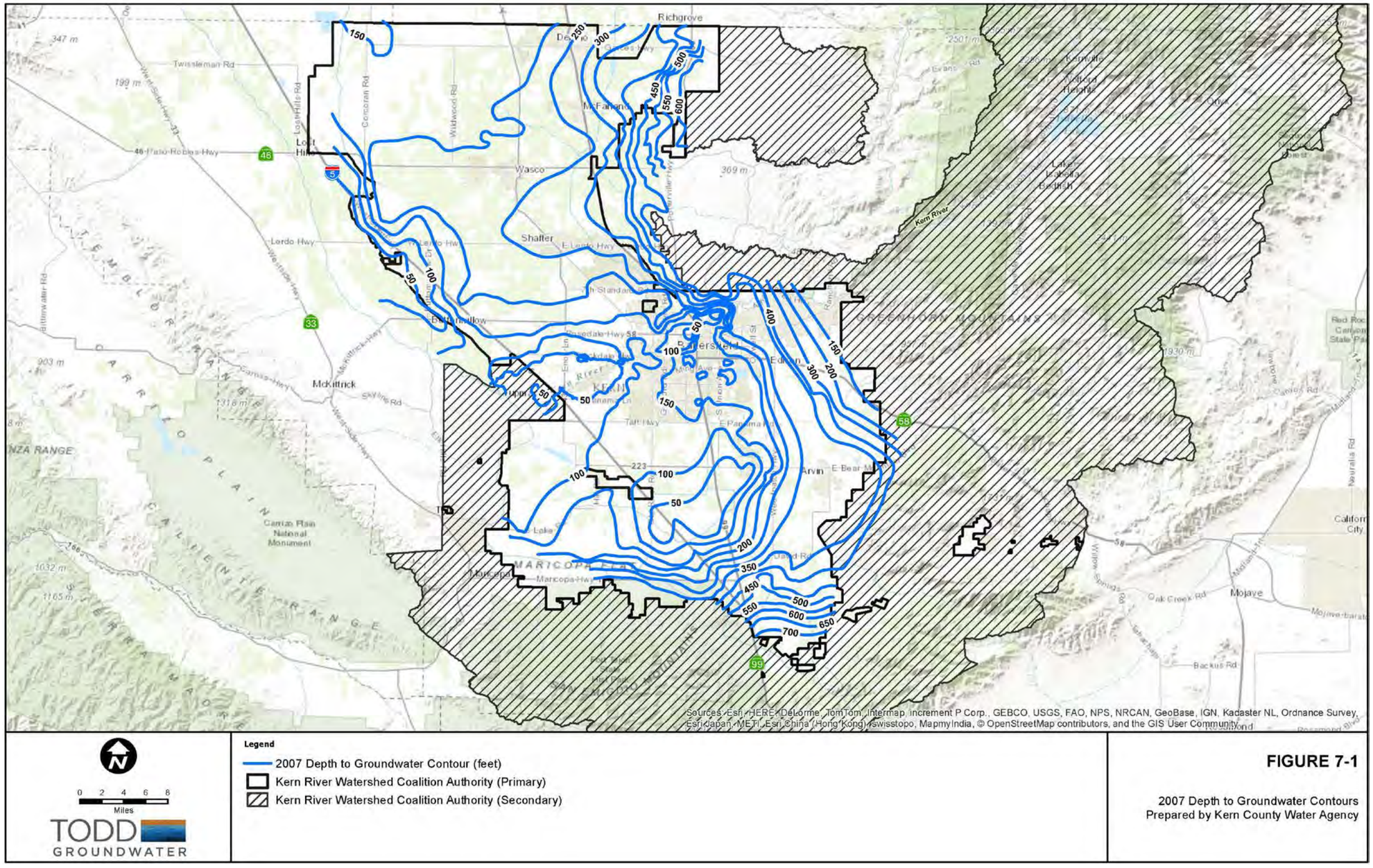


Figure 7-1. 2007 Depth to Groundwater Contours, Prepared by Kern County Water Agency

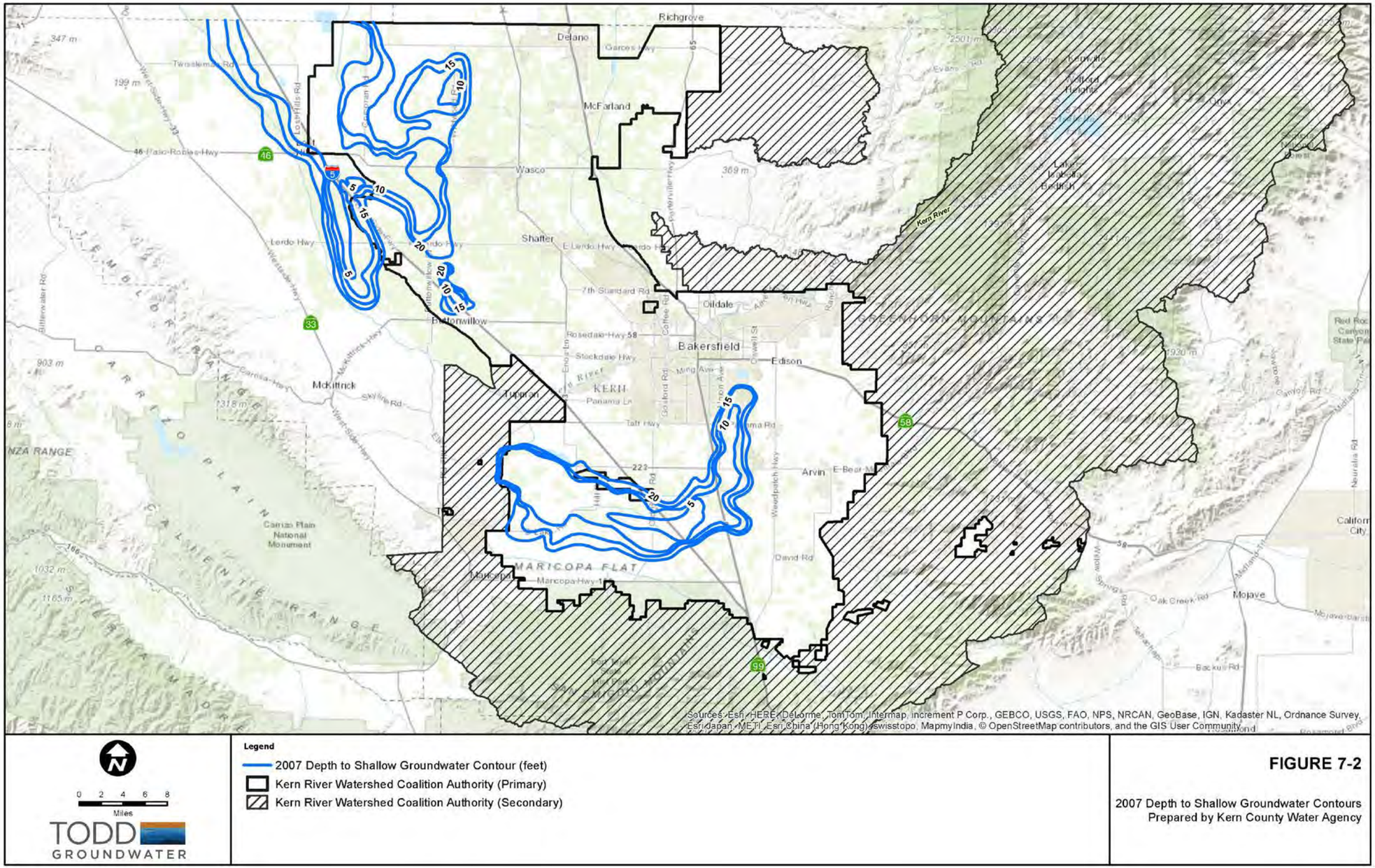


Figure 7-2. 2007 Depth to Shallow Groundwater Contours, Prepared by Kern County Water Agency

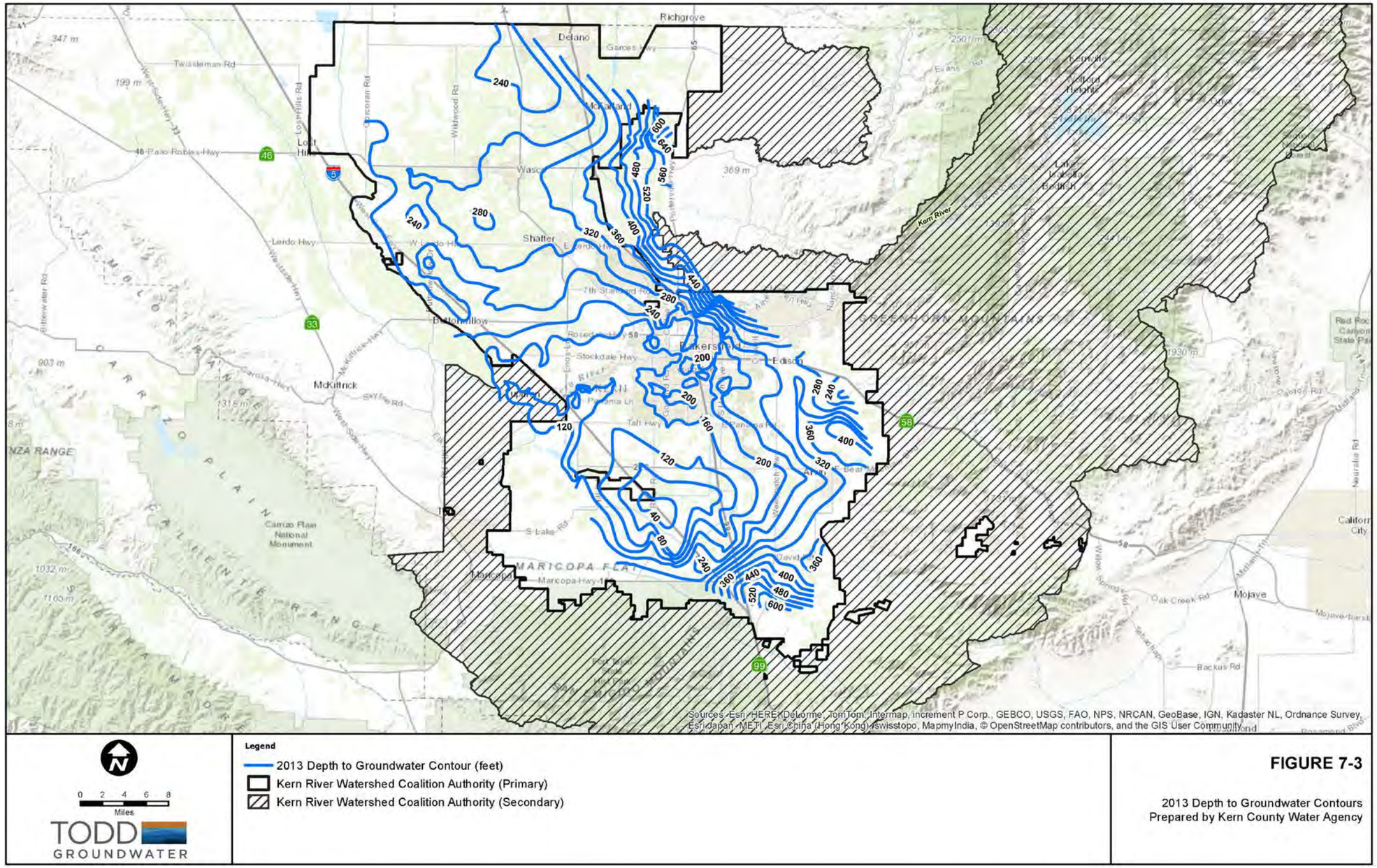


Figure 7-3. 2013 Depth to Groundwater Contours, Prepared by Kern County Water Agency

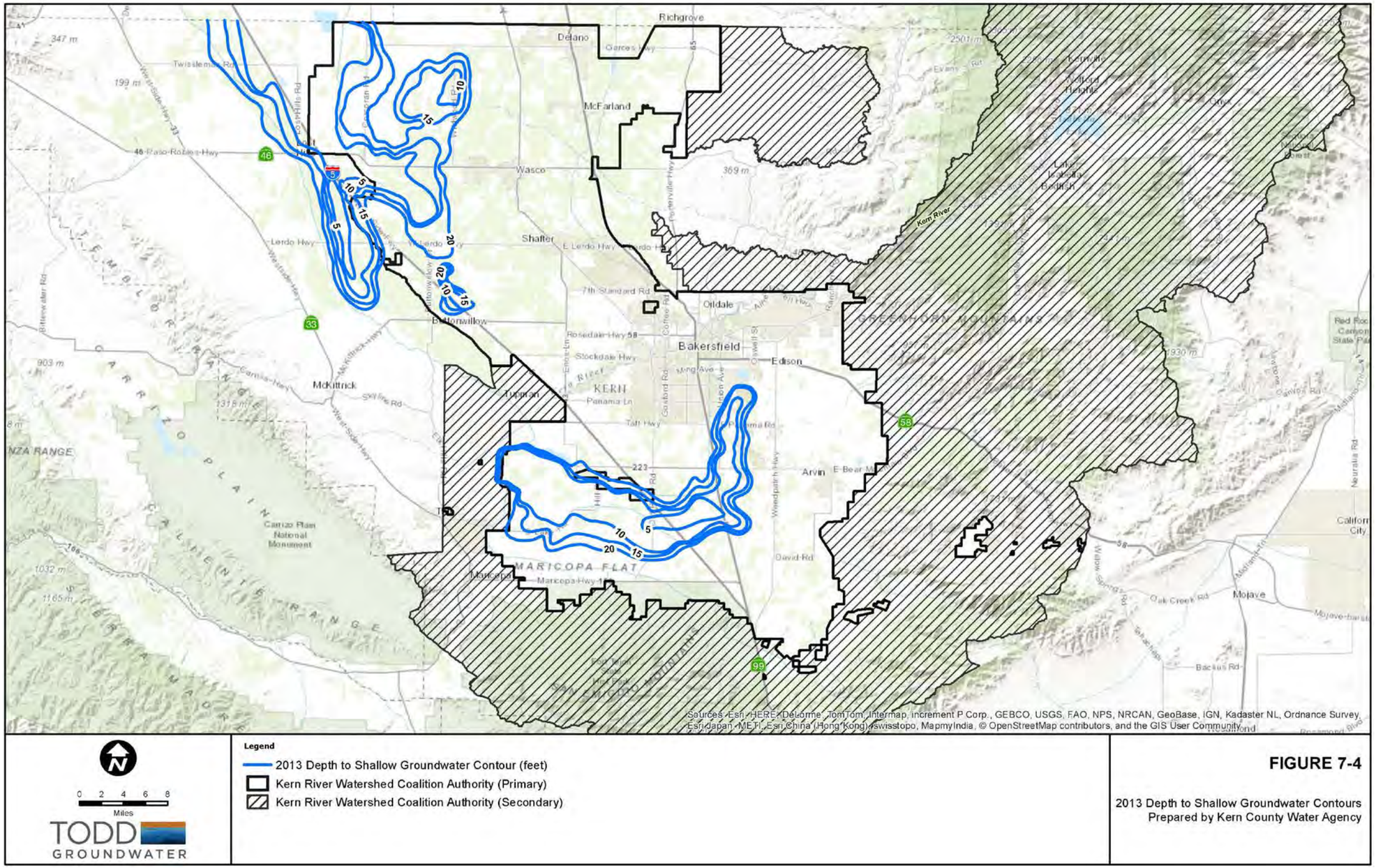


Figure 7-4. 2013 Depth to Shallow Groundwater Contours, Prepared by Kern County Water Agency

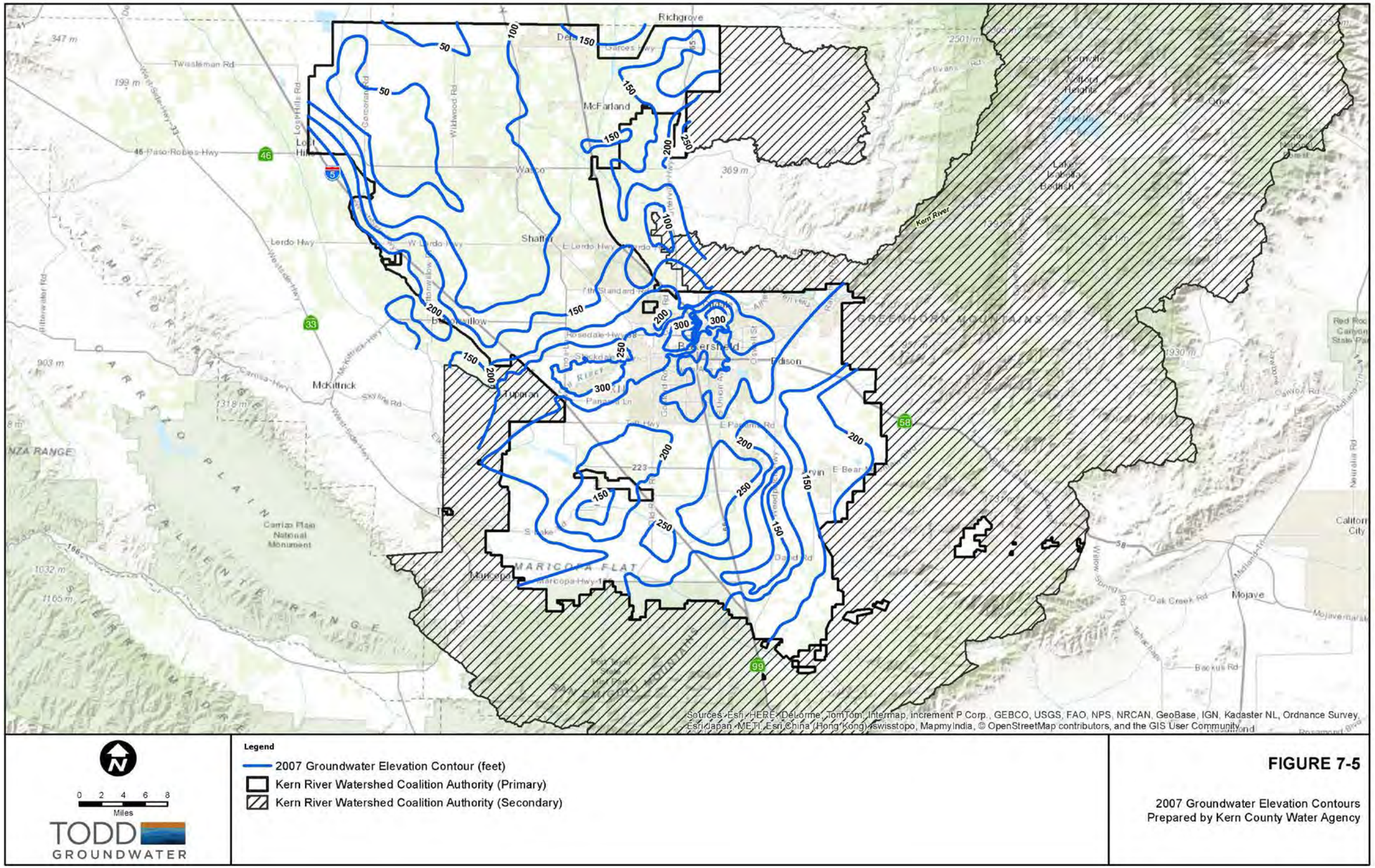


Figure 7-5. 2007 Groundwater Elevation Contours, Prepared by Kern County Water Agency

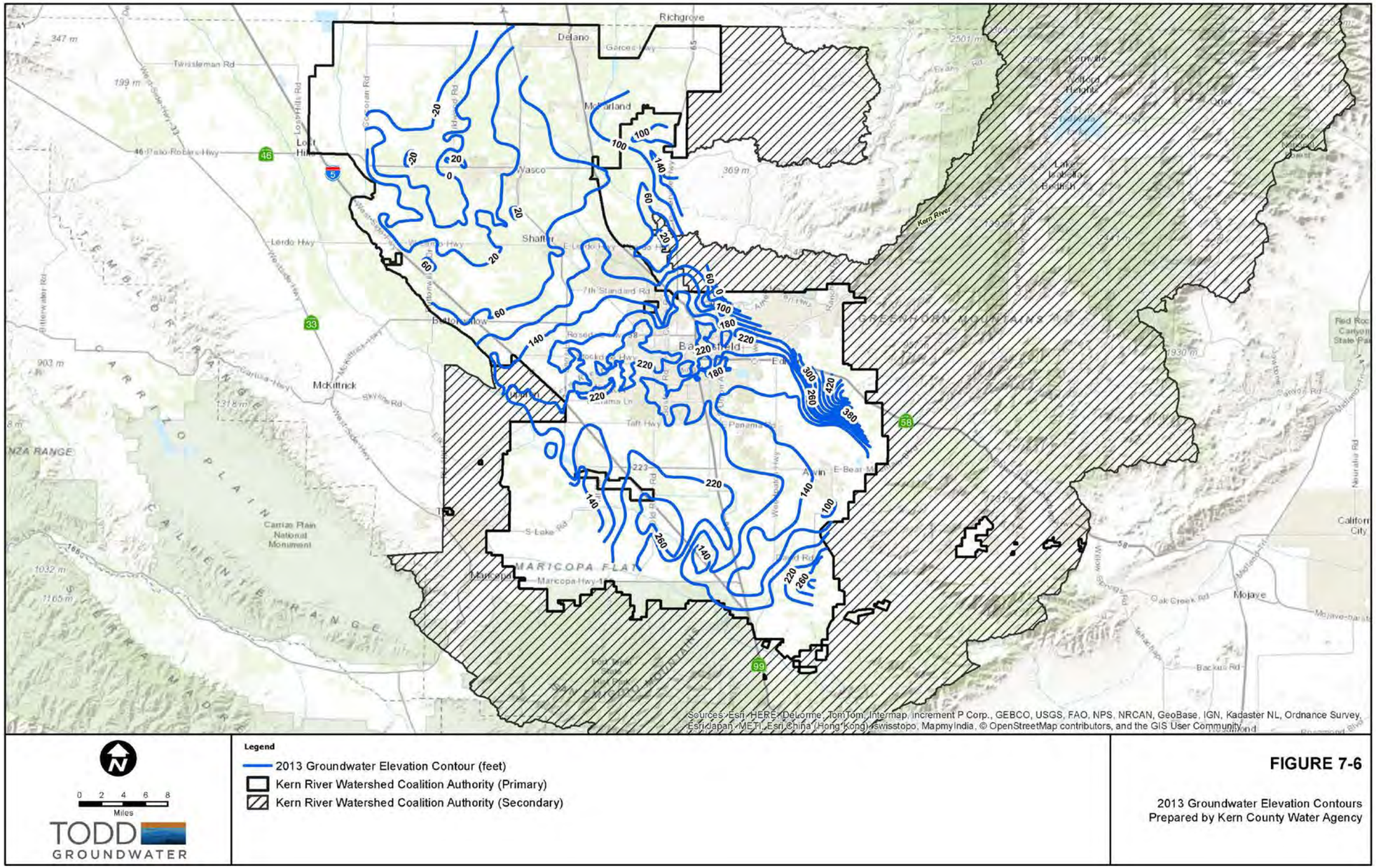


Figure 7-6. 2013 Groundwater Elevation Contours, Prepared by Kern County Water Agency

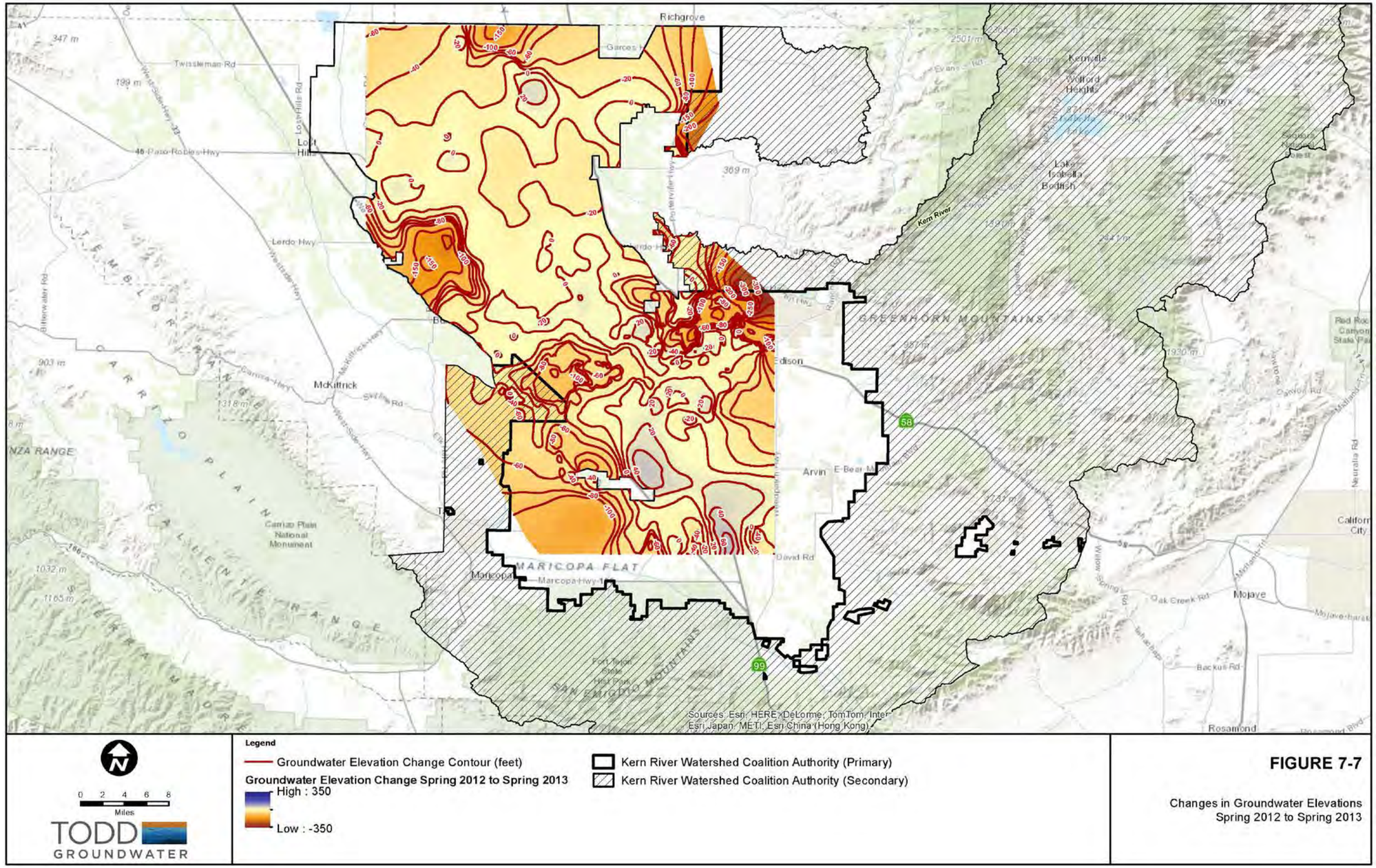


Figure 7-7. Changes in Groundwater Elevations, Spring 2012 to Spring 2013

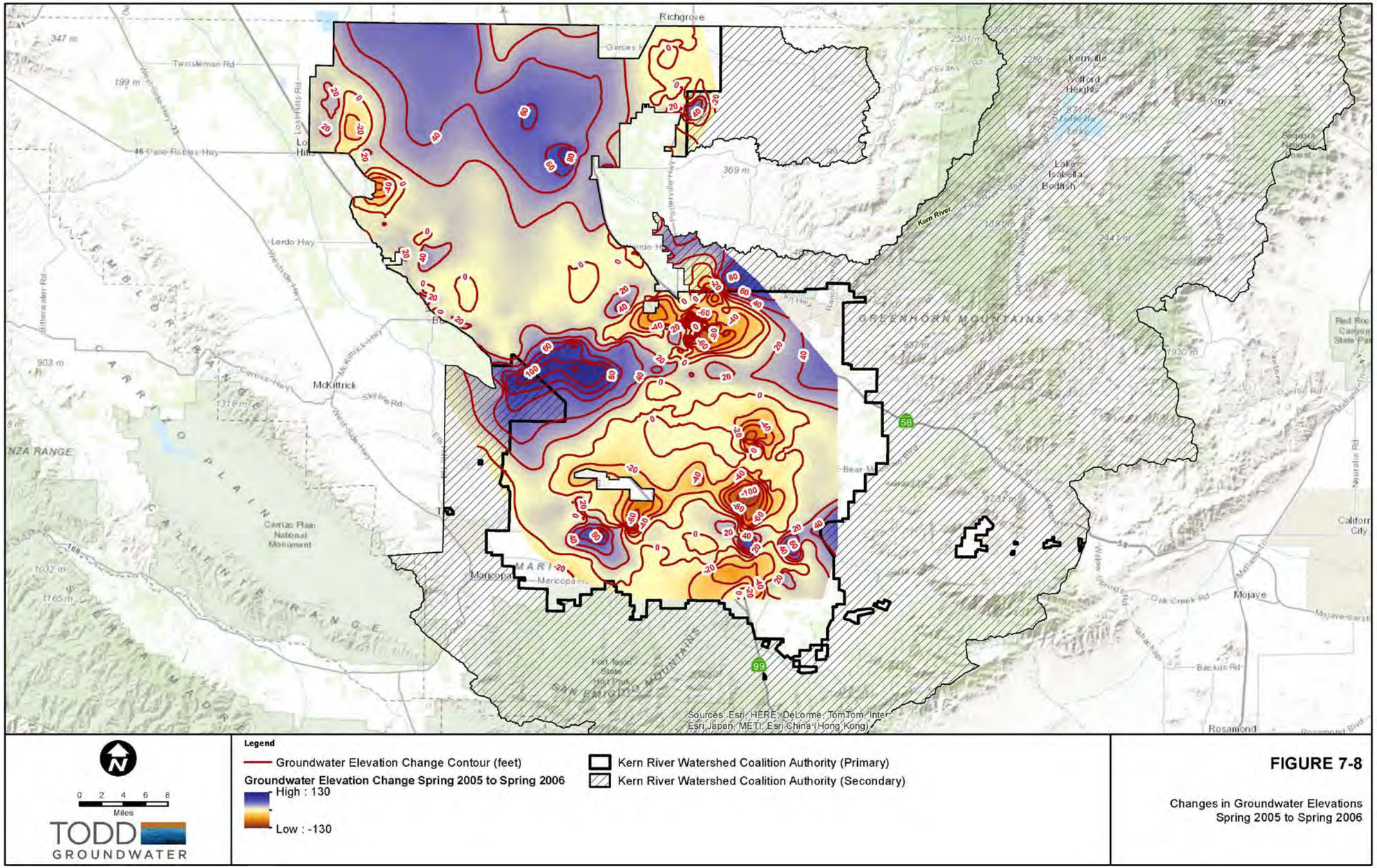


Figure 7-8. Changes in Groundwater Elevations, Spring 2005 to Spring 2006

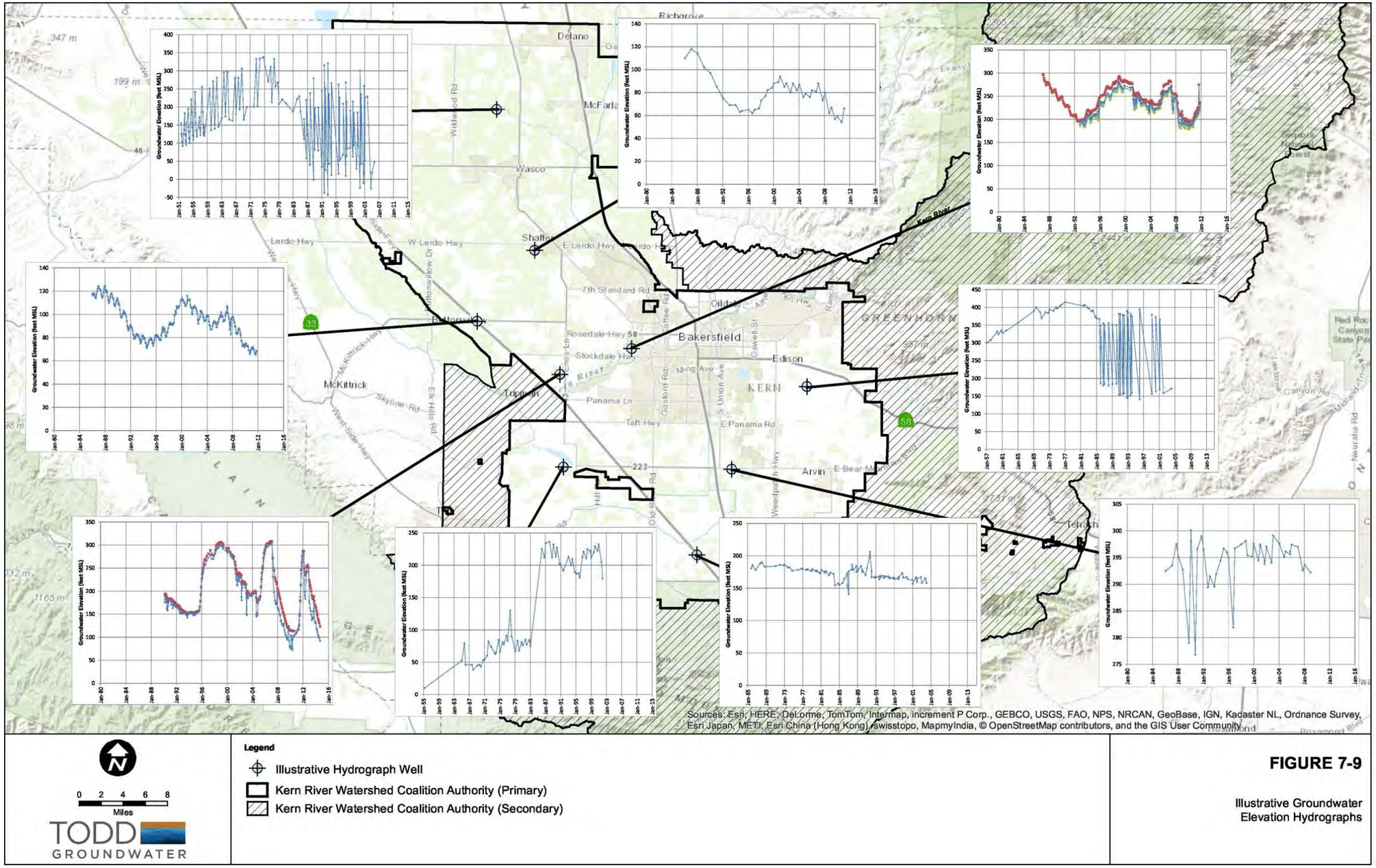


Figure 7-9. Illustrative Groundwater Elevation Hydrographs

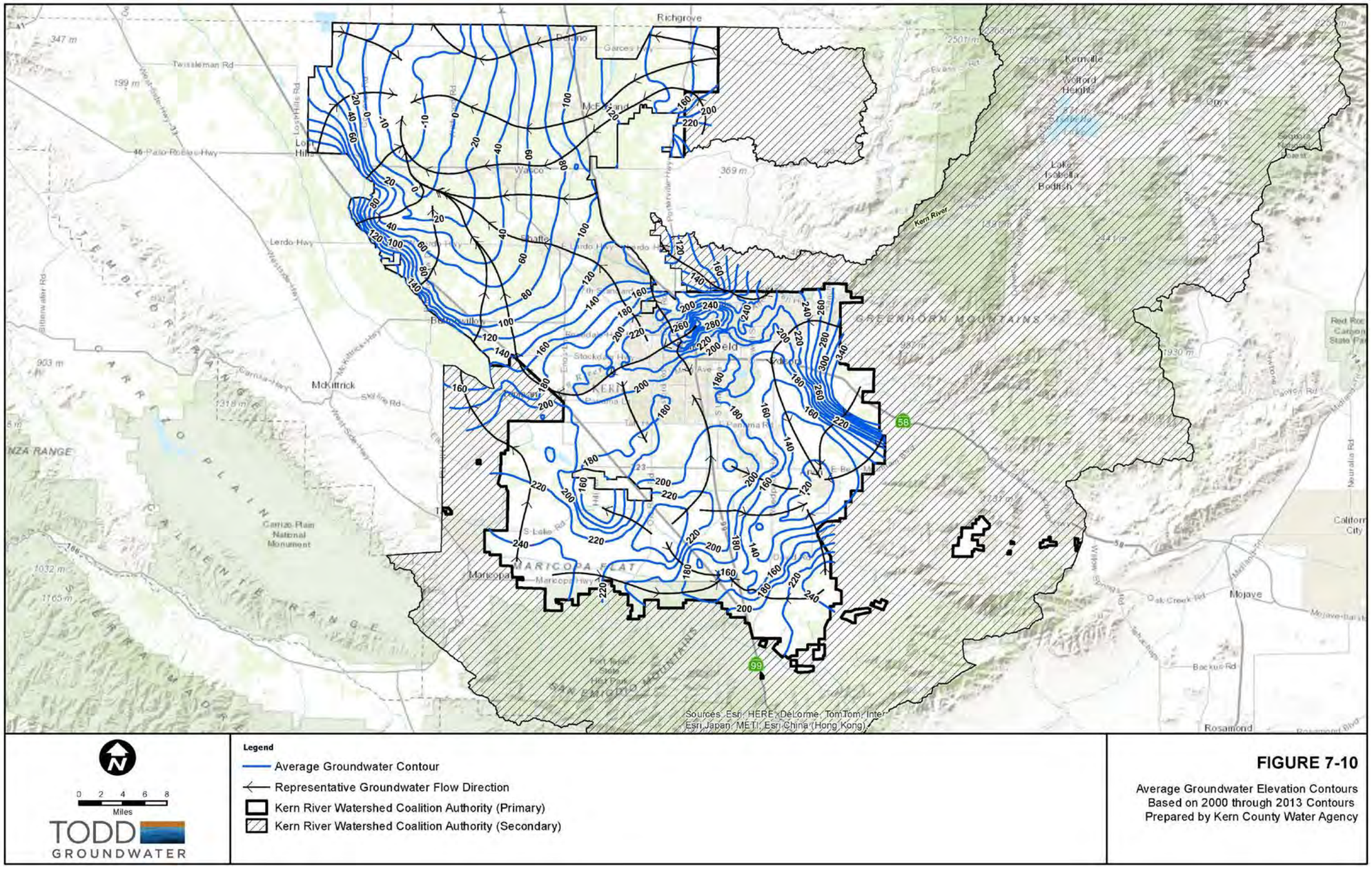


Figure 7-10. Average Groundwater Elevation Contours, Based on 2000 through 2013 Contours Prepared by Kern County Water Agency

8 Recharge to Groundwater

Groundwater recharge is the sum of the hydrogeologic processes through which water percolates from the ground surface into a groundwater aquifer. These processes require two basic components in order for groundwater recharge to occur, available water and permeable materials at the ground surface. Recharge cannot occur in a location without both of these components. The capacity for recharge is also largely a function of these two components; groundwater recharge is highest in areas with very permeable material and abundant surface water.

Source water quality is another recharge consideration. In general, highly effective recharge areas are a net benefit to water quality because they tend to dilute the concentrations of groundwater constituents. However, areas with poor quality surface water and high permeability could negatively impact groundwater quality.

8.1 Sources of Recharge

Groundwater recharge in the KRWCA area comes from a variety of sources, and each source has different water quality. It is likely that these recharge sources, including natural and managed recharge, generally have lower concentrations of nitrate and salinity than the receiving groundwater aquifer, while other sources (like some agricultural return flows and wastewater discharges) may have higher concentrations of nitrates and salinity. The main sources of recharge and their expected effect on the groundwater quality are discussed below.

8.1.1 Natural Recharge

For purposes of this report, natural recharge is percolation from rainfall on areas with native vegetation. Percolation from rainfall in cropped and urban areas is discussed in other categories below. In addition to precipitation and evapotranspiration (**ET**), natural recharge is also a function of how much water is stored in near-surface soils temporarily and later returned to the atmosphere via transpiration or through bare soil evaporation.

8.1.2 Agricultural Return Flow

Agricultural return flow is the water that runs off crop land and/or percolates past the root zone when more irrigation water is applied than the crop needs, or that the root zone can absorb or hold. Agricultural return flow results from applied irrigation water and precipitation in excess of the soil root zone water holding capacity and ET requirements of the crop. Return flows consist of the excess water that either percolates directly beneath the field or runs off and percolates in nearby areas When percolated water passes through the vadose zone and reaches the water table, it is considered groundwater. Because some groundwater can be “perched” on shallow clay layers, and variations in aquifer stratigraphy can confine and/or change flow directions, it is important to consider the particular groundwater zone that return flows encounter. The hydrogeology of the study area is discussed in **Section 5**. The water requirements of individual crops and the associated irrigation methods and efficiencies, result in a range of potential recharge rates from agricultural return flows.

8.1.3 Municipal Return Flow

Municipal return flow results from precipitation and water applied to the ground surface in municipal settings that exceeds evaporation, consumptive use, and root zone water holding capacity. It may also result from percolation from stormwater detention basins or water that flows through pavements. Demands are typically associated with urban and suburban irrigation or recreational uses. The major municipal purveyors in the KRWCA area include the City of Bakersfield, Cal Water, and other smaller purveyors, including but not limited to, the City of Shafter, City of Wasco, City of Delano, City of McFarland, Vaughn Water Company, Greenfield County Water District, West Kern Water District, Buttonwillow County Water District, Oildale Mutual Water Company, North of the River Municipal Water District, Stockdale Mutual Water Company, East Niles Community Services District, City of Arvin, and Lamont Community Services District.

8.1.4 Wastewater

Treated wastewater from wastewater treatment plants (**WWTPs**) within the KRWCA area is generally used for irrigation. When irrigation demands are low in the winter, effluent may be discharged to onsite ponds for storage, and/or evaporation and percolation, depending on permit conditions. These WWTPs are regulated by Central Valley Regional Water Quality Control Board (**CVRWQCB**) individual waste discharge requirements (**WDRs**) to control potential impacts to groundwater. Several WWTPs serve the metro Bakersfield area. Some of the WWTPs within the KRWCA area include the City of Bakersfield WWTP No. 2, City of Bakersfield WWTP No. 3, North of the River Sanitary District No. 1 WWTP, Kern Sanitation Authority WWTP, Lamont PUD, and the Shafter-Minter Field WWTP. Other cities and communities in KRWCA also have WWTPs with WDRs.

Some developed lands in the KRWCA utilize septic tanks with leach lines (septic systems). Recharge occurs from the septic systems.

Wastewater from food processors, confined animal operations, and other industries is also often used for irrigation, and contributes to recharge. In some cases, food processing wastewater flows to wastewater treatment plants. The CVRWQCB regulates wastewater discharges from these industries to control groundwater quality impacts.

8.1.5 Managed Recharge and Canal Seepage

Managed recharge and banking is performed in the area by multiple water agencies through various mechanisms, including canal seepage as water is conveyed, recharge ponds, and seepage from reservoirs. In-lieu recharge activities by displacing groundwater use with surface water is not evaluated in this section. For the purposes of this evaluation, no distinction is made between managed recharge conducted by water agencies and others to increase groundwater in storage for general resources improvement in the study area, and more formal banking projects where water is recharged for storage on behalf of an outside party for later recovery and use outside of the project area. Managed recharge associated with both of these practices is often accomplished in recharge or percolation ponds. As many of the canals and the Kern River used to transport water in the area are unlined, seepage from these canals is also used as a component of managed recharge. Seepage from lined canals, smaller water conveyance facilities (ditches and pipelines) also occurs and contributes to recharge. Local streams are also sometimes used for recharge. The water used in managed recharge comes either from

the Kern River, local streams, or from imported surface water conveyed through the State Water Project and Central Valley Project. These water supplies are generally of high quality, and managed recharge is considered to have an overall positive benefit to groundwater quality in the KRWCA area.

8.2 Significant Recharge Areas and Rates

8.2.1 Natural Recharge

Natural recharge is a function of precipitation, ET, and soil moisture holding capacity, as noted above. Precipitation and ET records for the primary KRWCA area are available from the California Irrigation Management Information System (**CIMIS**) Station. Average annual precipitation from the Shafter Station (No. 5) is 6.3 inches, which is relatively low compared to an annual potential evapotranspiration (**ET**) of 57 inches. As a consequence, deep percolation of precipitation past the root zone occurs infrequently or not at all. A daily soil moisture balance was completed for the Kern Fan (Todd, 2012) using the Thornthwaite and Mather method (1955 and 1957). This soil moisture balance showed that precipitation is generally consumed by evapotranspiration within a few days of a rainfall event, and there is no excess available water for recharge to groundwater.

In the secondary area where precipitation volumes are higher and evapotranspiration is generally lower, natural recharge is likely the primary source of recharge to groundwater. However, precipitation and runoff varies greatly, estimates of ET from vegetation are more difficult (due to the wide variety of vegetation and little research to support estimates), and there is little unconsolidated material in this area, as indicated in **Section 5**. The variations in precipitation and runoff, difficulty of estimating ET, limited extent of unconsolidated material, and predominance of fractured bedrock groundwater makes estimation of natural recharge in these areas infeasible.

8.2.2 Agricultural Return Flow

Return flows vary geographically with changes in crop type, soil type, and irrigation practices. A partial evaluation of these components for major crops was completed for the KRWCA primary area by New Fields Agricultural and Environmental Resources (Kimmelshue and Tillman 2013). These estimates considered all of the factors related to applied water for the major crops; including irrigation efficiencies in varying soil types, and the water required for cultural practices such as leaching of accumulated salts from the soil. Applied water estimates were prepared by Kimmelshue and Tillman (2013) for select crops by soil region and crop and irrigation system type. These estimates indicated a range of applied water rates from 2.7 acre-feet per year per acre (**AFY/ac**) for grapes in the foothills and 5.1 AFY/ac for alfalfa in the Kern Fan area. Kimmelshue and Tillman (2013) found that irrigation efficiency ranges from 75 to 95 percent over the KRWCA primary area, and that rates are generally higher in the foothills and southern Kern Fan. Return flow rates vary from 0.16 AFY/ac for grapes in the foothills to 1.23 AFY/ac for corn and wheat in the Kern Fan area.

The Kern County Water Agency (**KCWA**) estimates total agricultural return flow in Water Supply Reports as part of the hydrologic accounting of the Kern County Subbasin (KCWA 2002 through 2011). These estimates indicate that total agricultural return flows to the Kern County Subbasin range between 378,000 acre-feet per year (**AFY**) to 753,000 AFY.

8.2.3 Municipal Return Flow

Municipal return flows, landscape irrigation runoff, deep percolation, stormwater runoff and recharge occur mainly in urban areas and are limited in volume. Based on estimates in the Bakersfield area, 50 to 70 percent of municipal supply is used outdoors in some capacity. In addition storm water runoff from precipitation flows into unlined sumps that allow water to percolate to the groundwater. A reasonable assumption is that 12 percent of the outdoor use recharges the aquifer as return flow. In Bakersfield (the city and Cal Water systems combined), the estimated return flow over the period from 2006 through 2010 was 9,100 AFY over a combined service area of 65,587 acres, or 0.14 AFY/ac. While detailed data was not available from other water systems, the remaining communities in the KRWCA area are expected to have a similar rate of return flow.

8.2.4 Wastewater

Available information regarding the volumes discharged to WWTP disposal ponds is limited. However, the City of Bakersfield indicates that WWTP No. 3 and North of the River Service District WWTP No. 1 discharge 3,000 AFY to 7,200 AFY per plant into effluent ponds. Additional wastewater is used as an irrigation water source in other parts of the County. Treated wastewater is regulated by the CVRWQCB under specific wastewater discharge permits. Recharge from septic systems is significant in KRWCA, but is not measured or estimated.

Recharge from wastewater generated by food processing, confined animal facilities, and other industries may also result in high volumes of water for disposal. Because a high percentage of that wastewater is used for irrigation of crops, it is important not to double-count it in water balances.

8.2.5 Managed Recharge and Seepage

The rate of recharge for managed recharge projects and the recharge associated with seepage vary annually depending on hydrology. In normal and wet years, recharge and banking occur in large amounts, and more water is transported and recharged through canal, river, and stream flow. In dry years, banking generally does not occur, and recharge in canals, river, and streams are limited as well due to reduced duration and amounts of flows being conveyed. Because of the variability of rate and location, managed recharge and seepage is examined in detail in **Section 8.3**.

8.3 Groundwater Recharge Projects

There are a number of groundwater recharge projects in the KRWCA area. They range from agencies with one or two ponds used to recharge surplus water to large operations that bank and recover water on behalf of outside parties. The recharge facilities associated with these projects are shown on **Figure 8-1**. Agencies and major projects actively recharging groundwater within the KRWCA primary and secondary areas include:

- Arvin-Edison Water Storage District;
- Buena Vista Water District;
- The City of Bakersfield;
- Kern County Water Agency – Pioneer, Berrenda Mesa, and Kern River Banking;

- Kern Delta Water District;
- Kern Water Bank Authority;
- North Kern Water Storage District;
- Rosedale Rio Bravo Water Storage District;
- Semitropic Water Storage District;
- West Kern Water District;
- Golden Hills Community Services District; and,
- Tehachapi Cummings County Water District.

Estimates of recharged water by agency and major project in the primary Central Valley portion of KRWCA for the period of 2006 through 2010 are shown in **Table 8-1**. These are the most recent available managed recharge data. The largest recharge project is the Kern Water Bank (**KWB**), which recharged an average of 66,618 AFY during this time period. Even this large project has a large range of annual recharge, with a maximum recharge volume of 283,233 AFY in 2006 and no recharge occurring in the dry years of 2008 and 2009. The average rate of recharge for managed recharge was 37 AFY/ac, but the actual rate of recharge is variable over time and project, ranging from 0 AFY/ac in most projects in 2008 to 180.1 AFY/ac in 2006 for the Kern Delta Water District recharge ponds.

Canal, stream, and river seepage results in significant recharge to the aquifer, and this source of recharge is generally considered to be a managed recharge source, in addition to the projects listed above. The major unlined waterways in the KRWCA area are shown on **Figure 8-1**. The rates of loss to recharge from these waterways are dependent on the length of the canal and the total loss observed (**Table 8-2**). The highest volume of loss occurs along the Kern River, but the highest rate of loss occurs along the City of Bakersfield Carrier Canal, as shown in **Table 8-2**.

The managed recharge and waterway loss data presented here is from reporting by individual agencies and from the Kern River Hydrographic Annual Reports prepared annually by the City of Bakersfield in cooperation with the Kern River Watermaster (2006 through 2010). In-lieu recharge is a management practice wherein water from an alternative surface water source, that is normally unavailable, is provided to groundwater users to offset pumping. This practice does not actually result in increased recharge to groundwater or offset 100 percent of groundwater use, so it is not considered an actual managed recharge source and is not included in **Table 8-2.**

The managed recharge projects contribute relatively high quality water to groundwater. The exact benefit and extent of this high quality recharge is variable and cannot easily be quantified, but should be considered as an element that could improve water quality when delineating areas of groundwater vulnerability.

8.4 Managed Wetlands

The Kern National Wildlife Refuge (**KNWR**) is an area of restored and preserved wetland habitat that existed historically in the area near the Kern River prior to intense farming. The majority of the water available to the KNWR for wildlife habitat is available in the fall and winter. These habitat areas, including wetlands, are managed by the United States Fish and Wildlife Service (**USFWS**) who uses Central Valley Project refuge supplies for irrigation and ponding. The habitat areas are divided into the following categories:

- Seasonal wetlands: timothy;
- Seasonal wetlands: smartweed;
- Seasonal wetlands: watergrass;
- Permanent wetlands;
- Semi-permanent wetlands;
- Riparian;
- Irrigated pasture;
- Upland; and,
- Seasonal wetlands (no summer water).

The most predominant types of managed wetlands are timothy seasonal wetlands (2,096 acres) and seasonal wetlands with no summer water (3,795 acres) (Todd Engineers, 2012). In 2009, timothy seasonal wetlands had a total delivered water rate of 6,498 AFY and an estimated seepage rate of 1.20 AFY/ac. The seasonal wetlands with no summer water have an average delivered water total of 11,385 AFY and also have a seepage rate of 1.20 AFY/ac. On average, 19,331 AFY of water is delivered to the managed wetlands.

The duration of the flooding depends on type of water supply, with the goal of 5,900 acres being flooded infrequently (1 year in 10), 4,830 acres flooded on an intermediate basis (2 years in 10), and 2,110 acres flooded frequently (5 years in 10).

The geology of these managed wetlands is comprised of an upper layer of clay overlying a lower layer of sandy loam, clay loam, and fine sandy loam. These areas often have a seasonally high water table and have low soil permeability.

The managed wetlands may also receive return flows from agricultural fields in the early water delivery season which may contain high levels of nutrients and salt loading that often cause algal growth in the wetlands. The soils in these areas are also strongly alkaline and in some areas contain high boron. These water quality issues require water quality monitoring and frequent flushing of the wetlands for maintenance, as controlled by USFWS.

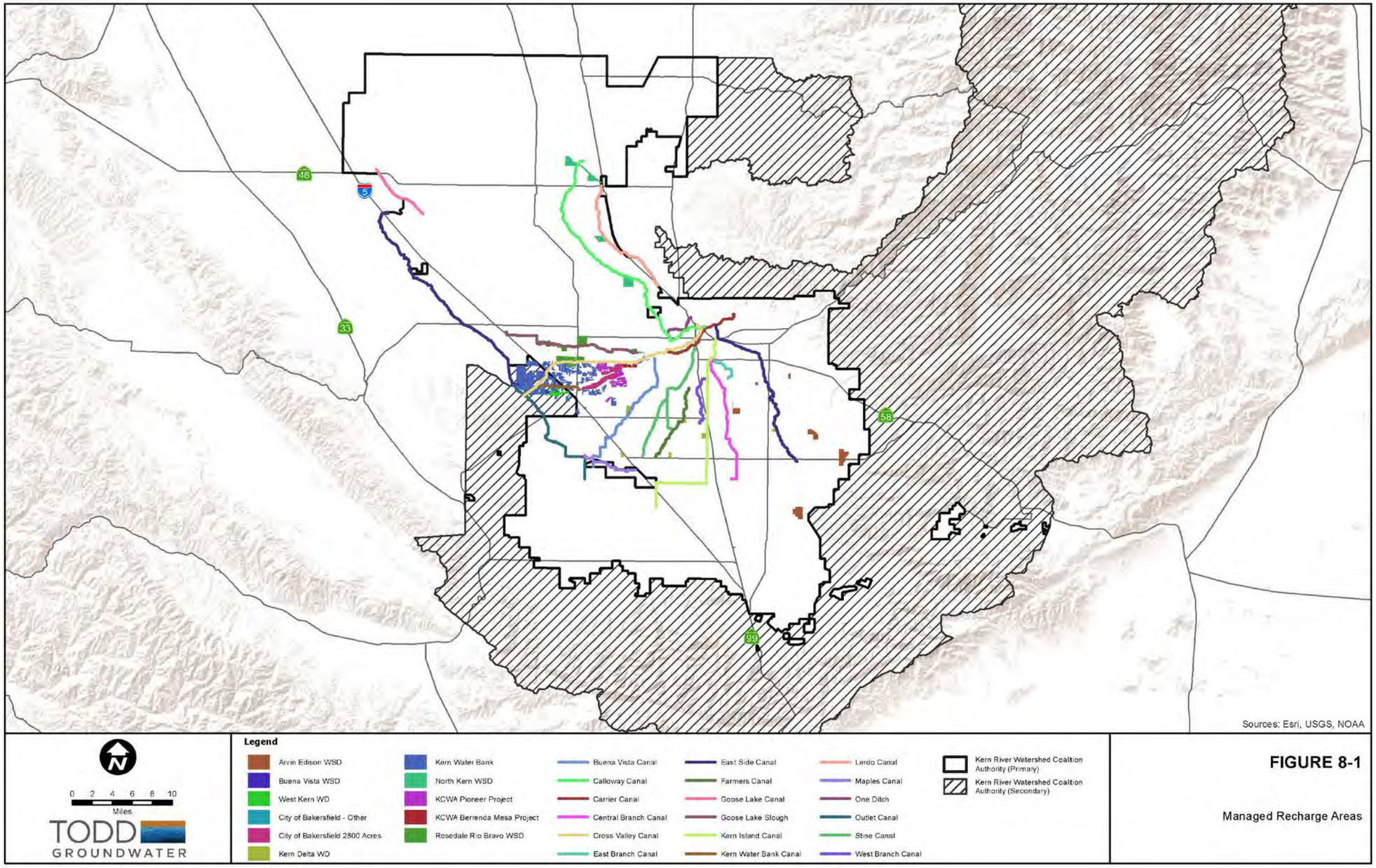


Figure 8-1. Managed Recharge Areas

Table 8-1. Managed Groundwater Recharge in KRWCA

Managed Groundwater Recharge in KRWCA									
Agency	**Project**	**Area (acres)**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average Annual Recharge**	**Average Recharge (AFY/acre)**
Arvin-Edison Water Storage District	Recharge Ponds	2,068	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Buena Vista Water Storage District	Elk Pen	186	28,519	0	0	3,000	25,545	11,413	61
City of Bakersfield	2800 Acres	1,749	81,521	4,495	0	0	7,039	18,611	11
	Other	46	5,174	2,463	1,613	2,097	3,606	2,991	65
Kern County Water Agency	Pioneer	1,259	61,228	4,813	0	0	0	13,208	10
	Berrenda Mesa	210	26,229	2,098	0	0	0	5,665	27
	Kern River Channel	N/A	825	0	0	0	0	165	N/A
Kern Delta Water District	Recharge Ponds	226	40,775	0	0	0	82,363	24,628	109
Kern Water Bank	Kern Water Bank	7,530	283,233	16,728	0	0	33,131	66,618	9
North Kern Water Storage District	Poso Creek and Recharge Ponds	1,892	164,940	30,151	2,487	14,156	27,615	47,870	25
Rosedale Rio-Bravo Water Storage District	Recharge Ponds	2,697	147,151	3,200	0	2,354	141,521	58,845	22
Semitropic Water Storage District	Southern Ponds	N/A	1,019	211	0	0	625	371	N/A
West Kern Water District	Recharge Ponds	529	23,954	3,923	3,318	13,244	26,061	14,100	27

All values in acre-feet per year (AFY), unless otherwise noted.

Table 8-2. Unlined Canal and River Losses to Recharge in KRWCA

Managed Groundwater Recharge in KRWCA									
Agency	**Canal Name**	**Total Canal Length (ft)**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**	**Average Recharge per Mile (AFY/mi)**
Buena Vista Water Storage District	Maples	33,440	1,335	0	0	0	0	267	42
	Main Bypass Canal	223,789	0	191	187	2,286	1,159	765	18
	Outlet Canal	35,626	15,366	8,069	10,579	3,881	12,608	10,101	1,497
	Minor Canals	46,735	12,934	7,710	8,085	11,564	13,868	10,832	1,224
City of Bakersfield	Cross Valley Canal	80,704	0	0	0	383	205	118	8
	KRCI Ditch	19,302	1,685	896	922	890	640	1,007	275
	Carrier Canal	3,088	7,013	5,071	5,510	7,917	6,718	6,446	11,022
Kern Delta Water District	Eastside	48,022	1,580	1,903	3,712	3,345	6,719	3,452	380
	Farmers	125,379	3,912	680	2,565	2,068	6,887	3,222	136
	Buena Vista	125,379	6,921	2,594	4,490	7,032	15,746	7,357	310
	Central Branch	103,307	12,211	12,437	11,314	10,379	16,568	12,582	643
	Kern Island Canal	19,270	17,197	17,515	15,934	14,616	23,332	17,719	4,855
	Stine Canal	72,201	24,276	4,462	11,770	18,640	35,742	18,978	1,388
North Kern Water Storage District	Calloway Canal	138,420	22,592	642	2,166	2,163	23,739	10,260	391
	Lerdo Canal	71,442	1,528	1,039	943	964	1,154	1,126	83
Kern River		124,834	90,728	11,658	10,863	12,244	95,296	44,158	1,868

All values in acre-feet per year (AFY), unless otherwise noted.

9 Data Review and Analysis

9.1 Land Use and Crop Types

9.1.1 Data Review and Analysis

Review of cropped acreage from 1990 through the present indicates that agriculture has expanded within the KRWCA area in general in recent history, but has likely reached its peak because of limited suitable land and water resources. Comparison of crop type distribution from 1990 (oldest spatial crop data on record) with that of 2013 shows that permanent crops have increased greatly in acreage, while cotton in particular has decreased greatly in acreage. Corn has also increased in acreage during this period, likely as the result of an increase in dairies.

Some crop types are concentrated in certain areas, likely because of soil types and microclimates that are suitable for those crops, while others are distributed throughout the KRWCA area. For example, grapes and citrus are concentrated in the northeast and southeast areas of the primary boundary, whereas field crops and alfalfa are distributed throughout the area. No permanent crops are found in the southwest corner of the area (because of soil and flooding limitations), which is dominated by field crops, whereas the northeast corner is dominated by permanent crops such as grapes and almonds, and includes very few field crops.

9.1.2 Limitations, Gaps and Biases

Spatial crop data from the Kern County Agricultural Commissioner is updated annually and is the most current and accurate source of spatial crop data (at the field level) for the Kern River Watershed Coalition Authority (**KRWCA**) area. The main limitation to this dataset is that it is populated when growers apply, obtain, and receive permits to apply pesticides from the California Department of Pesticide Regulation (**DPR**). Growers therefore must estimate the number of acres of each crop to which a pesticide will be applied.

To avoid underestimating and not having enough acres permitted, growers may over-estimate the number of acres of a crop in a particular field. This practice results in higher than actual acreage of some cropped fields digitized in the database, and in turn, overlapping field boundaries. In other words, one field or area of a field may be represented by more than one crop, even though only one crop was grown in the survey year, or in the case of multi-cropped fields, more than the two or three crops that are typically grown in a year. This is likely more prevalent in multi-cropped fields. The resulting crop database does not necessarily make the crop type data any less accurate for the purpose of mapping crops; rather, the crops that are typically grown in a particular field in a rotation of several years are presented. This also provides the potential maximum planted commodity acres for a given year.

Because the crop database is based on DPR permits, some crops may be represented more than others, depending on the number and types of pesticides that are typically applied to them. In addition, organic production may not be completely represented accurately/updated in the crop database if some/any of the pesticides applied to organic crops are not required to be permitted by DPR.

9.2 Soil Characteristics

9.2.1 Data Review and Analysis

Soils within the KRWCA primary boundary can generally be categorized into three types according to texture (fine, medium, and coarse), which are also indicative of other soil characteristics, such as electrical conductivity (**EC**) and pH.

Fine-textured soils (dominated by clay) are found in the southwest and northwest corners of the area. The northwest corner where these soils reside generally does not include irrigated agricultural land. The southwest corner where these clay soils are found comprises the historic Buena Vista and Kern lakebeds, and swamp and overflow lands. These soils are also saline and high in pH in some areas.

The remainder of the primary boundary area includes medium to coarse-textured soils (i.e. loams and sandy loams) which are relatively low in salinity and within the optimal pH range for crop production.

The soils that are high in clay, salinity, and pH require unique agricultural management, including leaching to avoid salt accumulation, but also have a very high saturation percentage because of their fine-textures, which indicates very low leaching potential. Soils that are medium to coarse-textures are more prone to leaching, but are typically used to grow permanent crops that cannot tolerate high saturation, and irrigated with highly efficient irrigation systems such as drip or micro-sprinkler irrigation. Therefore, their resulting leaching potential is relatively low.

9.2.2 Limitations, Gaps and Biases

Soil information for the KRWCA area was obtained from the Natural Resources Conservation Service (**NRCS**) Soil Survey Geographic (**SSURGO**) database. The SSURGO database has the following potential limitations:

i. It is not standardized, i.e. the soil survey was completed over many years by many different surveyors, who recorded soil properties according to different protocols; and,
ii. Survey information may be old and need updating. Updating is required because agricultural and other land use practices may change physical and/or chemical characteristics of soil.

Because of limitation in the soil database, the resulting maps showing changes in texture, EC and pH may appear to have anomalies, such as the abrupt line in the southern portion of the KRWCA area that indicates the boundary between two soil survey areas. This is not an indication of missing data; rather different standards and documentation procedures used by surveyors. Boundaries that result from soil surveys rather than natural soil characteristics exemplify the limitation of using SSURGO data to map large landscapes; they are not evident at the field scale.

The soil surveys for Kern County (northeast, northwest, southeast, and southwest parts) have all been recently updated. The northwest and southeast surveys are current, the northeast survey was updated in 2007, and the southwest survey was updated in 2009. Therefore, the data from these surveys likely reflects current/recent land use and changes resulting from agricultural and other practices.

9.3 Irrigation and Agricultural Management Practices

9.3.1 Data Review and Analysis

Figure 9-1 shows the percentage of cropped land that is irrigated by each irrigation system type. The most common irrigation type is drip or micro-sprinkler, which is typically the most efficient and most uniform irrigation application method. It typically uses the least water of the represented irrigation systems, and is common because it may reduce water usage and therefore water costs. Surface irrigation is typically the least efficient irrigation method, but it can be relatively efficient and uniform if it is optimally designed or used in conjunction with conducive soils and/or field slopes. Other management practices such as surge flow, higher flow rates, torpedoes, and tailwater return systems can also improve surface water irrigation system efficiency.

As the irrigation map in **Section 4** shows, surface irrigation is used where other types of irrigation are not suitable and not necessarily more efficient; and therefore would not represent cost savings. Sprinkler irrigation systems follow closely in percent coverage behind surface irrigation, and may be used in combination with surface or drip irrigation as supplemental irrigation. The sprinkler/surface category represents areas where both sprinkler and surface are used (sometimes on the same field), but there was no spatial information to determine where each was used individually.

Drip/micro irrigation is commonly associated with permanent crops, especially if they are recently planted. Surface irrigation is typically used on row and field crops, while sprinkler irrigation is commonly used on vegetables and some row and field crops such as alfalfa.

9.3.2 Limitations, Gaps and Biases

The quality and completeness of irrigation data depended on the type of records kept by each irrigation district from which irrigation data was obtained. For this reason, irrigation data in many forms were used, and was not consistent. In cases where incomplete or no spatial datasets were available, anecdotal information and/or 2006 California Department of Water Resources (**DWR**) land use survey information was used. In very few cases (63 fields out of over 17,000 fields, less than 1 percent) no irrigation information was available because both the field was not irrigated in 2006 when the last DWR survey was done, and current irrigation information was not available. For these 63 fields, field evaluations of current irrigation system types were conducted to obtain a full irrigation type dataset for the KRWCA primary area.

County scale fertilizer use and cropland data indicate that nitrogen fertilizer application has remained at approximately 68 pounds per acre (**lb/ac**) for the last 25 years. Fertilizer use on a county scale from sales data is limited because: i) it depends on accurate reporting and may not be complete; and, ii) it does not necessarily account for organic fertilizers other than manure.

Fertilizer practices associated with crops are generalized, and do not reflect the wide diversity in fertilizer use and application practices within an area such as KRWCA with a large variety of crops. The “representative rate” is a simple average of the recommended rate, and an average applied amount of nitrogen reported by a relatively small survey of growers. The crop specific fertilizer use data is presented in this report as the most recent data available and as a matter of interest. But as noted in its source, it may be incomplete and only account for some crops.

9.4 Hydrogeology

9.4.1 Data Review and Analysis

Aquifer parameters include hydraulic conductivity (both vertical and horizontal) and storage coefficients. Together, these parameters combined with groundwater usage (pumping) and recharge control groundwater flow and elevations. For the purposes of developing prioritization of the sensitive areas, aquifer parameters from the United States Geological Survey (**USGS**) Central Valley Hydrologic Model (**CVHM**) were evaluated (Faunt, 2009). The CVHM was developed as a tool to assess water availability in California's Central Valley and includes the Kern County Portion of the San Joaquin Groundwater Basin (DWR, 2006c).

Hydraulic conductivity parameters were distributed to the CVHM using the texture data and geographically specific multipliers for hydraulic conductivity of the coarse and fine-grained fractions. These aquifer parameter values were then modified during model calibration to better match local groundwater elevation observations. The calibrated CVHM includes horizontal and vertical hydraulic conductivity values for every cell in the model (i.e. every active mile-square cell in every layer).

9.4.2 Limitations, Gaps and Biases

There is limited direct measurement of aquifer parameters in the primary or secondary area of the KRWCA. While the CVHM provides estimates of these parameters, the actual hydraulic conductivity values may vary from this interpretation. The CVHM is not well calibrated in the Kern County Subbasin and unreliable datasets may have complicated calibration.

However, the CVHM does provide estimates of these parameters covering the entire primary KRWCA area. The CVHM does not extend to the secondary area, and no estimates of aquifer parameters are available in that area.

9.5 Groundwater Hydrology

9.5.1 Data Review and Analysis

Groundwater levels were used to identify the unsaturated zone thickness and areas with relatively shallow depth to groundwater. Groundwater level measurements have been collected in the primary portion of the KRWCA area for many decades by multiple parties, including the large scale long term monitoring programs of the California DWR, USGS, and Kern County Water Agency (**KCWA**). In addition to collecting data, KCWA prepares annual depth to groundwater and groundwater elevation contour maps. There is one annual spring map showing depth to groundwater in the unconfined aquifer throughout the Kern County Subbasin (**Figure 7-1** and **Figure 7-3**, respectively), another showing depth to water in shallow groundwater areas (**Figure 7-2** and **Figure 7-4**) where water is present at less than 20 feet below ground surface (**bgs**), and a third showing groundwater elevation contours (**Figure 7-5** and **Figure 7-6**). These datasets were used to estimate groundwater elevation changes in dry and wet periods, and groundwater flow patterns within the KRWCA primary area.

9.5.2 Limitations, Gaps and Biases

Groundwater levels are collected from wells that were generally not designed for groundwater monitoring purposes. As a result, these are often active production wells that are completed to variable depths and perforated in multiple groundwater aquifer zones. In addition, the construction details of most of these wells are unknown. As a result, it is unclear what hydrogeologic units the measured groundwater elevations represent. Therefore, KCWA generally assumes that groundwater elevations represent the unconfined regional aquifer. In addition, KCWA only produces maps for spring conditions and does not contour water levels during other seasons (i.e. fall). However, since groundwater levels were used to evaluate maximum groundwater elevation conditions, changes in groundwater elevations, and relative flow patterns, the regional aquifer spring maps are appropriate for illustrative purposes. This is due to the fact that spring measurements are usually indicative of the highest groundwater elevations, or lowest depth to groundwater, and are prior to the peak irrigation season.

The available groundwater elevation monitoring data does not include the KRWCA secondary area. Therefore, information regarding groundwater elevations and flow directions in this portion of the KRWCA area is not available.

9.6 Groundwater Quality

9.6.1 Data Review and Analysis

Groundwater quality data was used to identify areas that are impacted by concentrations of nitrate, total dissolved solids (**TDS**), and pesticides that exceed the respective maximum contaminant levels (**MCLs**). The data for these constituents was compiled from the following sources:

- State Water Resources Control Board Division of Drinking Water [**SWRCB-DDW**, formerly California Department of Public Health (**CDPH**)] [through the Groundwater Ambient Monitoring & Assessment Program (**GAMA**)];
- CDPH Archived Data;
- DWR;
- Cleanup Sites (EDF) (through the GAMA program);
- KCWA;
- DPR CDPH (through the GAMA program);
- USGS (through the GAMA program); and,
- Central Valley Regional Water Quality Control Board (**CVRWQCB**) Waste Discharge Requirements General Order for Existing Milk Cow Dairies (Order R5-2013-0122) Data.

The resulting database included over 145,000 records for the three constituents of focus from over 6,700 locations. These groundwater quality data represent available results from 1909 through 2014, spanning historical agricultural practices throughout the past century in the KRWCA.

One of the earliest, most comprehensive assessments of nitrates in the San Joaquin Valley that we have found was published by DWR and was based on data collected by the Department's Ground Water Quality Data Program and cooperating agencies from 1950 through September 1969 (DWR, 1970). One of the findings was that nitrate concentrations in ground waters in some areas appear to be correlated

to man's activities, while in other areas there is no apparent correlation to man's activities. The most significant areas of high nitrates were observed on the east side of the valley floor and in the vicinity of Kern and Buena Vista Lake Beds. Some of the natural sources of nitrate noted in the report include weathering granite, shales rich in organic matter, underground peat deposits, and oil field brines and connate waters.

The 1970 DWR report plotted maximum nitrate concentrations found by section in Kern County, from 1950-1969. This data was digitized and compared to the nitrate exceedance data aggregated to CVHM grid cells, used for the purposes of vulnerability designation in this Groundwater Quality Assessment Report (**GAR**), as described in **Section 6** (**Figure 9-2**). Much of the nitrate exceedance area indicated by all of the historical data presented in **Section 6** was already in exceedance as of the period of 1950-1969. Many of these historical nitrate exceedances or legacy impacts found throughout the eastern rim and southwestern portion of the KRWCA primary area are notably also presented in the historical DWR data.

Table 9-1 specifies the total square mile cells and gross acres of identified nitrate impacts in the KRWCA primary area for the GAR nitrate exceedance and DWR 1950-1969 data, as well as the intersection of these two datasets. Note that the orientation of the square mile cells used in the DWR nitrate study does not match the CVHM cell orientation, so an overlay or intersect analysis has limited spatial comparability. 178 (out of 339 total) GAR nitrate exceedance cells intersected DWR 1950-1969 cells in the primary area.

As irrigated agriculture began in the late 19th century and regional travel times range from decades to centuries today, it is plausible to deduce that the impacts recorded in the 1970 DWR report may be the result of early, inefficient, agricultural practices and/or natural sources. The greater extent of nitrate impacts noted in the GAR analysis may also be partly attributed to travel time, such that impacts reached groundwater after the 1950-1969 data collection effort, or from more data collected over a larger sample area after 1969.

9.6.2 Limitations, Gaps and Biases

Accurate locations for wells associated with available groundwater quality data are not available for all sources. Location information for wells associated with the SWRCB-DDW, KCWA, DWR, and DPR groundwater quality data are available only as approximations based on rectangular grids, as a means of protecting public water supply systems. As a result, there may be some inaccuracy associated with well locations used for the analyses that used these data. Some of the available groundwater quality data was associated with wells for which location information was not available at all; these data were not included in the analyses presented.

Figure 9-3 presents an overview of publicly available nitrate groundwater quality data coverage in the KRWCA using the USGS CVHM grid. Grid cells that have available nitrate groundwater quality data are colored green; grid cells that have no available nitrate groundwater quality data, but have existing groundwater wells, are colored purple; and, grid cells that have no available nitrate groundwater quality data or known existing groundwater wells are not colored. **Table 9-2** lists the gross acreage and irrigated acreage in the primary KRWCA area that is within each scenario. As shown on **Figure 9-3** and listed in **Table 9-2**, much of the irrigated acreage within the KRWCA primary area has nitrate groundwater quality data coverage (84 percent of irrigated acreage). Approximately 16 percent of the irrigated acreage within the KRWCA primary area does not have nitrate groundwater quality data; however, some of this area may not have wells to sample, such as in the Buena Vista lake basin and

other areas on the west side. Approximately 7 percent of the irrigated acreage is within grid cells with no known groundwater wells and consequently no nitrate data, rendering the nitrate groundwater quality data gaps in these areas impractical to fill. Therefore, approximately 90 percent of the irrigated land within the KRWCA is considered to have nitrate groundwater quality data coverage.

Well construction information is not generally available for the wells for which groundwater quality data are available. As a result, the analyses presented in the groundwater quality section do not include any evaluation of depth or aquifer material associated with groundwater quality results. All groundwater quality data were assumed to represent first encountered groundwater, although the majority of samples are from production wells.

The groundwater quality data could contain biases as wells may be more frequently monitored if they have high concentrations on constituents of concern or if they are in areas that may be impacted by a high concentration source.

9.7 Recharge to Groundwater

9.7.1 Data Review and Analysis

Recharge to groundwater was assessed to evaluate if recharge sources affected vulnerability. Data used in this evaluation was downloaded from the California Irrigation Management Information System (**CIMIS**). Data on return flows for select crops were available from Kimmelshue and Tillman (2013), but the report did not calculate the return flow rates for all of the crops in the area. Municipal return flows were estimated from water use data in the City of Bakersfield.

Sources of data for managed recharge include:

- Kern River Annual Operations Report published by the City of Bakersfield;
- Kern Water Bank (**KWB**);
- KCWA;
- Buena Vista Water Storage District;
- Kern Delta Water District; and,
- West Kern Water District.

9.7.2 Limitations, Gaps and Biases

Assessment of the natural recharge component of recharge relied on one CIMIS station. While precipitation does vary across the KRWCA primary area, it would have limited impact on the assessment. Natural recharge is a negligible source of groundwater, as compared to irrigation and municipal return flows, and managed recharge. As noted, data on return flows for all crops in the study area was not available. A range of values for the most commonly planted crops was presented and was adequate to show the variability associated with this source. Irrigation return flow is incorporated in the Nitrate Groundwater Pollution Hazard Index (**NHI**) and was not separately evaluated in the recharge section.

Data on municipal return flows was limited in spatial area. Estimates derived from the City of Bakersfield were used to illustrate the potential rates in other urban areas.

Finally, the estimated managed recharge was limited by the reported data. Some agencies reported only total recharged volume, but not location; and, most agencies report only physical deliveries of water for recharge and do not incorporate an estimate for evaporative losses. However, as the effect of the managed recharge facilities are treated qualitatively, not quantitatively in this assessment, these limitations would not affect the conclusions.

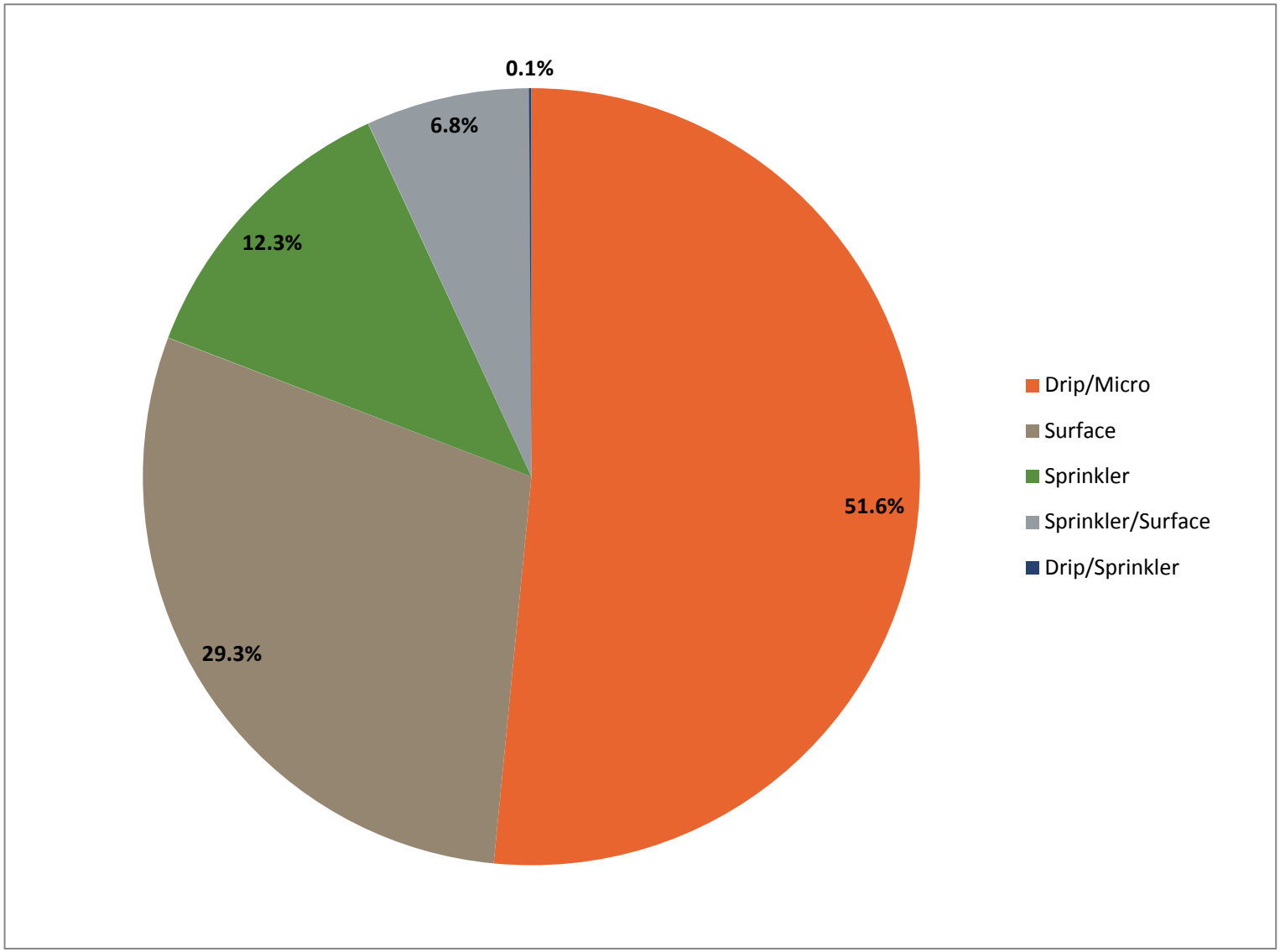


Figure 9-1. Percent of Cropped Land in KRWCA by Irrigation Type

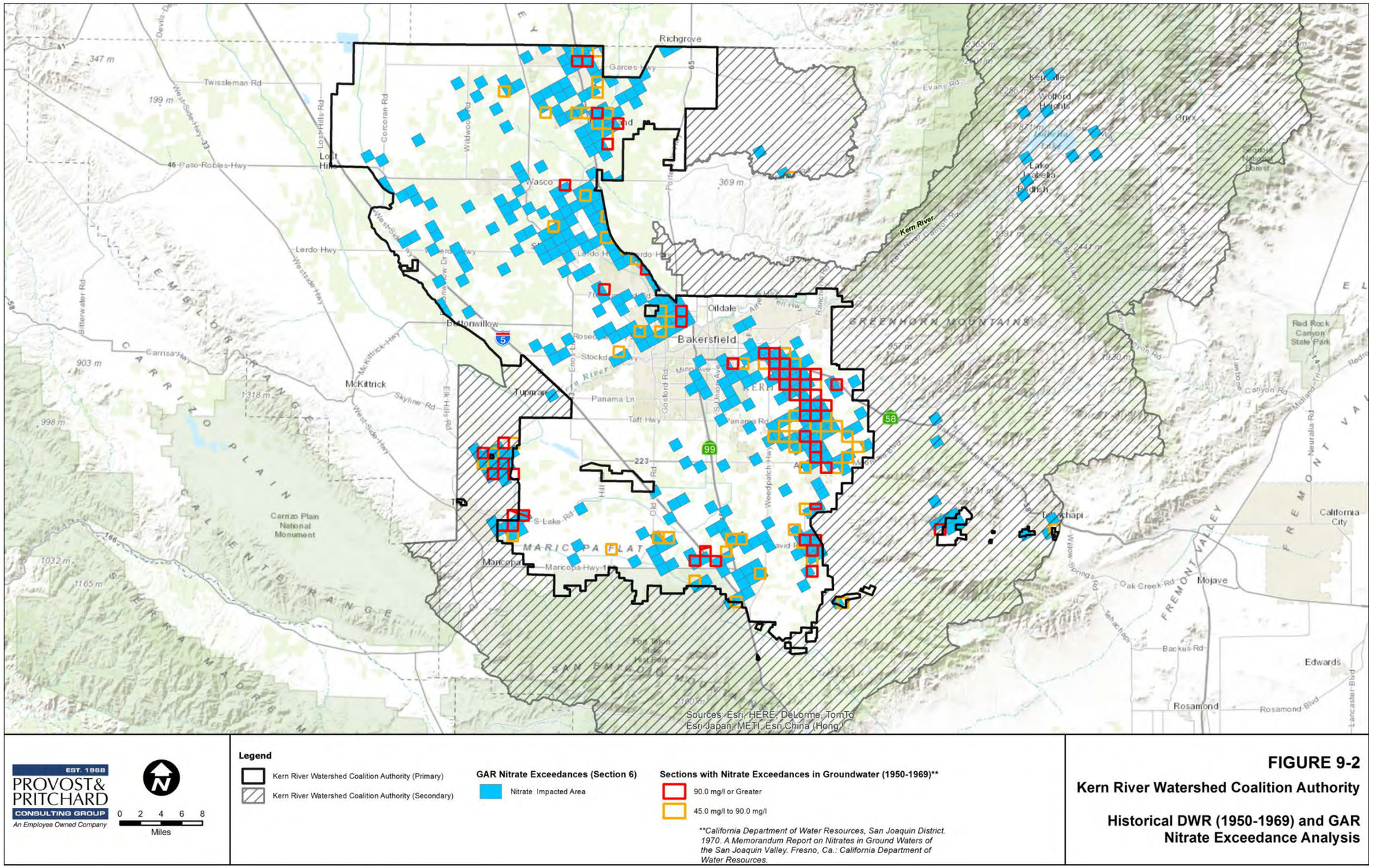


Figure 9-2. Historical DWR (1950 – 1969) and GAR Nitrate Exceedance Analysis

Table 9-1. Historical DWR (1950-1969) and GAR Nitrate Exceedance Analysis

Historical DWR (1950-1969) and GAR Nitrate Exceedance Analysis		
Data Source	**Number of Square Mile Cells Identified as Impacted**	**Identified Impacted Gross Acres (ac)**
CVHM Grid Cell Analysis	351	207,003
DWR Nitrate Report (DWR, 1970)	121	67,131
Intersect*	N/A	50,721

*Intersection of the GAR CVHM Grid Cell Analysis (**Section 6**) and DWR Nitrate Report data sets
CVHM - Central Valley Hydrologic Model
DWR - California Department of Water Resources

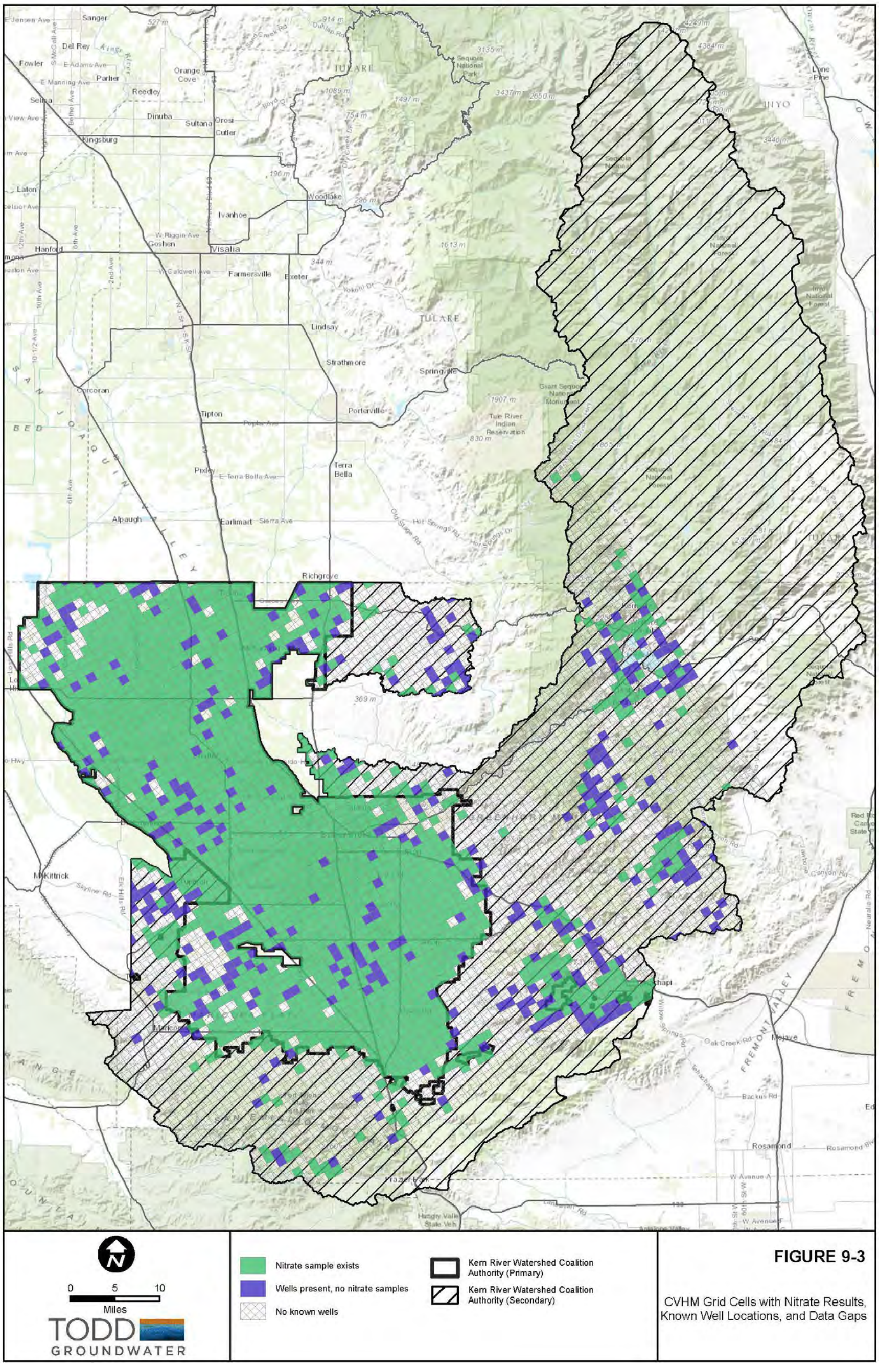


Figure 9-3. CVHM Grid Cells with Nitrate Results, Known Well Locations, and Data Gaps

Table 9-2. KRWCA Primary Boundary Nitrate Groundwater Quality Data Coverage

Nitrate Groundwater Quality Data Coverage			
Groundwater Quality Data Scenario	**Gross Acres (ac)**	**Irrigated Acres (ac)**	**Percent of Irrigated Acres (%)**
CVHM grid cells with nitrate data	824,299	518,628	83.8%
CVHM grid cells with existing wells, no nitrate data	100,908	58,918	9.5%
CVHM grid cells with no nitrate data or existing wells	98,226	41,677	6.7%

10 Groundwater Vulnerability Areas

10.1 Description of Approach

The approach to identify relative groundwater vulnerability for the Kern River Watershed Coalition Authority (**KRWCA**) Groundwater Quality Assessment Report (**GAR**) focused on an evaluation of nitrate leaching risk from the surface of irrigated land in addition to areas previously impacted by concentrations of nitrate and pesticides in excess of contaminant limits. Areas which have a high nitrate leaching risk from the land surface, are designated as a Groundwater Protection Area (**GWPA**) for leaching by the California Department of Pesticide Regulation (**DPR**), or have underlying water quality exceedances, were identified as high vulnerability lands. A description of the groundwater vulnerability analysis methods is provided below.

The assessment of vulnerable areas in this section does not include an intrinsic hydrogeologic component. Hydrogeology is an important factor in the susceptibility of groundwater to contamination. However, there is no combination of hydrogeologic conditions which indicate absolute vulnerability to contamination. The concept of absolute risk of contamination associated with the identification of an area as vulnerable implies a land use that could result in contamination to the subsurface.

Statistical, process based, and overlay and index methodologies for assessing groundwater vulnerability have been employed in many studies in the past (Focazio et al., 2002 and National Research Council, 1993). Statistical and process based methods of assessing groundwater vulnerability can result in identification of vulnerable areas. These methods require the establishment of a probabilistic relationship or transport models linking known groundwater contamination, land uses that likely resulted in the contamination, and the hydrogeology associated with transporting contamination from the source to groundwater. The groundwater quality constituents of concern for the KRWCA GAR are nitrate, pesticides, and total dissolved solids (**TDS**), as discussed in **Section 6**. Of these, nitrate and pesticides are the only constituents that could be used in statistical or process based vulnerability assessments, because TDS is naturally occurring in many locations. However, developing a statistical or process based approach for the KRWCA area would require detailed information regarding the historical locations and rates at which nitrogen fertilizers or pesticides were applied. This task is further complicated by the lack of detailed knowledge of the movement and transformation of said constituents. Given the long history of agriculture in the KRWCA area, it is not appropriate to assume that current conditions and land uses associated with these constituents are representative of past practices. Therefore, it is not possible to establish either statistical relationships between land use, hydrogeology, and groundwater contamination or to construct and calibrate contaminant source and groundwater transport models.

Since the methods for establishing absolute intrinsic hydrogeologic vulnerability are not suitable for implementation in the KRWCA area, this assessment focuses on land use and existing water quality conditions for the identification of vulnerable areas and will use relative hydrogeologic conditions in the prioritization (or tiers) of these vulnerable areas. The prioritization methodologies and results are presented in **Section 11**.

10.2 Groundwater Quality Data Interpretation

Groundwater quality data and analysis in the KRWCA area was presented and discussed in **Section 6**. To identify relative groundwater vulnerability based on water quality, all historical data was used to analyze nitrate and pesticide exceedances. The 45 mg/L nitrate as nitrate maximum contaminant level (**MCL**) was used as the basis for identifying nitrate impacted groundwater. Pesticide impacted groundwater in the KRWCA was identified by exceedances of published MCLs for the respective pesticide. As in **Section 6**, the impacted areas were identified using the United States Geologic Survey (**USGS**) Central Valley Hydrogeologic Model (**CVHM**) grid.

TDS was not used as a basis to identify areas of vulnerable groundwater. TDS in groundwater can originate from various naturally occurring and anthropogenic sources, as described in **Section 6**. The mapped areas of high TDS in the KRWCA generally correspond to the areas that are also associated with historic lakebed or marine derived sediments (Page, 1986; Wood and Dale, 1964; Wood and Davis, 1959 and DWR, 2006a). Naturally occurring salinity in groundwater is often associated with marine derived sediments, lacustrine (lakebed) deposits and swamp/overflow lands, and margins of alluvial fans. This is due to the general predominance of higher salts in parent material and/or fine grained material in these sediments that cause longer groundwater residence times and more evaporative concentration from lower permeabilities and historically more saturated conditions near the ground surface. These conditions result in more dissolution and concentration of TDS in the related groundwater. There is a long history of high TDS groundwater conditions in these areas that is likely the result of these conditions (Wood and Dale, 1964). No assessment of the source of this historically high TDS has been completed to date. It is possible to distinguish between naturally occurring and anthropogenic sources of TDS in groundwater. However, such assessments require detailed geochemical information that is not available at this time.

10.2.1 Areas Exceeding Water Quality Objectives (WQO)

Areas identified as exceeding nitrate and pesticide water quality objectives (**WQO**) to determine relative groundwater vulnerability are presented on **Figure 10-1**. Grid cells colored orange represent nitrate MCL exceedances, grid cells colored yellow represent pesticide MCL exceedances, and grid cells colored blue represent both nitrate and pesticide MCL exceedances. 132,232 irrigated acres are identified as impacted groundwater based on water quality data. The irrigated acreage impacted by nitrates, pesticides, or both nitrate and pesticide exceedances is shown comparatively on **Figure 10-2**. Of the 132,232 irrigated acres, 91 percent of the area is due to just nitrate exceedances, 3 percent is due to just pesticide exceedances, and 6 percent is due to both nitrate and pesticide exceedances.

10.3 Nitrate Leaching Risk Method Selection

10.3.1 Approach/Method Alternatives

While constituent (nitrate) characteristics cannot be changed, nitrate loading is determined by the concentration of nitrate and the amount of water passing below the root zone, which is influenced by agricultural systems and their management. Ideally an assessment of groundwater vulnerability should include an analysis of the factors contributing to the risk of nitrate leaching to groundwater from the agricultural characteristics that constitute the potential source.

Because it is not commonly known precisely how much water is applied to agricultural fields in California (SWRCB-AEP, 2014), and because it is very difficult to measure with certainty the amount of water that passes through the root zone and the corresponding nitrate concentration (Letey, 2013); it is not feasible at this time to use direct measurements to determine nitrate loading – the aspect of groundwater vulnerability that is of concern. Therefore, the best way to address the nitrate loading aspect of vulnerability without specific and measurable information is to evaluate the potential of nitrate passing through the root zone using other field-specific factors. This type of assessment not only identifies relative areas of higher leaching risk (acknowledging that there is uncertainty associated with all risk assessments), but also helps to determine which specific factors are contributing the most to nitrate leaching potential. By identifying factors that contribute the most to leaching potential, it becomes apparent which field-specific factors might be better managed.

Nitrate leaching risk can be influenced by management factors that affect nitrate loading such as:

- Optimizing nitrogen fertilizer placement, timing, application rate, and form (including accounting for nitrates in irrigation water);
- Maintaining irrigation systems to ensure optimum efficiency and distribution uniformity;
- Controlling infiltration by adjusting flow rate, furrow length, and duration of irrigations in surface irrigation systems;
- Adjusting timing of fertigation in relation to irrigation duration;
- Monitoring soil moisture using one of many alternatives, such as tensiometers, neutron probes, or soil sampling at dense temporal and/or spatial grids; and,
- Plant tissue moisture monitoring using instruments such as pressure chambers (pressure bombs).

To know which of these management factors improve groundwater protection in a particular scenario, agricultural systems must be identified. Since these systems change with each field, a field-scale analysis of agricultural system factors that influence nitrate leaching potential is necessary.

In numerous approaches to evaluate groundwater vulnerability (reviewed in NRC, 1993; EPA, 1993; Focazio, 2002), the ability to reflect the importance of these key field-specific factors is limited. This is largely because they cannot be quantitatively defined at this time, and approaches using absolute values, such as process simulation models and statistical models, cannot accommodate them. This limitation, among others, is not trivial when agricultural areas are under review for potential groundwater vulnerability. If it is accepted that agricultural systems, because of nitrate discharge below the root zone, are a potential cause of nitrate groundwater vulnerability then management of these agricultural systems (fields) is a modifiable factor that growers and regulatory bodies may use to protect groundwater.

10.3.2 Justification for Selection of Index and Overlay Approach

Seminal documents evaluating groundwater vulnerability assessments (NRC, 1993; EPA, 1993; USGS, 2002) emphasize the importance of considering the objective of the assessment when choosing a method to identify groundwater vulnerability. In this case, it is important to use an assessment methodology that not only considers agricultural systems, but also provides information to growers that can be used to decrease the potential of nitrate discharge to groundwater and increase the protection of groundwater. In groundwater vulnerability assessments used for land use planning or zoning, other

factors rise in importance. But in this case, where all land included in the assessment is already under agricultural production, agricultural systems and their irrigation and nitrogen management become paramount, and should be included in the vulnerability assessment.

As acknowledged by Osborne et al. (1998), tools that determine vulnerability attributed to hydrogeologic properties (such as DRASTIC) can be used with other information (such as land use, potential sources of contamination, and beneficial uses of the aquifer) to identify areas where special attention or protection efforts are warranted. USGS (Focazio, 2002) concludes that combining different vulnerability assessment tools can lead to more robust assessments than those that use only one.

For these reasons, KRWCA has selected a multilayered method to assess groundwater vulnerability that considers groundwater quality as well as agricultural management systems (irrigation, soil, and crop type). The tool used to assess agricultural systems was developed specifically to evaluate nitrate leaching risk in California agricultural systems at a field scale. The rationale for selecting this tool and the background of its development are described in the following section.

10.3.3 Rationale of Selected Methodology

Key agricultural system factors that influence nitrate leaching potential at the land surface in California agriculture, with readily available public information, are: soil type, crop type, and irrigation type (see **Section 10.3.4** for background information). To this end, an assessment of the contribution of soil, crops, and irrigation types to groundwater vulnerability using the Nitrate Groundwater Pollution Hazard Index (**NHI**) is included in the KRWCA groundwater vulnerability assessment. The specific objectives of using the NHI for this purpose are three-fold:

- Conduct an assessment of key agricultural factors contributing to nitrate leaching risk, and therefore to groundwater vulnerability;
- Determine which factors in particular contribute most to groundwater vulnerability, to focus efforts to modify agricultural management practices in effective and efficient ways; and,
- Provide an understandable and practical method of assessment that can educate and incentivize growers over the long-term to maintain and/or modify agricultural practices so that they are protective of groundwater.

The potential for agricultural management practices to significantly influence groundwater quality in California is widely acknowledged and reviewed (SWRCB-AEP, 2014; Nitrogen Tracking and Reporting Task Force, 2014). This correlation was most recently demonstrated in a long-term study called the Woodstock Study; a 10 year investigation of the effects of changing agricultural management practices on nitrate concentrations in groundwater needed for municipal uses (Haslauer et al., 2004; Tracy, 2014). Agricultural nitrogen management was modified on a 300 acre parcel of land situated above 100 foot wells used for drinking water supply. Though crop yields did not decrease, an intensive and multifaceted monitoring program of the soil root zone, vadose zone, and underlying groundwater aquifer using sampling and modeling indicated that groundwater nitrates decreased as a direct result of nitrate management changes. Additionally, the Woodstock Study modeling indicated that it would take 10 years (from the commencement of management changes) for the nitrates in the wells to reach safe drinking water levels from previous levels (a decrease of 20 percent). Though this study provides quantitative data demonstrating the effectiveness of agricultural management practices on

groundwater quality, it also indicates that there is a temporal disconnect related to depth to groundwater and resulting travel times for these effects to take place.

Therefore, the focus on current land surface management in the KRWCA assessment of groundwater vulnerability is intentional and paramount to understanding how groundwater can truly be protected.

10.3.4 Nitrate Groundwater Pollution Hazard Index

The concept underpinning the NHI was developed by the Nutrient Technical Advisory Committee (**Nutrient TAC**), solicited by the State Water Resources Control Board (**SWRCB**) and the California Coastal Commission for technical guidance related to the development and implementation of plans for reducing nonpoint source pollution in agricultural areas, as mandated by the Coastal Zone Act Reauthorization (1990). The Nutrient TAC's goal was to review California's Nonpoint Source Management Program, with the aim to identify water quality problems and to develop creative solutions to these problems. In the Nutrient TAC's report (1994), they state that "*monitoring water discharge below the root zone which migrates to groundwater is almost technically impossible*." They also acknowledged the difficulty in concentration-based water quality criteria, noting that a low concentration of nitrate or other constituents can be achieved by applying large quantities of water resulting in high leaching, thus diluting constituent concentration.

Furthermore, citing a major research program conducted by University of California (Broadbent and Rausch, 1974), they noted that "***Good management practices cannot be differentiated from bad management practices by merely using the nitrate concentration in the water leached beyond the root zone. Controlling nonpoint source pollution can more effectively be accomplished by monitoring management practices than by monitoring water quality."***

The Nutrient TAC's rationale for their recommendations is described as follows:

> *Agricultural operations in California are very diverse. Almost every crop is grown on a variety of soils and under various climatic conditions. Under these conditions, it is very difficult to prescribe management plans which are appropriate for every condition. Furthermore, some agricultural operations and settings create a much higher potential for water degradation than others. It would be unreasonable to impose management practices which may be necessary to protect groundwater under the most hazardous conditions to farmlands in which the hazard is minimal. Thus, the prescribed management should be specific for given crops, soils, and potential groundwater hazards. The recommendations of the Nutrient Management TAC were adopted after considering all of these factors.*

Their recommendation included an assessment to determine the risk of contributing nonpoint source pollution (focusing on nitrate) and to develop a management plan to minimize the contribution to water degradation. The NHI is the outcome of this risk assessment recommendation. The second part of their recommendation was a tool (worksheet) that growers could use to evaluate their current agricultural management practices in relation to the NHI score. The Nutrient TAC recommended that growers whose risk assessment (using the NHI), scored very low would be exempted from further evaluation, and those whose scores were relatively high would use the evaluation tool to help them improve agricultural management practices, with the aim of becoming more protective of groundwater. <u>These recommendations so clearly parallel the objectives of the groundwater vulnerability assessment process, and ultimately the GAR, Management Practices Evaluation Program (**MPEP**), and Long-term</u>

Irrigated Lands Regulatory Program (**ILRP**) in general, that it would be remiss to disregard the effort and recommendations of the Nutrient TAC.

The NHI focuses on the main contributors to nitrate leaching potential that interact on the land use level at the ground surface: soil type, crop type, and irrigation type. This approach is called an overlay and index method because these three datasets (soil, crop, and irrigation system type) are considered in combination to determine the overall nitrate leaching hazard. Each soil, crop and irrigation system type is assigned a hazard value based on its respective potential to leach nitrogen. For the area under evaluation, the corresponding soil, crop and irrigation system type hazard values are multiplied to arrive at an overall NHI score or index, illustrated by the matrix shown on **Figure 10-3**. On **Figure 10-3**, a NHI rating of 3 is outlined in red, and would be the result of a crop with a ranking of 1 (very low leaching potential), a soil ranking of 3 (moderate leaching potential), and an irrigation ranking of 1 (very low leaching potential).

Areas with NHI scores over 20 (highlighted in red) should be considered as areas where improvements (e.g. modified management) could decrease the leaching risk to groundwater. The difference between the scores from 1 to 80 has no linear or quantitative significance (i.e. a score of 60 does not indicate twice as much leaching potential as a score of 30). A score of 60 does, however, indicate a relatively higher potential to leach nitrate compared to a score of 30. The threshold of 20 is used to distinguish between combinations of factors that results in a relatively low leaching potential from those that result in a relatively high leaching potential. The threshold of 20 was developed in the original version of the NHI and applied by researchers that have since validated this methodology in California (Wu et al., 2005; Pettigrove, 2012; Dzurella, 2012). This threshold was selected to distinguish between relatively lower and higher leaching risk because the panel of experts that developed the NHI reasoned that any agricultural system with low-flow, pressurized irrigation should be considered a lower leaching risk. This means that a field with the highest soil and crop hazard values (5 and 4 respectively) but with drip irrigation (hazard value of 1) should be considered in the lower leaching risk category. In other words, individual soil and crop risk variables can be high, however if the driving force of leaching caused by irrigation is not present, then the nitrate leaching risk is low. This is especially true in the Kern Subbasin area where effective precipitation is minimal and irrigation water passing the root zone is the main driving force transporting nitrate to groundwater. Therefore, the value of 20 in the NHI is not an arbitrary threshold, but one that was chosen to reflect the major influence on nitrate leaching, which is volume of applied water. As demonstrated by the studies reference above, the threshold of 20 can be used successfully to distinguish between relative lower and higher nitrate leaching risk.

Some overlay and index methods use very subjective ratings for leaching factors such as high, medium and low, but the hazard values assigned to each soil, crop and irrigation system type in the NHI are numerical values, developed by the independent review of several experts (Plant Nutrient Management Technical Advisory Committee, 1994; Wu, 2005). Though the resulting NHI scores are relative and have little meaning in the absolute values, the numerical scoring approach results in a more suitable method of categorizing the wide range of soils, crops, and irrigation systems used in California agriculture.

This approach was further developed, refined, and validated by Wu et al. (2005). Soil hazard values range from 1 through 5, and were developed using soil series descriptions of 590 soils in the Western USA. Reviewers considered the typical pedon, range in characteristics, drainage, and permeability. A typical soil rating had complete agreement by up to seven independent reviewers. Irrigation system hazard values range from 1 to 4, and were developed considering distribution uniformity in addition to irrigation efficiency. Crop hazard values, ranging from 1 to 4, were developed by evaluating root depth;

ratio of nitrogen in the crop tops to the recommended nitrogen application; fraction of the crop top nitrogen that is removed from the field with the marketed product; magnitude of the peak nitrogen uptake rate; and whether the crop is harvested at a time when nitrogen uptake rate is high.

The rationale for using the NHI in the KRWCA groundwater vulnerability assessment is outlined by some of its important advantageous characteristics:

- It is an overlay and index method, the most widely used type of groundwater vulnerability assessment in the USA and around the world (NRC, 1993; EPA, 1993; Focazio, 2002);
- It was developed specifically for California agriculture;
- It reflects the complex nature of nitrogen leaching risk potential, as influenced by numerous soil and crop properties, instead of focusing on one or two properties (such as hydraulic conductivity or rooting depth);
- It can (and should) be modified for regional assessment purposes to optimize its utility when information is available to do so. The scientific literature provides numerous examples of improving overlay and index methods using regional modifications (e.g. Javadi et al., 2011; Neshat et al., 2013);
- It can be conducted with readily available data from Natural Resources Conservation Service (**NRCS**) Soil Survey Geographic data (**SSURGO**) (soil type data); numerous sources of crop and/or land use data, and irrigation/water districts irrigation information;
- It is compatible with GIS approaches;
- It is readily updated and modifiable, especially with the efficiency afforded by a geospatial approach; and,
- It was designed to be conducted at the field scale, the scale at which changes can be made in agricultural production to improve protectiveness of groundwater.

The limitations of the NHI were presented by Dr. Toby O'Geen, Soil Resource Specialist in Cooperative Extension, UC Davis to the Agricultural Expert Panel (May 9, 2014) http://www.itrc.org/swrcb/Presentations/video.htm#Meeting3. These potential shortcomings and how they are addressed in the KRWCA analysis are described in **Table 10-1**.

10.3.5 Application of NHI to KRWCA

As presented in previous sections of this GAR, soil, crop and irrigation type data were collected for each field within the KRWCA primary boundary. This information was supplemented by information from University of California Cooperative Extension (**UCCE**) staff and local growers (Nunez, personal communication; M. Mendes, personal communication, 2014) to make the following assumptions about irrigation system and fertigation use:

- Drip irrigated vegetable crops are fertigated (Nuñez, 2014);
- Sprinkler irrigated vegetable crops are fertigated (Nuñez, 2014); and,

- Permanent crops on drip/microspray are fertigated.

The hazard values for each crop, soil and irrigation type found within the KRWCA areas were assigned by extracting these values (associated with each soil, crop and irrigation type) from the database found here: http://wrc.ucanr.org/search2.php. Field NHI hazard values for crops, soils, and irrigation types for the KRWCA primary boundary are presented on **Figure 10-4**, **Figure 10-5**, and **Figure 10-6**, respectively.

10.3.5.1 Adaptation of NHI and Other Overlay and Index Methods for Regional Application

The NHI was developed specifically for agriculture in the western US states of Nevada, Arizona, and California. Therefore, California soils, crops, and irrigation methods are largely accounted for in the original format of the methodology. Overlay and index methods are modified when users have reason to believe that the original formats do not capture regional conditions and/or practices. However, these methods are used in their original format if the users believe that the original format reflects the regional conditions and/or practices well. For example, DRASTIC, a commonly used overlay and index method, has been used both in its original format and in modified formats to achieve satisfactory results (i.e. NRC, 1993; Jasem and Alraggad, 2010). In previous applications of NHI in California, some adjustments have been made for dual-irrigation systems (Dzurella et al., 2012) such as vegetable crop systems that are started on sprinkler but switch to drip for most of the season. These types of refinements will be possible with more detailed information on irrigation practices and can be addressed in the next GAR update, if warranted. During this iteration, one additional irrigation hazard value resulted from averaging sprinkler and surface irrigation hazard values on vegetables, where spatial information was not available to determine which fields are irrigated with each method. Limitations of the NHI that could warrant general refinement include the following:

- In the NHI crop hazard ratings, cabbage, broccoli and cauliflower are all rated hazard 4 (the highest hazard value for crops), but recent research (Smith, Hartz, Cahn, , 2013) shows that nitrogen (**N**) leaching below these crops is likely minimal partly because of deep rooting. New findings may provide rationale for adjusting the crop hazard value of these crops.
- NHI input options do not include:
  - Use of urease, nitrification inhibitors, etc;
  - Fertigation with surface irrigation;
  - Split applications versus large one-time applications of N fertilizer; and
  - Actual water and N fertilizer applied.
- NHI doesn't capture the potential of surface and sprinkler irrigation to be very efficient and/or uniform when designed, maintained and operated optimally. It only considers average or typical efficiencies.

During the 5 year GAR update, these limitations will be considered again and new information may provide justification for further refinements. At this time, the NHI has not been modified for application in KRWCA for the following reasons:

- The scope and timeframe of the GAR dictated by the General Order cannot accommodate these specific adaptations during the first iteration of the GAR;
- There was no obvious reason to believe that the NHI did not capture the soil, crop, and irrigation conditions in KRWCA; and,
- The NHI results for each crop system were reasonably relative to each other within KRWCA.

At this time, the KRWCA does not have any more refined information on which to base further adaptations of the NHI methodology.

10.3.6 NHI Results

The NHI results indicate that the majority of irrigated land (83 percent) within KRWCA falls into the lower nitrogen leaching risk category (**Figure 10-7**), largely either because of highly efficient and/or uniform irrigation systems used on deep-rooted crops, or irrigation systems with typically lower efficiency and/or uniformity used on fine-textured soils (that have low hydraulic conductivity). Examples of low nitrate leaching risk cropping scenarios include almonds irrigated with drip irrigation on medium-textured soils, and cotton irrigated with surface irrigation on historic lakebed clay soils, respectively.

10.3.6.1 Crop Systems with Relatively Higher Nitrate Leaching Risk

The KRWCA NHI results indicate that certain crop systems consistently fell into the higher nitrate leaching risk category. The following key cropping scenarios are examples of the agricultural systems that may be considered higher risk in the finalized NHI categorization (in order of acreage):

i. Silage corn on sprinkler or surface irrigation on medium to coarse-textured soils;
ii. Field crops (wheat) with surface irrigation on medium or light-textured soils;
iii. Potato on sprinkler or surface irrigation; and,
iv. Vegetables.

These crop systems are scattered throughout both northern and southern portions of KRWCA, but are concentrated in the Kern fan soils south of Bakersfield and the central and southern regions of the area northwest of Bakersfield. Silage corn and field crops are primarily grown in these latter areas, whereas potatoes and vegetables are primarily grown in the area south of Bakersfield.

10.3.6.1.1 Silage Corn on Sprinkler or Surface Irrigation

Silage corn accounts for over 34,000 acres of commodity acreage in the KRWCA area. Silage corn is irrigated with high-volume irrigation systems because it has a relatively high water crop usage and is a relatively low economic value crop. Silage corn that is grown on fine-textured soils ranks in the lower category of risk using the NHI.

10.3.6.1.2 Field Crops on Surface Irrigation and Medium to Coarse-textured Soils

According to the 2013 spatial crop database, field crops are one of KRWCA's major crop types and make up 16 percent of all crops. Wheat alone accounted for approximately 9 percent of all crops, or 78,700 commodity acres. Other field crops are small in acreage by comparison. Comparing the crop map with the irrigation map and the NHI results, it is evident that most field crops (the majority of which is wheat) are grown on coarse or medium-textured soils with surface or sprinkler irrigation. Wheat grown on fine-textured soils has a lower nitrate leaching risk, whereas wheat grown on medium and coarse-textured soils, especially coupled with surface irrigation, has a relatively greater risk of leaching nitrate.

10.3.6.1.3 Potato on Sprinkler Irrigation

Potatoes grow well on sandy (coarse-textured) soils and are typically irrigated with sprinklers. At least 20,000 commodity acres of potatoes are grown in KRWCA; some are in crop rotations with other field

crops or vegetable crops. The combination of relatively high rankings for all three NHI factors – soil, crop, and irrigation – places potato production in the higher risk category for nitrate leaching.

10.3.6.1.4 Vegetables

Vegetables in KRWCA are typically grown on medium or coarse-textured soils with sprinkler or surface irrigation, or with both sprinkler and drip irrigation. Truck crops (vegetables, melons and berries) in general represent one of the main crops in KRWCA, comprising about 160,000 commodity acres excluding carrots, another important vegetable crop. Vegetables typically grow better on loams (medium-textured soils) or coarse-textured soils because they require well drained soils. Irrigation systems that are typically more efficient are not suitable for some vegetables. There are agronomic reasons and physical constraints requiring many truck crops to continue to be irrigated with higher volume irrigation systems. For example, drip irrigation trials have not been successful on carrots, so they are still largely irrigated with sprinkler irrigation (Nuñez et al. 2008).

Some vegetable crops have a lower risk for leaching because of how they are irrigated, such as asparagus and tomatoes, which are typically drip irrigated; or because of their low crop ranking, such as sweet potatoes and carrots. Berries have low NHI values for both crop and irrigation rankings because of their nitrate requirements and because they are typically drip irrigated. Leafy greens and some crucifers (broccoli and cauliflower) have the highest crop ranking partly because of their shallow root zone, and unless they are drip irrigated, score in the higher range of risk. These are often grown in rotation with one another or with other vegetables.

10.3.6.2 Crop Systems with Relatively Lower Nitrate Leaching Risk

Crops that have relatively low nitrate leaching risk due to low NHI scores include:

- Alfalfa;
- Perennials with high efficiency irrigation;
- Pasture; and,
- Processing tomatoes.

Though some permanent crops such as almonds are high nitrate users, they are predominantly irrigated with drip irrigation, which results in a lower nitrate leaching risk rating for those crops. Alfalfa is a high water user and is high in acreage in KRWCA, but because alfalfa is a legume and fixes its own nitrogen from the atmosphere, it is not a priority in nitrate leaching risk management. Processing tomatoes are largely drip-irrigated in KRWCA yielding a low NHI score and also have relatively low acreage compared to other areas of the state.

10.3.6.3 Crop Systems with Relatively Lower Regional Risk

Crops that have relatively low nitrate leaching risk due to moderate or high NHI scores but low acreage include:

- Perennials with low efficiency irrigation;
- Field crops including cotton, barley, and oats, but excluding wheat; and,
- Forage and silage crops (alfalfa classified separately).

Permanent crops such as almonds and walnuts irrigated with surface systems may have NHI scores in the higher risk category; however, the acreage of this combination is very low. Field crops other than wheat may be likely sources of nitrate leaching, but their acreage is also very low. Forage crops often include legumes in a mixed crop, lowering the overall nitrate leaching risk, and in unmixed crops the acreage is so low that they are not a major consideration. Silage crops may include high NHI crops such as corn, but overall the average of silage and forage crops present a low nitrate risk.

10.4 Designation of High Vulnerability Areas

KRWCA identified high vulnerability areas (**HVAs**) are presented in **Figure 10-8**. As described above, the KRWCA high vulnerability area (**HVA**) was determined by groundwater quality exceedances (nitrate and pesticides), DPR GWPAs, and the NHI analysis. Grid cell discretization using the USGS CVHM (one square mile cells) was the basis for identifying impacted groundwater quality HVA. Using CVHM grid cells to identify impacted groundwater quality areas is a conservative approach and accounts for the spatial imprecision when identifying groundwater well locations and correlating to spatial water quality results. The NHI analysis identified irrigated fields where agricultural management practices (irrigation and cropping) and/or physical conditions (soil) increase the potential for nitrate leaching from the surface. The discrete field level approach for the NHI analysis is appropriate due to the spatial accuracy of the input data utilized as the basis for determining the field NHI (irrigation, crop, and soil). The field boundaries that were developed in the NHI analysis are used as the basis for designating the KRWCA HVA. The HVA decision matrix flowchart presented on **Figure 10-9** illustrates the process for identifying high vulnerability fields in the KRWCA area. For a field to be identified as being high vulnerability based on a CVHM grid cell groundwater quality exceedance (nitrate or pesticide), the majority of the field had to be within the respective grid cell. It is possible for a field to be within multiple CVHM grid cells; therefore, the respective field was assigned the ground water quality information from the grid cell that the majority of the field overlaid. For a field to be identified as high vulnerability and have a relatively higher nitrate leaching risk based on the NHI, the field must have a NHI score greater than 20, as stated above. For a field to be identified as high vulnerability based on a DPR GWPA leaching risk designation, the majority of the field must be located within the identified USGS section.

The KRWCA HVA identifies 211,040 irrigated acres within the primary boundary (34 percent of total irrigated acres) as high vulnerability based on water quality exceedances and the NHI analysis. See **Figure 10-2** for the high vulnerability area by designation type. Of the high vulnerability area, 37 percent is identified by an NHI score greater than 20, 49 percent is identified by groundwater quality exceedances, 13 percent is identified by both groundwater quality exceedance and NHI score greater than 20, and less than 1 percent is identified by DPR designated leaching GWPAs. The relationship between the three main designation scenarios and respective acreages is presented on **Figure 10-10**. Of the identified 211,040 KRWCA HVA irrigated acreage, 185,127 irrigated acres (88 percent) is currently enrolled under grower members in the KRWCA.

It is important to note, a NHI score that is equal to or less than 20 is indicative of agricultural systems (irrigation and cropping) and physical conditions (soil) that have relatively lower potential to leach nitrate beneath the root zone. As described in **Section 2**, **Section 4**, and comments provided to the Central Valley Regional Water Quality Control Board (**CVRWQCB**) by the KRWCA during the Draft General Order comment period (Kimmelshue and Tillman, 2014), the KRWCA area has experienced a dramatic change in the last 20 years from annual row crops that were traditionally surface irrigated, usually resulting in NHI scores greater than 20, to permanent crops that are irrigated with highly

efficient pressurized micro and/or drip systems, usually resulting in scores equal to or less than 20. Therefore, it is reasonable to deduce that the KRWCA HVA identified with a NHI score equal to or less than 20 are a minimal risk to leach nitrate below the root zone, due to efficient agricultural management practices and/or physical conditions. It is believed that the water quality exceedances identifying fields with NHI scores equal to or less than 20 as part of the HVA are a likely result from historical agricultural management practices, or legacy conditions. This scenario has been included in the KRWCA HVA to accommodate KRWCA's understanding of the CVRWQCB staff's interpretation of the high vulnerability definition set forth in the General Order (although the definition of HVA can be read to require an exceedance to be currently or in the future caused or contributed by irrigated agriculture). It is the KRWCA's position that areas identified to have agricultural management practices that have higher potential to leach nitrate beneath the root zone (NHI scores greater than 20) should be the only land identified as high vulnerability. The KRWCA reserves the right to refine the identified HVA in the GAR based on any determinations affecting definitions or HVAs from the pending SWRCB General Order appeals, and does not otherwise waive any rights affected by its or its Member's appeal to the SWRCB by submitting this GAR and related documents. In the interim, the KRWCA believes that fields with a NHI score less than or equal to 20 should be designated a lower priority than fields with a NHI score greater than 20. This will be discussed further in **Section 11**.

10.5 Comparison of High Vulnerability Area Results with Existing Vulnerability Assessment

There are two previously completed assessments of vulnerability that include the KRWCA area. These are the DPR GWPAs discussed above and the SWRCB Hydrogeologically Vulnerable Areas. The DPR GWPAs are included in the KRWCA HVA, so no further comparison is provided in this section. A discussion of the SWRCB Hydrogeologically Vulnerable Areas is presented below.

10.5.1 State Water Resources Control Board Hydrogeologically Vulnerable Areas

The SWRCB staff generated a statewide map of areas that may be more vulnerable to groundwater impacts. The mapping of vulnerable areas was completed based on published geologic information suggesting that recharge rates may be substantially higher than in lower permeability or confined areas of the same groundwater basin (SWRCB, 2000). This mapping was completed only for the California Department of Water Resources (**DWR**) designated groundwater basins (DWR, 2003), and no areas outside of those basin boundaries were assessed.

In the KRWCA area, the mapped SWRCB Hydrogeologically Vulnerable Areas are limited to the Kern County Portion of the San Joaquin Groundwater Basin, which is described in **Section 5** of this GAR. The SWRCB mapped Hydrogeologically Vulnerable Areas in the Subbasin is based solely on the absence of the Corcoran Clay. This assessment was based on the assumption that the Corcoran Clay is a barrier to the vertical flow of groundwater to usable aquifer units (SWRCB, 2000). As discussed in **Section 5** of this report, in Kern County, the permeability of the Corcoran Clay is not as low as it is further north. In addition, where it occurs in the Kern County portion of the San Joaquin Groundwater Basin, it is deeper than in other areas of the Central Valley and usable groundwater exists above the top of the clay in more than 90 percent of the Subbasin. These two factors indicate that the presence or absence of the Corcoran Clay should not be used alone to indicate vulnerability in the Kern County Subbasin of the San Joaquin Groundwater Basin. In addition, the SWRCB indicated that the mapped Hydrogeologically

Vulnerable Areas should be used as a large scale tool and should not override more recent or detailed information in smaller scale studies (SWRCB, 2000).

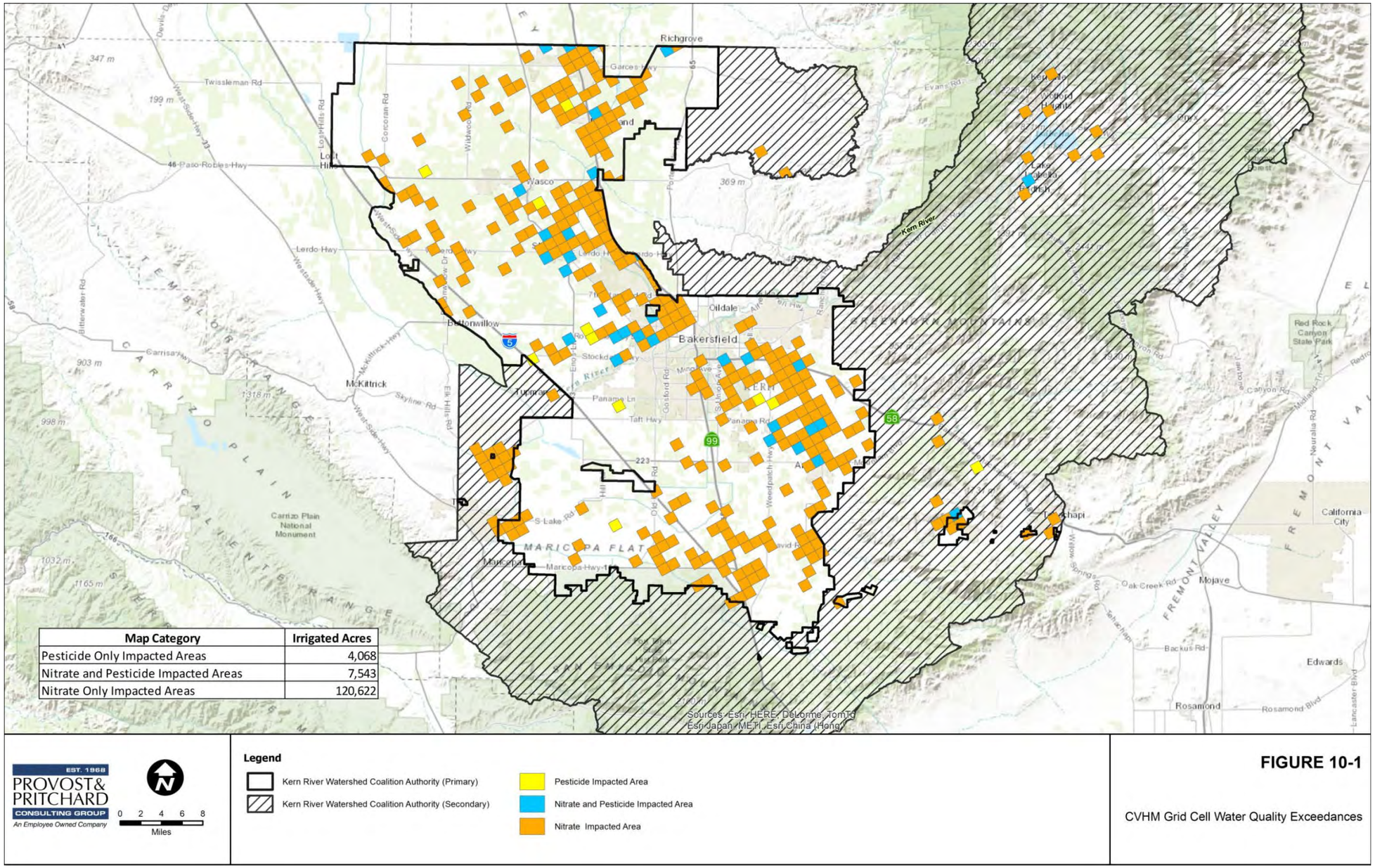


Figure 10-1. Areas Exceeding Water Quality Objectives

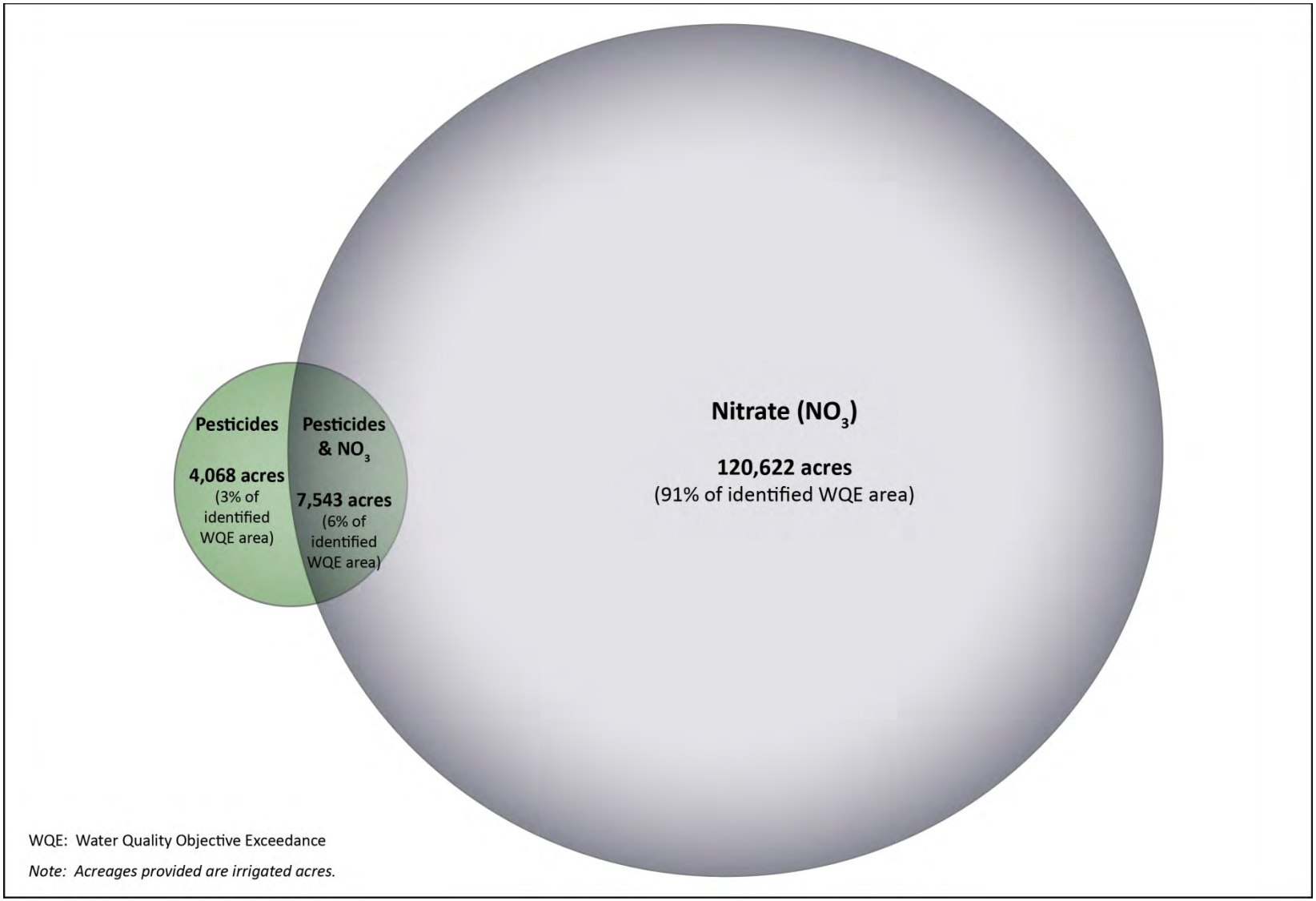


Figure 10-2. KRWCA Pesticides and Nitrates Water Quality Exceedance Venn Diagram

Crop	Soil 1	2	3	4	5	Irrigation
1	1	2	3	4	5	1
1	2	4	6	8	10	2
1	3	6	9	12	15	3
1	4	8	12	16	20	4
2	2	4	6	8	10	1
2	4	8	12	16	20	2
2	6	12	18	24	30	3
2	8	16	24	32	40	4
3	3	6	9	12	15	1
3	6	12	18	24	30	2
3	9	18	27	36	45	3
3	12	24	36	48	60	4
4	4	8	12	16	20	1
4	8	16	24	32	40	2
4	12	24	36	48	60	3
4	16	32	48	64	80	4

Figure 10-3. Nitrate Hazard Groundwater Pollution Index Matrix

Table 10-1. NHI Limitations and Solutions in KRWCA Groundwater Vulnerability Assessment

NHI Limitations and Solutions in KRWCA Groundwater Vulnerability Assessment	
NHI Limitation	**How limitation is addressed in KRWCA groundwater vulnerability assessment**
Soil hazard ratings are qualitative (based on expert opinion rather than being empirically derived or data driven) and as such: • may be biased; • are difficult to update; • lack transparency (cannot necessarily be replicated); and • do not make clear the significance or difference between different hazard values	Though O'Geen (May, 2014) represents soil hazard ratings as the combined opinion of three experts, Wu et al. (2005) states that the soil hazard ratings reflect the independent evaluation of as many as seven experts. The soil ratings are considered valid in the KRWCA groundwater vulnerability assessment despite their qualitative origin for these reasons: 1) the contribution of soil to groundwater vulnerability is based on several interacting factors that must be considered, not only one or two that are represented by empirical data; 2) soil survey, upon which soil ratings are based, is in part inherently qualitative; 3) quantitative methods used to produce absolute values related to vulnerability status have not consistently been proven to be more "correct" or representative of leaching conditions (NRC, 1993; EPA, 1993); 4) ranking methods are used worldwide with reasonable results when they are developed or modified for regional conditions (NRC, 1993; EPA, 1993; Neshat et al, 2013; Javadi et al, 2011), and there is no reason to assume that the NHI rankings are inadequate until a different method of evaluating soils in California agriculture is proven to be superior.
Soil hazard ratings are incomplete – some soils have not been rated	A comparison of the soils database for the KRWCA region and the NHI soils database revealed that the soils that have major agricultural significance in the KRWCA region are ranked. Those that are not ranked have little agricultural significance, i.e. they have very low occurrence and/or spatial extent and/or do not occur on irrigated land, and therefore do not represent a significant part of soil complexes or individual soil components. As a result, the omission of unranked soils does not have a major impact on the NHI analysis. Other NHI studies have been carried out in the Central Valley and have been documented (Pettigrove, 2012; Dzurella, 2012) without mention of missing NHI values affecting the analysis.
Doesn't consider climate	On a state-wide scale, climate would likely affect NHI results. However, on a regional scale, climate is not expected to influence NHI significantly. The climate throughout the KRWCA area is very similar.
Rates soil series instead of map units or components of map units – difficult to reconcile for soil complexes; masks the complexity of soil survey data	There can be several map units that represent one series, and these map units potentially have different nitrate leaching risk. Though this level of detail would potentially improve the NHI, it is not practical to add this level of detail to the current analysis, nor would it necessarily result in more accurate results. Studies validating the NHI to date (Wu, 2005; Pettigrove, 2012; Dzurella, 2012) have demonstrated reasonable results with the current NHI format and have not indicated that a greater level of detail is necessary.
Doesn't address all types of irrigation	Because irrigation technology and usage has changed dramatically during the last few decades, it is unsurprising that the NHI does not capture all types and usages of irrigation. However, modifying this factor and its assigned rankings is a reasonable approach, since other overlay and index methods have been proven to improve with regional modification (Javadi et al., 2011; Neshat, 2013), and has been demonstrated previously in California efforts (Dzurella, 2012).
Soils modified by water-restrictive horizons have been modified by deep tillage, but this condition has not been updated in most soil surveys	GIS analysis was used to find fields where vines or trees were planted, and the NHI soil hazard ratings for these fields were changed according to the deep ripping value for 2-5 feet in the NHI database. The assumption was made that all land prepared for trees or vines is deep ripped to 2-5 feet and is supported by information from Kern County UCCE and grower input (Kallsen, 2014; Sanden, 2014; Fisher, 2014).

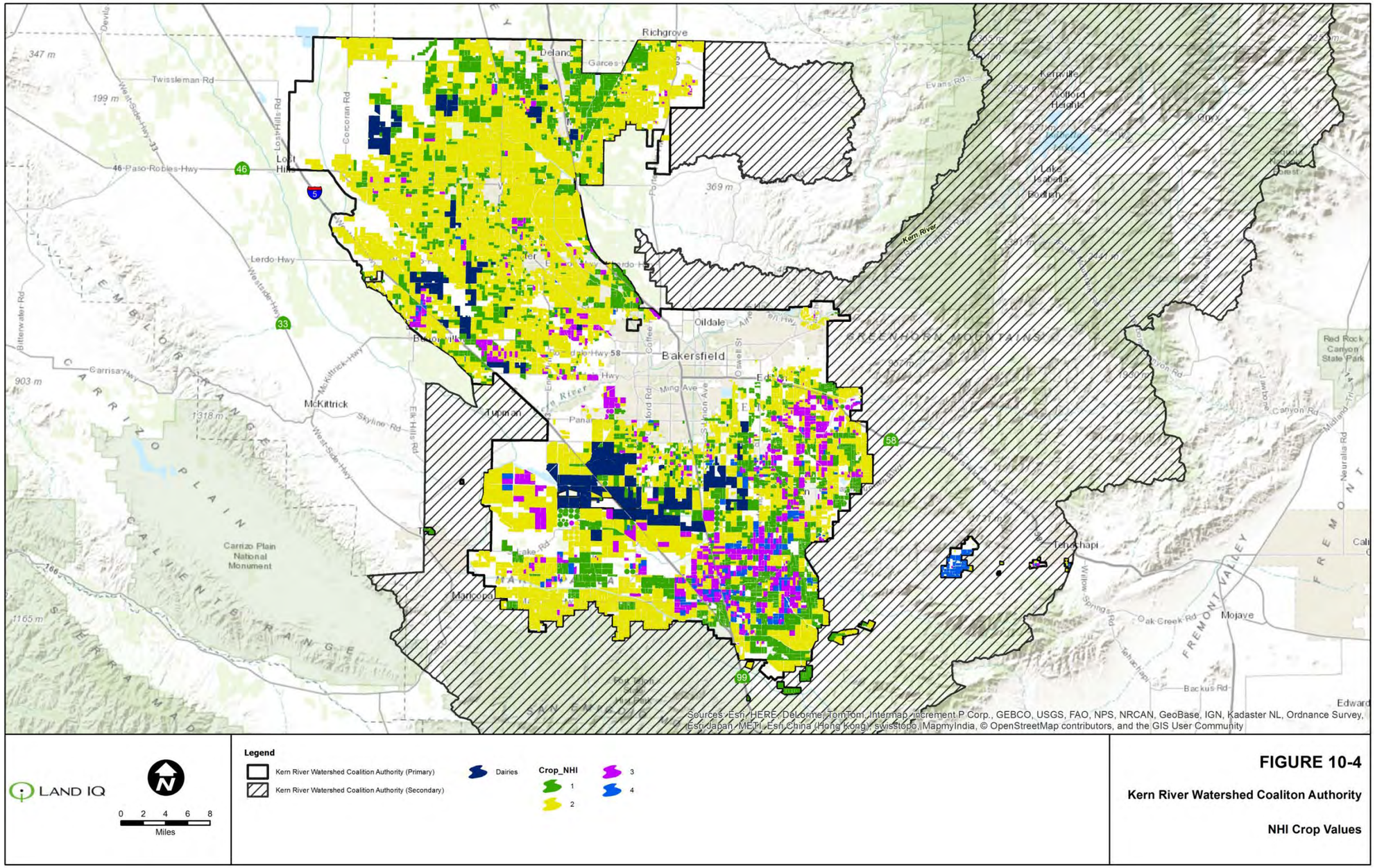


Figure 10-4. KRWCA NHI Crop Hazard Values

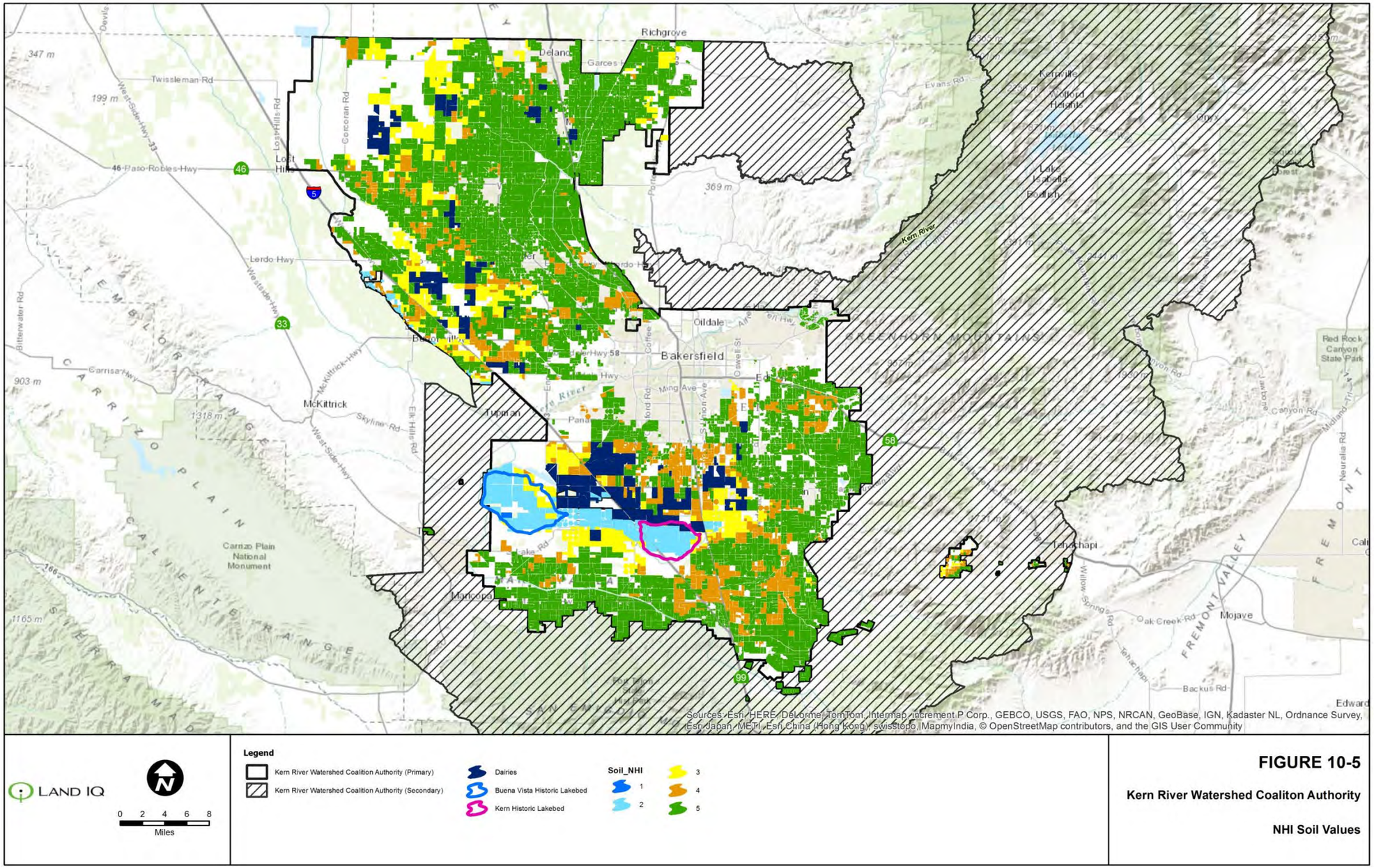


Figure 10-5. KRWCA NHI Soil Hazard Values

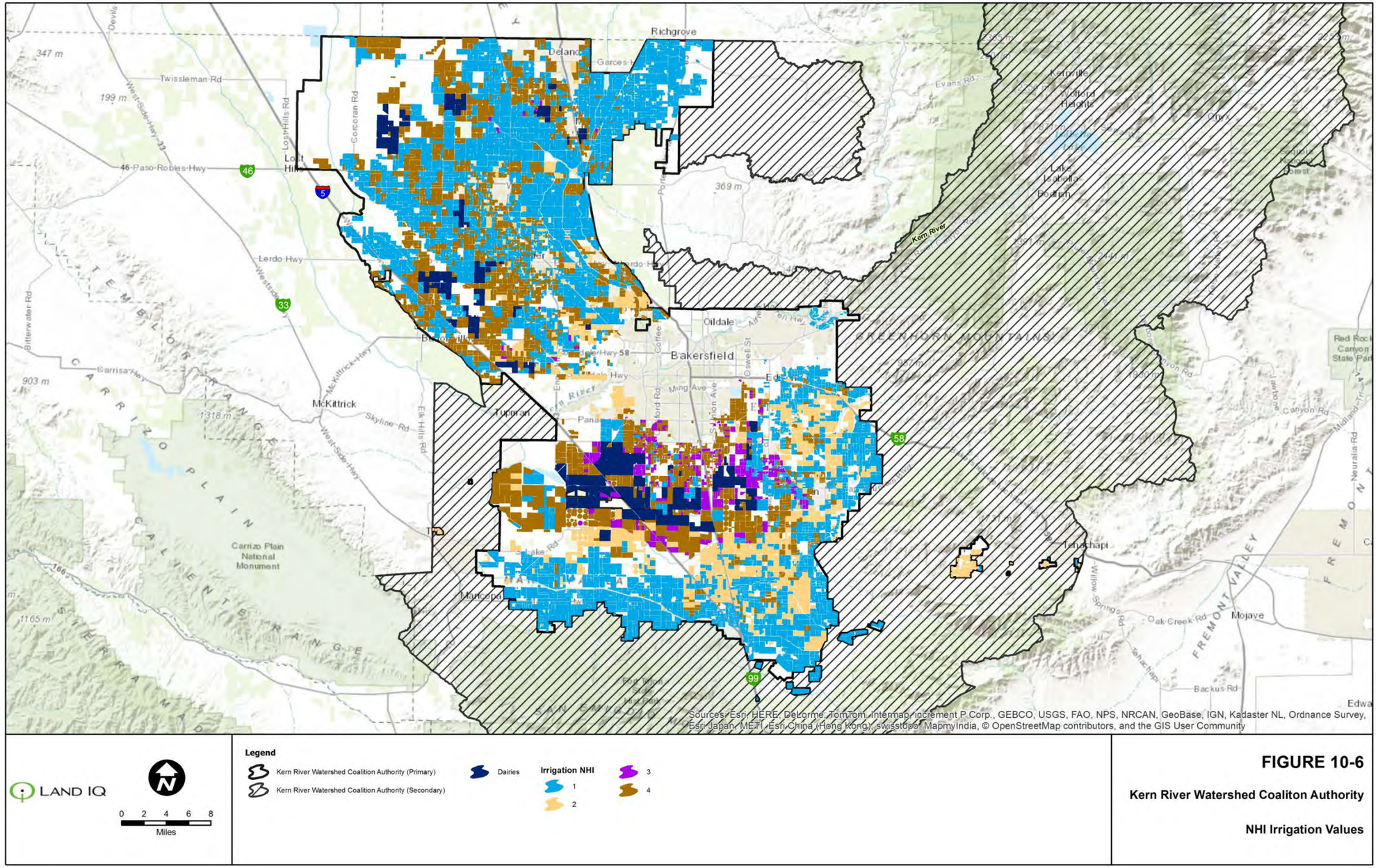


Figure 10-6. KRWCA NHI Irrigation System Hazard Values

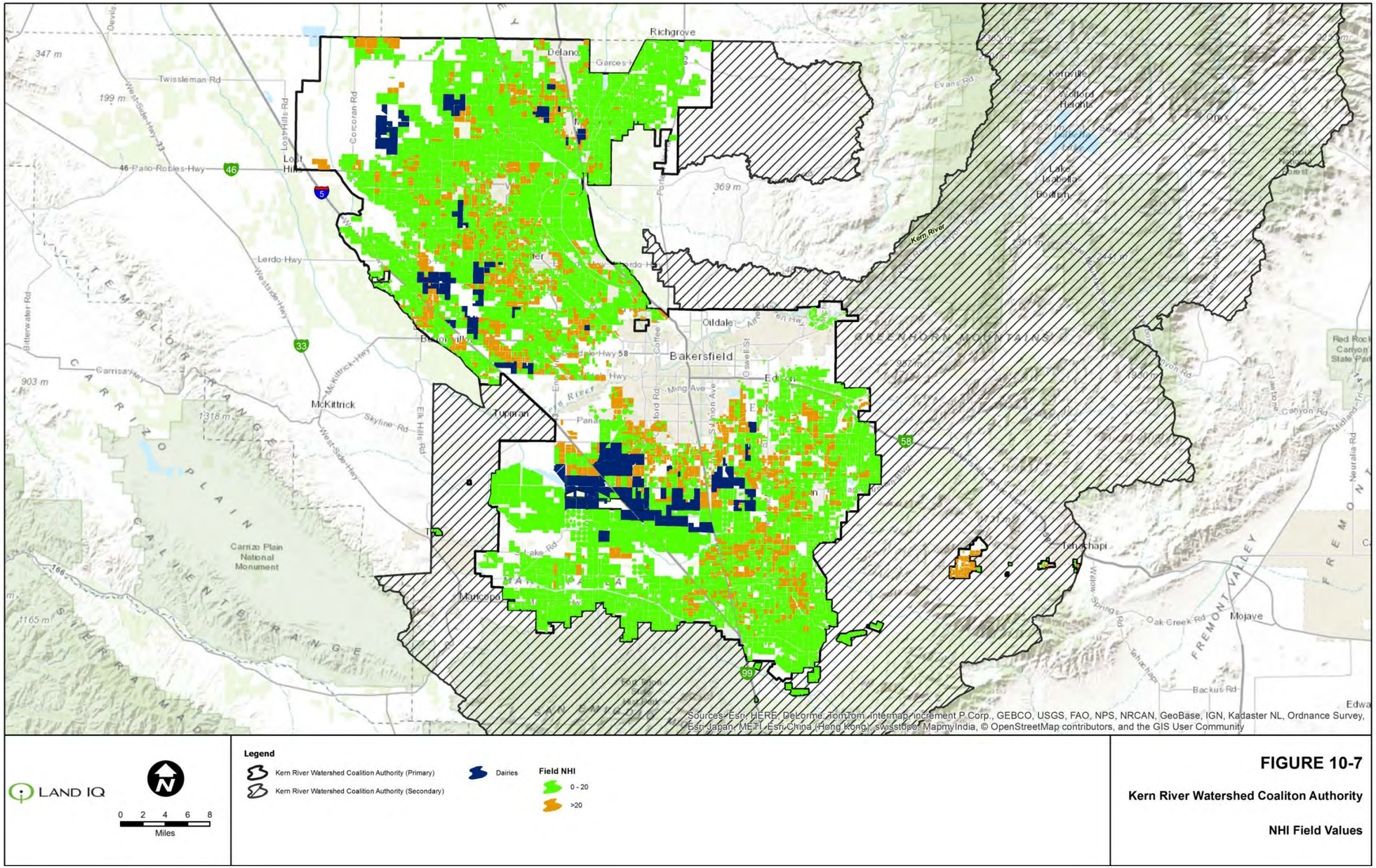
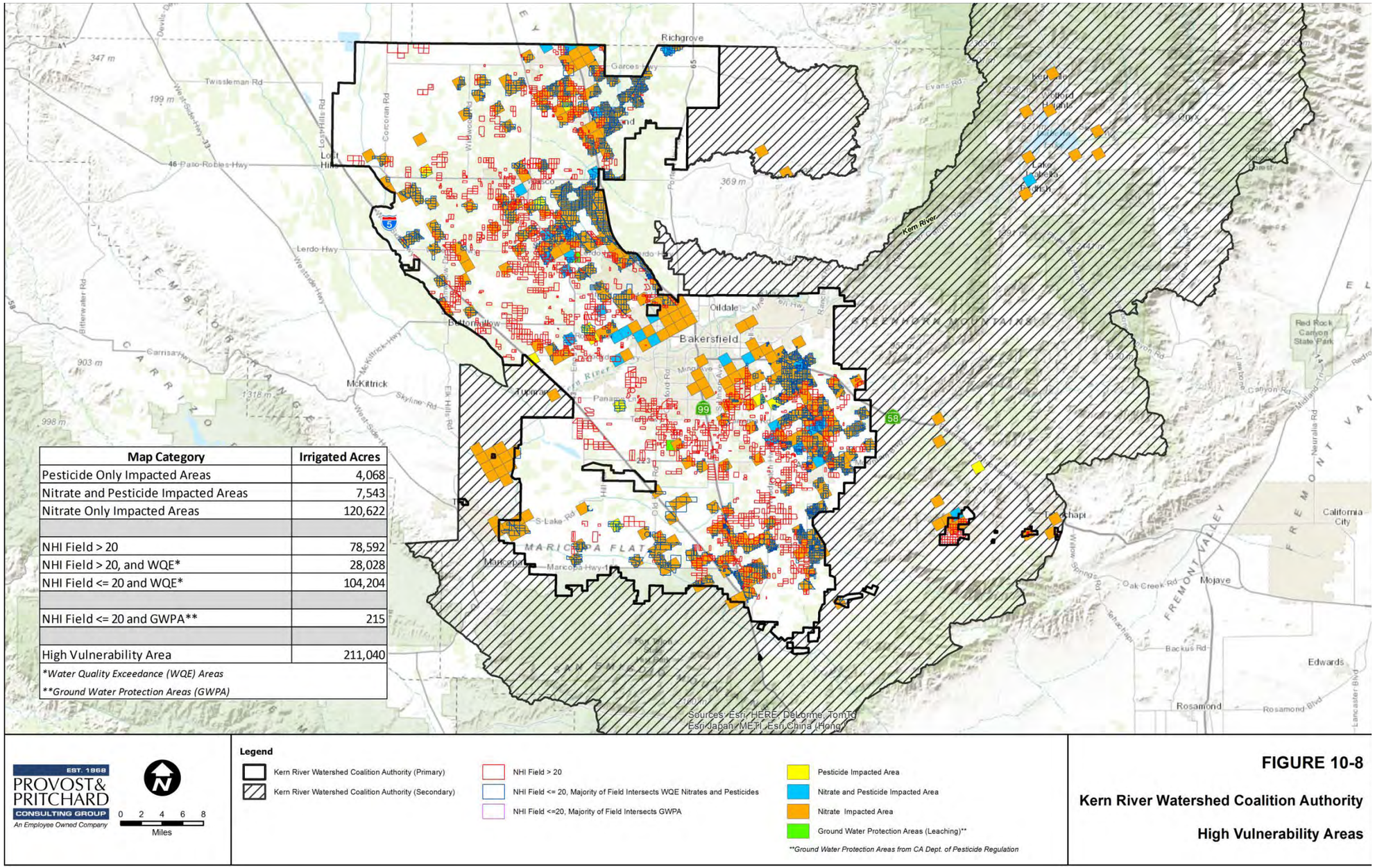


Figure 10-7. KRWCA NHI Field Values



Map Category	Irrigated Acres
Pesticide Only Impacted Areas	4,068
Nitrate and Pesticide Impacted Areas	7,543
Nitrate Only Impacted Areas	120,622
NHI Field > 20	78,592
NHI Field > 20, and WQE*	28,028
NHI Field <= 20 and WQE*	104,204
NHI Field <= 20 and GWPA**	215
High Vulnerability Area	211,040

**Water Quality Exceedance (WQE) Areas*
***Ground Water Protection Areas (GWPA)*

Figure 10-8. KRWCA High Vulnerability Area

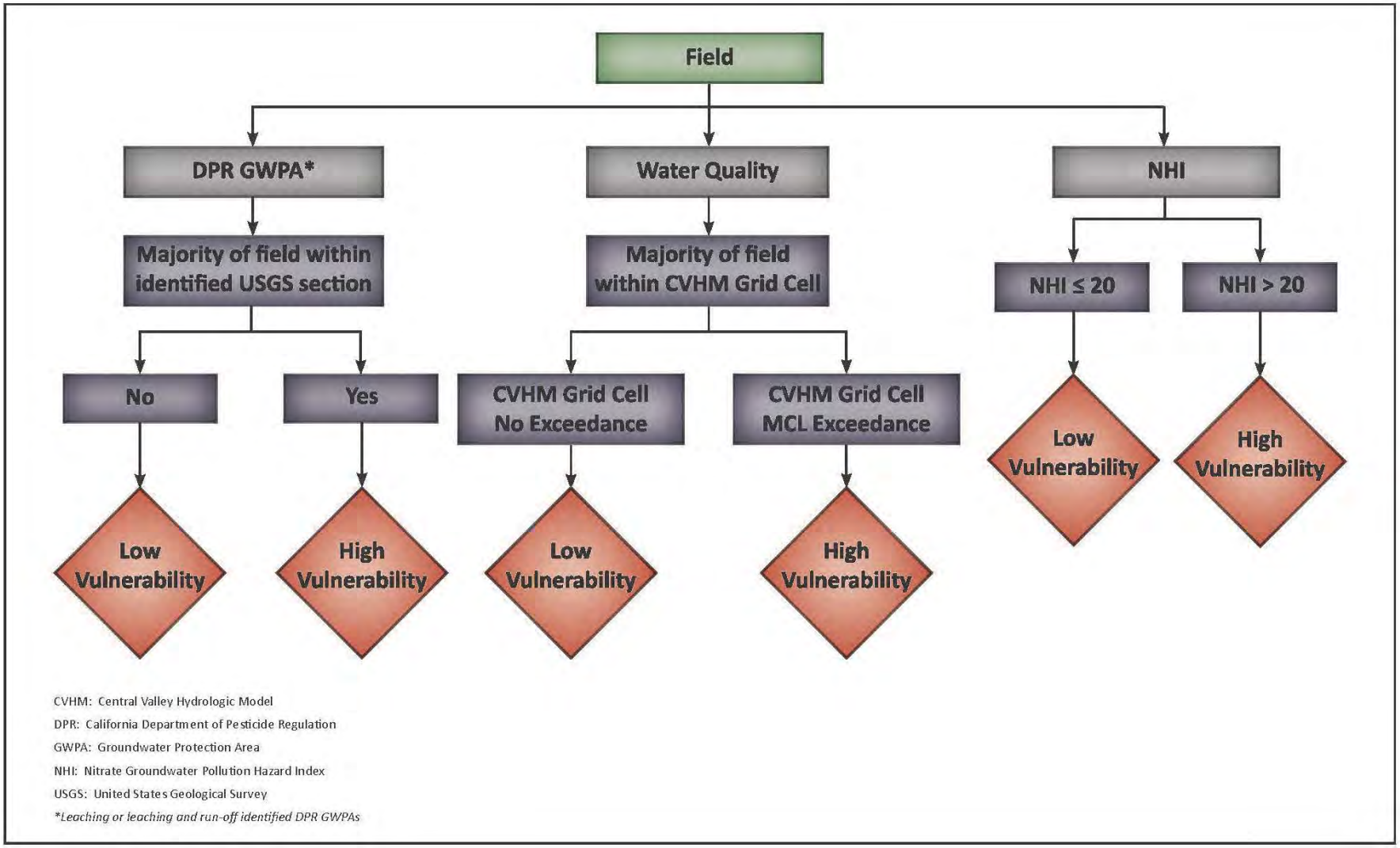
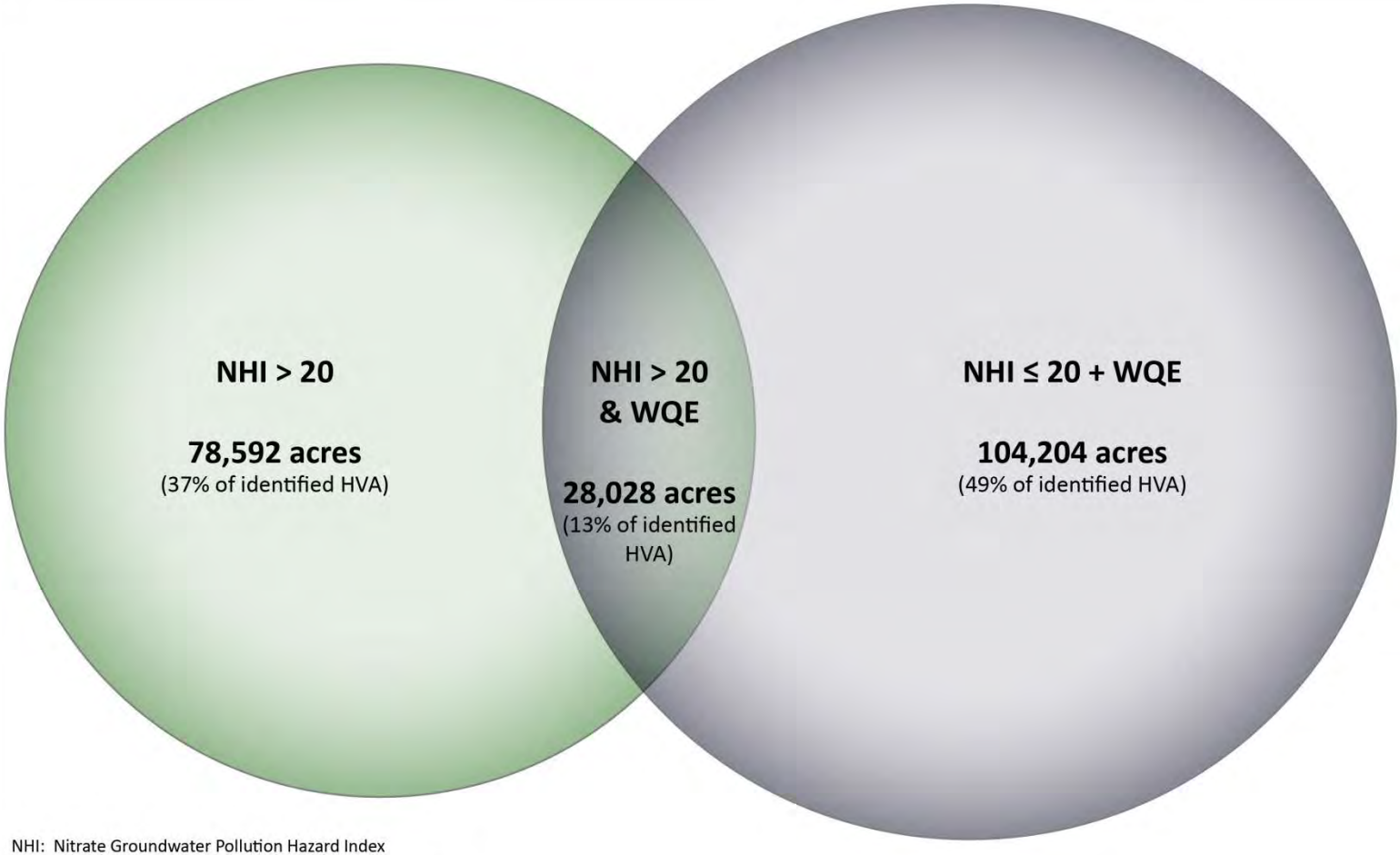


Figure 10-9. KRWCA High Vulnerability Decision Matrix Flow Chart

Table 10-2. KRWCA High Vulnerability Area by Identification Scenario

KRWCA High Vulnerability Area by Identification Scenario		
KRWCA HVA Identification Scenario	**Irrigated Acres (ac)**	**Percent of HVA (%)**
NHI Field Score > 20	78,592	37.2%
NHI Field Score > 20 & WQE	28,028	13.3%
NHI Field Score ≤ 20 & WQE	104,204	49.4%
DPR GWPA (Leaching)	215	0.1%
Total HVA:	**211,040**	**100.0%**

KRWCA: Kern River Watershed Coalition Authority
HVA: High Vulnerability Area
WQE: Water Quality Objective Exceedance
DPR: California Department of Pesticide Regulation
GWPA: Groundwater Protection Area



NHI: Nitrate Groundwater Pollution Hazard Index

WQE: Water Quality Objective Exceedance (Nitrate and/or Pesticides)

HVA: High Vulnerability Area

Note: Acreages provided are irrigated acres.

Figure 10-10. KRWCA NHI and Water Quality Exceedance HVA Venn Diagram

11 High Vulnerability Area Prioritization

To facilitate and focus the planning of future groundwater quality monitoring and agricultural management efforts on high vulnerability areas (**HVAs**) in the Kern River Watershed Coalition Authority (**KRWCA**) area and fulfill the requirements of the General Order, all identified KRWCA HVAs were prioritized into three (3) tiers. Attachment B [Monitoring and Reporting Program (**MRP**)] of the General Order identifies numerous factors that can be considered in prioritizing HVAs. These factors include, but are not limited to:

- Identified exceedances of water quality objectives for which irrigated agriculture waste discharges are the cause, or a contributing source;
- 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;
- Existing field or operational practices identified to be associated with irrigated agriculture waste discharges that are the cause, or a contributing source;
- The largest acreage commodity types comprising up to at least 80 percent of the irrigated agricultural acreage in the high vulnerability areas and the irrigation and fertilization practices employed by these commodities;
- Legacy or ambient conditions of the groundwater;
- Groundwater basins currently or proposed to be under review by Central Valley Salinity Alternatives for Long-Term Sustainability (**CV-SALTS**); and,
- Identified constituents of concern (e.g. relative toxicity, mobility).

To objectively incorporate multiple factors as part of the KRWCA high vulnerability area (**HVA**) prioritization, a system was developed to calculate priority values throughout the identified HVA. From the calculated priority values, a three tier system was used to generalize areas of high (Tier I), medium (Tier II), and low (Tier III) priorities to facilitate groundwater quality monitoring and agricultural management effort planning.

11.1 High Vulnerability Area Prioritization Parameters

The KRWCA HVA prioritization framework incorporates the following three distinct parameters to identify prioritization tiers for fields identified as high vulnerability:

- Hydrogeologic (intrinsic) sensitivity;
- The relationship between high vulnerability lands and public groundwater supply wells; and,
- The Nitrate Groundwater Pollution Hazard Index (**NHI**).

Each parameter is discussed in detail below.

11.1.1 Relative Hydrogeologic Sensitivity

Relative hydrogeologic sensitivity was the first component of the KRWCA HVA prioritization framework. The hydrogeologic sensitivity incorporated unsaturated zone thickness, horizontal hydraulic conductivity, and vertical hydraulic conductivity in a multiplicative overlay and index method. This index

method produced a representation of the combined relative hydrogeologic sensitivity in the KRWCA area.

11.1.1.1 Unsaturated Zone Thickness

As discussed in **Section 5**, the unsaturated zone is equivalent to the depth to shallowest groundwater. The thickness of the unsaturated zone in the KRWCA area has been identified from the spring depth to groundwater contour maps prepared by the Kern County Water Agency (**KCWA**) for spring 2007. As noted in **Section 5**, groundwater elevations were highest overall in spring 2007, as compared to the recent period from 2000 through 2013. Since the spring 2007 depth to water data corresponds to the highest groundwater elevations in the study period, it also corresponds to the shallowest depth to water and thinnest unsaturated zone. Thus, the spring 2007 depth to groundwater is representative of the thinnest and most conservative unsaturated zone thickness in the KRWCA area over the 14 year study period.

Unsaturated zone thickness values were interpreted for each United States Geological Survey (**USGS**) Central Valley Hydrologic Model (**CVHM**) grid cell in the KRWCA primary area. The range between the minimum and maximum unsaturated zone thickness values was divided into five equal increments. Each increment was assigned a relative sensitivity value between 1 and 5, with 5 being the most sensitive corresponding to the thinnest unsaturated zone, and 1 being the least sensitive and corresponding to the areas where the unsaturated zone is thickest. The relative unsaturated zone thickness sensitivity in the KRWCA area is presented on **Figure 11-1**.

11.1.1.2 Unsaturated Zone Hydraulic Conductivities

Horizontal and vertical hydraulic conductivity information for the KRWCA primary area was obtained from the USGS CVHM. As noted in **Section 5**, the aquifer parameters in the CVHM were generated from textural evaluation of well logs, and the resulting datasets provide the best available coverage of the entire KRWCA primary area. The CVHM hydraulic conductivity (horizontal and vertical) datasets are partially the result of model calibration, and are not measured values. As such, these data have been used as a representation of the relative distribution of aquifer characteristics, and not as absolute values.

As described in **Section 5**, horizontal and vertical hydraulic conductivity values for the unsaturated zone were calculated as thickness weighted averages for each CVHM grid cell. The total range of each dataset was then divided into five equal increments and each increment was assigned a relative sensitivity value between 1 and 5, with the highest hydraulic conductivity values assigned the highest sensitivity values and the lower hydraulic conductivity values assigned the lower sensitivity values. The resulting horizontal hydraulic conductivity sensitivities are shown on **Figure 11-2**, and the vertical hydraulic conductivity sensitivities shown on **Figure 11-3**.

11.1.1.3 Relative Hydrogeologic Sensitivity

A multiplicative overlay and index method was used to combine the intrinsic hydrogeologic factors and develop a combined relative hydrogeological sensitivity coverage. For each CVHM grid cell, the respective relative unsaturated thickness sensitivity value, relative horizontal hydraulic conductivity sensitivity value, and relative vertical hydraulic conductivity sensitivity value (as identified by the methods described above) were multiplied together to produce a combined relative hydrogeologic sensitivity score or index, illustrated by the matrix shown on **Figure 11-4**. On **Figure 11-4**, a relative

hydrogeologic sensitivity score of 3 is outlined in red, and would be the result of a relative vertical hydraulic conductivity value of 1, a relative horizontal hydraulic conductivity value of 1, and a relative depth to groundwater value of 3. The combined relative hydrogeologic sensitivity index coverage for the KRWCA area is shown on **Figure 11-5**. The combined relative hydrogeologic sensitivity values range between 1 and 125, and they have been divided into three equal categories of low, medium, and high on **Figure 11-5**. These sensitivity values do not indicate relative vulnerability, and no determination of absolute sensitivity has been made or implied for these data.

11.1.2 High Vulnerability Areas Upgradient of Public Groundwater Supply Wells

The location of identified HVAs relative to public groundwater supply wells was included in the KRWCA HVA prioritization framework. To identify HVAs upgradient of public groundwater supply wells, a well capture zone analysis was utilized. Identification of public water system groundwater supply wells and the well capture zone for the respective wells is described below.

11.1.2.1 Public Water System Groundwater Supply Wells

Public water system groundwater supply wells were identified using State Water Resources Control Board Division of Drinking Water (**SWRCB-DDW**) (formerly California Department of Public Health) source data obtained from the SWRCB Groundwater Ambient Monitoring and Assessment (**GAMA**) online database (SWRCB, 2014a). Kern County Water Agency (**KCWA**) and Kern County Environmental Health Services (**KCEHS**) data was not used because the databases do not distinguish between public and non-public water supply groundwater wells. Two methods were used to associate source data from GAMA to public water supply systems:

i. SWRCB-DDW public water supply system identification numbers (**system ID**), and

ii. The Disadvantaged Community Water Study for the Tulare Lake Basin (**TLB DAC Study**) (Provost & Pritchard, et al., 2014).

For sources that had a SWRCB-DDW system identification number embedded in the source name, the source was linked to a master water systems table provided by SWRCB-DDW (SWRCB, 2014b). Each source was linked to the system identification number, system name, population served, and number of connections data provided by the SWRCB-DDW master water systems table. The TLB DAC Study community water systems geographical information system (**GIS**) layer was used to link sources that did not contain a system identification number to a municipal or community water system identified in the study. **Figure 11-6** presents the public water system groundwater supply wells identified in the KRWCA area. A total of 472 public groundwater supply wells were identified in the analysis.

11.1.2.2 Disadvantaged Community Public Water Systems Groundwater Supply Wells

Public groundwater supply wells within disadvantaged communities (**DACs**) were also incorporated in the KRWCA HVA prioritization framework. DACs are defined as places or communities whose median household income (**MHI**) is 80 percent or less of the statewide MHI. DAC boundaries in the KRWCA area are presented on **Figure 11-7.** DAC identification and boundaries were obtained from the TLB DAC Study for unincorporated communities that were not United States Census cities and designated places (Provost & Pritchard, et al., 2014). DAC identification and boundaries were obtained from the California Department of Water Resources (**DWR**) for United States Census cities and designated places (DWR, 2014b). The TLB DAC Study emphasized disadvantaged unincorporated communities and their water

systems. Small water systems (**SWS**), state small water systems (**SSWS**), and community water systems (**CWS**) were identified that served DACs. A SWS is a community water system that serves less than 200 connections and is not a non-community water system[1] or transient non-community water system[2]. A SSWS is a water system that serves at least 5, but not more than 14 connections, and does not provide drinking water to more than 25 individuals for more than 60 days out of the year. A CWS serves at least 15 connections used by yearlong residents, or at least 25 yearlong residents. Information used to define DACs and their respective boundaries presented on **Figure 11-7** was collected from PolicyLink, SWRCB-DDW, Self-Help Enterprises, Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater (Harter T., et al. 2012), U.S. Department of Commerce, Fresno County Local Agency Formation Commission (**LAFCo**), Tulare County LAFCo, Kern Integrated Regional Water Management (**IRWM**), Kings County LAFCo, as well as various other sources (Provost & Pritchard, et al., 2014).

All identified public water system groundwater supply wells presented on **Figure 11-6** located within DAC boundaries are assumed to serve the respective DAC's public water supply system. Wells were assigned DAC status using the system identification number or name from the public water supply systems identified in the TLB DAC Study and DWR DAC data. Well locations were identified as described in **Section 11.1.2.1**. DAC wells are included on **Figure 11-6** in yellow along with non-DAC public water system groundwater supply wells. A total of 126 public groundwater supply wells associated with DACs were identified.

11.1.2.3 Public Groundwater Supply Well Capture Zone

Capture zones for all of the public groundwater supply wells discussed above were estimated using the uniform flow equations (Todd and Mays 2005). The uniform flow equations are a means of approximating the area of an aquifer that contributes flow to a well operating in sloping groundwater surface. In these conditions the contribution of flow to a well is not equal from all directions, but extends upgradient, with a stagnation point in the downgradient direction. The extents of the zone of contribution, or capture zone, in these cases are described by the following equations (Todd and Mays 2005):

$$y_L = \pm\frac{Q}{2Kbi} \qquad \text{and} \qquad x_L = -\frac{Q}{2\pi Kbi}$$

Where:

y_L = Limit of the capture zone in the y, or cross-gradient direction

x_L = Limit of the capture zone in the x, or downgradient direction

Q = Discharge rate of the well in cubic feet per day (ft^3/day)

K = Horizontal hydraulic conductivity of the aquifer in feet per day (ft/day)

b = Aquifer saturated thickness in feet

[1] A non-community water system is a public water system that is not a community water system and can serve either a transient or non-transient population.
[2] A transient non-community water system is a non-community water system that does not regularly serve at least 25 of the same persons over six months per year.

i = Background groundwater gradient (unitless)

The use of the uniform flow equations is recommended for the estimation of capture zones and identification of well head protection areas in the SWRCB-DDW Drinking Water Source Assessment in Protection (DWSAP) Program guidelines (CDPH, 1999). Since the equation for estimating the limit of capture zones in the cross-gradient (y) direction results in larger values than the equation for the downgradient direction, it was used to generate estimates of capture zone distances in all directions to be conservative. Groundwater gradients were estimated for each public water supply well individually based on the average groundwater elevation and flow direction map presented in **Section 7** as **Figure 7-10**. Flow-lines ending at each public supply well were drawn in GIS and then the corresponding average groundwater gradients were calculated. The resulting groundwater gradients were used in combination with conservative assumed values for well discharge, horizontal hydraulic conductivity, and aquifer saturated thickness. Since no specific information relating to the wells or locations in question was available, the same discharge, conductivity, and thickness values were used for all well locations. A daily discharge value was calculated based on the conservative estimate of an instantaneous pumping rate of 1,000 gallons per minute (**gpm**) sustained for 16 hours per day, resulting in a discharge rate of 128,325 cubic feet per day (**ft^3/day**). A conductivity value of 100 feet per day (**ft/day**) and a saturated thickness of 200 feet (**ft**) were used to complete the capture zone distance calculations for each well. The relatively low conductivity and thickness values were chosen to be conservative, since they are used in the denominator of the uniform flow equation.

The flow-lines ending in each well were buffered in GIS using the individually calculated capture zone distance estimated from the uniform flow equation. These capture zones were extended upgradient to a distance equivalent to 10 years of flow. Groundwater flow velocities were estimated for this purpose using the average linear velocity from the Darcy flow equation (Fetter 2000):

$$V_x = \frac{Ki}{\emptyset}$$

Where:

V_x = Average linear Darcy velocity, or seepage velocity, in ft/day

$\emptyset$ = Effective porosity of aquifer materials

The conductivity value used in this calculation was the same as that in the uniform flow equation, and a conservative value of 0.15 was used for effective porosity for all the capture zones. The estimated 10 year capture zones for all of the public water supply wells, including the DAC wells, are shown on **Figure 11-8**.

11.1.3 Nitrate Groundwater Pollution Hazard Index

The NHI field analysis detailed in **Section 10** was included in the KRWCA HVA prioritization framework. The NHI focuses on the main contributors to potential nitrate leaching at the land-use level on the surface (soil, crop, and irrigation type) and therefore it is important to include in the prioritization of the HVA. The NHI was developed to be used as an assessment of relative leaching potential as well as an evaluation tool to help improve agricultural management practices to become more protective of groundwater. Incorporation of the NHI in the KRWCA prioritization framework allows for resources to

be focused on areas where practices have a relatively higher potential to leach nitrate in the area. See **Section 10.3.4** and **Section 10.3.6** for NHI background information and NHI analysis results, respectively.

11.2 High Vulnerability Area Prioritization Matrix

An additive overlay and index approach was used to identify prioritization tiers in the KRWCA HVA. Points were assigned to each identified HVA field based on the various prioritization parameters. **Figure 11-9** provides a flowchart of the various prioritization parameters, the scenarios for each parameter, and the points applied to each respective scenario. Identified HVAs upgradient of public water supply wells are assigned 1 point. If the identified public water supply well serves a DAC, an additional point was assigned to the HVA, for a total of 2 points. Identified HVAs that are not upgradient of public water supply wells are assigned 0 points. Identified HVAs overlying low relative hydrogeologic sensitivity areas are assigned 0 points; HVAs overlying medium relative hydrogeologic sensitivity areas are assigned 1 point; and, HVAs overlying high relative hydrogeologic sensitivity areas are assigned 2 points. HVAs with NHI scores equal to or less than 20 (low) are assigned 0 points, while HVAs with NHI scores greater than 20 (high) are assigned 3 points. For each identified HVA field, the respective upgradient of public water supply well scenario, relative hydrogeologic sensitivity scenario, and NHI scenario points were added together to arrive at an HVA field prioritization score, illustrated by the matrix shown on **Figure 11-10**. On **Figure 11-10**, a HVA field prioritization score of 5 is outlined in red, and would be the result of 1 point from being upgradient of a non-DAC public water supply well, 1 point from overlying a medium relative hydrogeologic sensitivity, and 3 points from having a NHI score greater than 20.

Table 11-1 lists each HVA prioritization scenario, respective prioritization score, and resulting prioritization tier. A three tier system was used to generalize the HVA prioritization area. Areas of high priority are classified as Tier I, areas of medium priority are classified as Tier II, and areas of low priority are classified as Tier III. The prioritization tier for HVA fields was determined from each HVA field's respective prioritization score. HVA prioritization scores from 0 to 2 are classified as Tier III; scores from 3 to 4 are classified as Tier II; and, scores from 5 to 7 are classified as Tier I.

11.3 High Vulnerability Area Prioritization Results

KRWCA HVA prioritization analysis is presented on **Figure 11-11**. The identified irrigated acres within each tier are presented in **Table 11-2**. Of the 211,040 irrigated acres identified as HVA (see **Section 10** for HVA designation), 5percent are classified as Tier I, 46 percent are classified as Tier II, and 48 percent are classified as Tier III. The identified irrigated acreage within each prioritization parameter scenario by crop type is presented in **Table 11-3**.

The total irrigated acreage by crop type in the identified HVA is presented in **Table 11-4**. The top 80 percent of identified KRWCA HVA, by irrigated acreage, includes almonds, truck crops, grapes, potatoes, field crops, cotton, and corn. **Table 11-5** presents the KRWCA prioritization tiers by crop type and the respective irrigated acreages. The top three crops classified in Tier I, by acreage, are almonds, truck crops, and field crops. **Table 11-6** presents the KRWCA prioritization tiers by irrigation system type and the respective irrigated acreages. **Table 11-7**, **Table 11-8**, and **Table 11-9** present the KRWCA prioritization tiers by both crop and irrigation types, with irrigated acreages for each scenario, for Tiers I, II and III, respectively.

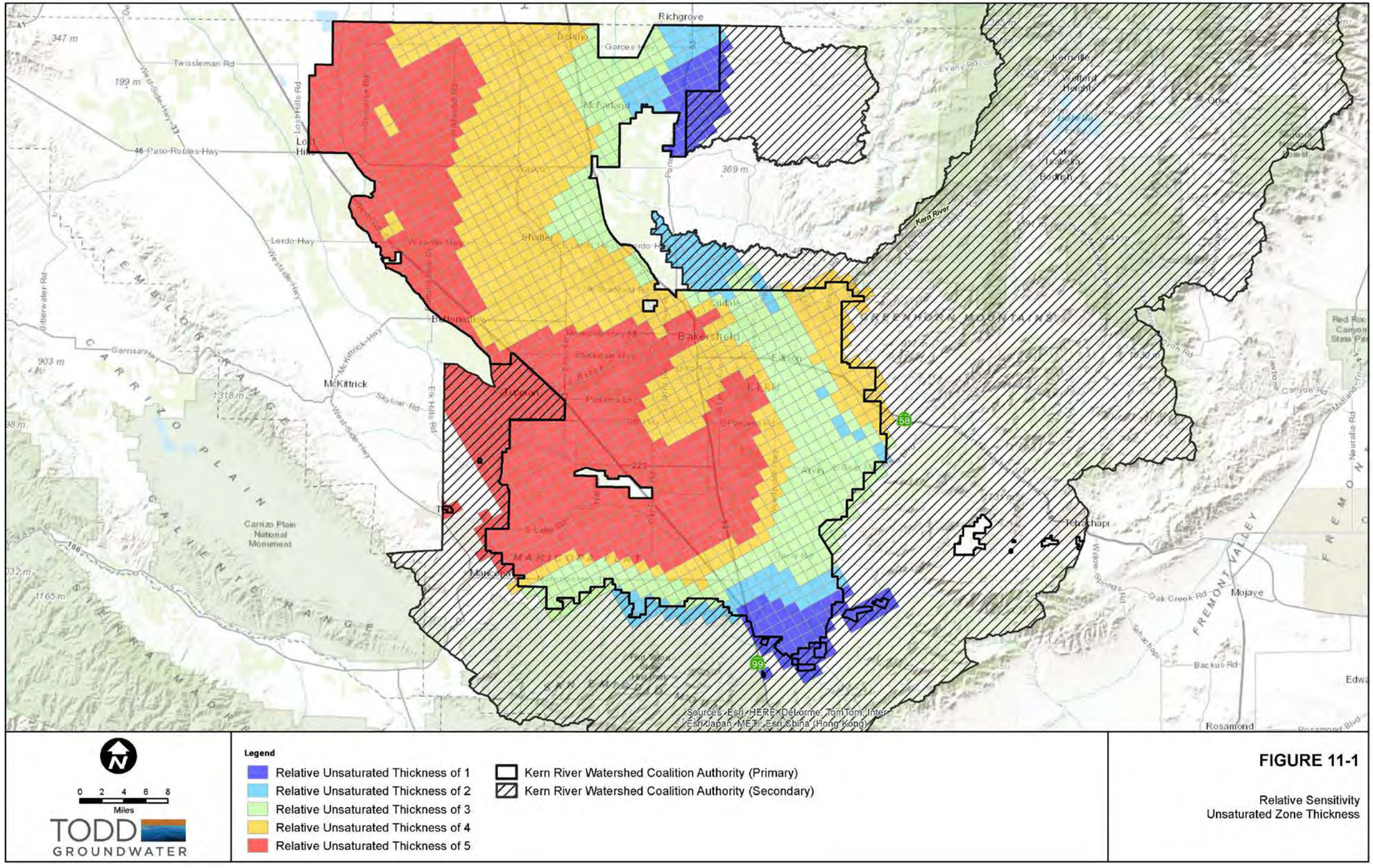


Figure 11-1. Relative Sensitivity, Unsaturated Zone Thickness

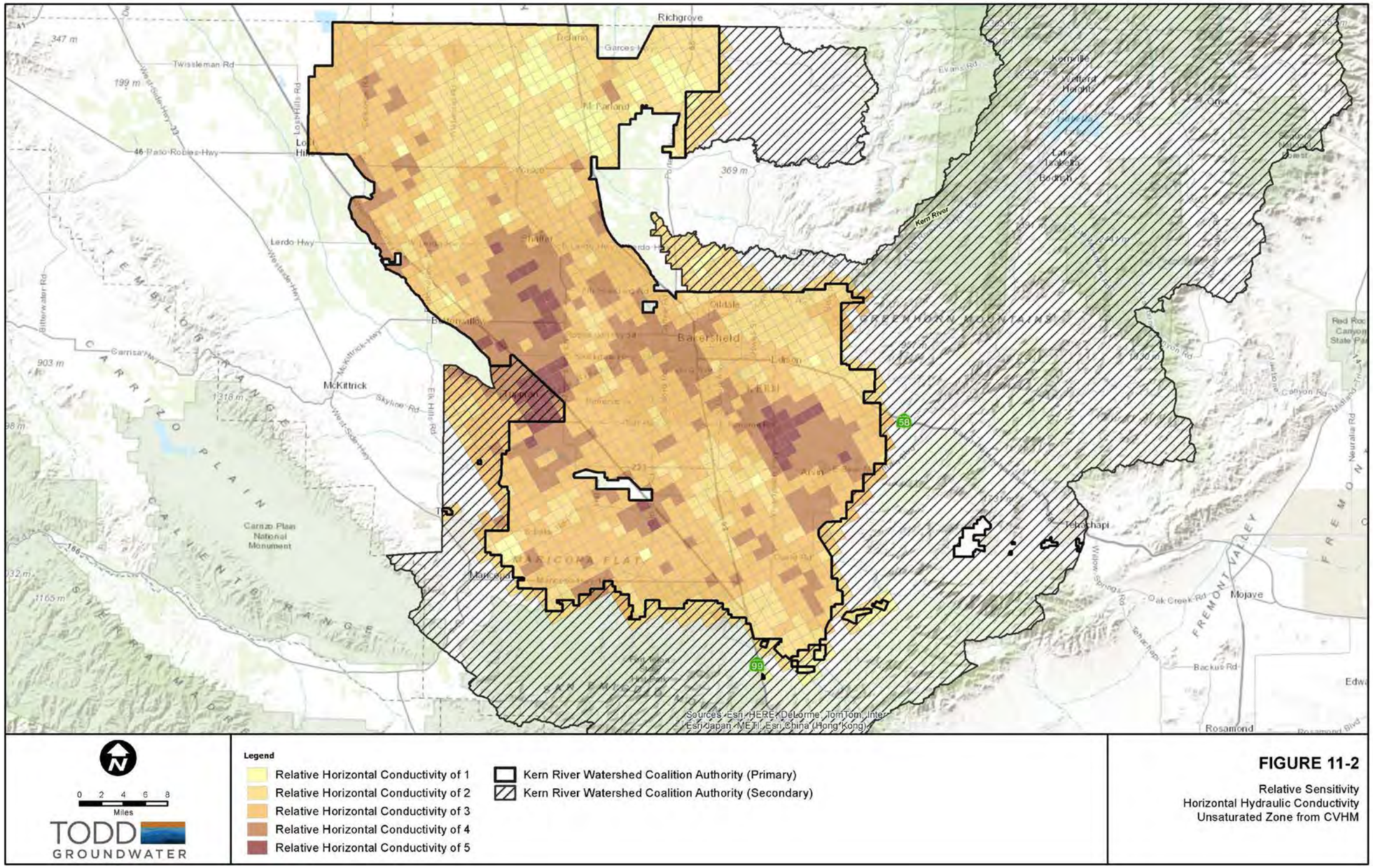


Figure 11-2. Relative Sensitivity, Horizontal Hydraulic Conductivity

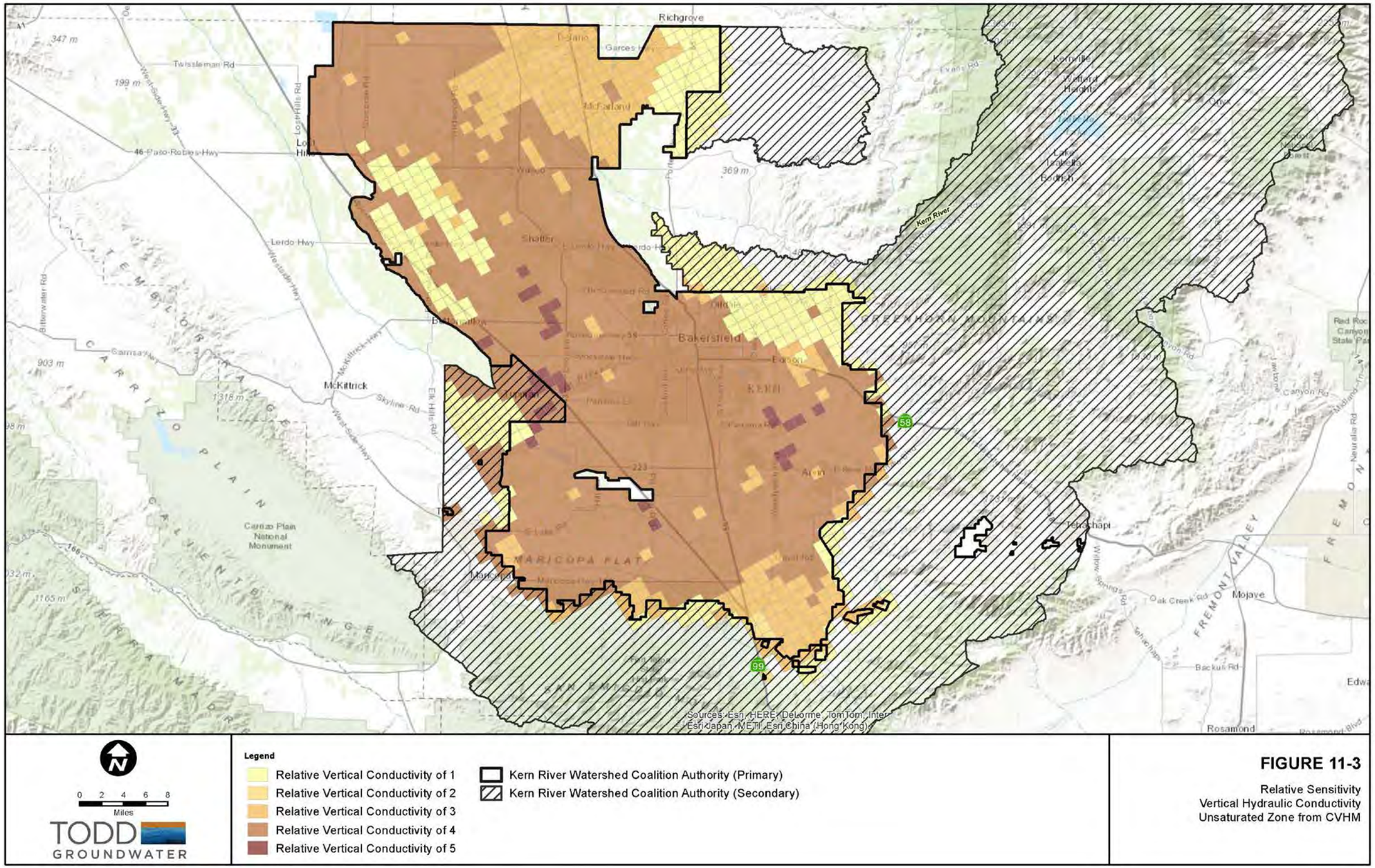


Figure 11-3. Relative Sensitivity, Vertical Hydraulic Conductivity

K_V	Unsaturated Thickness 1	2	3	4	5	K_H
1	1	2	3	4	5	1
1	2	4	6	8	10	2
1	3	6	9	12	15	3
1	4	8	12	16	20	4
1	5	10	15	20	25	5
2	2	4	6	8	10	1
2	4	8	12	16	20	2
2	6	12	18	24	30	3
2	8	16	24	32	40	4
2	10	20	30	40	50	5
3	3	6	9	12	15	1
3	6	12	18	24	30	2
3	9	18	27	36	45	3
3	12	24	36	48	60	4
3	15	30	45	60	75	5
4	4	8	12	16	20	1
4	8	16	24	32	40	2
4	12	24	36	48	60	3
4	16	32	48	64	80	4
4	20	40	60	80	100	5
5	5	10	15	20	25	1
5	10	20	30	40	50	2
5	15	30	45	60	75	3
5	20	40	60	80	100	4
5	25	50	75	100	125	5

K_V - Unsaturated Vertical Hydraulic Conductivity

K_H - Unsaturated Horizontal Hydraulic Conductivity

Figure 11-4. Combined Relative Hydrogeologic Sensitivity Matrix

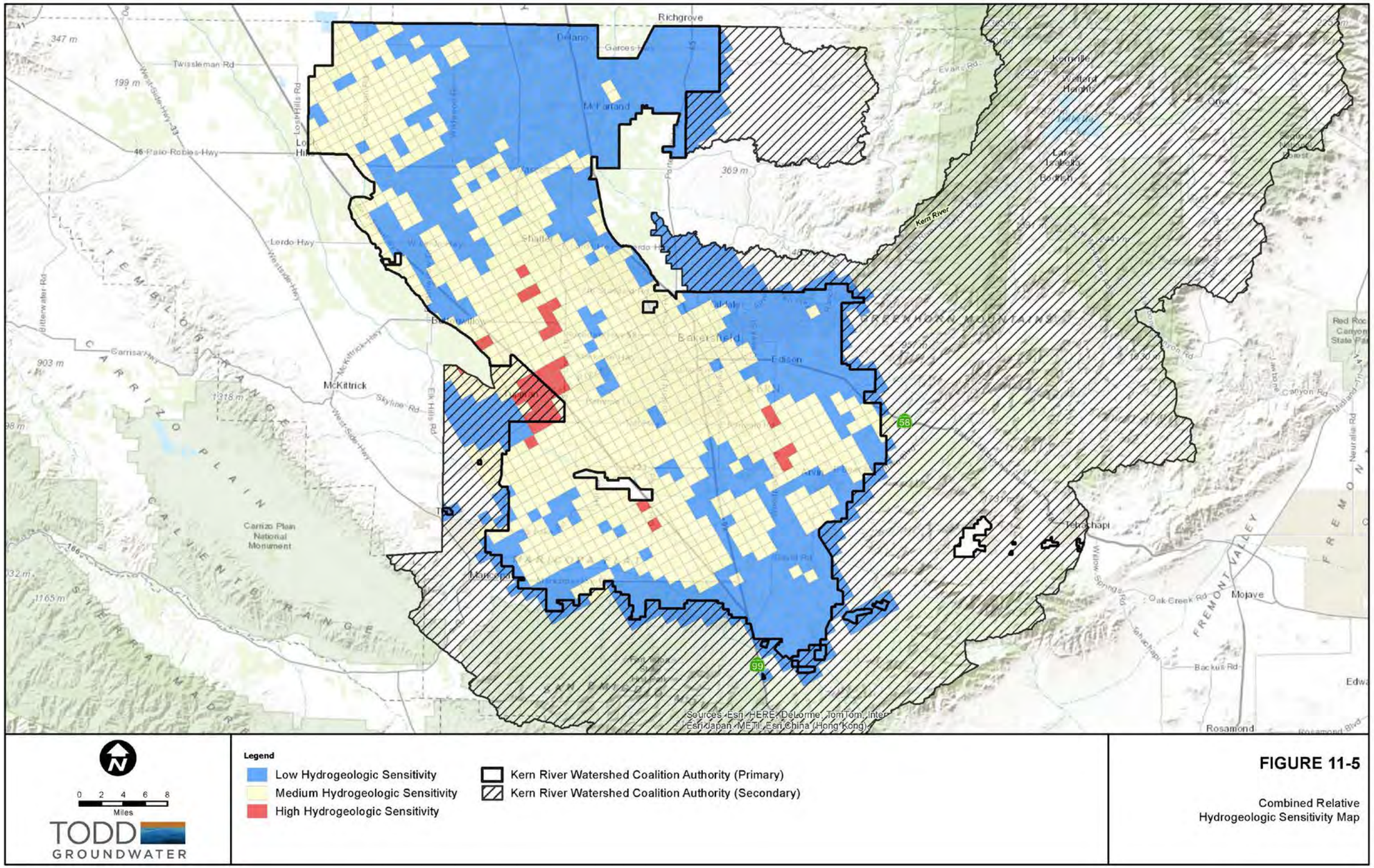


Figure 11-5. Combined Relative Hydrogeologic Sensitivity Map

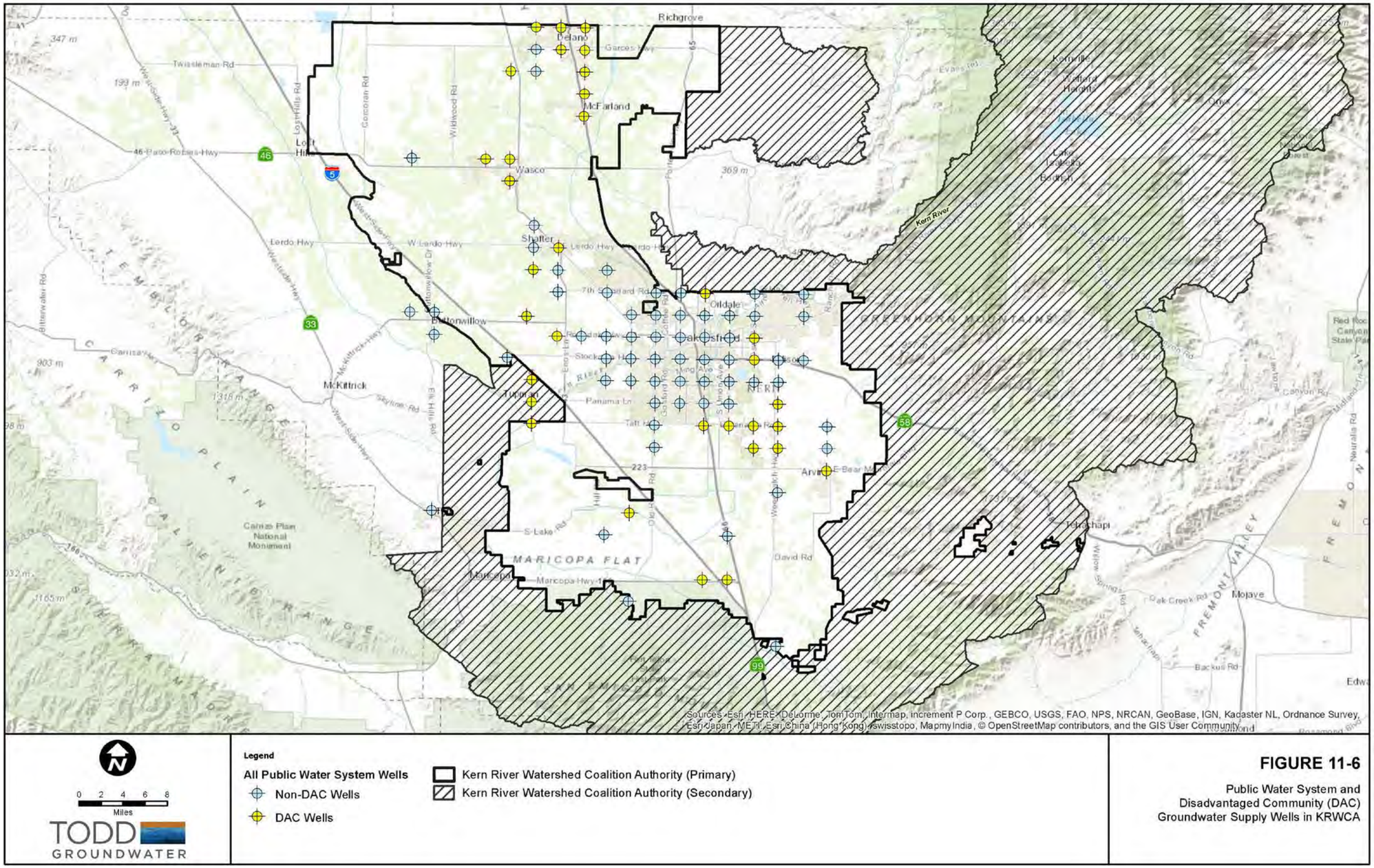


Figure 11-6. Public Water System and Disadvantaged Community (DAC) Groundwater Supply Wells in KRWCA

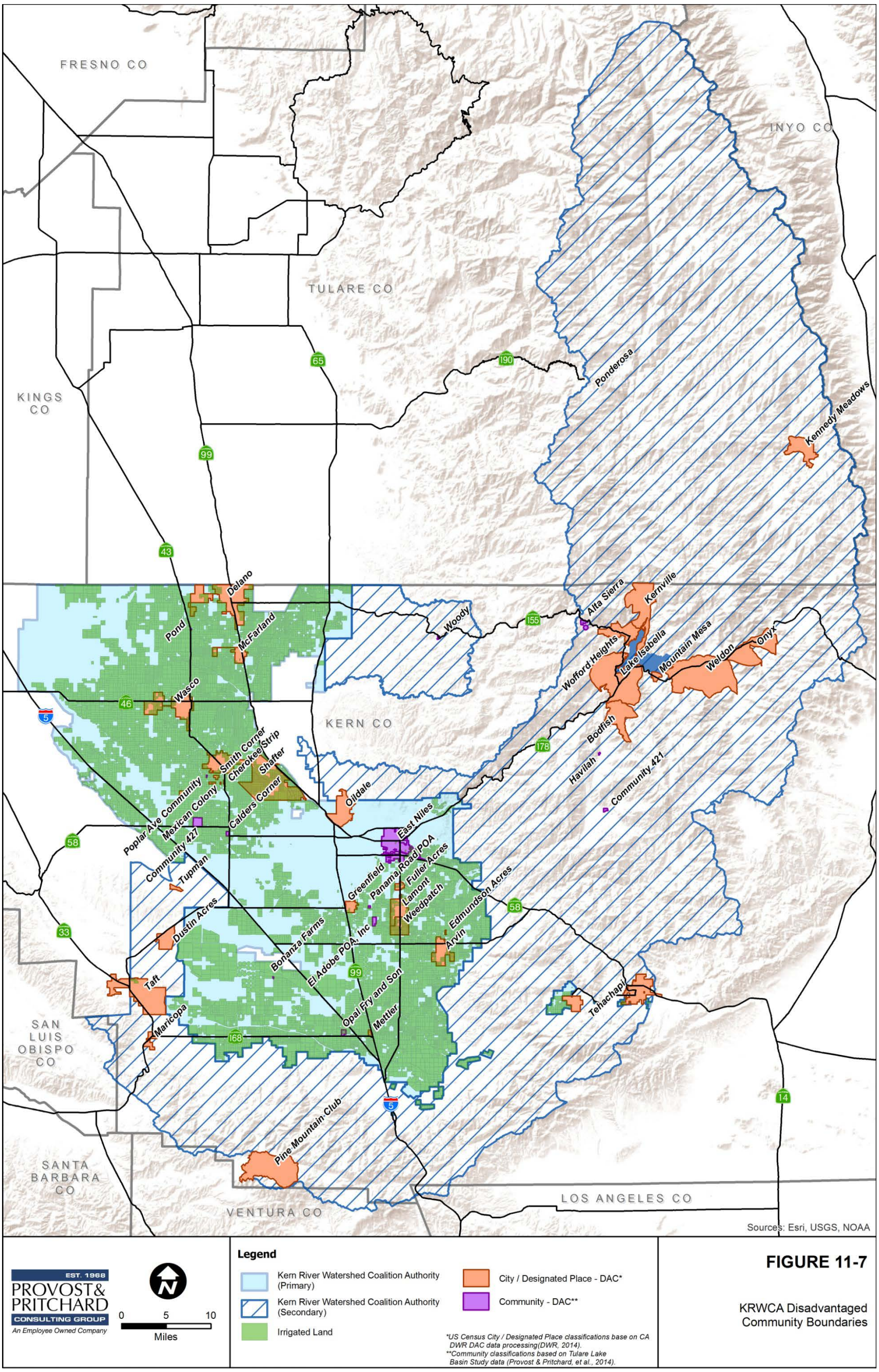
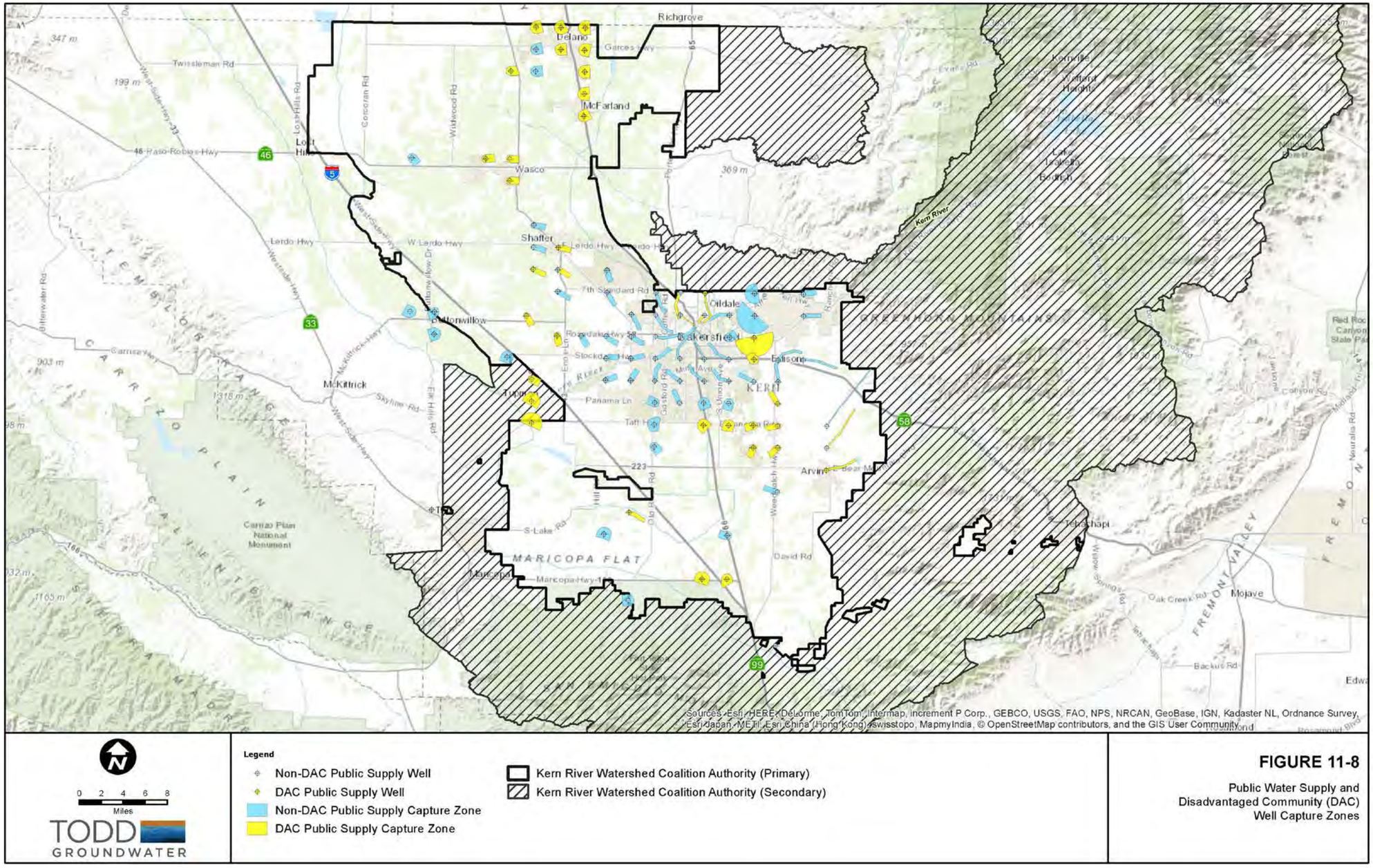


Figure 11-7. KRWCA Disadvantaged Community Boundaries



0 2 4 6 8
Miles

TODD GROUNDWATER

Legend

- Non-DAC Public Supply Well
- DAC Public Supply Well
- Non-DAC Public Supply Capture Zone
- DAC Public Supply Capture Zone
- Kern River Watershed Coalition Authority (Primary)
- Kern River Watershed Coalition Authority (Secondary)

FIGURE 11-8

Public Water Supply and Disadvantaged Community (DAC) Well Capture Zones

Figure 11-8. Public Water Supply and Disadvantaged Community (DAC) Well Capture Zones

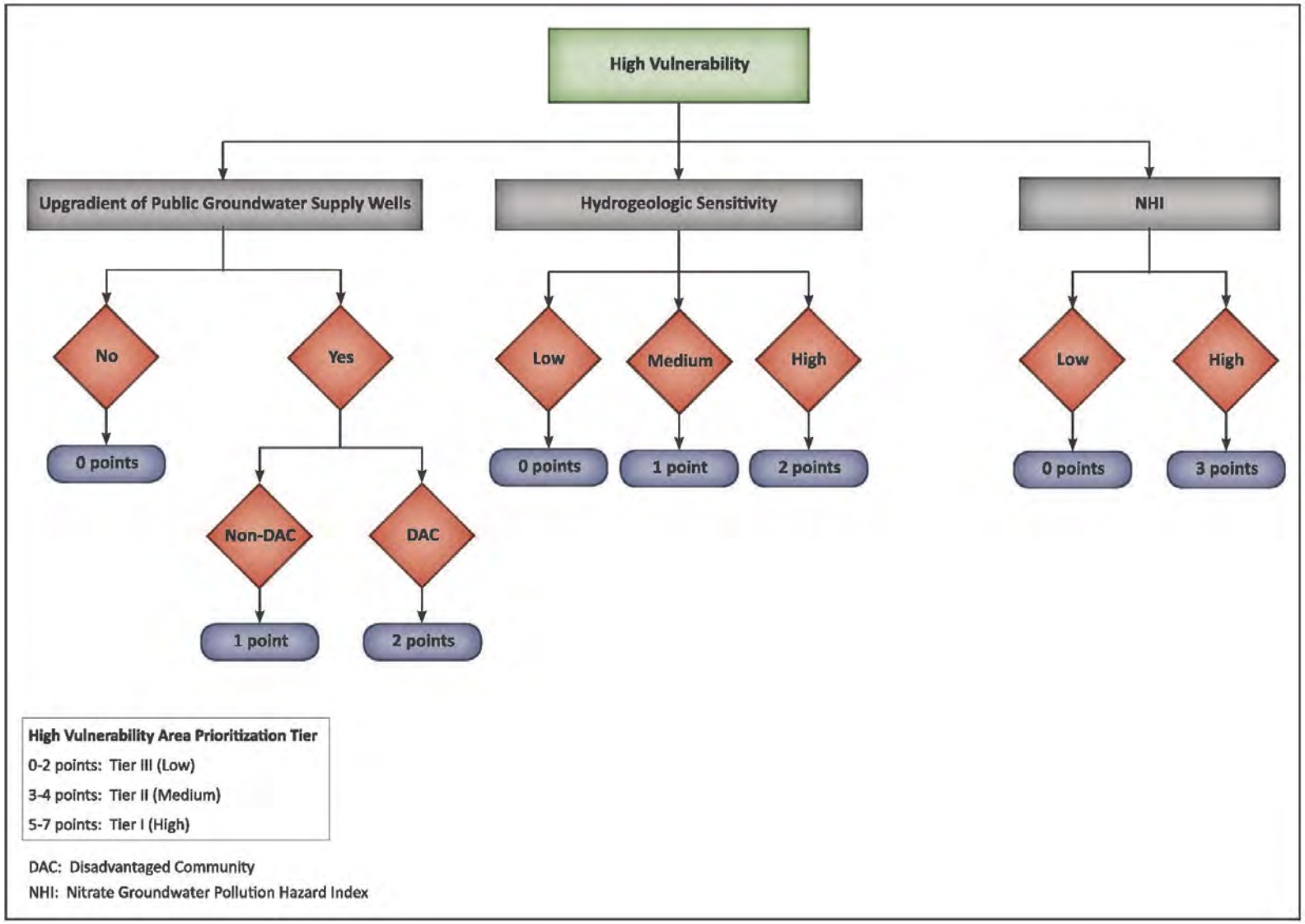


Figure 11-9. KRWCA Prioritization Framework Flowchart

Upgradient PWSS Well	Relative Hydrogeologic Sensitivity			NHI
	0	1	2	
0	0	1	2	0
0	3	4	5	3
1	1	2	3	0
1	4	5	6	3
2	2	3	4	0
2	5	6	7	3

PWSS - Public Water Supply System

Figure 11-10. High Vulnerability Area Prioritization Matrix

Table 11-1. High Vulnerability Area Prioritization Scenarios and Resulting Tiers

High Vulnerability Area Prioritization Scenarios and Resulting Tiers				
Upgradient of Public Groundwater Supply Wells	**Hydrogeologic Sensitivity**	**NHI**	**Points**	**Prioritization Tier**
DAC	High	High	7	Tier I
Yes	High	High	6	Tier I
DAC	Medium	High	6	Tier I
Yes	Medium	High	5	Tier I
DAC	Low	High	5	Tier I
No	High	High	5	Tier I
Yes	Low	High	4	Tier II
DAC	High	Low	4	Tier II
No	Medium	High	4	Tier II
Yes	High	Low	3	Tier II
DAC	Medium	Low	3	Tier II
No	Low	High	3	Tier II
Yes	Medium	Low	2	Tier III
DAC	Low	Low	2	Tier III
No	High	Low	2	Tier III
Yes	Low	Low	1	Tier III
No	Medium	Low	1	Tier III
No	Low	Low	0	Tier III

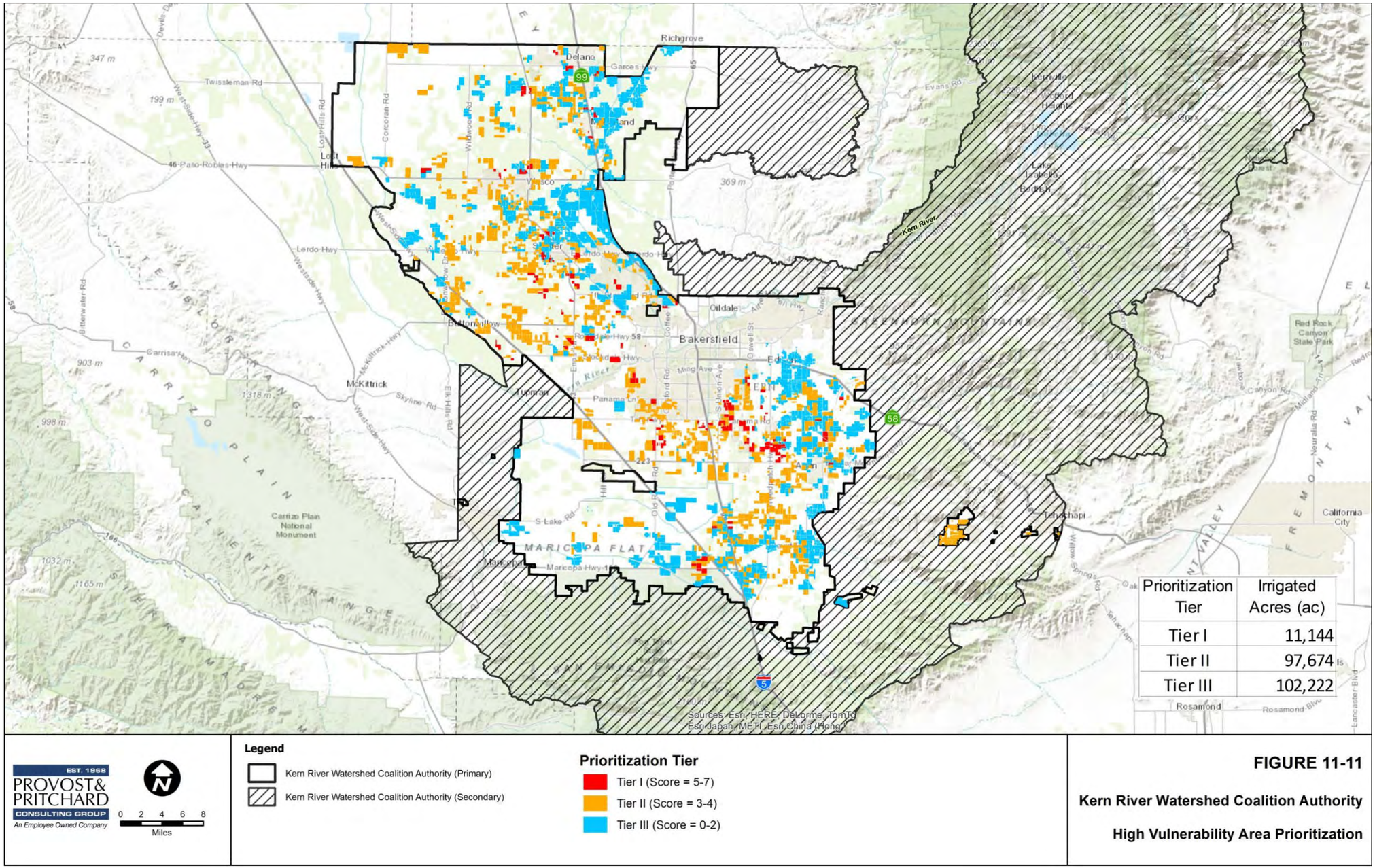


Figure 11-11. KRWCA High Vulnerability Area Prioritization

Table 11-2. KRWCA High Vulnerability Area Prioritization Tier Acreage

KRWCA High Vulnerability Area Prioritization Tier Acreage		
Prioritization Tier	**Irrigated Acres (ac)**	**Percent of Total (%)**
Tier I	11,144	5.3%
Tier II	97,674	46.3%
Tier III	102,222	48.4%
Subtotal:	211,040	100%

Table 11-3. KRWCA High Vulnerability Area Prioritization Parameters Acreage by Crop Type

KRWCA High Vulnerability Area Prioritization Parameters Acreage by Crop Type								
	Hydrogeologic Sensitivity (ac)			Upgradient of Public Groundwater Supply Wells (ac)			NHI (ac)	
	Low	Med	High	No	Yes		Low	High
					Non-DAC	DAC		
Crop	0 pts	1 pt	2 pts	0 pts	1 pt	2 pts	0 pts	3 pts
Alfalfa	3,707	3,742	215	6,166	457	1,041	5,797	1,866
Almonds	29,123	25,534	459	49,899	2,066	3,152	35,052	20,065
Citrus	8,246	2,192	0	9,708	614	117	10,121	318
Corn	2,654	8,356	227	9,968	503	765	377	10,860
Cotton	2,637	9,981	86	11,614	758	332	4,007	8,697
Field Crops	6,336	11,633	143	15,788	1,376	949	5,358	12,754
Fruit Tree	3,433	2,545	4	5,415	187	380	3,991	1,990
Grapes	18,925	8,482	328	25,631	937	1,168	27,728	8
Nut Tree	886	319	40	1,177	8	61	82	1,163
Pasture	57	92	0	94	5	50	18	132
Pistachios	4,429	4,770	7	8,941	70	195	3,821	5,384
Potatoes	6,918	11,552	194	16,680	1,340	645	1,276	17,389
Tomatoes	2,090	1,961	0	3,441	389	221	1,394	2,657
Truck Crops	15,742	12,681	312	26,569	477	1,689	5,397	23,338

Table 11-4. KRWCA High Vulnerability Area by Crop Type

KRWCA High Vulnerability Area by Crop Type			
Crop	**Acres (ac)**	**Percent of Total (%)**	**Cumulative Percent (%)**
Almonds	55,117	26.1%	26.1%
Truck Crops	28,735	13.6%	39.7%
Grapes	27,736	13.1%	52.9%
Potatoes	18,665	8.8%	61.7%
Field Crops	18,112	8.6%	70.3%
Cotton	12,704	6.0%	76.3%
Corn	11,236	5.3%	81.6%
Citrus	10,439	4.9%	86.6%
Pistachios	9,205	4.4%	91.0%
Alfalfa	7,664	3.6%	94.6%
Fruit Tree	5,981	2.8%	97.4%
Tomatoes	4,051	1.9%	99.3%
Nut Tree	1,245	0.6%	99.9%
Pasture	149	0.1%	100.0%

Table 11-5. KRWCA Prioritization Tier Acreage by Crop Type

KRWCA Prioritization Tier Acreage by Crop Type		
Prioritization Tier	**Crop**	**Total Acres (ac)**
Tier I	Almonds	2,319
	Truck Crops	2,121
	Field Crops	1,916
	Potatoes	1,597
	Corn	1,228
	Cotton	930
	Tomatoes	299
	Alfalfa	293
	Fruit Tree	215
	Nut Tree	100
	Citrus	53
	Pasture	46
	Pistachios	27
Tier II	Truck Crops	21,360
	Almonds	18,885
	Potatoes	15,842
	Field Crops	10,866
	Corn	9,632
	Cotton	7,767
	Pistachios	5,357
	Tomatoes	2,358
	Alfalfa	1,917
	Fruit Tree	1,882
	Nut Tree	1,062
	Citrus	349
	Grapes	311
	Pasture	86
Tier III	Almonds	33,913
	Grapes	27,424
	Citrus	10,037
	Alfalfa	5,454
	Field Crops	5,330
	Truck Crops	5,254
	Cotton	4,007
	Fruit Tree	3,884
	Pistachios	3,821
	Tomatoes	1,394
	Potatoes	1,226
	Corn	377
	Nut Tree	82
	Pasture	18
	Total Acres (ac):	**211,040**

Table 11-6. KRWCA Prioritization Tier Acreage by Irrigation System Type

KRWCA Prioritization Tier Acreage by Irrigation System Type		
Prioritization Tier	**Irrigation System Type**	**Total Acres (ac)**
Tier I	Surface	5,799
	Sprinkler/Surface	3,558
	Sprinkler	1,787
Tier II	Surface	57,890
	Sprinkler	24,667
	Sprinkler/Surface	13,642
	Drip	1,423
	Drip/Sprinkler	52
Tier III	Drip	74,155
	Surface	14,553
	Sprinkler	12,534
	Sprinkler/Surface	907
	Drip/Sprinkler	73
	Total Acres (ac):	**211,040**

Table 11-7. KRWCA Prioritization Tier I Acreage by Crop and Irrigation System Type

KRWCA Prioritization Tier I Acreage by Crop and Irrigation System Type			
Prioritization Tier	**Crop**	**Irrigation System Type**	**Total Acres (ac)**
Tier I	Almonds	Surface	2,319
	Truck Crops	Sprinkler/Surface	1,108
		Surface	529
		Sprinkler	484
	Field Crops	Sprinkler/Surface	1,141
		Surface	776
	Potatoes	Sprinkler	1,299
		Sprinkler/Surface	240
		Surface	58
	Corn	Sprinkler/Surface	781
		Surface	447
	Cotton	Surface	865
		Sprinkler/Surface	65
	Tomatoes	Surface	217
		Sprinkler/Surface	77
		Sprinkler	4
	Alfalfa	Sprinkler/Surface	146
		Surface	146
	Fruit Tree	Surface	215
	Nut Tree	Surface	100
	Citrus	Surface	53
	Pasture	Surface	46
	Pistachios	Surface	27
		Total Acres (ac):	**11,144**

Table 11-8. KRWCA Prioritization Tier II Acreage by Crop and Irrigation System Type

KRWCA Prioritization Tier II Acreage by Crop and Irrigation System Type			
Prioritization Tier	**Crop**	**Irrigation System Type**	**Total Acres (ac)**
Tier II	Truck Crops	Sprinkler	11,060
		Surface	6,071
		Sprinkler/Surface	4,215
		Drip/Sprinkler	14
	Almonds	Surface	17,481
		Drip	1,103
		Sprinkler	36
		Sprinkler/Surface	264
	Potatoes	Sprinkler	12,679
		Surface	2,011
		Sprinkler/Surface	1,102
		Drip	50
	Field Crops	Surface	8,209
		Sprinkler/Surface	2,654
		Sprinkler	3
	Corn	Surface	5,216
		Sprinkler/Surface	4,413
		Sprinkler	2
	Cotton	Surface	7,499
		Sprinkler/Surface	268
	Pistachios	Surface	5,357
	Tomatoes	Surface	1,396
		Sprinkler	664
		Sprinkler/Surface	298
	Alfalfa	Surface	1,518
		Sprinkler/Surface	400
	Fruit Tree	Surface	1,736
		Sprinkler	79
		Drip/Sprinkler	38
		Drip	28
	Nut Tree	Surface	1,062
	Citrus	Surface	265
		Drip	83
	Grapes	Drip	159
		Sprinkler	144
		Surface	8
	Pasture	Surface	59
		Sprinkler/Surface	27
		Total Acres (ac):	**97,674**

Table 11-9. KRWCA Prioritization Tier III Acreage by Crop and Irrigation System Type

KRWCA Prioritization Tier III Acreage by Crop and Irrigation System Type			
Prioritization Tier	**Crop**	**Irrigation System Type**	**Total Acres (ac)**
Tier III	Almonds	Drip	32,663
		Sprinkler	1,250
	Grapes	Drip	20,394
		Surface	6,736
		Sprinkler	234
		Sprinkler/Surface	61
		Drip/Sprinkler	1
	Citrus	Drip	9,833
		Sprinkler	204
	Alfalfa	Surface	4,332
		Sprinkler	944
		Drip	178
	Field Crops	Sprinkler	3,679
		Sprinkler/Surface	756
		Surface	658
		Drip	238
	Truck Crops	Sprinkler	2,619
		Drip	2,451
		Surface	113
		Drip/Sprinkler	72
	Fruit Tree	Drip	3,294
		Sprinkler	590
	Pistachios	Drip	3,816
		Sprinkler	6
	Tomatoes	Drip	1,012
		Sprinkler	382
	Potatoes	Sprinkler	999
		Drip	227
	Corn	Surface	373
		Drip	4
	Nut Tree	Sprinkler	75
		Drip	8
	Pasture	Sprinkler	17
		Drip	1
		Total Acres (ac):	**102,222**

12 Existing Groundwater Monitoring Programs Assessment

There are many local agencies/entities that historically and currently conduct groundwater monitoring in the Kern River Watershed Coalition Authority (**KRWCA**) area. This monitoring includes groundwater quality and/or groundwater elevation data collection. The wells included in these monitoring programs are spread throughout the entire KRWCA area.

The General Order of Waste Discharge Requirements R5-2013-120 (**WDR**) specifies that within one year after approval of the Groundwater Quality Assessment Report (**GAR**), the KRWCA shall develop a Management Practices Evaluation Program (**MPEP**) workplan. If a group effort among other coalitions is undertaken, the MPEP workplan is due two years after GAR approval. The MPEP workplan must include a scientifically sound approach to evaluating the effect of management practices on groundwater quality. An approach, as outlined by the Central Valley Regional Water Quality Control Board (**CVRWQCB**), may include groundwater monitoring, modeling, vadose zone sampling, and/or other scientifically sound and technically justifiable methods for meeting the objectives of the MPEP. In addition, as required by the CVRWQCB, any groundwater quality monitoring that is part of the MPEP workplan must be of first encountered groundwater. Thus, existing groundwater monitoring programs may be limited with regards to what may be able to be incorporated as part of the MPEP workplan.

The WDR specifies that within one year from the approval of the GAR, the KRWCA shall develop a workplan for conducting groundwater quality trend monitoring that meets the objectives and minimum CVRWQCB requirements of the Monitoring and Reporting Program (**MRP**). The objectives for the trend monitoring program are to determine current water quality conditions of groundwater relevant to irrigated agriculture and develop long-term water quality information that can be used to evaluate the regional effect of irrigated agriculture and its practices.

The design and implementation of the trend monitoring program, as mandated by the CVRWQCB, will include a groundwater monitoring network workplan that may address:

i. Groundwater quality in high and low vulnerability portions of the KRWCA area;

ii. The potential suitability of existing monitoring programs and networks; and,

iii. The rationale for the distribution of the trend monitoring wells.

Existing state and local groundwater quality and elevation monitoring programs are summarized in this section to provide a preliminarily assessment as a basis for the KRWCA's MRP. There is very little readily available information relating to well construction associated with the existing monitoring programs. As a result, the MRP workplans may include further evaluation of the components of these monitoring programs to identify appropriate wells for inclusion, if any.

12.1 Summary of Existing Groundwater Monitoring Programs

The entities that monitor groundwater quality in the KRWCA area are summarized below. Some of these parties also monitor groundwater elevations, which are described separately.

12.1.1 California Department of Water Resources

The California Department of Water Resources (**DWR**) manages the water resources of California in cooperation with other agencies. DWR monitors groundwater elevations and quality throughout California. Water quality samples were historically collected directly from selected monitoring wells by DWR and combined with data from other State agencies, along with county and local agency data, in a comprehensive database. The DWR monitoring program covers the entire state of California, including both the primary and secondary portions of the KRWCA area. However, the majority of the monitored wells are within the primary area, given the higher density of wells and groundwater use as compared to the secondary area.

DWR measures groundwater elevations in 773 wells in the KRWCA area on an annual basis. The specific wells used vary from year to year. The majority of these wells are reported to be deep wells with perforations past first encountered groundwater. Some of these wells are completed in shallow perched zones, where salinity monitoring is also conducted. Besides this salinity monitoring, there is currently no other groundwater quality monitoring conducted by DWR in the KRWCA area. Construction information is available for approximately 200 of the 773 wells monitored by DWR in the KRWCA area; however, this information is not publicly available.

12.1.2 Kern County Water Agency

Kern County Water Agency (**KCWA**) has many water supply and management roles in Kern County. This includes monitoring groundwater elevations and groundwater quality throughout Kern County, with a focus on areas served by State Water Project water. KCWA also closely monitors groundwater banking projects on the Kern River alluvial fan. KCWA collects and interprets this data for various Kern County interests. In the KRWCA area, groundwater elevations are collected semi-annually from 800 production wells and 200 monitoring wells. Of these, groundwater elevations are collected from approximately 350 production and monitoring wells monthly within the Kern River Alluvial Fan area. Groundwater quality is also monitored from selected production wells at a frequency that varies by area and well.

12.1.3 State Water Resources Control Board Division of Drinking Water

Public water systems are required to report water quality parameters to the State Water Resources Control Board Division of Drinking Water [**SWRCB-DDW**, formerly a section of the California Department of Public Health (**CDPH**)] on a triennial or more frequent schedule, depending on the location of the system and specific circumstances that may require more frequent testing and reporting. This data collection responsibility of the SWRCB-DDW extends to all public water systems in the State. Currently, groundwater quality data for 4,458 individual well locations within Kern and Tulare county portions of the KRWCA boundary are being reported to the SWRCB-DDW. The monitoring frequency varies by water system and well as a function of past detections and nearby sources of potential contamination. The water quality constituents that are monitored in these wells also vary as a function of potential sources of contamination and past detections. Total dissolved solids (**TDS**), nitrate, and other nitrogen species are generally required for all public water supply wells. Some of these wells are also monitored for pesticides, but these monitoring requirements are less frequent. Construction information associated with these wells is not generally available.

12.1.4 California Department of Pesticide Regulation

The California Department of Pesticide Regulation (**DPR**) groundwater protection program evaluates and samples wells for pesticides, identifies areas sensitive to pesticide contamination, and develops mitigation measures to prevent impacts. As of 2007, DPR was sampling 255 wells in Kern County. In the 255 wells in Kern County, methods were employed to detect 86 chemicals, and 36 wells had detections of one or more pesticides. These wells are monitored annually, and monitoring does not include collection of groundwater elevation data. Construction information is not available for these wells.

12.1.5 Groundwater Ambient Monitoring and Assessment Program

The Groundwater Ambient Monitoring and Assessment Program (**GAMA**) program is California's comprehensive groundwater quality monitoring program. GAMA was created by the State Water Resources Control Board (**SWRCB**) in 2000 and expanded by the Groundwater Quality Monitoring Act of 2001. The GAMA program includes four components: the Priority Basin Project, the Domestic Well Project, the Special Studies Project, and GeoTracker GAMA. Data for GAMA comes from a variety of sources, depending on the component. These data sources include the United States Geological Survey (**USGS**), Lawrence Livermore National Laboratory (**LLNL**), the SWRCB-DDW (formerly CDPH), DWR, DPR, and volunteer private well owners. Data is collected by testing wells for naturally-occurring and man-made chemicals. GAMA compiles these test results with existing groundwater quality data into a database that is publicly-accessible through the GeoTracker website. There are a total of 3,669 GAMA monitored wells within the KRWCA area, with most located within the primary boundary. These sites include all regulated permitted underground storage tanks (**UST**), leaking UST cleanup sites, cleanup program sites, land disposal sites, military bases, military cleanup sites, and military UST sites. The frequency and constituents monitored for each of these regulated facilities are determined by individual regulatory agencies based on the site type and occurrence of spills or other releases. Monitoring frequency can be monthly, quarterly, semi-annually, or annually, and monitored constituents vary widely. Groundwater elevation monitoring is generally included as a component of these monitoring programs. Construction information is not publicly available for wells in the GAMA program.

12.1.6 Central Valley Regional Water Quality Control Board (CVRWQCB)

Existing production wells located on dairy properties regulated under the Waste Discharge Requirements General Order for Existing Milk Cow Dairies (Order R5-2013-0122) (**Dairy General Order**) are required to be monitored. Within the KRWCA, there are 50 dairies that are monitored by the CVRWQCB. This program focuses on nitrate detections from these monitored wells. The nitrate detections that are above the California maximum contaminant level (**MCL**) are flagged for review. Currently, 16 of the 50 dairies have nitrate levels that are above the MCL of 45 milligrams per liter (**mg/L**) for nitrate as nitrate (nitrate as NO_3). These wells are monitored annually, and monitoring does not include collection of groundwater elevation data. Construction information is not available for the production wells in the CVRWQCB Dairy General Order.

Some dairies have individual first encountered groundwater monitoring networks. Most dairies under the Dairy General Order comply with groundwater monitoring requirements by participation in a Representative Monitoring Program (**RMP**). One dairy in Kern County is monitored as part of the Central Valley Dairy Representative Monitoring Program (**CVDRMP**). Information on the groundwater quality monitoring networks can be obtained from the CVRWQCB through a public information request.

The CVRWQCB also oversees groundwater monitoring programs for individual WDRs for operations including, but not limited to, landfill sites, wastewater treatment plants (**WWTPs**), processed water treatment facilities, agricultural processing, and applied reclaimed water sites. The WDR groundwater monitoring programs are to determine if the activities of the individual waste discharger are affecting current groundwater quality, generally focusing on first encountered groundwater. Information on the groundwater quality monitoring networks can be obtained from the CVRWQCB through a public information request.

12.1.7 California Statewide Groundwater Elevation Monitoring Program

The California Statewide Groundwater Elevation Monitoring (**CASGEM**) program tracks seasonal and long-term trends in groundwater elevations across all groundwater basins within the State. This program is a collaboration between local monitoring entities and DWR to collect groundwater elevation data. The CASGEM program was initiated by State legislation in 2009 that amended the California Water Code to include a mandate for monitoring groundwater elevations in designated groundwater basins.

The CASGEM program relies on established local long-term groundwater monitoring and management programs, with DWR acting in a coordination and database maintenance role. This program functions independently from the DWR monitoring program described above. Monitoring and reporting for CASGEM began in 2011. The following agencies within the KRWCA primary area are CASGEM monitoring entities:

- Arvin-Edison Water Storage District (12 CASGEM wells, 28 voluntary wells);
- Deer Creek & Tule River Authority (3 wells);
- Kern County Water Agency Improvement District No. 4 (4 wells);
- Kern River Fan Group (34 wells);
- Kern Water Bank Authority (15 wells);
- North Kern Water Storage District (9 wells);
- Semitropic Water Storage District (46 wells); and,
- Shafter-Wasco Irrigation District (2 wells).

In addition to the CASGEM monitoring entities in the Kern County portion of the San Joaquin Basin, the County of Ventura Watershed Protection District is the monitoring entity for the small Cuddy Ranch Area Basin located in the secondary portion of the KRWCA area. The County of Ventura Watershed Protection District monitors five wells in this Basin and only one of them has construction information.

CASGEM only includes groundwater elevation data collection, and no water quality data is collected or submitted to DWR as part of this program. The entities listed above establish the monitoring frequency for each program independently; with the guidance that data collection should show both long and short-term trends in groundwater elevations and be semi-annual at a minimum. Well construction information is available for 132 of the 154 wells in the CASGEM programs listed above. Voluntary wells do not have readily available construction details. The areas covered by these monitoring entities are shown on **Figure 12-1.**

12.1.8 Individual Water District Groundwater Management Plans

In addition to the monitoring plans listed above, there are also several water districts within and surrounding the KRWCA area that have developed Groundwater Management Plans (**GMPs**) under provisions of the California Water Code. The water districts with existing GMPs are[1]:

- Arvin-Edison Water Storage District* (76 District production wells);
- Bear Valley Community Services District (25 wells);
- Buena Vista Water Storage District (11 wells);
- KCWA Improvement District No. 4 (4 wells);
- Kern Delta Water District* (more than 1,000 wells);
- Olcese Water District* (unknown number of wells);
- Poso Creek Regional Management Group, including Cawelo Water District, Delano-Earlimart Irrigation District, Kern-Tulare Water District*, North Kern Water Storage District*, Semitropic Water Storage District* (100 total wells)[2];
- Rosedale-Rio Bravo Water Storage District* (27 wells);
- Southern San Joaquin Municipal Utilities District* (unknown number of wells);
- Tehachapi-Cummings Community Water District (unknown number of wells);
- West Kern Water District (8 wells); and,
- Wheeler Ridge-Maricopa Water Storage District* (6 wells).

These GMPs often include a component of monitoring for groundwater elevations and/or quality. However, these data are not publicly available and are maintained for individual district or management group use. The areas covered by each of these water districts or groups are shown on **Figure 12-2**.

12.1.9 SB4 – Oil and Gas Well Stimulation Monitoring

Senate Bill 4 – Oil and Gas Well Stimulation Monitoring (**SB4**) will be addressed in KRWCA Groundwater Quality Trend Monitoring Program (**GTMP**) as these programs are still in development.

12.2 Applicability of Existing Groundwater Monitoring Programs

The existing monitoring programs provide good groundwater elevation and groundwater quality data coverage for the primary portion of the KRWCA and fair coverage of the secondary portion. These plans are more consistently designed to collect groundwater elevation data but groundwater quality data is also collected, in some cases. Groundwater datasets do not have consistent well construction information readily available to perform an adequate evaluation of depth specific groundwater elevation and quality.

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[1] '*' denotes KRWCA member water districts.

[2] The Poso Creek Regional Management Group member districts have also developed individual GMPs for their respective boundary area.

Of the known monitoring locations in the KRWCA area, there are 7,331 locations in the primary area (1,173 from SWRCB-DDW, 3,126 from DWR, 29 environmental monitoring wells, 2,150 from KCWA, and 853 water supply wells), and 1,327 in the secondary area (730 from SWRCB-DDW, 287 from DWR, 1 environmental monitoring well, 217 from KCWA, and 92 water supply wells).

The existing monitoring programs appear to offer many opportunities for KRWCA's MRP. However, in the development of this program, through the respective workplans, it will be necessary to further evaluate the availability of well construction information for key wells.

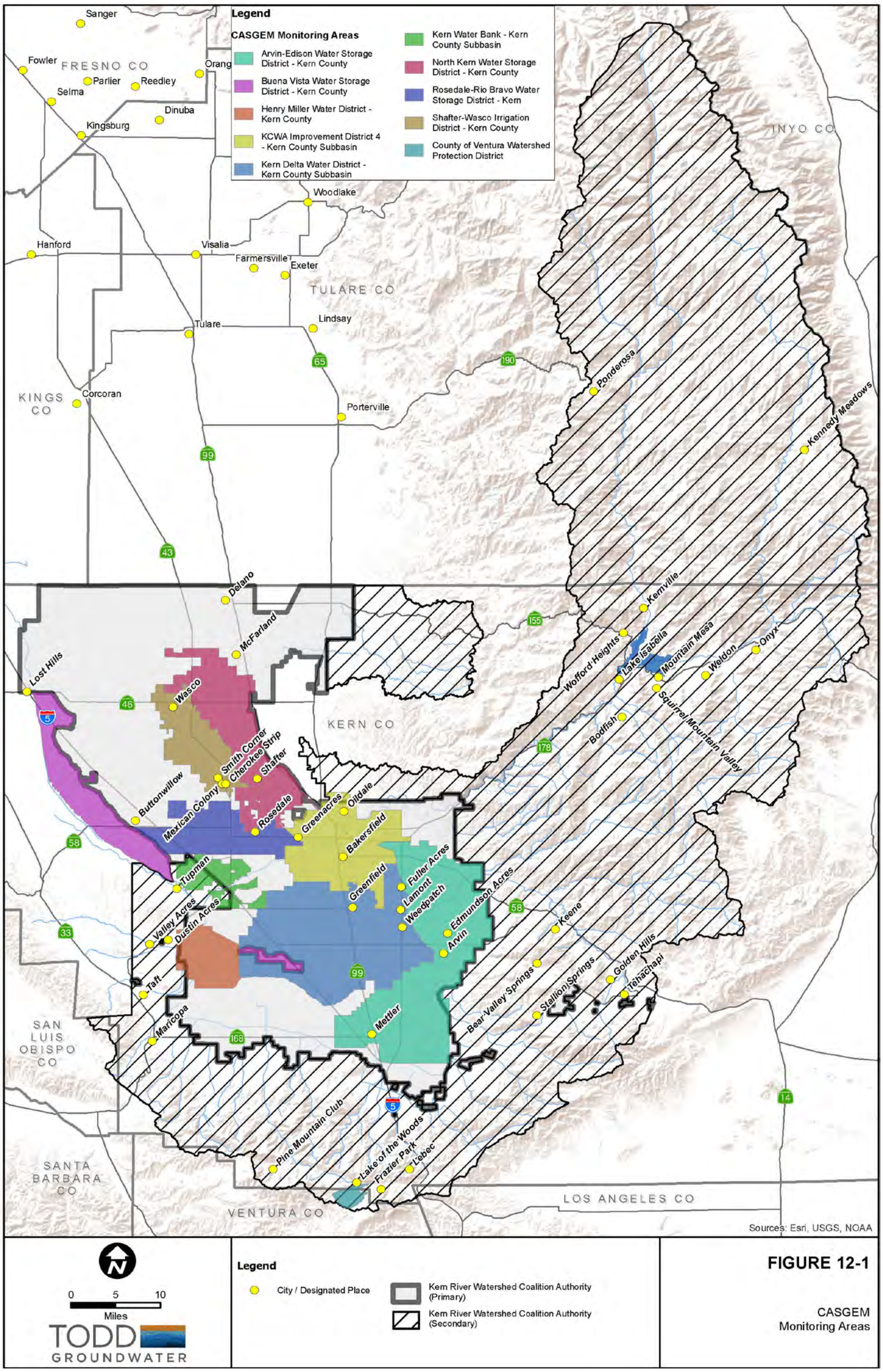

Figure 12-1. CASGEM Monitoring Areas

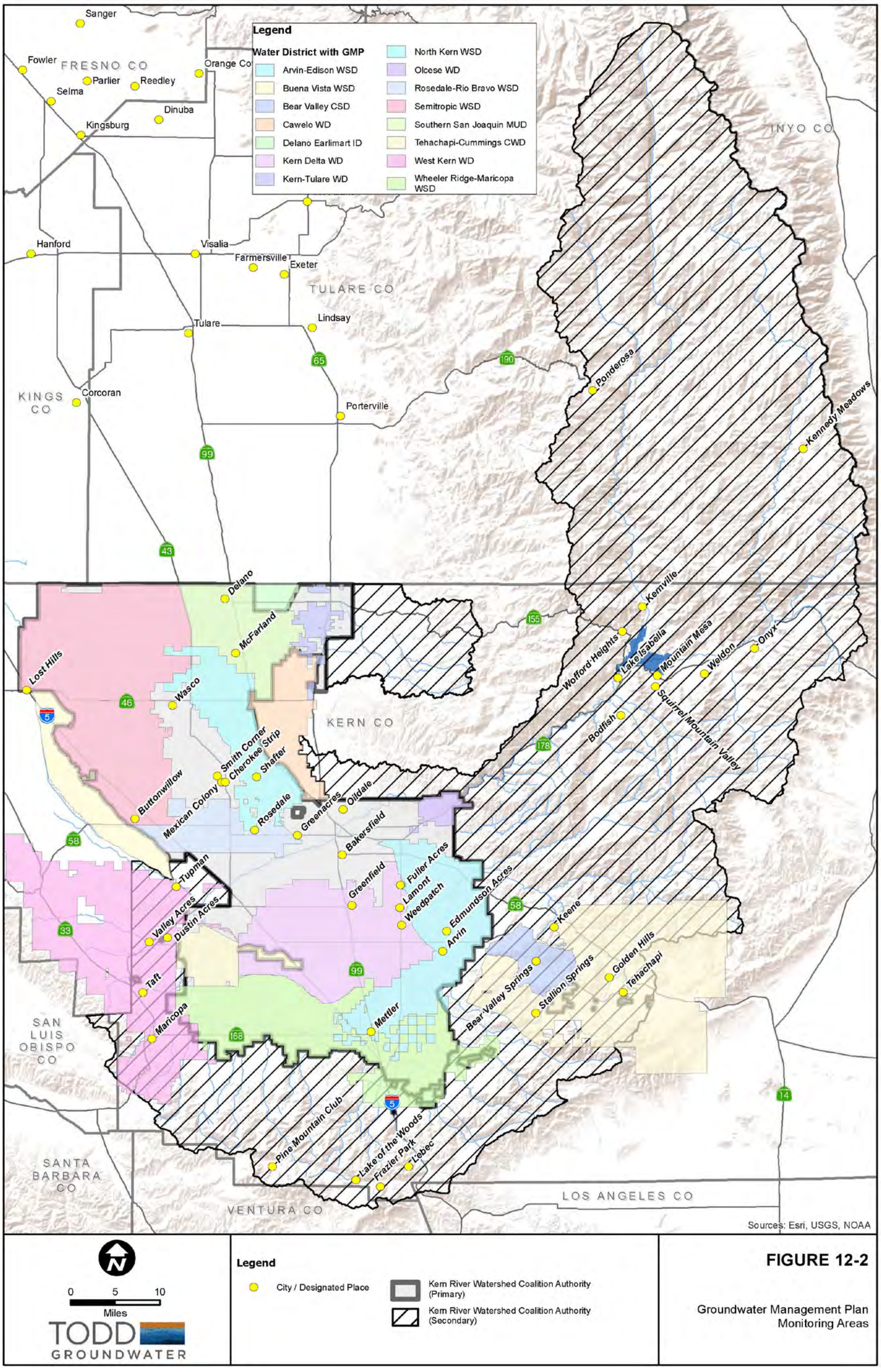

Figure 12-2. Groundwater Management Plan Monitoring Areas

13 Summary and Recommendations

13.1 Management Practice Evaluation Program Recommendations

The Kern River Watershed Coalition Authority (**KRWCA**) has entered into a coordination agreement for the Management Practice Evaluation Program (**MPEP**) group option, dated November 18, 2014. The following additional coalitions are parties to this agreement:

- Kings River Watershed Coalition Authority;
- Tule Basin Water Quality Coalition;
- Kaweah Basin Water Quality Association; and,
- Cawelo Water District Coalition.

As specified in the General Order, the purpose of the MPEP is to determine the effects that irrigated agricultural practices may have on first encountered groundwater under different conditions that could affect the discharge of waste from irrigated lands to groundwater (e.g., soil type, depth to groundwater, irrigation practice, crop type, nutrient management practice, etc.). As paraphrased by the State Water Resources Control Board Agricultural Expert Panel (**SWRCB-AEP**), the intent of the MPEP is to develop a link between a proxy metric and actual discharge through a 'representative practice evaluation' (SWRCB-AEP 2014). Overall, this objective, to establish a direct relationship between the nitrogen mass balance, nitrate discharge below the root zone, and groundwater quality monitoring as related to specific representative agricultural management practices and physical conditions, is extremely difficult to achieve. In defining nitrate discharge, numerous scientific studies corroborate the difficulty of tracking nitrogen leaching past the root zone as well as the error in extrapolating nitrate leaching between sites (Harter et. al 2012). Additionally, individual practices may contribute to overall good irrigation and nutrient management, but the interaction of the practices with one another is what influences nitrate leaching. As such, it is the position of the KRWCA that practices which are protective of groundwater quality are a function of overall irrigation and nutrient management, rather than the intrinsic effectiveness of individual practices.

13.1.1 Define Best Management Practices

To define a specific practice, or set of practices, as protective of groundwater is an over simplification of the myriad of interacting physical and biological processes within any given agricultural management system. There is limited benefit in prescribing best management practices (**BMPs**) as inherently protective of groundwater quality in isolation from the unique context of an irrigated agricultural management system at the field level. Quite feasibly, the prescription of BMPs to achieve optimal groundwater protection may contribute to increases in nitrate leaching if growers are required to adopt practices which may not be relevant to their unique field specific context.

Technically and economically feasible practices should be prioritized by cropping scenarios defined as having a relatively higher nitrate leaching potential. The practices outlined by research specific to California agriculture, such as those noted by Dzurella et. al (2012) provides an initial starting point for identifying practices applicable to these priority cropping systems. These practices cannot be defined as protective outside of the context of an individual cropping system. Generally, practices should seek to

contribute to good overall irrigation and nutrient management. This includes limiting nitrate leaching by minimizing deep percolation through uniform and efficient irrigation, while still accounting for the leaching requirement to control root zone salinity. It also includes managing crops to capture more nitrogen, which can be influenced by crop rotation and tillage choices, and ultimately contributing to increased nitrogen use efficiency (**NUE**) through fertilizer practices that pay close attention to application rate, timing, placement and source of fertilizer materials.

There is no specific knowledge of the absolute reduction in the quantity of nitrate leaching correlated to particular individual practices.

13.1.2 High Vulnerability Areas and Cropping Systems

Evaluation of agricultural management practices on a field level will be focused on cropping systems that are estimated to have a relatively higher potential to leach nitrate by the Nitrate Groundwater Pollution Hazard Index (**NHI**). These cropping systems identified as having relatively higher nitrate leaching potential are thus considered to constitute high vulnerability. Prioritized cropping systems may then be evaluated for field specific crop, irrigation, physical, and nitrogen management challenges, and technically and economically feasible agricultural management practices. The initial review, presented in **Section 10** of the Groundwater Assessment Report (**GAR**), indicates that over 80 percent of the irrigated fields within the KRWCA have a lower risk for nitrate leaching beneath the root zone. As noted in **Section 10**, the following cropping scenarios are examples of the agricultural management systems that may represent higher regional risk:

- Silage corn on sprinkler or surface irrigation, on medium to coarse-textured soils;
- Field crops (wheat) with surface irrigation, on medium or light-textured soils;
- Potato on sprinkler or surface irrigation; and,
- Vegetables.

Crops that may be high nitrogen users, but represent relatively low commodity acreage in the KRWCA, or represent relatively high commodity acreage in the KRWCA, but have a low nitrate leaching potential, should be excluded from MPEP studies. Such cropping scenarios include:

- Alfalfa;
- All perennials;
- Field crops other than wheat; and,
- Processing tomatoes.

The focus of the MPEP on current agricultural management systems (cropping systems and field practices) that contribute to nitrate leaching risk as determined by NHI reflects the power that growers have to improve management methods and practices to minimize nitrate leaching risk. While groundwater quality reflects past practices because of transport time, mixing of waters from different aquifers, etc, the only indicator of how nitrate leaching risk can be improved presently is agricultural practices themselves (SWRCB-AEP, 2014). This difference between historical and current risk to groundwater and how it changes over time with improved management methods is demonstrated by a comparison of NHI applied to historical crops and irrigation systems (1990) and NHI applied to current crops and irrigation systems (2013) (**Figure 13-1** and **Figure 13-2**, respectively).

The general change in the NHI map from 1990 to 2013 (**Figure 13-3**) is a result of trends and significant changes in crop type and irrigation methods. A predominant crop in 1990 (DWR, 1990) was cotton, accounting for about 236,000 irrigated acres (over one third of cropped irrigated acres). Cotton, field crops (small grains, hay and forage), alfalfa, and truck crops (vegetables, melons and berries) made up almost 80 percent of the cropped irrigated acreage (aerial extent); however, almond, grape, and citrus were beginning to become significant individual crops at this time.

In 2013 the total cropped commodity acreage (acreage including fields counted multiple times if double or triple cropped) within the primary boundary was 806,000 commodity acres. Cotton acreage decreased to approximately 38,000 irrigated acres in 2013 (less than 20 percent of its acreage in 1990). In contrast, almond and pistachio acreage increased from 62,000 to 162,000 irrigated acres and 3,000 to 44,000 irrigated acres, respectively. Corn also increased from 6,000 acres to 40,000 irrigated acres, replacing some of the alfalfa acreage, and much of the range and pasture acreage, which fell from 4,000 to 400 irrigated acres.

Therefore, the proportion of permanent crops grown within the KRWCA primary boundary has increased significantly in the past 20 years. In the majority of cases, pressurized irrigation systems have been installed on these new acreages of permanent crops, often where less efficient irrigation systems existed before. Because irrigation method is an important driver in determining nitrate leaching risk using the NHI method, fields that have been converted from non-permanent crops irrigated with typically less efficient methods to permanent crops irrigated with drip or micro-sprinkler changed the NHI value from over 20 to under 20. Modifications (conversion to pressurized systems) have also occurred even without a crop change simply to better manage costly water supplies, deliver nutrients more precisely, and increase yields and crop quality.

While nearly 83 percent of KRWCA irrigated land is considered low risk (**Figure 13-2**) to nitrate leaching when NHI is applied to 2013 data (NHI less than or equal to 20), only approximately 40 percent of KRWCA irrigated land resulted in low risk (**Figure 13-1**) to nitrate leaching when NHI was applied to 1990 cropping data. The importance of recognizing this significant change in a relatively short time helps explain the complexity of attempting to compare surface conditions to existing concentrations of nitrate in groundwater. This is especially true with commonly longer transport times to groundwater within the KRWCA area.

13.1.3 Best Practices Implementation

There has been extensive research on California agricultural management practices, particularly for irrigation and nutrient management. The KRWCA will attempt to unify formerly conducted research, best practices, and current knowledge to determine realistic time frames for implementation, decipher where data gaps truly exist, and assess the barriers to implementation of identified best practices in a variety of agricultural management scenarios. This analysis will employ available documented resources produced by State agencies, as well as relevant regional knowledge. Failing to address barriers to adoption, especially cost, technical resources, and time related barriers, can result in negligible implementation rate and regulatory program failure (Logan 1990).

Relevant practices for the selected priority cropping scenarios will be evaluated in field scale studies to investigate nitrate leaching and uptake, as compared to standard regional practices. Surface level metrics, specifically plant and soil indicators, will be relied upon to determine the impact of agricultural management practices on nitrate leaching, and ultimately groundwater protection. As noted previously,

accurate measurement of nitrate leaching through other methods is technically complex and unreliable. When the data is summarized and reported, it will be shared with growers as outlined in the Comprehensive Groundwater Quality Management Plan (**CGQMP**), which focuses on outreach and education to improve irrigation and nutrient management. Overall, it is recommended that the evaluation of practices, and ultimately the success of implementation, be inferred from metrics such as the nitrogen applied versus removed ratio (**A/R ratio**).

13.1.3.1 Member Requirements and Implementation Timelines

As outlined in the General Order, the MPEP group option workplan is due two years after GAR approval. Members will be identified to participate in the field level evaluation of practices within this time frame. The Management Practices Evaluation Report (**MPER**), due six years after implementation of each phase, may provide the first opportunity for the conclusions of the MPEP to influence the CGQMP, leading to Member implementation. The timeline of MPEP phases may also be influenced by the cost of implementation and available funding, discussed below.

13.1.3.2 Costs

The cost estimates for the implementation of the MPEP provided by the CVRWQCB, as well as independent calculations, indicate that the MPEP will probably need to be divided into phases over time. In this approach, specific phases will be initiated at intervals, with each phase having an independent summary monitoring report at six years. With this in mind, it may require decades to fully achieve the objectives of the MPEP.

13.1.4 Groundwater Monitoring

The suggested MPEP groundwater monitoring intends to evaluate the effects of various surficial agricultural management practices on first encountered groundwater quality. As discussed above and in **Section 10**, precisely analyzing the impact of surface level nitrate discharge on groundwater quality is extremely difficult. Monitoring groundwater quality in field scale studies may not be representative of the impacts of current practices due to the spatial and temporal disconnects inherent to KRWCA hydrogeology (Gailey 2013). Using proxy groundwater monitoring to characterize nitrate leaching relationships to agricultural management practices implementation may not be conclusive in a relatively short time frame. Additionally, under certain circumstances, such as high irrigation efficiency, nitrate migration would occur at a higher concentration but lower volume, possibly indicating degradation at first encountered groundwater, despite overall lower nitrate loading.

As discussed in the GAR, it is not possible to eliminate the leaching of nutrients beneath the root zone while maintaining suitable root zone salinity. As such, all agricultural management practices may have some effect on first encountered groundwater.

13.2 Groundwater Quality Trend Monitoring Program Recommendations

The intent of the Groundwater Quality Trend Monitoring Program (**GTMP**) is to determine current groundwater quality conditions and to develop long-term groundwater quality information that can be used to evaluate the regional effects of irrigated agriculture. As extensively documented throughout the

GAR, the KRWCA region is uniquely unsuited to representative monitoring to indicate the benefit or detriment to groundwater quality caused by current agricultural management practices. This is due to characteristically long hydrogeologic travel times to groundwater, and high rates of managed groundwater extractions and recharge, creating spatial and temporal disconnects between surface activities and potential groundwater impacts. As such, only a general evaluation of the cumulative impact of irrigated agriculture is possible. Additionally, the trends analyzed from collected data will likely include a great deal of variability, and as recommended by the SWRCB-AEP (2014), multi-year analysis is necessary to smooth out the random fluctuations that occur on an annual basis.

13.2.1 Monitoring Location

Monitoring locations will be representative of Public Land Survey (**PLS**) townships within the KRWCA, as well as PLS sections of the KRWCA that do not currently have groundwater quality data. Sections for which there are data gaps require short-term groundwater monitoring to establish current groundwater quality data. This information is necessary for accurate spatial analysis of nitrate impacts within the KRWCA region, and to complete the high vulnerability analysis provided in **Section 10**. A number of the regions which lack data are located in areas where there is no usable groundwater or wells, including but not limited to, the Buena Vista Lake area. Long-term groundwater monitoring will occur within each designated township to evaluate ongoing nitrate patterns and trends in groundwater.

13.2.1.1 Selection Criteria

The representative long-term monitoring wells chosen in each township will be determined by monitoring priority. Specifically, the number of monitored wells in the township will be proportional to the percent of high vulnerability land within the respective township, and related to the local data gaps and high vulnerability area (**HVA**) prioritization tiers within the township. It is expected that an average of one to three wells per township will be required to accomplish the objectives of the GTMP. Currently, the areas on **Figure 13-4** indicate irrigated agricultural areas without nitrate water quality data, as well as the identified HVA with respect to townships. In an attempt to more closely approximate first encountered groundwater, the shallowest wells in targeted areas will be chosen for inclusion in the program.

13.2.2 Sampling & Methodology

Selected long-term GTMP wells will be sampled annually for nitrate. The collected data will be maintained in a comprehensive database for the KRWCA. The analysis of groundwater quality will focus on multi-year long-term evaluations of the collected data to define trends, as opposed to trying to account for the variation in year to year sampling. The long-term monitoring periods should also be reflected in compliance schedules. The GTMP methodology, to be detailed in the workplan due one year from GAR approval, will consider the input of the Groundwater Monitoring Advisory Workgroup (**GMAW**) that was convened by the CVRWQCB in 2011**.**

13.3 Groundwater Quality Management Plan Recommendations

The focus of the KRWCA CGQMP relies on the understanding that surface level activities can drive nitrate leaching beneath the root zone. To effectively address the surface level management practices that influence nitrate leaching, a clear understanding of the nature of regional nitrate transport, the

requirements of a range of agricultural management systems, and the factors that influence management choices is necessary.

13.3.1 Management Plan Actions

CGQMP implementation will focus efforts on addressing irrigation and nutrient management practices through extensive outreach and education for all irrigated lands included in the scope of the CGQMP. The outreach will also address multiple surface level metrics, including irrigation efficiency and the nitrogen A/R ratio, to help growers gauge the impact of management decisions on fields and their potential impact to groundwater quality. Additional partner driven research will be required to improve the available data, particularly for estimating nitrogen removal, required for nutrient ratios for a variety of agricultural management systems.

The KRWCA intends to conduct a thorough literature review of current knowledge pertaining to efficient irrigation and nutrient management practices, particularly as they relate to identified priority crops and agricultural management scenarios. There is currently a large body of work which has been produced to serve as one basis to develop effective and relevant outreach materials. This literature review will not be dependent on the content or execution of the group option MPEP; although resources and outreach developed may support one another.

13.3.2 Outreach and Education

Outreach events will focus on providing resources to members and improving irrigation and nutrient management. Outreach events are planned to occur quarterly and include presentations of applicable information from the literature review conducted by the KRWCA. Irrigation management and nutrient management training will be organized by the KRWCA in partnership with the University of California Cooperative Extension (**UCCE**), Natural Resources Conservation District (**NRCS**), California Department of Food and Agriculture (**CDFA**), various commodity groups, and/or the Kern County Agricultural Commissioner to educate growers in efficient and effective management. Additional efforts will extend resources to facilitate mitigation efforts, including pump-and-fertilize (**PAF**), which requires knowledge of the source irrigation water nitrogen concentration and how the nitrogen can be relied on to meet crop needs, offsetting other fertilizer applications. As noted in Harter et. al (2012), regional scale management of irrigation water nitrate and optimized fertilizer application (pump-and-fertilize, PAF) are the most promising actions and will likely put the groundwater quality on an upward trajectory.

The KRWCA will also assist in Member nutrient management plan self certification efforts.

13.3.3 Monitoring and Compliance

Due to the nature of nitrate as a non-point source contaminant (in this circumstance), large knowledge gaps, and inadequate data, it is infeasible to retroactively trace local nitrate impacts back to specific agricultural management systems. Similar barriers exist in tracing the impacts of newly implemented management practices and their respective nitrate impact on groundwater, due to the spatial and temporal disconnects prevalent throughout the KRWCA, as noted previously.

Generally, individual practices do not have a quantifiable decrease in nitrate loading to groundwater, so the absolute protectiveness or effectiveness of a given management practice decision cannot be calculated. The general limitation, as defined, is the impossibility of eliminating the potential to leach

nitrate. Management practice effectiveness is also limited by correct implementation. Feedback on compliance will be provided from Member data from Nitrogen Management Plan Summary Reports and Farm Evaluations. The A/R ratio is an indication of overall nutrient efficiency, and an indirect indication of irrigation efficiency. If irrigation efficiency is low, more nitrogen is likely to be flushed from the root zone, requiring additional nitrogen applications to maintain yields, leading to a higher A/R ratio. The Farm Evaluation will provide statistics on the adoption of other promoted management practices.

13.4 Groundwater Assessment Report Update Recommendations

13.4.1 Possibilities for Enhancements to NHI, at 5 year GAR Update

As described in **Section 10**, the NHI is a tool that includes soil, crop, and irrigation variables for the purpose of qualitatively assessing an individual management unit's relative risk of leaching nitrate below the root zone. For KRWCA, the NHI was used as a spatial tool because accurate spatial soil, crop, and irrigation data were available, to a large degree.

At this time, only the soil, crop, and irrigation parameters as originally developed have been used to conduct the KRWCA NHI analysis. These parameters have been supported in refereed scientific literature. Because the NHI is a multiplicative index approach, parameters can be added, as they are developed, to the NHI to create a more robust predictive tool. It is feasible that parameters can be added to the NHI to enhance its predictive capabilities as long as there is supporting research to do so. Potential NHI enhancements for future GAR updates include the following modifications to soil and irrigation hazard values, and other potential NHI factors.

13.4.1.1 Soil Hazard Values

One of the improvements that could be made to the NHI methodology is a more objective way to determine soil hazard values using data from soil surveys. Because the methodology for determining soil hazard values is based on expert opinion considering information from soil survey, it is difficult to repeat and update, and is subject to some bias. This type of methodology was used to determine current soil hazard values because some of the information in soil surveys is qualitative. For example, a soil that is described as "moderately well drained" does not have an absolute value associated with it, and therefore could not be used in a quantitatively determined soil hazard rating.

Dr. Toby O'Geen, University of Davis, Department of Land, Air and Water Resources, is currently working on a more data-driven method to determine soil hazard values for NHI (personal communication, April 2014). According to O'Geen, "*The goal of this project is to develop a data-driven soil hazard value for every soil in California. A tool is being developed that links digital soil survey data to HYDRUS, a process-based hydrological model capable of predicting nitrate leaching over infinite scenarios of soil variability. In addition to soils, the modeling will include crop, nitrogen and irrigation management scenarios and couple nitrate leaching hazard ratings with BMPs to improve nitrogen management*."

KRWCA sees this as an opportunity to improve NHI results for the area within its primary boundary, if results from the soil hazard update effort can be validated. These updated soil hazard ratings are expected in about three years.

13.4.1.2 Irrigation Information and Irrigation Hazard Values

The majority of irrigated areas within the KRWCA boundary had irrigation methods for each management unit. For some minor areas, spatial irrigation data was not available. In these cases, assumptions were made about the type of irrigation used on specific crops in specific locations. For example, the Southern San Joaquin Municipal Utility District had information on the acreage of each crop irrigated with each type of irrigation, but there was no information on where those fields were located. In that case, older (2006) irrigation information from DWR is currently being used to determine which fields of a certain crop were irrigated with each type of irrigation. This information is clearly not up to date. Groundtruthing or spatial irrigation data would make the NHI results for these areas more accurate, however the approximations at this time are the best information available and results are reasonable.

During the NHI update, minimal effort will be required to update areas with reliable and current spatial information because an accurate base layer was developed for the initial GAR. However, more effort can and should be spent before and during the GAR update on areas where spatial irrigation information had to be estimated.

The irrigation hazard value can also potentially be updated. While there are hazard values for basic irrigation types, some irrigation scenarios are not represented by the hazard values in the current NHI. For example, there is no hazard value for surface irrigation using fertigation. There are also no hazard values for irrigation method combinations, such as the use of sprinklers to start vegetables and drip to finish out their season.

It should be noted that development of and results from the MPEP will likely contain newly created data and information that can be used in the future to further enhance the NHI. This will be discussed in more detail in the MPEP.

13.4.1.3 Additional NHI Factors

Additional “layers” that could be added to existing NHI factors have been considered. In a multiplicative index, other factors could be included and multiplied to achieve more refined hazard ratings; however, a new numerical threshold would need to be determined to distinguish between high and low leaching potential. With an additional factor, the threshold between low and high leaching risk would increase from 20 to a higher number that would need careful consideration of current research.

For example, an additional factor in NHI could be a nitrogen A/R ratio. The SWRCB-AEP (2014), in their Final Report, recommended the use of such a ratio, which would compare the amount of nitrogen applied (to a particular field) to the amount that is assumed to be, or measured as removed by the crop on that field. While application rates are simple to document, removal rates vary widely between crops, soil, irrigation methods, and management practices, and represent a multiplicity of scenarios that would require assumptions. Research would be needed to determine how to make these assumptions. The time required to complete this type of research is unknown at this time; however, some research on parameters such as a nitrogen A/R ratio, which includes factors relating to nitrogen use efficiency, has already been conducted. Modifications to the NHI would need to apply these and other research findings to KRWCA specifically.

An additional factor that may have merit, particularly if the NHI were to be applied across a much wider geographical area, is effective precipitation. This would be useful in making comparisons between the

KRWCA and areas further to the North. This factor would provide little additional insight when solely examining the KRWCA, as effective precipitation does not vary much, if at all, across the region.

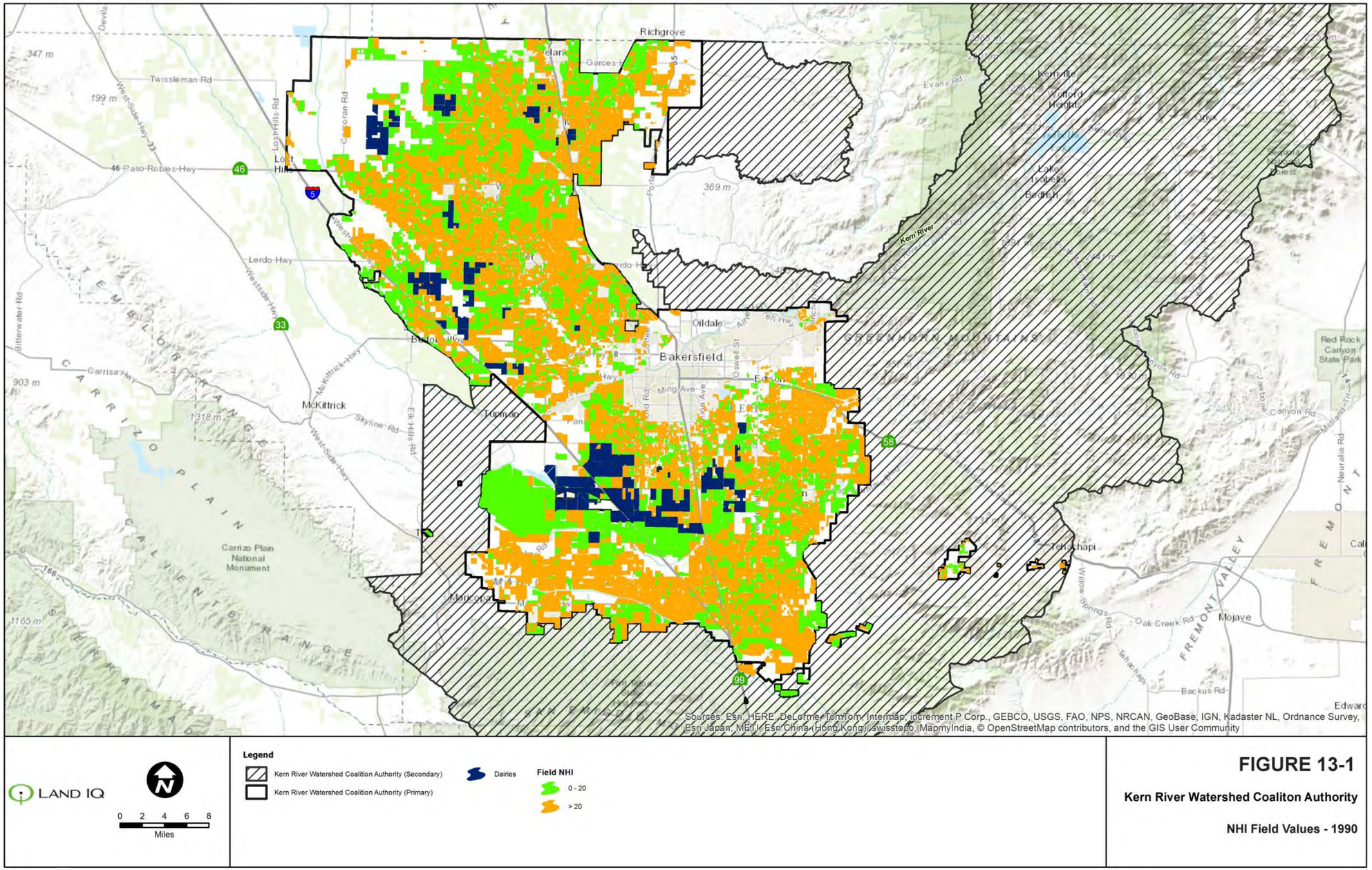

Figure 13-1. NHI Field Values - 1990

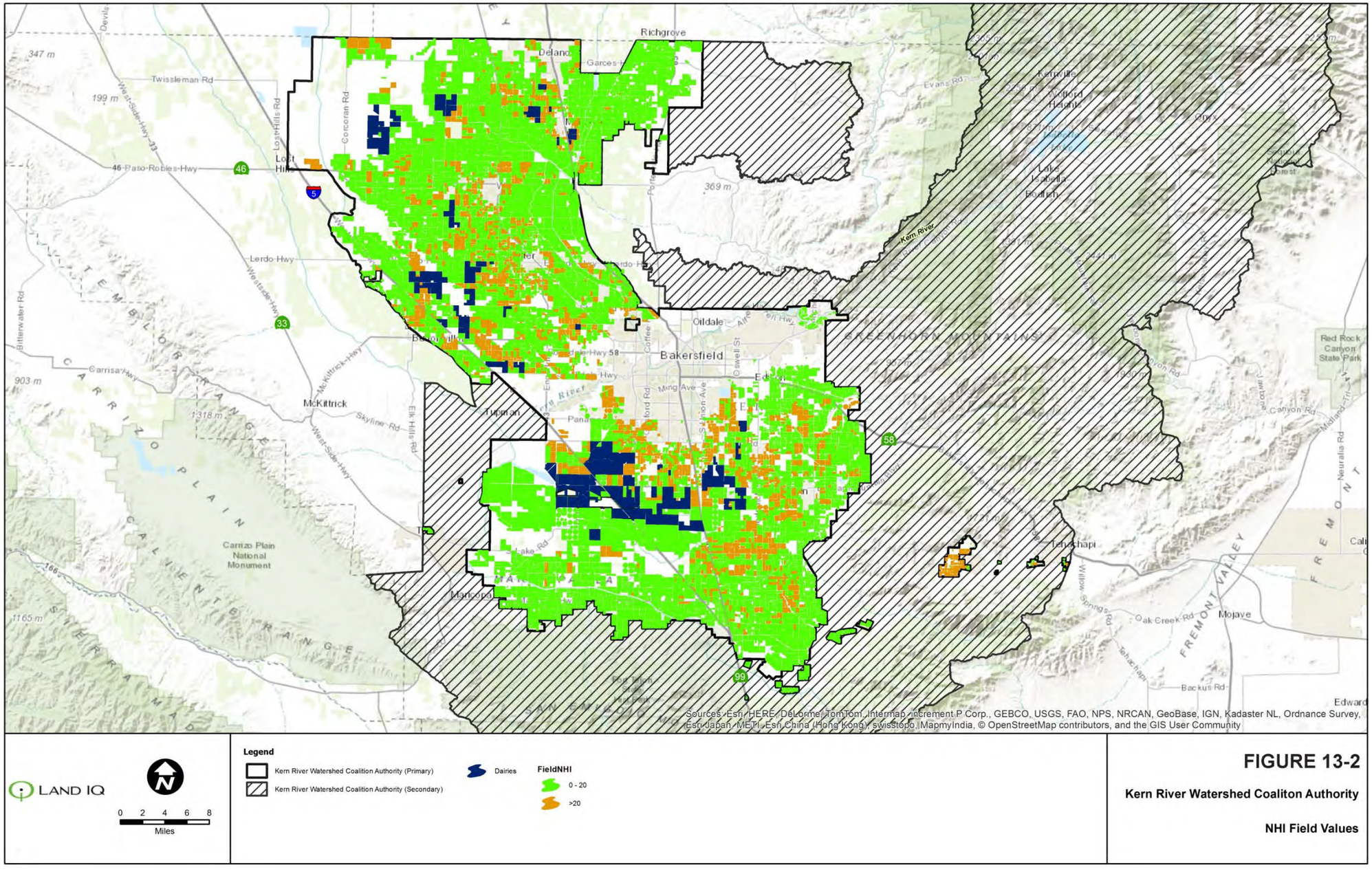

Figure 13-2. NHI Field Values – 2013

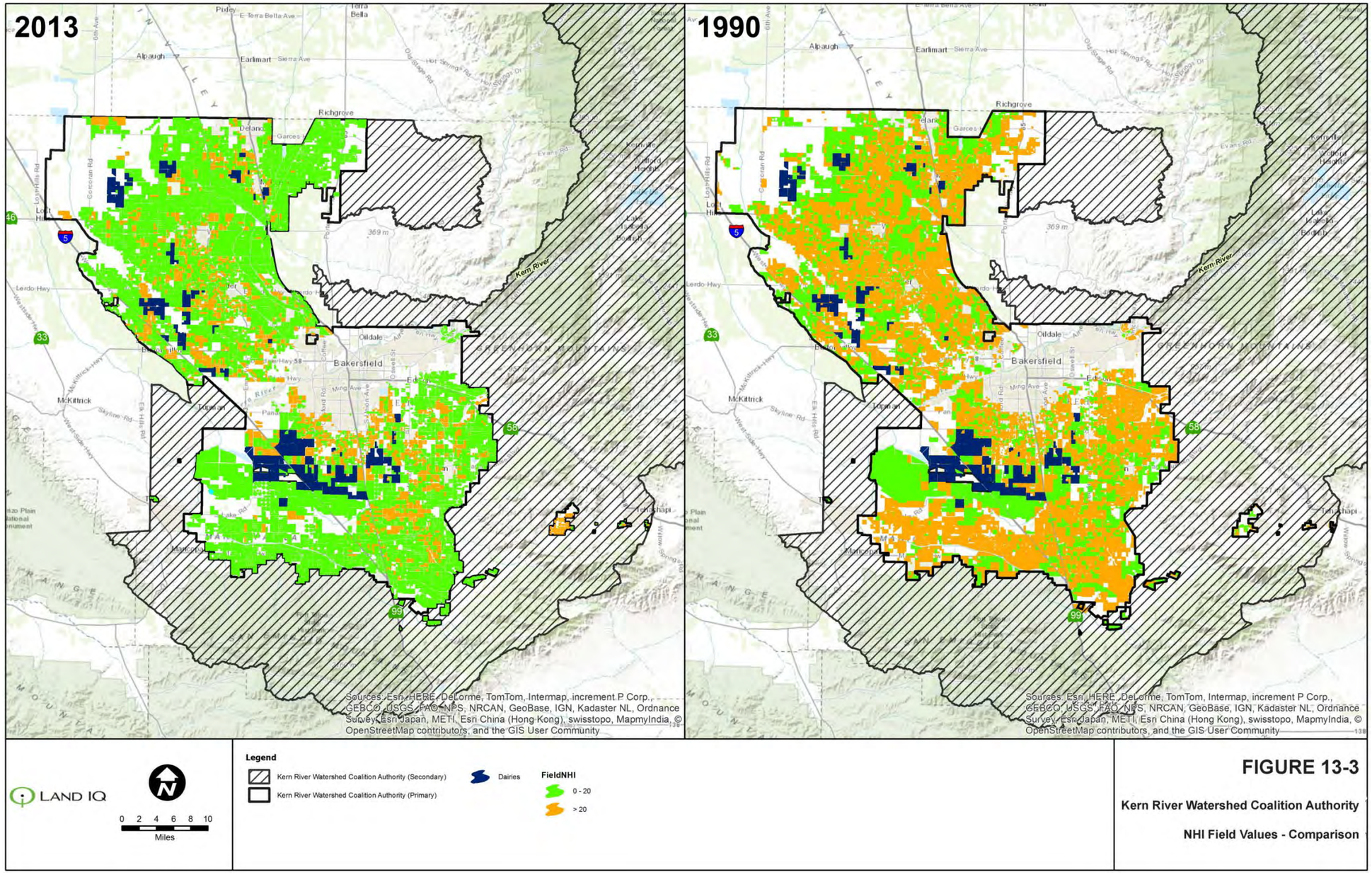

Figure 13-3. NHI Field Values - Comparison of 2013 to 1990

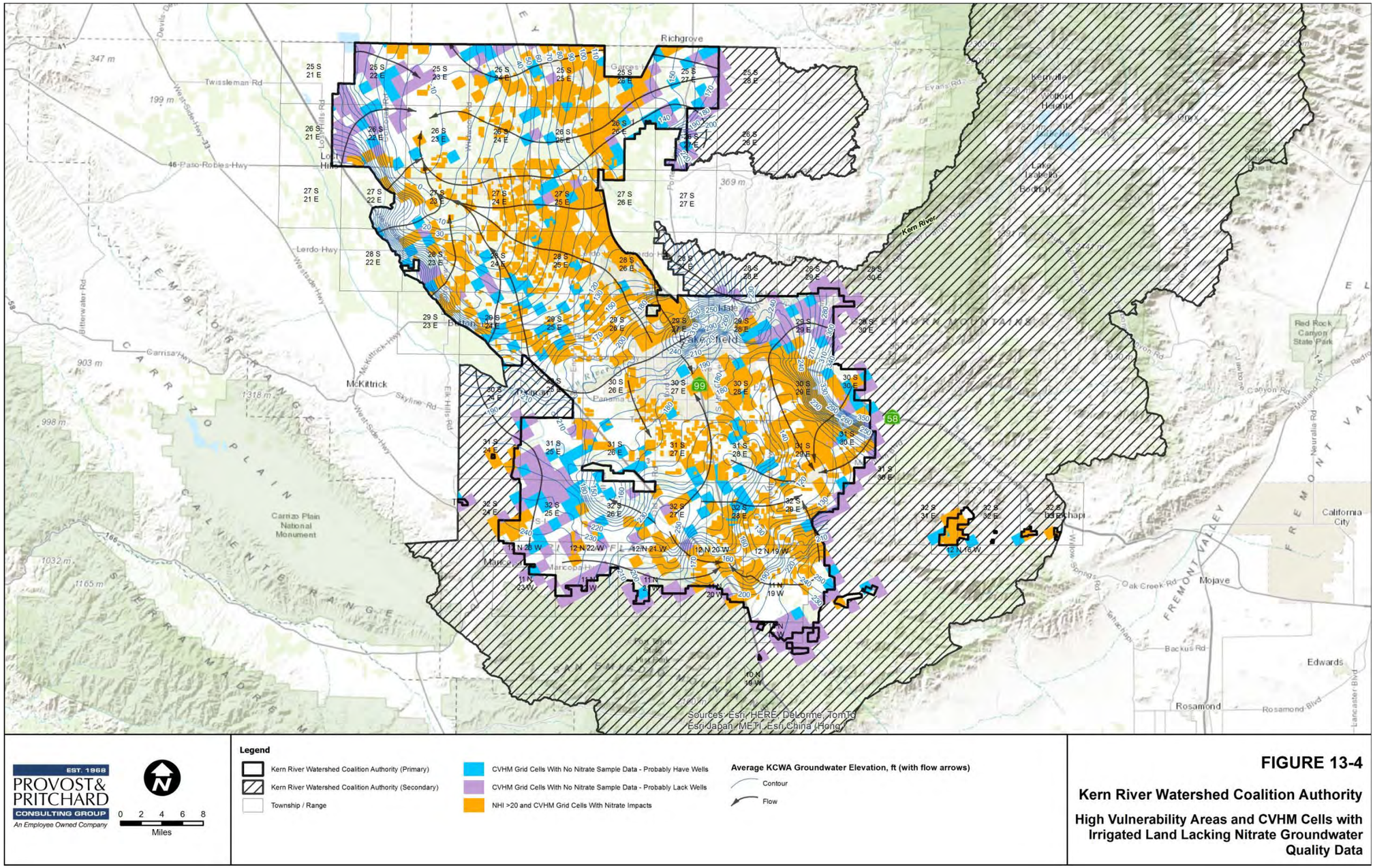

Figure 13-4. High Vulnerability Areas and CVHM Cells with Irrigated Land Lacking Nitrate Groundwater Quality Data

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Appendix

Table App-1. Association of Crop with Crop Category

Association of Crop with Crop Category	
Crop	**Crop Category**
Alfalfa	Alfalfa
Almond	Almond
Asparagus	Truck Crop
Average of berries	Truck Crop
Barley	Field Crop
Beans (snap)	Truck Crop
Beans- dry	Truck Crop
Beets- red	Truck Crop
Blackberries	Truck Crop
Blueberries	Truck Crop
Broccoli	Truck Crop
Brussels sprouts	Truck Crop
Cabbage- head	Truck Crop
Canola/rape seed	Field Crop
Cantaloupe	Truck Crop
Carrots	Carrots
Cashew	Nut Tree
Cauliflower	Truck Crop
Celery	Truck Crop
Chestnut	Nut Tree
Citrus (mandarin)	Citrus
Citrus (pummelos)	Citrus
Collards	Truck Crop
Corn (sweet)	Corn
Corn- silage	Corn
Cotton- lint	Cotton
Cucumbers	Truck Crop
Daikon	Truck Crop
Dates	Fruit Tree
Eggplant	Truck Crop
Fruit tree	Fruit Tree
Garlic	Truck Crop
Grapefruit	Citrus
Grapes- fresh	Grapes - Table and Wine
Honeydew melon	Truck Crop
Kale greens	Truck Crop
Kiwifruit	Fruit Tree

Association of Crop with Crop Category	
Crop	**Crop Category**
Kohlrabi	Truck Crop
Kumquats	Fruit Tree
Leek	Truck Crop
Lemons	Citrus
Lettuce- head	Truck Crop
Lettuce- leaf	Truck Crop
Lettuce- romaine	Truck Crop
Mustard- greens	Truck Crop
N-greenhouse plant	Truck Crop
N-outdoor plants	Truck Crop
Oats	Field Crop
Of-bulb	Truck Crop
Onions- dry	Truck Crop
Onions- green	Truck Crop
Onions- seed	Truck Crop
Op-flwrng plant	Truck Crop
Op-rose	Truck Crop
Oranges	Citrus
Parsley	Truck Crop
Pasture	Range/Pasture
Pecans	Nut Tree
Peppers- bell	Truck Crop
Peppers- chili	Truck Crop
Pistachios	Pistachios
Potatoes	Truck Crop
Pumpkins	Truck Crop
Radishes	Truck Crop
Rutabaga	Truck Crop
Ryegrass- hay	Field Crop
Ryegrass- seed	Field Crop
Safflower	Field Crop
Sorghum- forage	Field Crop
Sorghum- grain	Field Crop
Spinach	Truck Crop
Squash (total)	Truck Crop
Strawberries	Truck Crop
Sudangrass- seed	Field Crop
Sweet potatoes	Truck Crop

Association of Crop with Crop Category	
Crop	**Crop Category**
Tangelo	Citrus
Tangerine	Citrus
Tangerine/sdls	Citrus
Tomatoes	Truck Crop
Turnip	Truck Crop
Walnuts- English	Nut Tree
Watermelon	Truck Crop
Wheat	Field Crop

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