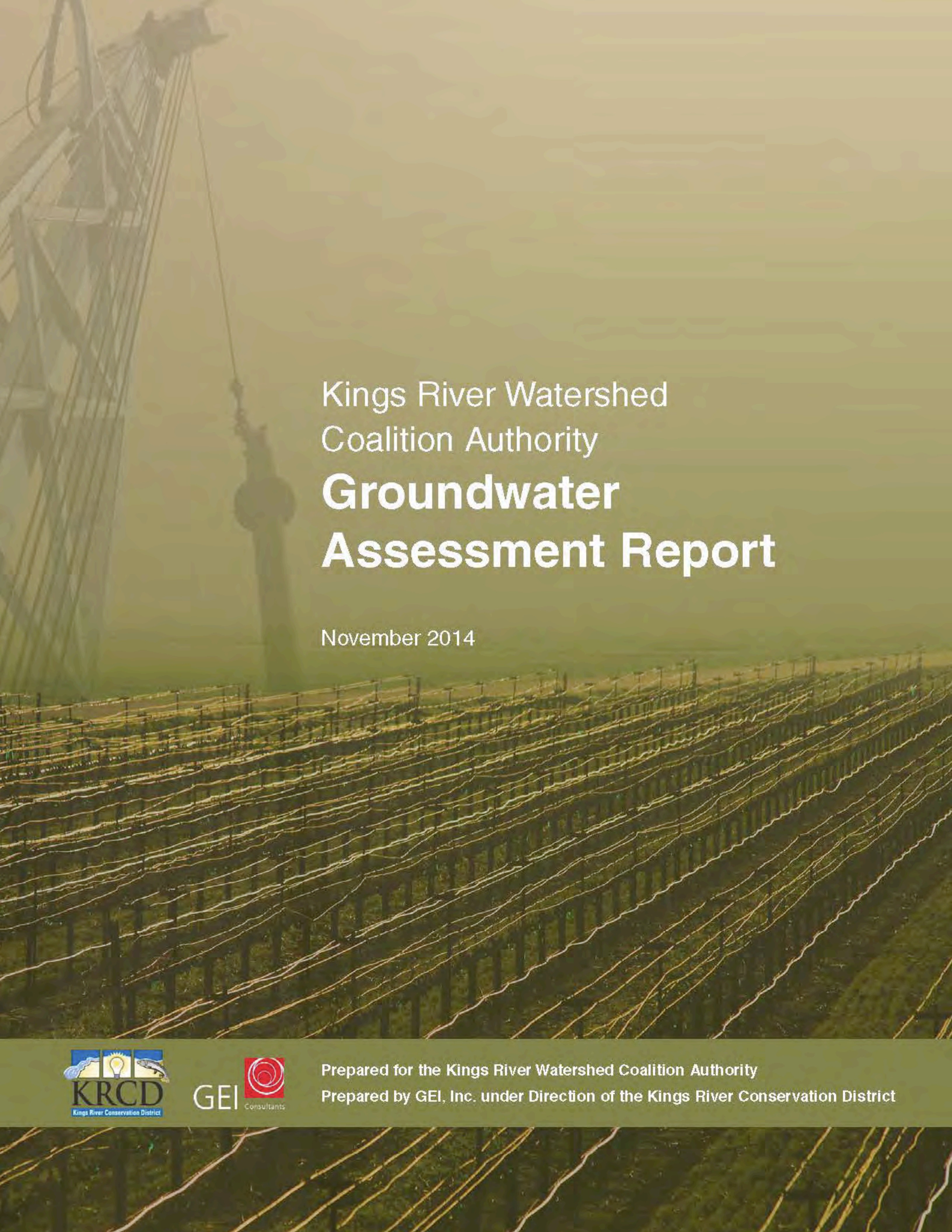

Kings River Watershed Coalition Authority

Groundwater Assessment Report

November 2014

Prepared for the Kings River Watershed Coalition Authority
Prepared by GEI, Inc. under Direction of the Kings River Conservation District

Kings River Watershed Coalition Authority Groundwater Assessment Report

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Acronyms

Acronym List

AGR	agricultural
AID	Alta Irrigation District
BOR	Bureau of Reclamation
CalEPA	California Environmental Protection Agency
CAML	California Augmented Multisource Landcover
CDEC	California Data Exchange Center
CID	Consolidated Irrigation District
C2VSIM	California Central Valley Groundwater-Surface Water Simulation Model
CVHM	Central Valley Hydrology Model
CVP DMC	Central Valley Project Delta Mendota Canal
CV-SALTS	Central Valley Salinity Alternatives for Long-term Sustainability
DAC	Disadvantaged Community
DHS	California Department of Health Services
DMC	Delta Mendota Canal
DPR	California Department of Pesticide Regulation
DWR	California Department of Water Resources
EPA	United States Environmental Protection Agency
ESJ GAR	Eastern San Joaquin Groundwater Assessment Report
ET	evapotranspiration
FID	Fresno Irrigation District
GAMA	Groundwater Ambient Monitoring and Assessment
GAMA-EDF	Groundwater Ambient Monitoring and Assessment Environmental Defense Fund
GAR	Groundwater Assessment Report
GQMPs	Groundwater Quality Management Plans

IGSM	Integrated Groundwater and Surface Water Model
ILRP	Irrigated Lands Regulatory Program
IOG	Index Overlay Grid
IRWMP	Integrated Regional Water Management Plan
ITRC	Irrigation Training and Research Center
JID	James Irrigation District
KCWD	Kings County Water District
KRCD	Kings River Conservation District
KRWQC	Kings River Water Quality Coalition
LLNL	Lawrence Livermore National Laboratory
LU	land use
MAF	million acre-feet
MCLs	maximum contaminant levels
MPEP	Management Practices Evaluation Program
MUN	municipal
NCGC	National Cartography and Geospatial Center
NHI	Nitrate Hazard Index
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
PLSS	Public Land Survey System
POTW	publically owned treatment works
PUR	Pesticide Use Reports
QA/QC	Quality Assurance/Quality Control

RWQCB	Regional Water Quality Control Board
SNMP	Salt and Nutrient Management Plan
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
TDS	total dissolved solids
TID	Tranquility Irrigation District
TLDD	Tulare Lake Drainage District
TOT	(Groundwater) Time of Travel
USGS	United States Geological Survey
WARMF	Watershed Analysis Risk Management Framework
WCD	Water Conservation District
WDRs	waste discharge requirements

KRCD
Kings River Conservation District

GEI Consultants

Chapter 1. Introduction

Chapter 1. Introduction

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Chapter 1. Introduction

1.1 Background

Nitrate and salts from agricultural and non-agricultural sources have resulted in groundwater contamination beneath some California agricultural areas. Over time, salts and nutrients may increase in groundwater due to a range of factors, including naturally occurring conditions, on-farm agronomic practices, regional water management, and other nonagricultural contamination sources. These factors vary throughout a groundwater basin and over time, making some areas more vulnerable to contamination. Defining which areas are the most vulnerable is needed to develop monitoring and management strategies and priorities to protect beneficial uses of groundwater. The Kings Groundwater Assessment Report (Kings GAR) was prepared for Kings River Watershed Coalition Authority (Coalition) to evaluate the range of factors that contribute to groundwater vulnerability to contamination from irrigated agriculture, to define vulnerable areas that have been, or could be impacted by irrigated agricultural sources, and to provide a foundation for further taking action.

1.1.1 General Order and Requirements

The Coalition is producing the Kings GAR to comply with Regional Water Quality Control Board (**RWQCB**) Order R5-2013-0120 (Order), "Waste Discharge Requirements General Order for Growers within the Tulare Lake Basin Area That Are Members of a Third-Party Groups" (RWQCB, 2013). The Order is part of the long-term Irrigated Lands Regulatory Program (ILRP) in the Tulare Lake Basin Area and establishes the general waste discharge requirements (WDRs) from irrigated lands (or "discharges") that could affect ground and surface waters of the state. The discharges result from runoff or leaching of irrigation water and stormwater from irrigated lands. This Order applies to owners and operators of irrigated lands within the Tulare Lake Basin and they are expected to follow the RWQCB strategy to comply with the Order. The RWQCB strategy for evaluating groundwater quality and protection of the resource consists of: 1) a Groundwater Quality Assessment Report (GAR), 2) a Management Practices Evaluation Program (MPEP), and 3) a Groundwater Quality Trend Monitoring Program.

1.1.2 Kings River Watershed Coalition Authority

Owners and operators subject to the Order may form 'third party' coalitions to help members comply with the Order. The Coalition is one of the third party groups formed within the Tulare

Lake Basin to represent growers and support compliance with the Order. The RWQCB accepted the designation of the Coalition as the third party administrator by notice on November 20, 2013. The Coalition area is shown in **Figure 1-1**. The Kings GAR study area includes intensive agricultural production within the Tulare Lake Hydrologic Region.

1.2 Purpose of Groundwater Quality Assessment Report (GAR)

1.2.1 Purpose and Intended Use of GAR

It is important that credible and comprehensive scientific information on nitrogen use be available to support evidence-based policy-making. Without information based on sound science, nitrogen policies may be poorly prescribed, ineffective, cause unintended consequences or even be counterproductive (Rosenstock, et al., 2013). The purpose of the GAR is to provide the technical basis informing the scope and level of effort for development and implementation of the MPEP and groundwater monitoring requirements. The GAR describes the data and technical analysis methods used to identify high and low vulnerability areas in the groundwater basins. The RWQCB Order basic requirements for the GAR are relatively straight forward though the Order is not prescriptive of a technical method for the groundwater vulnerability analysis.

The GAR is part of the technical documentation needed to comply with the terms and conditions of this Order and to assure protection of waters of the state. The RWQCB Executive Officer will review the Coalition's proposed high and low vulnerability areas and make the final determination of these areas. High and low vulnerability areas will be reviewed and updated throughout the implementation of this Order. To accomplish the purpose, the GAR must include the following:

- 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
- Provide a basis for establishing groundwater quality management plans in high vulnerability areas and priorities for implementation of those plans

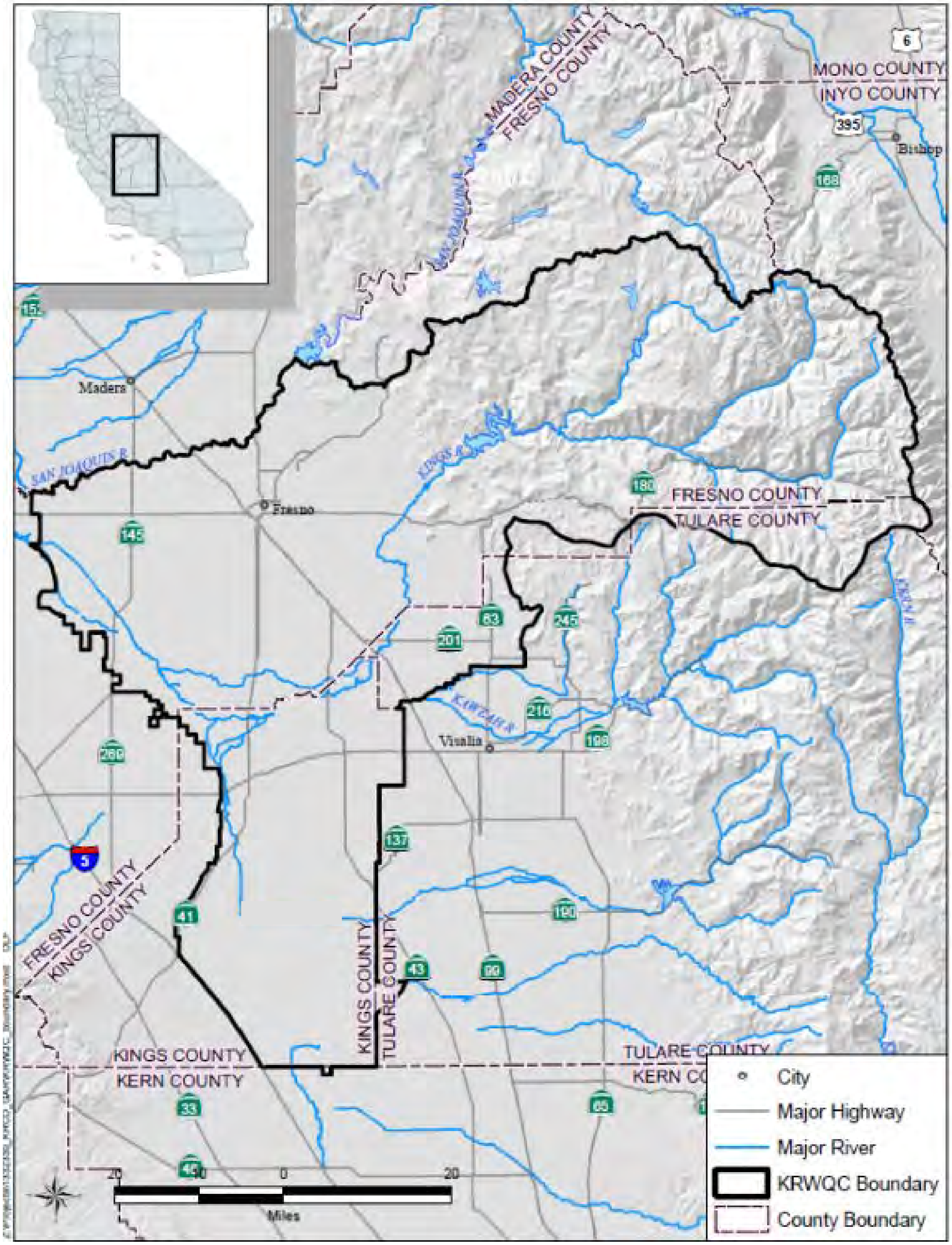

Figure 1-1. Kings River Watershed Coalition Authority Area

The required components for the GAR include:

- Land use information identifying the largest acreage commodity types compromising up to at least 80% of the irrigation acreage
- Depth to groundwater contours
- Groundwater recharge information, including identification of areas contributing recharge to groundwater that serve as a significant source of supply
- Soil survey information including significant areas of high salinity, alkalinity and acidity
- Shallow groundwater constituent concentrations
- Information on existing groundwater data collection and analysis efforts

The GAR review and analysis is to use the above data and other information to:

- Determine where known groundwater quality impacts exist for which irrigated agricultural operations are a potential contributor or where conditions make groundwater more vulnerable to impacts from irrigated agricultural activities
- Determine the merit and feasibility of incorporating existing groundwater data collection efforts, and their corresponding monitoring well systems for obtaining appropriate groundwater quality information, including specific findings and conclusions
- Prepare a ranking of high vulnerability areas to provide a basis for prioritization of work plan activities
- Discuss pertinent geologic and hydrogeologic information and utilize GIS mapping applications, graphics, and tables, as appropriate, in order to clearly convey pertinent data, support data analysis, and show results
- Designate high/low vulnerability areas for groundwater

The Coalition may further prioritize high vulnerability areas and may consider:

- 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
- Existing field or operational practices identified to be associated with irrigated agriculture waste discharges
- The largest acreage commodity types comprising up to at least 80% of the irrigated agricultural acreage in the high vulnerability areas and the irrigation and fertilization practices employed by these commodities
- Legacy or ambient conditions of the groundwater
- Identified constituents of concern (e.g., relative toxicity, mobility)

This report may also support regional water management decisions occurring within the groups formed to prepare and update the regional water management plans and groundwater management plans.

1.2.2 Scientific and Management Objectives

Assessments of the vulnerability of groundwater to contamination range in scope and complexity from simple, qualitative, and relatively inexpensive approaches to rigorous, quantitative, and costly assessments. Assessments generate insights through the synthesis and integration of available information to distinguish that which is known and well established from that which is unknown and scientifically uncertain. The GAR pieces together the best available information to inform decision making on where groundwater is most vulnerable while acknowledging uncertainty. Tradeoffs must be carefully considered among the competing influences of the cost of an assessment, the scientific defensibility, and the amount of acceptable uncertainty in meeting the objectives of the water-resource decision maker.

A scientifically defensible groundwater vulnerability assessment is one that follows the scientific method and includes adequate documentation of data, observations, and method of investigation to allow for independently reproducible results. Understanding the natural hydrogeologic processes as well as the associated anthropogenic effects on a groundwater resource is required for complete scientific understanding of groundwater vulnerability (USGS, 2002).

The RWQCB General Order governs the objectives for the Kings GAR analysis. The method chosen should be based on both scientific and management objectives.

> ***Management Objective**: To make best use of the available resources and to lay the technical foundation for development of the Management Practices Evaluation Program (MPEP) and Monitoring Program that will be developed in subsequent steps to comply with the Regional Order; and produce results that are readily explained to growers, the public and decision makers. To leverage the investments in, and make use of, the data bases, technical analysis and models applied to the analysis of the water budgets, salts and nitrates in the Kings River Area.*
>
> ***Scientific Objective**: To apply technically defensible methods to identify the intrinsic susceptibility to groundwater contamination based on the physical characteristics of the Kings Region and the vulnerability to contamination from overlying irrigated agricultural operations.*

1.3 RELATED REQUIREMENTS

1.3.1 Basin Plan and Beneficial Use

The Kings GAR study area is covered by the Water Quality Plan for the Tulare Lake Basin (Basin Plan) last revised in January 2004 (RWQCB, 2004). The State Water Resources Control Board (SWRCB) and the RWQCB use the Basin Plan to designate the beneficial uses for water bodies, and establish water quality standards and numerical objectives as required by the Porter–Cologne Water Quality Control Act. Groundwater recharge is a designated beneficial use of the Kings River.

Water rights permits or licenses also define the intended beneficial use of the water. In addition to the primary beneficial use for agricultural purposes, surface water rights in the Kings Study are used for groundwater recharge. The Tulare Lake Bed area groundwater is also being considered for a Basin Plan amendment that would de-designate the municipal use (MUN) and agricultural use (AGR).

1.3.2 Water Quality Requirements

1.3.2.1 Water Quality Objectives and Standards

The Basin Plan identifies the numerical or narrative water quality objectives for specific pollutants and chemical constituents. The standards and objectives are to protect the designated beneficial uses and prevent third party effects and impacts to the environment. The potential for a project to exceed these limits is the basis for evaluating threats to water quality and the likelihood of impairment to groundwater or surface water. The water quality objectives and standards also serve as the yardstick to measure whether water quality is “impaired”. Known water quality problems are identified by the RWQCB by comparing monitoring data to the standards and objectives for each of the beneficial uses. Surface waters that do not meet standards are placed on the 303(d) List of Water Quality Limited Segments that identifies water bodies of impaired quality. The RWQCB does not designate impairment specifically for groundwater.

1.3.2.2 Agricultural Water Quality Requirements

Agriculture is dependent on an adequate supply of good quality water. Water quality requirements vary by crop types and agronomic conditions, but some general guidelines have been developed (Ayers, et al., 1985). Water quality objectives to protect agricultural uses are reflected in the numerical water quality standards of the RWQCB in the Basin Plan.

1.3.2.3 Municipal and Domestic Water Quality Requirements

The U.S. Environmental Protection Agency (EPA) and the California Department of Health Services (DHS) set maximum contaminant levels (MCLs) for trace elements, including salt and nitrogen; and for organic contaminants, microbial (biological) contaminants to ensure that the water is safe for human consumption. Title 22 of the California Code of Regulations contains primary drinking water standards that are legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water. Title 22 Drinking Water Standards are used to evaluate water quality conditions and impacts to municipal and domestic beneficial uses of groundwater pursuant to RWQCB policies.

1.3.3 SWRCB Policies

1.3.3.1 Sources of Drinking Water Policy

SWRCB Resolution No. 88-63, "Sources of Drinking Water" policy (adopted on May 19, 1988) specifies that, except under specifically defined exceptions, all surface and ground waters are suitable or potentially suitable for municipal use. The Basin Plan and SWRCB policies do not require improvements over baseline conditions or naturally occurring background concentrations, and the objectives are to ensure that there is no further degradation over historical conditions.

1.3.3.2 Antidegradation Policy

SWRCB Resolution No. 68-16, “Statement of Policy with Respect to Maintaining High Quality of Water in California” (adopted on October 28, 1968), also known as the Antidegradation Policy is intended to maintain high quality waters and establishes criteria that the RWQCB must satisfy before allowing discharges that may reduce water quality of surface water or groundwater even though such a reduction will still protect beneficial uses and would not exceed standards. In simple terms, the policy means the RWQCB cannot allow reduction in groundwater quality beyond what currently exists (baseline groundwater quality). Further degradation of water quality may be allowed by the RWQCB only if the change is consistent with maximum benefit to the people of the state, does not unreasonably affect present and anticipated beneficial uses, and does not result in water quality less than that prescribed in Basin Plan policies.

In addition, the Antidegradation Policy has never been applied to large scale agricultural areas in respect to groundwater. The State Board is actively engaged in a process to review the application of that policy in this agriculture groundwater setting. When that policy is amended, certain provisions of the GAR may need to be amended.

1.3.3.3 Recycled Water Policy

Publically owned treatment works (POTW) can be a source of salt and nitrogen. SWRCB Resolution 2013-0003, "Policy for Water Quality Control for Recycled Water" (adopted January 22, 2013) is intended to protect long term water quality, and ensure that every groundwater basin/sub-basin in California has a consistent Salt and Nutrient Management Plan (SNMP). The Recycled Water Policy requires that entities seeking to reclaim or recycle municipal waste water prepare a SNMP by 2014. The intent is to facilitate basin-wide management of salt and nutrient from all sources in a manner that optimizes recycled water use while ensuring protection of groundwater supply and beneficial uses, agricultural beneficial uses, and human health. The RWQCB, through its regulation of discharges, now requires operators of publicly owned treatment works (POTW) to develop implementation plans to meet the objectives of the Recycled Water Policy, including preparation of SNMP. SNMPs must include a basin/sub-basin monitoring plan designed to determine water quality in the basin. The SNMPs will then be adopted by the RWQCB as amendments to the region's Basin Plan.

1.3.4 Related RWQCB Permitting Requirements for Potential Dischargers

The RWQCB has a number of regulatory authorities and permitting tools that apply to the point and nonpoint discharges that could be contributing salt and nitrates to groundwater. These include Waste Discharge Requirements (WDRs), National Pollution Discharge Elimination System (NPDES) Program, construction storm water permits, and water quality certifications of wetlands (401 permits).

1.3.4.1 Confined Animal Facilities

Confined animal facilities may be a source of nitrates and salts to groundwater in the Coalition area. RWQCB Confined Animal Facility Program is implemented through the adopted Waste Discharge Requirements General Order R5-2007-0035 for Existing Milk Cow Dairies (Dairy General Order). The Dairy General Order prohibits the discharge of waste or storm water from the production area to surface water, wastewater to surface water from cropland, and storm water to surface water from a land application area where manure or wastewater has been applied. The Dairy General Order requires that the owners and operators of existing milk cow dairies (dischargers), develop and implement a Waste Management Plan for the production area, develop and implement an Nutrient Management Plan for all land application areas that are under the discharger's control, monitor all discharges from the production area and land application areas, and monitor the nutrient content of all solid manure and wastewater applied to land application areas that are under the discharger's control. Discharges from irrigated agricultural parcels are regulated by the Dairy General Orders if the owner or operator of the parcel applies dairy waste from its dairy operation. Irrigated agricultural parcels that receive dairy or other confined animal facility are required to comply with the Dairy General Order.

1.3.5 Related State Policies Food and Agricultural Code

The California Department of Pesticide Regulation (DPR) within the California Environmental Protection Agency (CalEPA) is responsible for administering state regulations for the safe permitting, use, and storage of pesticides.

1.4 RELATED PROGRAMS AND PLANNING EFFORTS

1.4.1 CV-SALTS

The General Order is being developed on a parallel, but separate, path to the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) Initiative. The CV-SALTS initiative has the goal of developing sustainable solutions to the increasing salt and nitrate concentrations that threaten the achievement of water quality objectives in Central Valley surface and groundwater. It will provide for an amendment to the Basin Plan. Prior to any amendments to the Basin Plan, the Order is to be used to minimize impacts to beneficial uses of groundwater.

CV-SALTS is using a portion of the Kings coalition area as a prototype to test models used to evaluate movement of salts, nitrogen and assimilative capacity. Additional work may be planned in the Kings area to further test and refine process-based simulation models (CVHM-WARMF-Mixing model) to evaluate ambient conditions, assimilative capacity, fate, and transport of contaminants and areas vulnerable to contamination.

1.4.2 Integrated Regional Water Management Plans

The Order encourages coordination with the IRWMPs for the covered areas. IRWMP may contain components for control of saline water, regulation of the migration of contaminated water, monitoring groundwater levels and storage and related programs which may be included in the IRWMP. The Order requires the Coalition to develop regional groundwater monitoring work plans and, where necessary, Groundwater Quality Management Plans (GQMPs). Under the Order, the Coalition is encouraged to coordinate with local groundwater management plans and integrated regional water management plans when developing regional groundwater monitoring work plans and GWMPs. There may be related salt or nutrient management projects that could be included in the prevailing IRWMP and could be a candidate for funding. Upper Kings IRWMP includes a large part of the Coalition area. The Coalition is also contiguous to, or partially contained in the Kaweah River Basin, Tule, Poso and Kern County IRWMP areas.

1.4.3 Groundwater Management Plans

Groundwater Management Plans have been prepared for much of the area. These plans served to define local groundwater management and monitoring efforts.

- Fresno Area Regional Groundwater Management Plan. (P&P, et al., 2006)
- Consolidated Irrigation District Groundwater Management Plan. (GEI, 2009)
- Lower Kings Basin Groundwater Management Plan (WRIME, 2005)
- James Irrigation District and the City of San Joaquin Groundwater Management Plan. (P&P, et al., 2010)
- Groundwater Management Plan for the Riverdale Irrigation District (P&P, et al., 1995)
- Amended Groundwater Management Plan, Alta Irrigation District (2010)
- Groundwater Management Plan, Kings County Water District. Adopted January 1993. (P&P, et al., 2011)
- Tulare Lake Bed Coordinated Groundwater Management Plan was originally adopted in 1995 and amended to be SB 1938 compliant in July 2012. (Summers, et al., 2012)
- Tranquility Irrigation District, Fresno Slough Water District Groundwater Management Plan. (P&P, et al., 2009)
- Groundwater Management Plan Kings County Water District (P&P, et al., 1993)

1.5 REPORT CONTENT

The Kings GAR Report contains eight (8) chapters:

Chapter 1, Introduction – sets the stage for the Kings GAR, describing the purpose of the GAR, related requirements and related programs and planning efforts.

Chapter 2, Conceptual Model & Approach – identifies nitrates and Total Dissolved Solids (TDS) as the primary contaminants of concern. It defines the approach to identifying risk, susceptibility and vulnerability in terms of the three primary systems analyzed, namely the land use, water management and geological systems; and explains the system, systems features, vulnerability factors and potential risk variables included in the conceptual model. It describes the basis for defining subareas and the sources of salt and nitrates in the Coalition area, along with the fate and transport mechanisms the influence susceptibility and vulnerability to potential contamination form irrigated agriculture. The alternatives for conducting the vulnerability analysis are described along with the selected approach and basis for selection.

Chapter 3, Data Collection – describes the data collection effort, approach to prioritizing what data would be applied in the Kings GAR, and an inventory of data collected.

Chapter 4, Susceptibility and Vulnerability Factors – Groundwater, Water Management and Land Use Systems are reviewed to select vulnerability factors and risk variables.

Chapter 5, Groundwater Quality – reviews the historical and existing nitrate, TDS and pesticide conditions using data from the available sources. This includes presentation of the spatial and time series data to characterize the groundwater quality. Areas where groundwater quality sampling and testing indicate exceedence of drinking water standards are identified so that these can be compared to the vulnerability maps developed.

Chapter 6, Groundwater Vulnerability Analysis – explains the data synthesis, methods and results of the analysis to assign the vulnerability index variables applied in the Kings GAR analyst tool to map the high and low vulnerability designations. It explains the functionality and application of the Kings GAR analyst tool. The results of the analysis are shown in terms of the intrinsic susceptibility, regional vulnerability and on- farm vulnerability. The vulnerability of the drinking water systems is used to establish priorities for the areas identified as highly vulnerable to contamination that potentially results from irrigated agricultural. This chapter also presents where alternate sources of contamination may be contributing to the problem.

Chapter 7, Groundwater Monitoring – describes the current programs and the feasibility for incorporating existing groundwater data collection efforts and data sharing. The existing monitoring networks are categorized as ambient, compliance and special study. This chapter is to support the Coalition's subsequent efforts to develop the groundwater quality trend monitoring program. The opportunities and constraints related to integrating existing networks and sharing data are discussed.

Chapter 8, Summary of Results and Observations – provides the results of the study and a summary of the approach taken, shortfall in the datasets, lessons learned, and follow-up investigations not included in this initial phase effort.

Chapter 9, References - lists the references in the report.

Chapter 2. Conceptual Model & Approach

Chapter 2. Conceptual Model & Approach

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Chapter 2. Conceptual Model & Approach

2.1 Contaminants of Concern

The Kings GAR is an analysis of the risks to groundwater from salts and nitrates that may originate from irrigated agriculture. In the Coalition area, nitrates and salts are the primary constituents of concern since they that could impair groundwater beneficial uses. Nitrates in groundwater can impair drinking water beneficial uses, but do not typically impair agricultural beneficial uses. Salts in groundwater can impair both drinking water and agricultural groundwater beneficial uses.

The National Academy of Science and U.S. Geological Survey (USGS) have developed terminology used to support assessment of risk, susceptibility and vulnerability. The Kings GAR applied this terminology (NRC, 1993) (USGS, 2011). The USGS and others have developed conceptual models and analytical tools that can be applied to assess contamination risk and where considered in developing the Kings GAR. The Kings GAR conceptual model was developed by reviewing the physical process and interactions which occur between the land use, surface water/water management and groundwater systems; and the sources, fate and transport of salts and nitrates in the Coalition area. Alternative analytical approaches were reviewed and a final approach selected for the King's GAR. A hybrid Index Overlay approach was chosen based on the scientific and management objectives, available data, and the resources available to conduct the analysis.

2.2 Conceptual Model

2.2.1 Risk, Susceptibility, Vulnerability

The National Academy of Science, Water Science and Technology Board appointed a committee on Techniques for Assessing Groundwater Vulnerability (NRC, 1993). The committee defined groundwater vulnerability as: "*The tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer*."

Estimates of groundwater vulnerability can be separated into intrinsic susceptibility and specific vulnerability (**Figure 2-1)**. The primary risk of contamination from irrigated agricultural operations is related to the potential to degrade drinking quality and beneficial use such that they exceed the maximum contaminant levels established under California Drinking Water Standards set by Title 22 of the California Code of Regulation. For purposes of the Kings GAR, risk is comprised of four risk categories comprised of two elements; susceptibility and vulnerability. Both of these elements of risk have dynamic properties, those which can change with time like water table depth and streamflow; and static properties which are relatively time invariant such as aquifer material or soil texture. Susceptibility has one risk category stemming from the naturally occurring conditions of the aquifer and soil properties. Vulnerability has three risk categories: On-Farm, Regional and Drinking Water.

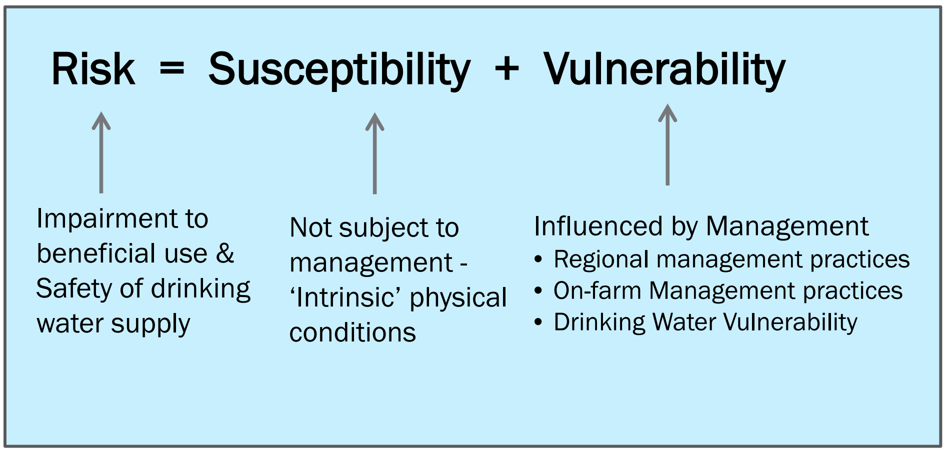


Figure 2-1. Risk, Susceptibility and Vulnerability

For purposes of the Kings GAR, the definitions of intrinsic susceptibility and vulnerability are as follows:

Intrinsic Susceptibility, also referred to as susceptibility, is related to naturally occurring factors associated with the physical conditions in the Coalition Area. An aquifer may be susceptible to contamination but is not vulnerable until a contaminant is introduced. Susceptibility factors are dynamic and change with time (natural streamflow; depth to groundwater), while others are static (soil or aquifer texture); and are spatially variable. They influence how water and contaminants move through the systems. The intrinsic naturally occurring properties of the basin include the following:

- Soil Permeability
- Soil Transmissivity
- Depth to Groundwater
- Aquifer Thickness
- Aquifer Confinement
- Clay Layer Thickness

- Natural Streamflow

Vulnerability is related to the type, sources and mechanisms which transport a potential contaminant. This includes factors which are subject to management actions by the grower to reduce the potential for future risk of contamination, or remediate existing contamination as a result of the consequences of past practices; and actions protective of drinking water resources.

- ***Regional vulnerability*** is related to those management actions of water districts through such actions that influence the water balance and the salt and nutrient balance. This includes such things as artificial recharge, conjunctive use, importation of water and reservoir operations. Regional management actions (macro scale) may vary over time. In agricultural regions this is typically in response to grower need. Operation of the regional surface water and groundwater systems also influence groundwater vulnerability to nitrate and salt contamination by changing the rate and direction of groundwater flow. Regional water management actions may also include things such as sewering of areas reliant on septic systems (regional vulnerability), recycling wastewater, or development of surface or groundwater treatment plants.
- ***On-farm vulnerability*** is related to factors over which a grower has some level of management control such as quantity, rate, timing, and methods of nitrogen application, irrigation systems used for water application, and cropping (micro scale). The Order applies to on-farm activities only. The on-farm management practices may change over time in response to market conditions and hydrologic variability. On-farm and agricultural land use practices operate in context of the larger regional water surface and groundwater management activities. As such there is both a micro and macro scale to be considered when evaluating groundwater vulnerability to contamination. The on-farm activities represent the micro scale, where individual growers have an influence over irrigation and nutrient management.
- ***Drinking water vulnerability**,* including municipal and domestic systems, is considered in the Kings GAR. Individual wells, small community water systems and municipal water systems are vulnerable to nitrate contaminants that potentially originate from irrigated agricultural lands and other sources.

2.2.2 Systems Affecting Risk

The Order regulates on-farm activities. On-farm activities are in context of the larger regional water surface and groundwater management activities. As such there is both a micro and macro scale to be considered when evaluating groundwater vulnerability to contamination. The on-farm activities represent the micro scale, where individual growers have an influence over irrigation and nutrient management. The growers operate in context of the regional water management activities which represent the macro scale. Operation of the regional surface water and groundwater systems also influence groundwater vulnerability to nitrate and salt contamination. The Conceptual Model is used to describe the three major systems that govern the sources, transport and fate of contaminants of nitrates and salts. This approach factors that both on-farm and regional water management systems have changed overtime. The three major systems include:

- **Land Use System –** Land use defines related beneficial uses of water and identifies potential surface sources and loading of contamination. The land and water use system can be influenced by management actions both at the micro, on-farm scale, and at the regional scale based on land use planning. For purposes of the Order, the land use system is where growers have an influence on vulnerability factors related to irrigation and nutrient management and efficiency. Agricultural land use and crop type drive water demands and provide the primary driver for how the water management and surface/groundwater systems are operated to meet on farm demands; and the selection of irrigation systems. The land use system also includes other potential sources of nitrate or salt loading such as septic systems, wastewater disposal practices, confined animal operations or industrial dischargers.
- **Surface Water/Water Management System –** Defines how surface water is managed and applied to meet all beneficial uses. The surface water system is connected to the groundwater systems through the recharge discharge relationships that influence contaminant fate and transport. The system is affected by both intrinsic susceptibility factors and regional vulnerability factors which govern the water balance and nutrient/salt mass balance. For example, the sources of surface water, conjunctive use and intentional recharge operations influence the volume of water applied which may ultimately result as recharge to groundwater.
- **Groundwater System –** Governs how water and sources of natural or human contamination move through the shallow soils zone, and the unsaturated and saturated zones of the underlying geologic soil structure. The groundwater system is connected to the land use and water use system since it represents the water demand and water quality requirements (beneficial uses and quality of water that meets standards). It influences fate and transport, and has a primary bearing on the intrinsic susceptibility factors, but influences vulnerability factors through pumping regimes and conjunctive use operations which affect time of travel and groundwater flow direction.

2.2.3 Sources of Salt and Nitrates

The land use system has the primary influence on the human sources of nitrates. Potential sources of nitrate include agricultural application of nitrogen fertilizers, Publicly Owned Treatment Works (POTWs), confined animal facilities including dairies, septic systems, waste discharges from food processing and other industrial facilities, and urban use of fertilizers. In the Kings Study area, the predominant land use is agriculture. Volumetrically, agricultural represents the largest potential source of nitrates (UCDAVIS, 2012) and is the focus of the Order. The Nitrogen cycle is shown in **Figure 2-2**.

Both the vadose zone and aquifer have nitrates and salts in storage that are the result of past land use practices. This is part of the existing baseline conditions and represents a reservoir of contamination that will continue to migrate over time and effect the observed concentration in wells now and in the future. This is important from both and on-farm management standpoint and from a regional management planning, and regulatory perspective.

Salt originating from outside of the Kings Study area is imported water from the Sacramento – San Joaquin Delta via the Central Valley Project Delta Mendota Canal (CVP DMC) or the State Water Project's (SWP) California Aqueduct.

There are naturally occurring sources of salt in the region including runoff from the Coastal Range, groundwater flow through the marine sediments from the Coastal Range, and residual salts that concentrate through evaporation of the runoff into poorly drained areas at the land surface (surface sinks). Even before any agricultural development, salts concentrated in these poorly drained areas due to evaporation of water at the land surface. High TDS observed in groundwater is also the result of high groundwater tables overlying the clay layers. Under predevelopment conditions, the water table was close enough to the land surface to experience evaporation. This allowed for salts to concentrate. Under post development conditions, applied water for irrigation can also raise the water table high enough to where evaporation from the groundwater table may concentrate salts either at the water table, or in areas where groundwater meets the land surface.

High TDS water is also found naturally in the deeper part of the aquifer below the Corcoran clay and is likely of marine origin. The issue for agriculture is that irrigation can mobilize the naturally occurring salts resulting in discharge of the salts to groundwater or to surface water via agricultural drainage.

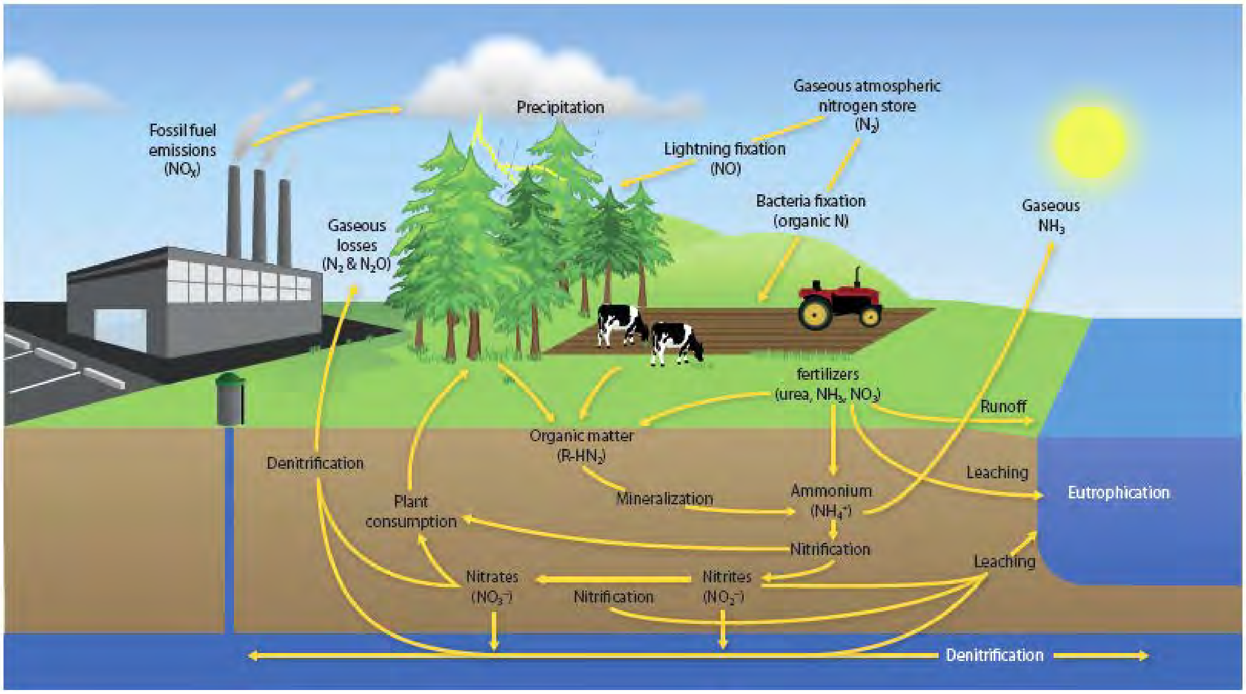


Figure 2-2. Nitrogen Cycle

2.2.4 Transport and Fate of Salt and Nitrates

Transport mechanism refers to the manner and means that salt and nutrient move through the land use, surface water, and groundwater systems. The fate is where the contaminants ultimately end up. Salts generally move with the surface water and groundwater. The transport and fate of nutrients, specifically nitrate (NO3), is more complex than for salts as a result of plant uptake and chemical transformations that occur in soil as a result of biological activity **Figure 2-2**. On-farm and regional management affect contaminant fate and transport.

At the micro scale, the land use system and on-farm water and nutrient management practices influence the transport and fate of salt and nitrates from the root zone, downward through the unsaturated zone, and ultimately to the aquifers. On farm management has changed over time and there have been improvements to both irrigation and nutrient management practices. The implication is that contaminant concentrations observed at a well today may be the result of practices in place historically and may not be representative of current on-farm practices which are the target of the RWQCB order.

At the macro scale, regional water management practices influence the flow of surface water and groundwater, and thus, the fate and transport of salts and nitrates. The water management facilities are used to store and distribute Kings, Tule, Kaweah and imported water, and provide for conjunctive use of local surface and groundwater, and have a strong influence on the water budgets and salt and nitrogen mass balance. How much and where the different surface water sources are delivered or intentionally recharged, the mix of groundwater and surface water use, and the influence of pumping on the water table all affect contaminant transport. Areas that do not receive surface water are 100 percent dependent on groundwater. This affects the water and salt budget since these areas do not experience additional recharge or dilution from applied surface water or other intentional recharge from spreading, canal leakage or dedicated recharge facilities. The macro scale transport mechanisms also define the fate of contaminants which may be transported out of the area by groundwater or surface water flow; diluted in transport or via mixing, and the where there are surface water or groundwater sinks.

2.2.5 Kings GAR Conceptual Model

Conceptual models support regional analysis and are a way of simplifying and visualizing complex processes. There have been a number of valuable studies of regional aquifers in the Southwestern United States and San Joaquin/Tulare Lake Hydrologic units that have supported the development of basin scale conceptual models and identified key factors used to evaluate susceptibility and vulnerability to different of contaminants (USGS, 2010a) (USGS, 2010b) (USGS, 2012) (USGS, 2012). Conceptual models help generate understanding of the primary natural and human-related factors commonly affecting groundwater quality, thereby building a regional understanding of the susceptibility and vulnerability of the aquifers to contamination from salts, nitrates, and other contaminants that may originate from overlying irrigated agricultural operations and other sources.

The generalized conceptual model of the interaction between the land use, surface water and groundwater systems is shown in **Figure 2-3**. It represents the potential contaminant flow driven pathways for an introduced contaminant, and for migration of natural contaminants. The three systems and the generalized model are used to describe and understand the risk factors that may lend to groundwater contamination from irrigated agricultural operations. The hydrogeology of the Tulare Lake Bed has been studied extensively for purposes of reviewing the beneficial use designations (Schmidt, et al., 2014). This study demonstrates that the clay layers underlying the Tulare Lake Bed are thicker than the other GAR sub-areas, creating little economically available groundwater. When combined with naturally occurring salts, the agricultural use of this area becomes limited.

The types, quantity, and source of scientific data used to further develop the conceptual model are listed in **Table 2-1**. Review and assessment of the available data helped to identify uncertainties, prioritize efforts to fill data gaps and establish analysis requirements.

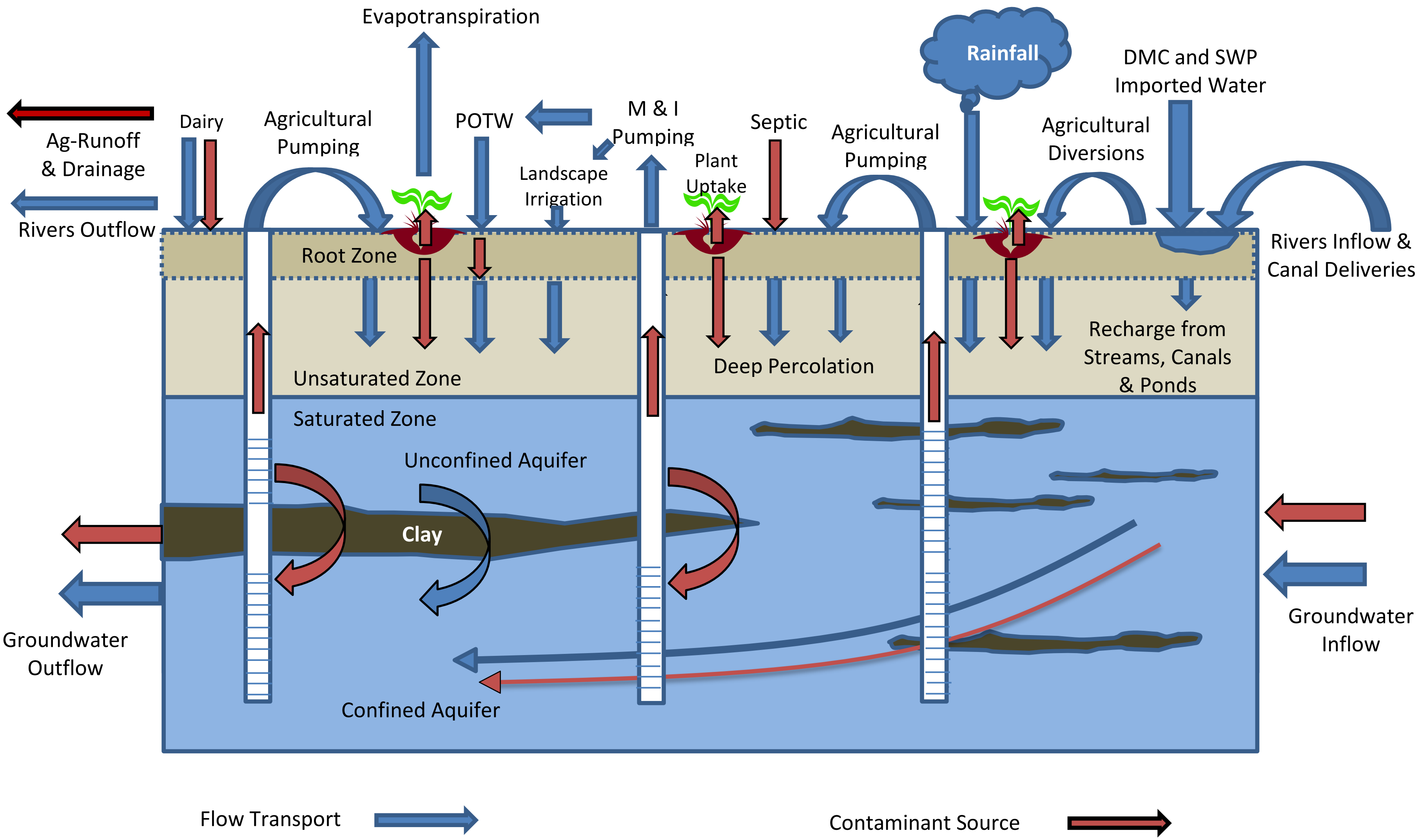


Figure 2-3. Conceptual Model of Typical Groundwater Systems

Table 2-1. Primary Systems Feature, Data Used

Primary Systems Feature	Category, Index Variable, System of Transport	Source and Data Used
Shallow Soils Characterization by Soil Type	**Intrinsic** Surface Soil Permeability **System of Transport** Water Management	Shallow soils characterization has been done for numerous models with the highest resolution being the Kings IGSM model and perhaps the SBX2 study. For purposes of this analysis, the USDA soils coverage (SSURGO) was deemed best because it contains much of the same data used in previous models and can quickly be resolved to the IOG to calculate a weighted soils index which agrees closely with the CVHM model. Additional data as attributes to the SSURGO dataset include field capacity, wilting point, pH, alkalinity, and salinity.
Aquifer Characteristics	**Intrinsic** Underlying Clay Thickness and Rate of GW Movement **System of Transport** Groundwater	The CVHM model provides a practical method of soil transmissivity through their detailed percent coarse soils study (resulting in the texture model). To improve certainty, even at a low resolution, Percent Coarse Data on the CVHM grid level is used to correlate the relative vertical transmissivity between each CVHM cell. The presence of the Corcoran clay is very apparent in the Texture Model (layers 4 and 5 of the CVHM model). The thickness of the unsaturated aquifer is a factor influencing the concentrations of pollutants above the clay layer, and the clay layer's thickness is an indicator of the risk of high concentration water leaking into clean water aquifers beneath the Corcoran clay as the clay becomes thinner and fragmented.
Depth to GW	**Regional Management** Depth of GW Over Clay Layer **System of Transport** Groundwater	Depth to GW varies over time based on hydrologic conditions and groundwater use and recharge practices. Since GW (piezometric) head data already exists with CVHM, a calibrated model, the level of confidence is suitable for this effort over calculating individual GW elevation contour maps using CASGEM or other by-well data sources where large data gaps exist. CVHM data is taken from the average of layers 6, 7, and 8. These aquifer layers of the model have the largest aerial extent of the regional Central Valley Aquifer.
Source Water	**Regional Management** Water Source (Applied Surface Water and Applied Salts) and Percent Surface Water to Groundwater **System of Transport** Water Management	The question of increased concentration or dilution of salts and nitrates is answered by the attributes of source water for recharge and applied water. Monitored surface water diversion locations and water quality data associated with each provides the amount of imported contaminants (and volume of surface water) to the study area. The application of these waters varies by year and by water district. Expert knowledge is used to roughly approximate the allocation of imported surface waters (and use of groundwater) to the demand sinks associated with agricultural and urban uses. Source water is attributed as both a positive benefit through dilution of nitrates, and can have a negative benefit through importation of salts. Both depend on the location and concentration of water applied.
Stream Recharge	**Regional Management** Improved Dilution of Contaminants Along Stream Channels and Recharge Ponds **System of Transport** Water Management	Clean water recharge from the Kings river comes from natural and manmade channels, and from intentional recharge spreading areas. As a clean water source, Kings River recharge is assumed to have a dilution benefit over the path of all channel alignments traveling east to west and south to north across the study area. Benefit is assigned to each IOG cell a certain number of grid values from the stream centerline based on the quantity of recharge occurring. The alignment and quantity of stream recharge comes from the stream budget of the Kings IGSM model.

Table 2-1. Primary Systems Feature, Data Used, Continued

Primary Systems Feature	Category, Index Variable, System of Transport	Source and Data Used
Land Use/Consumptive Use Data	**On Farm Management** Applied Water and Applied Nitrogen to Calculate Surface Recharge from Deep Percolation and Nitrogen Efficiency **System of Transport** Land Use	Since the amount of water used is directly linked to the land use where water is being applied, the land use (i.e., crop types) and consumptive water use are closely tied. Land use information came from the CAML dataset, given its aggregated sources of data, and two years of complete data for 2010 and 1990 in electronic format. Consumptive use (or applied water) is anticipated as being a calculated value based on crop data, crop efficiencies (irrigation practices), etc.
Agricultural Irrigation Practices	**On Farm Management** Surface Recharge from Deep Percolation **System of Transport** Land Use	Similar to the nitrate loading, the SBX2 study contains much of the information along with local experience. The groundwater models also provide irrigation efficiencies and amount of applied water in any given hydrologic year-type. Ultimately, the report titled, "Spatial Analysis of Application Efficiencies in Irrigation for the State of California" (USGS, June 2013) is used for irrigation efficiencies because of its resolution, peer review status, and handling of multiple time periods (2010 and 2001) for comparison of efficiencies and irrigation practices over time.
Nitrate Loading	**Regional Management** Nitrogen Efficiency **System of Transport** Land Use	The SBX2 study is considered to be a primary source for the nitrate loading index. KRWCA Coalition members have asked for a reality check on the data. To get at nitrogen loading from fertilizer applications, the crop type data under land use is modeled to understand the relative potential loading of nitrogen through leaching action below the root zone. This is explained in the Applied Water Model Utility in **Appendix C**.
Population on GW	**Level of Priority** Population on Groundwater	Priority is given to the risk to human health, and is related to the proximity of population on groundwater, whether it is from a public drinking water supply or from private wells. This category is a measure of risk to public health, if contamination were to occur. Census data and water district attributes are used to identify the average number of people on groundwater for each IOG cell. A high number of capita on groundwater implies a potentially high risk.
Ambient Water Quality	**Comparative** Ambient Nitrate Ambient Salinity	The existing presence of a contaminant is considered a pre-existing condition which is not under the direct control of water management practices of today or in the future. Concentration data from published studies and public databases are used to generate ambient conditions for use in comparing the calculated high risk areas with where contamination exceedance is already being found. While not to be used for delineating high risk areas, the ambient water quality conditions should align well with the GAR's delineation of high risk of contamination. Areas not in agreement should carry an explanation as to why, seeking other potential sources as the cause.
Septic Systems and Point Source Discharges	**Other Sources of Nitrogen** Other Potential Sources of Nitrogen	Septic tanks and permitted point source discharges are considered to be another source of the leading cause of nitrate concentration build-up in areas without public sewers. Often times leach fields (or dry wells) penetrate the protective surface soils allowing for transport to shallow aquifers and fractured rock sources (in the higher elevations) of drinking water supplies. Point source discharges from dairies, feedlots, wastewater treatment plants, canning industries, and similar industrial uses can be a potential source of nitrogen and salinity if not managed correctly.

The types of data, data needs, and data sources were evaluated to further refine the conceptual model used to represent one or more of the scientific elements of the water cycle. Development of the conceptual model sought to ensure there was no duplication or double counting of any one water cycle attribute. Each dataset was selected so as to fill in those attributes leading to the possibility of high concentration contamination in groundwater. As a simple illustration, the intrinsic elements associated with the degree of the physical action of creating high concentrations of contaminants above a confining clay layer (**Figure 2-4**) are the following:

- permeability of the surface soils
- the vertical transmissivity of the unsaturated and saturated soils above the clay layer
- depth of groundwater above the clay layer
- difference in piezometric head between the upper unconfined and lower confining aquifers (i.e., illustration shows unconfined aquifer being higher, creating a downward pressure from the unconfined to the confined aquifer)
- thickness and heterogeneity of the clay layer
- natural ambient conditions

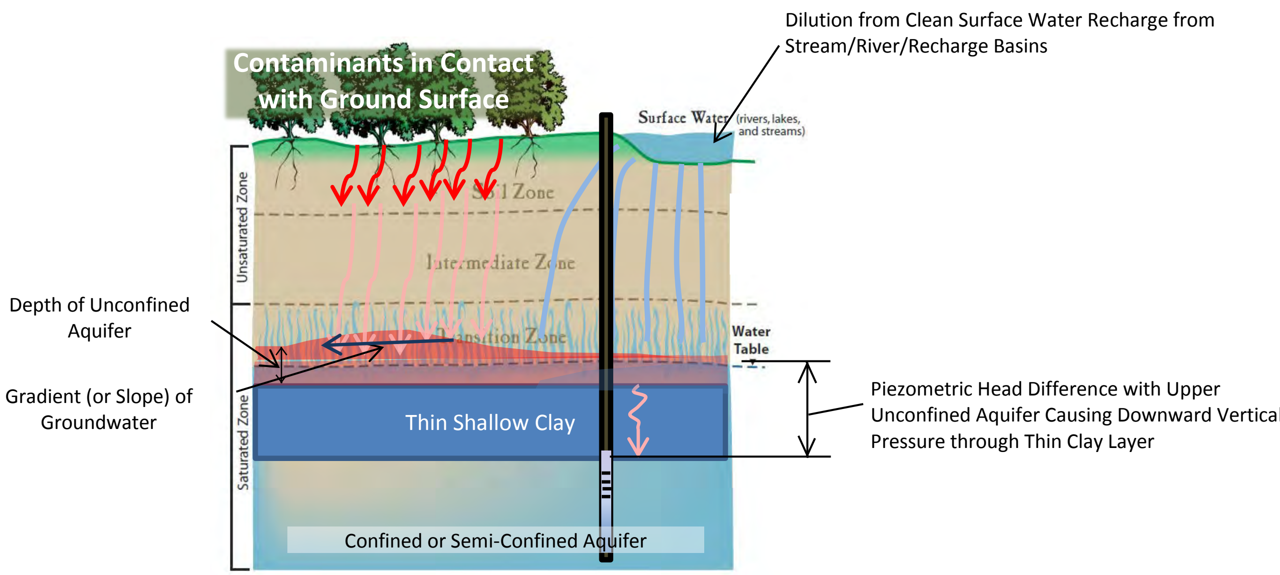


Figure 2-4. Effects of Underlying Clay to Build-up of Contaminant Concentrations

A step-by-step idealized description of the physical actions taking place from intrinsic and regional management actions, including farming practices, and level of risk to drinking water is provided below as an example to identify the datasets (in bold), and to note how each action is accounted for (with no double-counting) in the analysis process:

1. Contaminants are introduced at the surface at a rate based on the **Nitrogen Efficiency** of the crop under current farming practices**.**
2. Water is applied, causing plant uptake and downward migration of free nitrogen. Water travels through root zone due to gravity, and at a rate dependent on the **Surface Soil Permeability** and porosity.
3. The amount of **Deep Percolation** of water from beneath the root zone containing free nitrogen is dependent on the applied water as irrigation, the nitrogen use efficiency, soil porosity, and the amount of precipitation throughout the year.
4. Over time, based on the **Rate of Groundwater Movement** and **Depth to Groundwater,** waterborne free nitrogen migrates through the unsaturated zone to the groundwater table of the unconfined aquifer.
5. A mounding effect of higher nitrogen concentration water occurs in the unconfined aquifer based on the depth of groundwater above the clay layer and the **Underlying Clay Thickness**. The greater depth of groundwater provides dilution and the greater clay layer thickness reduces further vertical movement downward depending on the piezometric head difference between the upper and lower aquifers.
6. The nitrogen concentration will continue to mound and move horizontally in a manner consistent with the gradient of the groundwater table. Some nitrogen may migrate through the clay layer if a positive head difference exists between the upper and lower aquifer, leading to contamination of the lower aquifer.
7. High concentration contamination sinks will likely occur in areas of shallow groundwater depth above an impervious clay layer where the groundwater gradient is low. Contaminants can also contribute to these sinks from lateral up-gradient movement over the clay layer.
8. A source of dilution is **Stream Recharge** coming from good quality surface water flowing in natural rivers, and where intentional groundwater recharge is occurring. The ability to direct clean water into the aquifer is considered a management practice of positive benefit through dilution. Hydraulically disconnected rivers offer the greatest recharge potential whereas hydraulically connected rivers hold back recharge. Regardless, both are considered beneficial.
9. Similar to stream recharge, use of imported surface water supplies for recharge and crop irrigation has a dilution effect on nitrogen through deep percolation below the root zone. Use of surface water as the **Water Source (applied surface water)** for irrigation has a positive effect on the overall reduction of nitrate concentrations.

10. Some surface water sources can be attributed to the overall accumulation of salt in the soil and in the groundwater. Some farming practices flush salts from shallow soils prior to the growing season, pushing the salts accumulated from the previous year's growing season into the aquifer system where salinity contamination can occur. In some cases, tile drains are used to capture the salt laden water and transport the water to dedicated disposal sites. **Water Sources (applied salt)** has a negative effect in this case, and is sensitive to the actual salinity concentrations found in the imported surface water source and where the water is applied.

To complete the overall risk determination, the following level of risk actions include:

11. Prioritizing management steps to reduce risk of contamination to public drinking water supplies depends on the proximity of the above actions taking place near drinking water supply wells. **Well Protection Zones** are delineated for both public and small water system wells as included as high risk areas of concern to reduce the overall risk to public drinking water supplies.
12. The number of people who depend on the groundwater as a drinking water supply (i.e., both from public and private wells), also increases the risk of a contamination event. The geospatial **Population on Groundwater** provides another level of protection zone delineation for setting priority areas of management.
13. Lastly, a narrative comparison is made with existing known groundwater contamination areas:
14. **Ambient Nitrogen** and **Ambient Salinity** represent existing water quality conditions resulting from past and present practices (urban and agriculture) and/or natural conditions. The existing presence of a contaminant in sufficiently high concentrations is a concern for setting management priorities to reduce risk; however, agriculture is only one of the potential sources of contamination.
15. **Other Sources** of nitrogen and salts can occur from nitrates from septic systems, land disposal of solid waste from wastewater treatment plants, feed lots, dairies, and canning industries are just a few of the types of practices which need to be included in the larger management solution, but are currently under a point source permitting program. This overlay comparison is used to explain why nitrogen is being measured in areas not associated with farming uses.

2.2.6 Coalition Sub Areas

The spatial variability in risk factors within the Water Management System and Groundwater Systems are used to define subareas. Figure 2-5 shows how the area is broken into four major

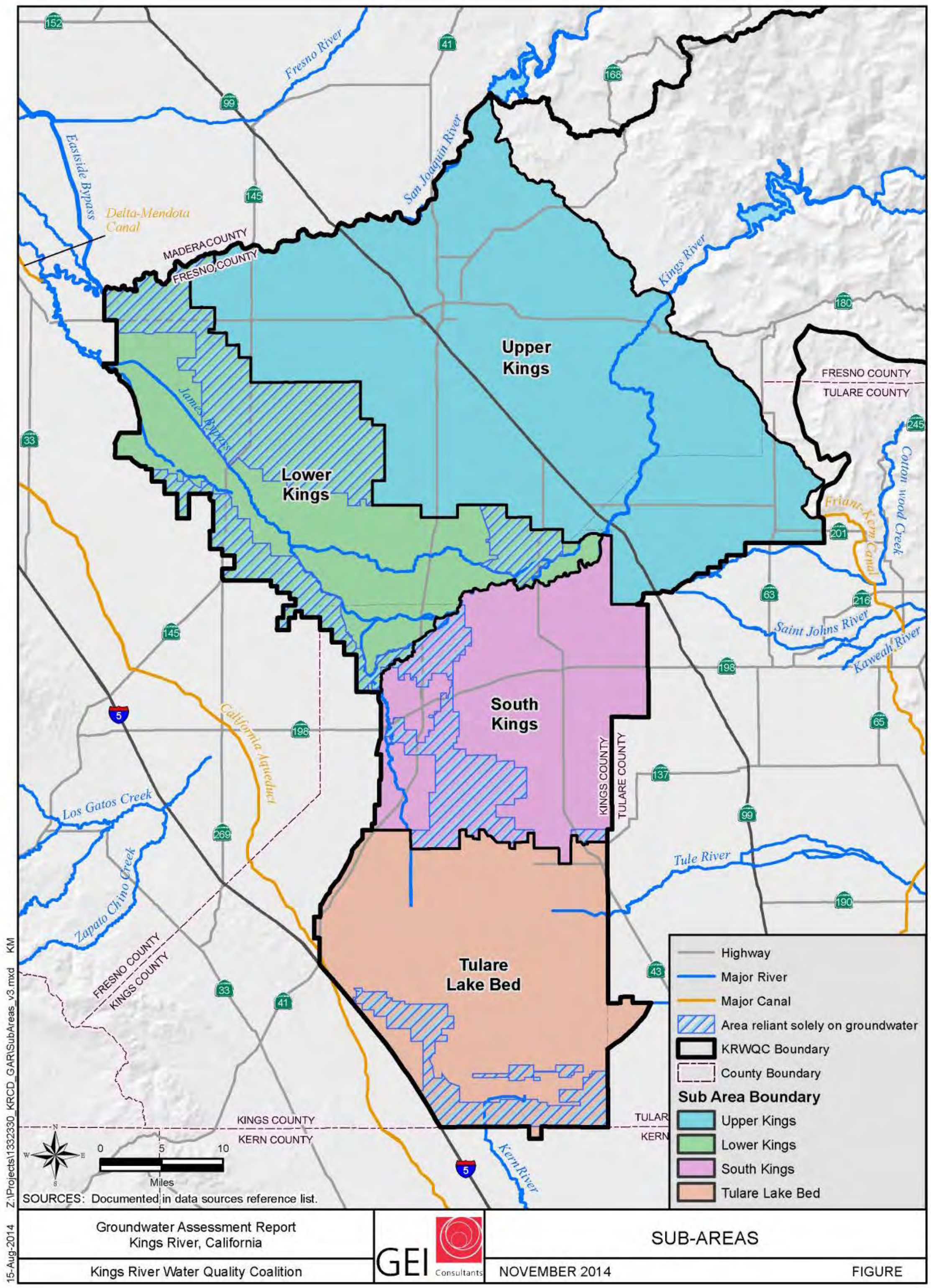


Figure 2-5. Kings River Watershed Sub-Areas

subareas to reflect the regional water management and groundwater systems. The delineations are based on the sources of surface water, conjunctive use water management systems operations, and intrinsic physical conditions of the groundwater basin, primarily the presence of the Corcoran Clay which creates an upper, unconfined aquifer and a lower, confined aquifer, and the more highly permeable alluvial fans found in the eastern part of the Coalition area. The subareas are also based on jurisdictional boundaries of the water management agencies. The areas in the Lower Kings that are 100% dependent on groundwater are shown (hatched pattern). These areas will cycle nutrients and salts through the groundwater and land use systems and do not receive surface water and the related benefits of deep percolation of applied recharge for dilution of ambient contaminant concentration observed in groundwater.

The hatched area in the Southern Kings and Tulare Lake Bed subarea is also indicated. These are areas without public water districts but distribute water through private ditch companies and rely on groundwater when sources of surface water are not available.

The upland areas in the eastern part of the Coalition area are not an intensively cultivated, have a different geology and water management scheme, have less population and are relatively less observed nitrate concentrations that could be attributed to agriculture. They are a lower priority at this time.

2.3 Alternative Analysis Methods

A defensible groundwater vulnerability assessment is one that follows proven scientific methods and includes adequate documentation of data, observations, and method of investigation to allow for independently reproducible results. Understanding the natural hydrogeologic processes as well as the associated anthropogenic effects on a groundwater resource is required for a complete scientific understanding of groundwater vulnerability (USGS, 2002) (USGS, 2010b).

Assessments of the vulnerability of groundwater to contamination range in scope and complexity from simple, qualitative, and relatively inexpensive approaches, to rigorous, quantitative, and costly assessments. Assessments generate insights through the synthesis and integration of available information to distinguish that which is known and well established from that which is unknown and scientifically uncertain. Tradeoffs must be carefully considered among the competing influences of the cost of an assessment, the scientific defensibility, and the amount of acceptable uncertainty in meeting the objectives of the water-resource decision maker.

2.3.1 Alternative Methods

There are three basic methods of assessment of groundwater vulnerability: 1) overlay and index methods, 2) statistical methods, and 3) methods using process-based simulation models. These are listed from least to most costly, data intensive, and complex. Each has different characteristics related to data requirements, analytical rigor, ease of use, and ease of ability for decision makers and the public to understand the results.

- **Index/Overlay** methods assign numerical scores or ratings directly to various the intrinsic susceptibility and vulnerability factors (on- farm, regional) related to the different systems to develop the relative risk of contamination. The index method is used because it is relatively inexpensive, straightforward, and uses data that are commonly available or estimated, and produces an end product that is easily interpreted and incorporated into the decision-making process.
- **Statistical methods** range from simple summary or descriptive statistics of concentrations of targeted contaminants, to more complex analyses that incorporate the effects of several predictor variables. Statistical methods seek to define the probability to contamination, are data intensive, and are more complex to apply and explain to decision makers.
- **Process based methods** simulate physical and chemical processes. There are a wide range of models for evaluating groundwater and assessment of interacting factors controlling both groundwater/surface water flow and contaminant fate and transport. They can be quite complex, data intensive and sources of uncertainty may be hard to quantify. Results may be more easily explained than for statistical methods.

2.3.2 Related Process Modeling Efforts in the Coalition Area

There are a number of modeling efforts that have produced analysis results which were reviewed for use in selecting the final approach to be applied in the Kings GAR. This includes:

- Central Valley Hydrology Model (CVHM) developed by the USGS
- Kings Basin Integrated Groundwater and Surface Water Model (Kings IGSM).
- Hydrus 1D, UC Davis SB 2X Modeling of Vadose Zone
- CV Salts Modeling of Salt and Nutrient Budgets
- California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM)
- Kaweah Delta MODFLOW Model

2.3.2.1 Central Valley Hydrology Model (CVHM).

CVHM developed by the USGS and covers the entire Sacramento and San Joaquin Valley bottom (Faunt, et al., 2010). CVHM includes a texture model to that characterizes the aquifer-system deposits (USGS, 2009). CVHM is being applied by CV SALTS and linked with the WARMF model to evaluate salt and nitrate loading (CVSALTS, 2013). The model uses a 1 square mile grid and includes the entire Kings study area. The model grid and the associated texture model data set were used to evaluate the water budget, represent potential time of travel through the unsaturated zone, and to register other physical characteristics governing intrinsic susceptibility. Use of CVHM as the base grid allowed the Coalition to take advantage of the extensive USGS data collection and interpretation efforts, including evaluation of the underlying aquifer parameters and the CVHM texture model. The model also supported the development of the conceptual model.

2.3.2.2 Kings Basin Integrated Groundwater Surface Water Model.

The Kings IGSM (WRIME, 2007a) was developed for the Upper Kings Water Forum in cooperation and with funding from the California Department of Water Resources (DWR) to support the Kings Basin Integrated Regional Water Management Plan (Kings IRWMP). It is the most detailed surface and groundwater budget analysis of the Kings Basin. It does not include the Tulare Lakes part of the southern Kings study. For the Kings GAR, it was used to describe the basic surface water and groundwater budget for the Upper Kings and Lower Kings as part of the conceptual model and basin description.

2.3.2.3 Hydrus 1D, UC Davis SB 2X Modeling of Vadose Zone

The lag time for a contaminant to travel from beneath the soils zone to the saturated part of the aquifer has an influence on the observed contamination concentration in the aquifers. UC Davis used the HYDRUS 1D model to produce three maps based on three homogeneous soil types: sand, loam, and clay soil, representing the quickest, intermediate, and slowest probable travel times of nitrate to the water table, respectively (UCDAVIS, 2012). Fluxes of agricultural return water were determined by mass balance using the differences between calculated evapotranspiration (ET) from a field and the amount of water applied through natural precipitation and irrigation (including various irrigation technologies and their associated efficiencies).

UC Davis modeling showed that travel time is driven by the amount of water that infiltrates past the root zone of a crop, the depth of the water table, and the hydraulic properties of a soil. The hydraulic conductivity of unsaturated soils is a function of the water content, and therefore the rate in which water (and dissolved solutes) travels in the subsurface is influenced by the quantity of water infiltrating past the root zone of a crop. Factors such as irrigation efficiency, annual precipitation, and crop evapotranspiration contribute to this flux. Six representative crops grown in the study area (alfalfa, citrus, cotton, almonds, corn, and grain) were represented in the model to simulate solute travel time of a conservative solute like nitrates and salts to the water table. UC Davis used daily water budgets for each crop was calculated to determine the amount of water leaching past the root zone. The study also shows that the variation in travel time can be significant, depending on the soils present, crops being grown, and depth to the water table. For the Kings GAR, these maps were obtained and tested for use in order to provide estimates of the time of travel of a contaminant to the aquifer.

2.3.2.4 WARMF- CV Salts Modeling of Salt and Nutrient Budgets

CV SALTS selected a method that integrated the USGS CVHM model and the Watershed Analysis Risk Management Framework (WARMF) model (Systech Engineering, 2001). CVHM provided water budgets and estimates of deep recharge and groundwater flow, while WARMF was used for establishing nitrate loading rates and leaching from different land uses. The Kings Basin served as prototype to test the concepts for evaluating salt and nitrate loading. The WARMF model was not developed for the Kings Basin but the data from the other areas where WARMF was applied were abstracted to the CVHM grid for the prototype. CV SALTS also sought to establish ambient water quality conditions, and then model the long term effects of the salt and nutrient loading from agricultural land uses and other sources. For the Kings effort, the results were reviewed in development of the conceptual model. The nitrate loading estimates from the land uses were also reviewed and tested for purposes of the Index/Overlay analysis.

2.3.2.5 California Central Valley Groundwater-Surface Water Simulation Model (C2VSim)

The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) is an integrated numerical model that simulates water movement through the linked land surface, groundwater and surface water flow systems in California's Central Valley. It was developed by DWR covers the Kings GAR study areas. It was not used for purposes of the Kings GAR.

2.3.2.6 Kaweah Delta MODFLOW Model

The Kaweah Delta Water Conservation District has developed an applied a MODFLOW model to evaluate basin conditions and evaluate project solutions. It was calibrated from 1981 to 1999.

2.4 Selected Approach

Figure 2-6 shows the trade-offs between complexity, uncertainty and cost. The selected approach for the Kings GAR fits into the fourth quadrant and uses a GIS-based Hybrid Index Overlay analysis to assess groundwater vulnerability from agricultural sources. As stated earlier, the Kings GAR methodology focuses on using the best available information to inform decision making on where groundwater is most vulnerable while acknowledging uncertainty.

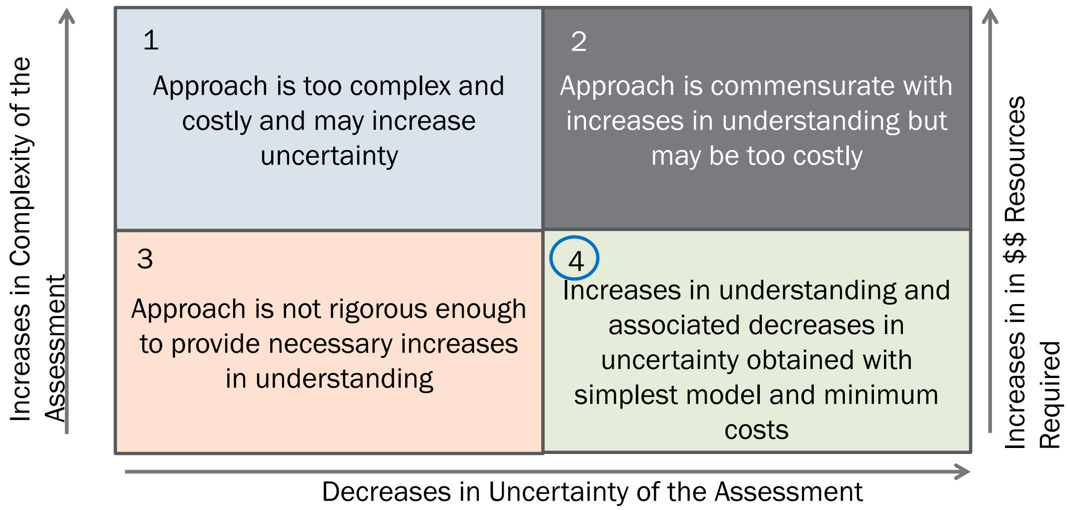


Figure 2-6. Decision Matrix

This approach was selected to:

- Meet the scientific and management objective
- Use available resources as efficiently as possible to produce a defensible result
- Reduce uncertainty by making use of the available data and by applying the results of more complex modeling analyses where available and peer reviewed
- Evaluate and determine the relative risk and identify the major factors contributing to risk
- Make the analysis transparent and understandable so that it is supported by both the grower and regulatory community in developing the MPEP and monitoring program
- Support evaluation of alternative risk ratings, evaluate the relative benefits or impacts from changes to land use and on- farm management

The selected approach recognizes the tradeoffs between scale, process, objectivity and complexity. The Kings GAR pieces together the best available information to inform decision making on where groundwater is most vulnerable. The approach supports an impartial analysis that is reproducible, scientifically defensible, and representative of the physical and management environment in the Coalition area. It was selected based on the inventory, resolution, and quality of available scientific data; and because it requires less data than statistical or numerical modeling methods.

The Kings GAR analysis approach is referred to as a 'hybrid' method because the approach seeks to make use of the analysis results and investments from other related statistical or process modeling efforts; and allows for use of models where calibrated, documented and available.

The other alternative approaches have significant drawbacks. Deterministic and stochastic models have a large amount of uncertainty in the spatial and temporal information required as parameter inputs. The limited data in the Coalition area makes these tools impractical and not cost effective, also making it challenging to produce a good fit between observed and simulated or forecasted data. The lack of data would have required numerous assumptions, greater uncertainty, an inability to calibrate a model and additional costs. The models are harder to communicate to decision makers and the public; and the increased the complexity of these models may not produce a better result, especially in the absence of water quality, well construction, irrigation schedules, nitrogen application rates and other data sets.

2.4.1 Use of CVHM as the Index Overlay Grid (IOG)

The GAR Analysis Tool was developed to aggregate to a one square mile grid based on the USGS Central Valley Hydrologic Model (CVHM) grid. The CVHM is the best source of information on aquifer parameters and is a calibrated model accepted through the USGS peer review process. The gridded maps of risk can then be overlaid and a cumulative risk score can be determined for the coalition area. The CVHM grid and the overlay concept are shown in **Figure 2-7**.

The Index Overlay Grid (IOG) preserves the detailed database of risk factors at the highest level of resolution and can be queried to understand what measurable attributes make the cell more or less vulnerable than the other. Risk values for each IOG cell are based on the weighted average of the different variables found within the grid. Risk variables are evaluated and ranked based on the statistical distribution, conceptual model, related studies and journal articles; and input from experts and local sources. This approach allows for normalization of the risk factors and an 'apples to apples' comparison when grids of different data types are overlaid and a cumulative risk score is calculated.

Risk can be measured by the relative impacts or benefits at a specific location within the study area for a specific snapshot in time using index variables reflective of a given time period. The risk factors can measure increased risk or reduction in risk from management actions. The assignment of risk is discussed further below for each of the susceptibility and vulnerability factors that were mapped for the Kings GAR.

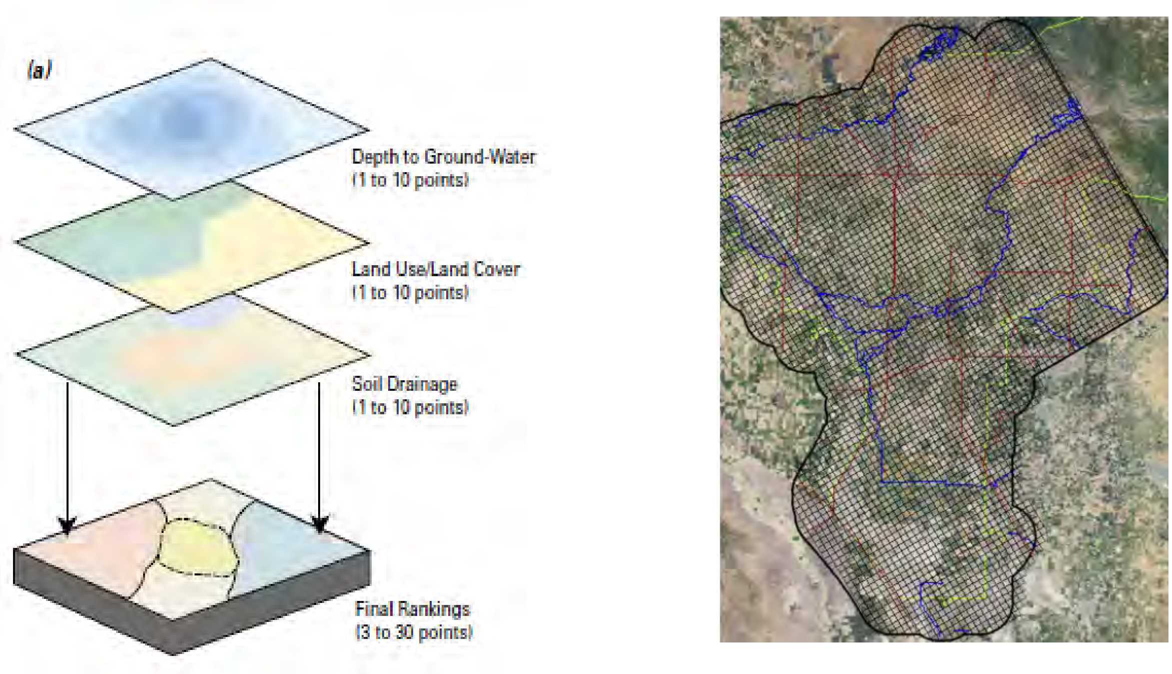


Figure 2-7. Index Overlay Concept and Index Overlay Grid (IOG)

2.4.2 Indices and Risk Factors

The Kings GAR Index Overlay analysis is similar to the Nitrate Hazard Index (NHI) (Wu, 2005) which evaluates nitrate leaching risks based on indexes for soils, irrigation practices and crop types. The NHI recognizes that farm management practices heavily influence the fate of applied Nitrogen, but equally important are the innate soil attributes, crop characteristics, and method of water delivery. UC Davis applied the NHI at a regional scale in the Tulare Hydrologic Region (UCDAVIS, 2012).

The Kings GAR Index Overlay analysis seeks to develop indices for additional risk factors identified in the conceptual model, including factors for regional water management and the vulnerability to drinking water. The Kings GAR approach also allows for evaluation of change to risk related to dynamic, time variant factors (e.g.; cropping, changes in irrigation systems). It can also reflect the relative risk related to variability in hydrology by providing a basis for comparing wet, normal, and dry years in instances where the hydrologic data is available. The approach to developing the risk indices is relatively straight forward and is shown conceptually in **Figure 2-8**. A systems feature is related to a risk factor and the index variable is analyzed to assign the relative risk rating and distribution for that data set. The resultant risk factor map has measurable variables that can then be evaluated using a map overlay process.

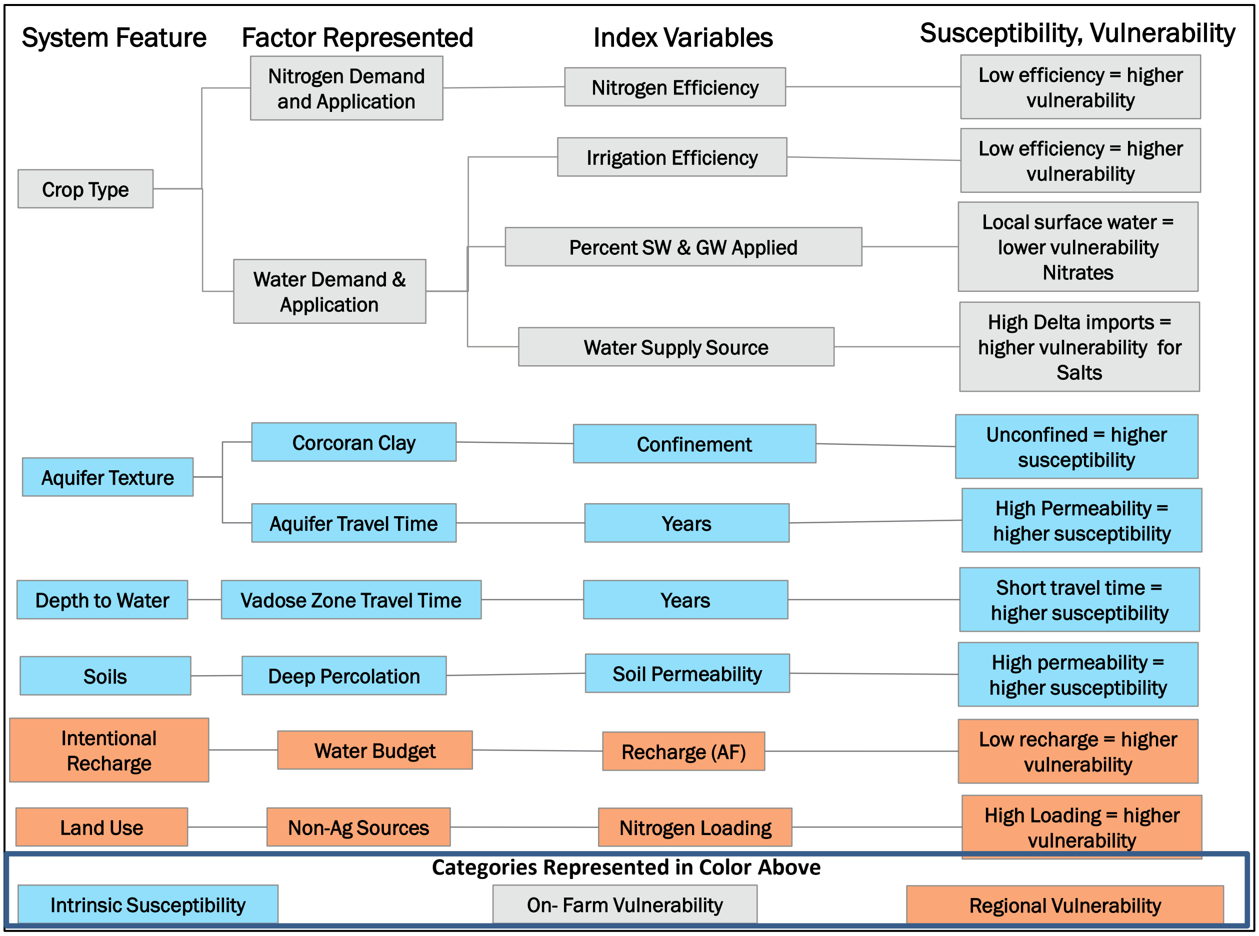
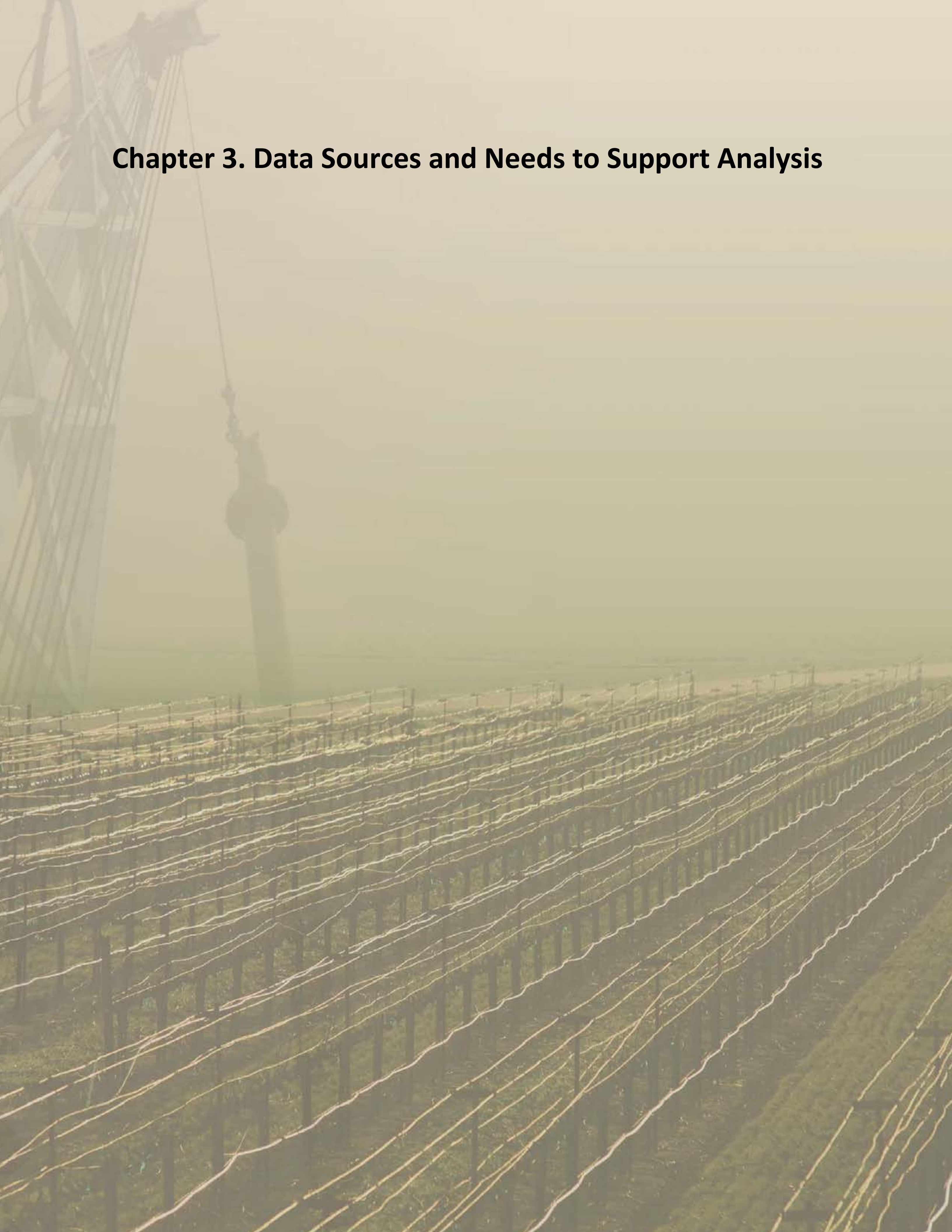


Figure 2-8. Example Process for Defining Risk Variables

The Kings GAR Index Overlay analysis tool uses other susceptibility and vulnerability variables not applied in the NHI. The results of the Index/Overlay analysis or risk is compared to the observed groundwater quality conditions to evaluate where the risk evaluation is consistent with the groundwater quality exceedence values at observation wells, primarily drinking water wells. Where the risk does not reflect the observed exceedence, the locations of other potentially contaminating activities are evaluated to explain uncertainty and seek to explain why these wells exceed standards.

Chapter 3. Data Sources and Needs to Support Analysis



Chapter 3. Data Sources and Needs to Support Analysis

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Chapter 3. Data Sources and Needs to Support Analysis

3.1 Introduction

The method of analysis taken in this assessment considers the inventory, resolution, and quality of available scientific data, and produces a meaningful result for a broad audience, including, but not limited to, regulatory agencies, affected stakeholders, and the public. In each case, the available datasets were reviewed to help further the understanding of the required risk variables ultimately to be applied in the groundwater index overlay analysis completed in **Chapter 6 – Groundwater Vulnerability Analysis**.

The steps taken to assess the data and develop a defensible approach and tools to identifying and ranking susceptibility and vulnerability to groundwater supplies included:

- Perform data and methodology research
- Decide on data and methodology given the scope and resources
- Acquire and develop the scientific tools to be used in the analysis
- Perform data analysis for secondary datasets and link to the CVHM grid if necessary
- Invite local experts to review primary and secondary datasets
- Create visualizations for purposes of quality check and understanding of solution
- Perform comparisons with other published data and document findings

In this chapter, the complete inventory of data is captured, reviewed, and rated for its use in conducting the assessment (i.e., applicability, coverage, quality, availability, etc.).

3.2 Primary and Secondary Datasets

In the reviewing and consideration of using a dataset, it is important to distinguish whether it is primary data, or secondary data. Primary data is collected first hand from the original source, while secondary data is collected or generated by the method of abstraction either using one or multiple primary data sets. In this study, both primary and secondary data were used to make statistical inferences regarding their potential contribution to groundwater susceptibility and vulnerability. Data used from a secondary source was closely examined to make sure it reflects the present, both in time and space, and is consistent with other datasets. If the secondary data originates within the GAR study, such as evaluation of deep percolation, it is detailed in this report in terms of the analysis methods used so as to make all calculations repeatable and to ensure consistency. The types, quantity, and source of scientific data used for the GAR indexing are listed in Table 2-1 of **Chapter 2 – Conceptual Model & Approach**.

3.3 Scoring of Datasets and Selection

The process of collection, storage, visualization, and selection took significant effort, and in some cases, time, due to the availability and current ownership of some datasets; especially, various levels of confidentiality are currently in-place to protect ownership and source of the data. The result of this effort is a set of tables looking at each dataset for each of the data categories, and ultimately judging and scoring each based on the utility of the data, and on the following characteristics:

- **In the Public Domain –** does the data exist in the public domain where the reader can reach out either over the internet, or with a public agency, and acquire the data freely with no constraints
- **Already Have the Data –** does the project client, or consultant, already of the dataset, and has it been reviewed
- **Applied to CVSalts or ESJ GAR –** is the data being used concurrently by on-going or past parallel efforts where data has been through a QA/QC process and accepted by regulatory stakeholders
- **Validated / Peer Reviewed –** has the data gone through any documented QA/QC process where the need for additional QA/QC is minimized
- **Data Formatted to CVHM Grid –** is the data formatted spatially on the CVHM model grid (i.e., the grid selected for the groundwater index overlay method)
- **Readily Accessible Format –** is the data in a digital format that will require minimal manual entry and pre-processing to use.
- **Spatial Coverage –** does the dataset cover the entire (or virtually the entire) area of the irrigated lands of the Coalition
- **Temporal Coverage –** does the data cover multiple or extended time periods

3.3.1 Key Factor Data Categories

The data categories are based on the Chapter 2 discussion of the conceptual model and the different key factors used to evaluate susceptibility and vulnerability to a range of contaminants. These key factor categories[1] are listed and defined as follows:

[1] Water Quality Data is covered in **Chapter 5 – Water Quality**, and is also a data category for determining ambient

- **Land Use/Consumptive Use Data –** Data describing uses taking place spatially on the ground surface where either actual data or calculated outdoor consumptive water use data can be performed based on agricultural crop types or urban uses, such as parks, etc.
- **Depth to GW Data –** Data providing measured and modeled values to calculate both depth to groundwater and groundwater elevations
- **Top Soils Characterization Data –** Data providing a scientific characterization of the permeability of shallow soils where on-farm activities are taking place
- **Agricultural Nitrate Loading Data –** Data to be used as a validated source for approximating the nitrate loading from agricultural activities and crop categories
- **Agricultural Irrigation Practices Data –** Data for use in identifying current irrigation practices and efficiencies for various crop categories over the study area
- **Aquifer Characteristics Data –** Data providing estimates of hydraulic conductivity and preferential flow paths where rapid groundwater movement takes place.
- **Time of Travel Data –** Data to calculate how fast or slow water moves through the vadose zone and into the aquifer.

The category tables are listed below with hyperlinks to each:

conditions and areas (or points) of water quality exceedances of nitrate and salinity over the study area. For this report, the CVSalts dataset is used exclusively, since CVSalts data currently has the highest level of quality review, and is being used by other studies currently ongoing or published.

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Table 3-1. Land Use/Consumptive Use Data

Land Use/Consumptive Use Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Land Use/Consumptive Use Data – Data Selection Criteria: In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	**Score**
CVHM - ModFlow	Farm Package includes consumptive use of urban and agriculture with 19 land use categories in use over model area.	Pre-processing averages site-specific data within each cell. Farm package usage in-house is currently limited. Consumptive use parameters are available by land use category.	1	1	1	1	1		1	1	**7**
C2VSim-IWFM	Low res model calculates consumptive use with 17 categories of land use over model area and provides output in various forms.	Low res but good data source showing the consumptive use parameters and results by element and sub-region. Sufficient data to perform limited calculations or pull data from output by element.	1	1		1			1	1	**5**
DWR- Land Use Surveys	Detailed land use data on a 5 to 10 year timeframe with some areas not surveyed since 2000.	Land use data source is very high resolution but is somewhat dated. Other studies and models often use this data as the foundation for their dataset.	1	1					1	1	**4**
CVSalts -WARMF	WARMF calculates limited consumptive use data and contains low-res land use data.	Model is focused on volume of runoff and routing of mass loads through stream systems. Not considered to be a consumptive use model.	1		1				1	1	**4**
UCD SBX2 Nitrate Study	UC Davis SBX2 CAML Data Set	Good overall source of land use data with UCD review of sources and use in previous studies. Includes 1990 and 2010 coverages, although not certain how accurate.	1	1					1	1	**4**
KRCD IGSM and IWFM Ver 4.0	Kings IWFM Demand Calculator Model (IDC)	Hi-res source of consumptive use data but not ready for public use. Does not cover entire study area.		1		1				1	**3**
KRCD On-Farm Data	Local grower water use and quality	By farm Crop data and water use information can provide good source of validation. Data expected to be sparse and not uniform over study area.									**0**

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Table 3-2. Depth to Groundwater Data

Groundwater Level Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Depth to GW – Data Selection Criteria: In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	Score
CVHM - ModFlow	Includes Ground Surface and modeled GW Head data by cell and limited calibration comparison data from actual measurements.	Concerns with use of model data versus actual measured data. Data from a calibrated model may be just as good or better than raw groundwater measurement data.	1	1	1	1	1	1	1	1	**8**
DWR-CASGEM	Groundwater elevation data from CASGEM website downloaded for each well in study area.	Actual data downloaded from CASGEM has not been reviewed and could mislead the study without specific knowledge of the well and how measurements were taken.	1	1				1	1	1	**5**
DWR-Water Data Library	Historic water levels	Water level data from Water Data Library has been integrated into CASGEM	1	1				1	1	1	**5**
KRCD IGSM and IWFM Ver 4.0	Kings IGSM model can provide good GW Head data .	Only applies to KRCD portion of study area.		1				1		1	**3**
C2VSim-IWFM	Includes Ground Surface and modeled GW Head data by model node with limited calibration comparison data from actual measurements.	IWFM is a lower resolution model with the same concerns as CVHM with use of model data, but calibration implies a certain amount of confidence.				1			1	1	**3**
KRCD	District water level monitoring network	KRCD performs water level monitoring for their annual water level monitoring report. Coverage is limited to Upper and Lower Kings subareas		1				1		1	**3**
KRCD On-Farm Data	Local grower water use and quality	Local growers may have some gw level data for their own wells.									**0**

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Table 3-3. Top Soils Characterization Data

Top Soils Characterization Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Top Soils Characterization – Data Selection Criteria: In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	Score
CVHM - ModFlow	CVHM makes use of only 3 agricultural soil types for surface conditions and then percent coarse soils for various depths below surface based on actual well lithology records.	Good source of below surface data. Surface data is considered to be less desirable because of limited soil classifications. The importance of how much rainfall and applied water makes it through the root zone and top 3 feet makes this source weak.	1	1	1	1	1	1	1		**7**
USDA	SSURGO	Given the importance of the soil types to amount of water making it through the root zone and vadose zone, GEI aggregation of USDA data is considered worthwhile. Soil parameter data below ground assumed from CVHM Coarse Soil analysis.	1	1	1	1	1		1		**6**
CVSalts -WARMF	WARMF has soils data for making runoff determinations.	Not sure of the source of the dataset and does not go below the root zone.	1		1				1		**3**
C2VSim-IWFM	IWFM uses four soil types USDA, 1985 and weights per element. Soil Parameter data also included.	Low res of model makes this dataset less desirable but can be a good check.	1	1							**2**
KRCD IGSM and IWFM Ver 4.0	IGSM uses four soil types and has soil parameter data.	Does not cover entire study area.		1				1			**2**
KRCD On-Farm Data	On-farm data may be used for spot checking of USDA data.										**0**

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Table 3-4. Agricultural Nitrate Loading Data

Agricultural Nitrate Loading Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Agricultural Nitrate Loading – Data Selection Criteria: In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	Score
CVHM - ModFlow	Output files from Farm Package	Model output files contain some data that could be useful to determine nitrate loading. In-house usage of farm package is minimal.	1	1		1	1		1	1	**6**
UCD SBX2 Nitrate Study	The SBX2 study has addressed nitrate loading at a high degree of resolution. Expected understanding of loading rates by crop category can provide ability to increase or decrease loading as part of phase 1.	Obtaining the rights to use UC data is uncertain and likely application by GEI may differ from original intent of data.	1			1			1	1	**4**
GEI Developed Data	GEI to use SBX2 study data and create a dataset suitable for the study area based on knowledge of crop types and local knowledge of farming practices.	Working with KRCD, nitrate loading can be assumed based on SBX2 Report, and local experience and experts. Dilution concepts may be needed if nitrates are shown to be reaching groundwater, or reported artificial recharge or prewetting are taking place.	1				1		1	1	**4**
CVSalts - WARMF		Nitrate loading is only measured overland and not past the root zone. May be a good source if looking at nitrates in waters diverted for irrigation along the SJR river system.			1	1				1	**3**
CEDEN	Monitored water quality data can be used to understand the past nitrate loading and how nitrates move through groundwater system.		1						1	1	**3**
GeoTracker	Same as CEDEN		1						1	1	**3**
KRCD On-Farm Data	Can determine On-Farm fertilization use by farmers for different crop categories and variance of applications within same crop categories.	Could be good source of data but likely to be sparse and unlikely to be in accessible format.							1	1	**2**
CDPR	Pesticide permitting program can provide some sense of applied chemicals, but nitrate loading is not likely a traceable event.	An assessment of the permitting program is necessary to identify a means to monitor the use of fertilizer or soil amendments, in addition to pesticides.	1						1		**2**

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Table 3-5. Agricultural Irrigation Practices Data

Agricultural Irrigation Practices Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Agricultural Irrigation Practices – Data Selection Criteria								Score
			In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	
CVHM - ModFlow	Farm Package includes irrigation efficiencies.	Requires ability to pull crop irrigation efficiencies assumed for each cell in model over time. The generalized land use category (or crop type) by cell based on predominant land use can be problematic.	1	1		1	1	1	1		**6**
USGS and California Institutes for Water Resources	Report titled, "Spatial Analysis of Application Efficiencies in Irrigation for the State of California" provides irrigation efficiencies for zones of CA and by crop type.	Provides a defensible value with a high degree of resolution for various crop categories	1	1		1			1	1	**5**
CVSalts -WARMF	WARMF should have limited irrigation practices and efficiency data to calculate runoff.	Not sure of the source of the dataset.	1		1	1			1		**4**
UCD SBX2 Nitrate Study	Irrigation practices are a part of the SBX2 study. Not sure of the source.	Not sure how available this data is from the SBX2 study which calculates the potential of nitrate leaching as a function of the crop grown, the irrigation system type in use, and the soil characteristics of each individual field.	1			1			1	1	**4**
DWR-Land Use	DWR Land use data attributes include irrigation practices for a number of the farm locations, as observed when the inventory was taken.	Data is somewhat dated and practices have been changing over the past 10 years.	1	1				1	1		**4**
KRCD IGSM and IWFM Ver 4.0	IGSM and IWFM IDC module can provide a good understanding of irrigation efficiencies over time for KRCD study area	Similar to IWFM above, the IGSM model provides clear data sets in irrigation efficiencies over hydrologic periods and time.		1						1	**2**
C2VSim-IWFM	IWFM has crop efficiencies by crop type over time and hydrologic periods.	IWFM provides acreage of each crop type in the element versus going with a predominant crop type as in CVHM. This makes this a good source of data to develop a lookup table of irrigation efficiencies for crop types under different hydrologic periods.									**0**

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Table 3-6. Aquifer Characteristics Data

Aquifer Characteristics Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Aquifer Characteristics – Data Selection Criteria								Score
			In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	
CVHM - ModFlow	Best source of aquifer parameter data and activity taking place within each cell over model period. The Percent Coarse Texture Grid provides a simple method of determining relative permeability along the soil column for each cell.	Percent Coarse data may not be of sufficient resolution, depending on the top layers. With refinement of the top soil layer, this problem should be remedied.	1	1		1	1	1	1		**6**
GEI Developed Data	GEI to calculate hydraulic conductivity for each cell based on Percent Coarse assignment to each cell in model.	GEI to provide a good relative scale of how quickly water can move through the vadose zone to the groundwater. Horizontal movement can likely to be based on slope of GWHead vector at each node or cell.	1	1		1	1	1	1		**6**
C2VSim-IWFM	Good source of aquifer parameter data.	Easily pulled out of model for each element or parametric grid element (if used). Low resolution is a problem.	1	1		1		1			**4**
DWR	Driller's well logs	Well logs are available to the Coalition for this study, but well logs are only available as pdf's and the number of logs in the area is large. CVHM has used a texture model of well logs to develop their percent coarse.							1		**1**
UCD SBX2 Nitrate Study	Potentially a source of soil parameter data, depending on level of data resolution used in study.		1						1		**2**
KRCD IGSM and IWFM Ver 4.0	Good source of aquifer parameter data.	Does not cover entire study area.		1				1			**2**

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Table 3-7. Time of Travel Data

Time of Travel Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Time of Travel – Data Selection Criteria: In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	Score
CVHM - ModFlow	Use Percent Coarse and GW Head model gradients as basis for time of travel. While ModFlow has Particle tracking capabilities, particle tracking is not within the scope of this first phase.	Considered to be best source for both vertical and horizontal flow in the saturated zone.	1	1	1	1	1	1	1		**7**
GEI Developed Data	GEI to calculate TOT based on the aquifer characteristics above and gradient information from the model for each cell.	Each Cell is assigned a vertical and horizontal TOT based on simple (defensible) calculation.	1	1			1		1		**4**
C2VSim-IWFM	Use model gradients as basis for time of travel.	Model is considered to be too low in resolution as compared to CVHM.	1	1		1					**3**
KRCD IGSM and IWFM Ver 4.0	Use layer flux and model gradients as source for TOT.	Good for study area covered by IGSM model, but inadequate for extrapolation.		1				1			**2**
UCD SBX2 Nitrate Study	Likely a good source for TOT, but need to verify.		1						1		**2**
CVSalts - WARMF	Only applies to above ground time of travel.			1							**1**

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Table 3-8. Groundwater Quality Data

Groundwater Quality Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Groundwater Quality – Data Selection Criteria								Score
			In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	
CVSalts	Water quality data compiled as part of Task 3 requirement of the Phase II Conceptual Model Workplan	Compiled and reviewed data from RWQCB Dairy Program, CDPH, DWR, USGS, and GAMA program.	1			1		1	1	1	**5**
SWRCB GeoTracker	CDPH drinking water quality analyses, DPR, GAMA Priority Basins, GAMA Domestic Wells, Environmental Cleanup sites,	Clearinghouse for groundwater quality data.	1	1	1				1	1	**5**
SBX2 Nitrate Study SWRCB/UCDavis	CASTING	Provides a peer-reviewed compilation of all available datasets for groundwater nitrate concentrations.	1			1		1	1	1	**5**
GAMA SWRCB/USGS	Priority Basins and Domestic Wells Programs	Both programs designed to monitor ambient groundwater quality, but have only performed one set of analyses. Domestic Wells program only implemented in Tulare County to date. Data Included in GeoTracker, CASTING, and CVSalts.	1	1	1	1			1		**5**
CDPR	Groundwater quality monitoring	Regular monitoring of public supply wells. Included in GeoTracker and CASTING.	1	1	1				1		**4**
Dairy Program RWQCB	Dairy CARES program	Waste Discharge Requirement monitoring data. Included as part of CASTING and CVSalts.	1	1	1				1		**4**
Irrigation Districts/ Growers	Water quality information	Data not readily available							1	1	**2**
Counties	County Health Departments	Water quality data for new domestic wells and small systems with local primacy. Data not available in accessible format, Nitrate data included as part of CASTING.							1		**1**

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Table 3-9. Groundwater Quality Data

Surface Water Quality Data

Data Source	Data Set Names	Dataset Descriptions and How Applies to GAR	Surface Water Quality – Data Selection Criteria: In the Public Domain	Already Have the Data	Used in CVSalts or ESJ GAR	Validated / Peer Reviewed	Data Formatted to CVHM Grid	Readily Accessible Format	Spatial Coverage	Temporal Coverage	Score
DWR	Water Data Library	WDL has historic, long-term surface wq data for California Aqueduct, Friant-Kern Canal, Kaweah River, and Tule River	1	1				1		1	**4**
GEI Developed Data	Combined data from KRCD, BOR, and WDL.	Used combined datasets for salt loading estimates of Kings and imported water.	1	1				1	1	1	**5**
KRCD	Surface water and interceptor drain water quality monitoring	KRCD monitors water quality at several stations along the Kings River. This provides the most comprehensive dataset for that river.		1				1		1	**3**
BOR	Water quality at Mendota Pool	The Bureau of Reclamation monitors water quality at the Mendota Pool.	1					1		1	**3**
DWR	CDEC	CDEC has water quality data, but does not have long-term records for rivers in Coalition area.	1					1	1		**3**
USGS	NAWQA	NAWQA clearinghouse has surface water quality data, but is not as comprehensive as WDL and other sources	1					1			**2**

3.4 Data Sources Used

The datasets used for the GAR were chosen based on the above criteria and specific needs for the GAR analysis. The datasets actually used in the GAR are shown in **Table 3-10**.

The methods of acquiring the dataset varied based on the ownership of the data. **Table 3-10** shows the source of data with hyperlinks internet sources, where available. In some cases, data is not available online or confidentiality excludes the ability to publish source locations. For these sources, an agency contact is provided.

Table 3-10. Data Sources Used in the GAR

Type of Data	Agency Name	Data Set Description	Source of Data
Land Use/Consumptive Use	DWR	Land Use Surveys	http://www.water.ca.gov/landwateruse/lusrvymain.cfm
	UCD SBX2 Nitrate Study	CAML	http://plone.ice.ucdavis.edu/sjvgreenprint/data-collections/data-listing
Groundwater Level	KRCD	Kings IGSM model water level data	Rick Hoelzel, KRCD Project Manager
	KRCD	District water level monitoring network	Rick Hoelzel, KRCD Project Manager
Top Soils Characterization	USDA	SSURGO	http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
Agricultural Nitrate Loading	GEI Consultants	GEI used SBX2 study data and create a dataset suitable for the study area based on knowledge of crop types and local knowledge of farming practices.	Matt Zidar, GEI Project Manager
Agricultural Irrigation Practices	USGS and California Institutes for Water Resources	Report titled, "Spatial Analysis of Application Efficiencies in Irrigation for the State of California"	http://watermanagement.ucdavis.edu/research/application-efficiency/
Aquifer Characteristics	CVHM	Percent Coarse from model layers	http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html
	GEI Consultants	GEI calculated hydraulic conductivity for each cell based on Percent Coarse from CVHM.	Matt Zidar, GEI Project Manager
Time of Travel	GEI Consultants	GEI calculated TOT based on the aquifer characteristics gradient information from the CVHM model for each cell.	Matt Zidar, GEI Project Manager
Groundwater Quality	CVSalts	Water quality data compiled as part of Task 3 requirement of the Phase II Conceptual Model Workplan. Nitrate and TDS.	Richard Meyerhoff, CVSalts Technical Project Manager
	SWRCB	GeoTracker GAMA data for pesticides.	http://geotracker.waterboards.ca.gov/
Surface Water Quality	DWR	Water Data Library	http://www.water.ca.gov/waterdatalibrary/
	KRCD	Surface water and tile drain wq monitoring	Rick Hoelzel, KRCD Project Manager
	BOR	Water quality at Mendota Pool	Bureau of Reclamation
	GEI Consultants	Combined DWR, KRCD, and BOR datasets	Matt Zidar, GEI Project Manager
Other	CDPH	Public Drinking Water Systems	Drinking water systems boundaries: http://www.ehib.org/page.jsp?page_key=762 Well location data obtained through data request by KRCD.
Other (cont.)	County Assessors	Parcel GIS layers to determine high density septic.	http://gis.co.fresno.ca.us/zoning/ http://www.countyofkings.com/departments/assessor Mike Hickey, Tulare County
	County LAFCOs	Sewer districts to determine high density septic	Samantha Hendricks, Fresno County Joanna Walker, Kings County Anthony Toto, Tulare County
	RWQCB	Permitted site locations and information (NPDES, WDR, etc.)	Anthony Toto, RWQCB Region 5
	DWR	CDEC climate and precipitation data	http://cdec.water.ca.gov/

Chapter 4. Susceptibility and Vulnerability Factors

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Chapter 4. Susceptibility and Vulnerability Factors

4.1 WATER MANAGEMENT AND SURFACE WATER SYSTEM

To overcome variability in the hydrologic cycle and water supply, the Coalition area is managed through conjunctive use, the combined use of surface water and groundwater supplies and storage. Over the years, to further improve the agricultural productivity of the basin, the natural system has been modified by water districts or private interests through construction of canals, dams and reservoirs, and groundwater recharge ponds. The management and distribution of water has an important bearing on the sources, fate and transport of salts and nitrogen. Regional water management factors vary in the Coalition area and will have differing effects on vulnerability to nitrate and salt contamination. The Kings GAR seeks to recognize regional water management effects and related vulnerability factors that may have a positive or negative effect.

Large amounts of relatively fresh water are distributed via water rights and contracts held by water districts and private land owners. The volume of surface water available is variable based on the nature of the water rights, contracts, hydrologic cycle and environmental regulations intended to protect aquatic and related resources which helps balance the groundwater basin and potentially dilutes ambient concentrations of salt and nitrates, but this deep percolation may also leach salts and nitrates from the root zone. This large amount of fresh water is recharged through deep percolation of applied irrigation water. This affects the groundwater budget and the mass balance of salt and nitrogen. A large amount of surface water is also intentionally used for groundwater recharge through unlined canals and recharge ponds, also serving to dilute any ambient nitrate or salt concentrations. This effect varies throughout the groundwater basins.

Major water sources, reservoirs and regional conveyance systems are shown in (**Figure 4-1**). Different surface water source have different water quality. Imported Sacramento-San Joaquin Delta (Delta) water delivered through the State Water Project (SWP) via the California Aqueduct and the Federal Central Valley Project (CVP) via the Delta Mendota Canal Water (DMC) are a source of salt carried with the imported water. Historically, irrigation in the basin has been facilitated by the availability of surface water low in total dissolved solids (TDS) from the Sierra Nevada via the San Joaquin, Kings River, Tule, Kaweah and smaller streams which flow across the alluvial fans.

Different areas have different access to surface water and this effects groundwater demand and pumping to meet crop water requirements. Areas more reliant on groundwater do not derive the recharge benefits of applied surface water. This implies that contaminants in groundwater may build up over time without the dilution effects of imported fresh water.

4.1.1 Regional Hydrology

This section briefly discusses the hydrologic regime which influences the water supply and management system, including discussion of the streamflow, designation of wet and dry periods, precipitation and evapotranspiration.

4.1.1.1 Wet and Dry Period

The Coalition area has a Mediterranean climate with wet and dry periods that strongly influence streamflow, recharge and how the water systems are operated. The Kings River systems are representative of the general flow regime in the rivers in the Coalition area and data from the Kings River is used to describe the general hydrology and implications to water management. **Figure 4-2** shows the climatic trends by presenting the cumulative departure from the long term mean for the Pre-Piedra unimpaired stream flow for the Kings River from 1897 through 2008. These Pre-Piedra flows represent the unimpaired natural streamflow that would have occurred without any upstream reservoir storage and regulation. The wet periods are indicated in upward trends in the line (blue shading), when the average annual flow is above the long term annual average; and dry periods are indicated when there are downward trends on the line (brown shading), when the average annual flow is below the long term annual average over a period of time. For purposes of the GAR, critically dry years are defined as single or multiple years when unadjusted stream flow is less than 50% of the average annual flow. These are shown in with red bars along the lower axis. As can be seen, the periods from 1959 through 1961, 1976 and 1977, and 1987 to 1992 which were critically dry.

Figure 4-3 shows the regulated Kings River flow below Pine Flat Reservoir for the period from 1964 through 2008, also showing the dry periods as defined above. The surface water systems in the Coalition area have been highly modified over time to increase the reliability of supply and get the area through the dry periods. Reservoirs such as Millerton on the San Joaquin and Pine Flat on the Kings River are used to capture rainfall and snow melt runoff so that it can be managed for flood control, water supply and groundwater recharge.

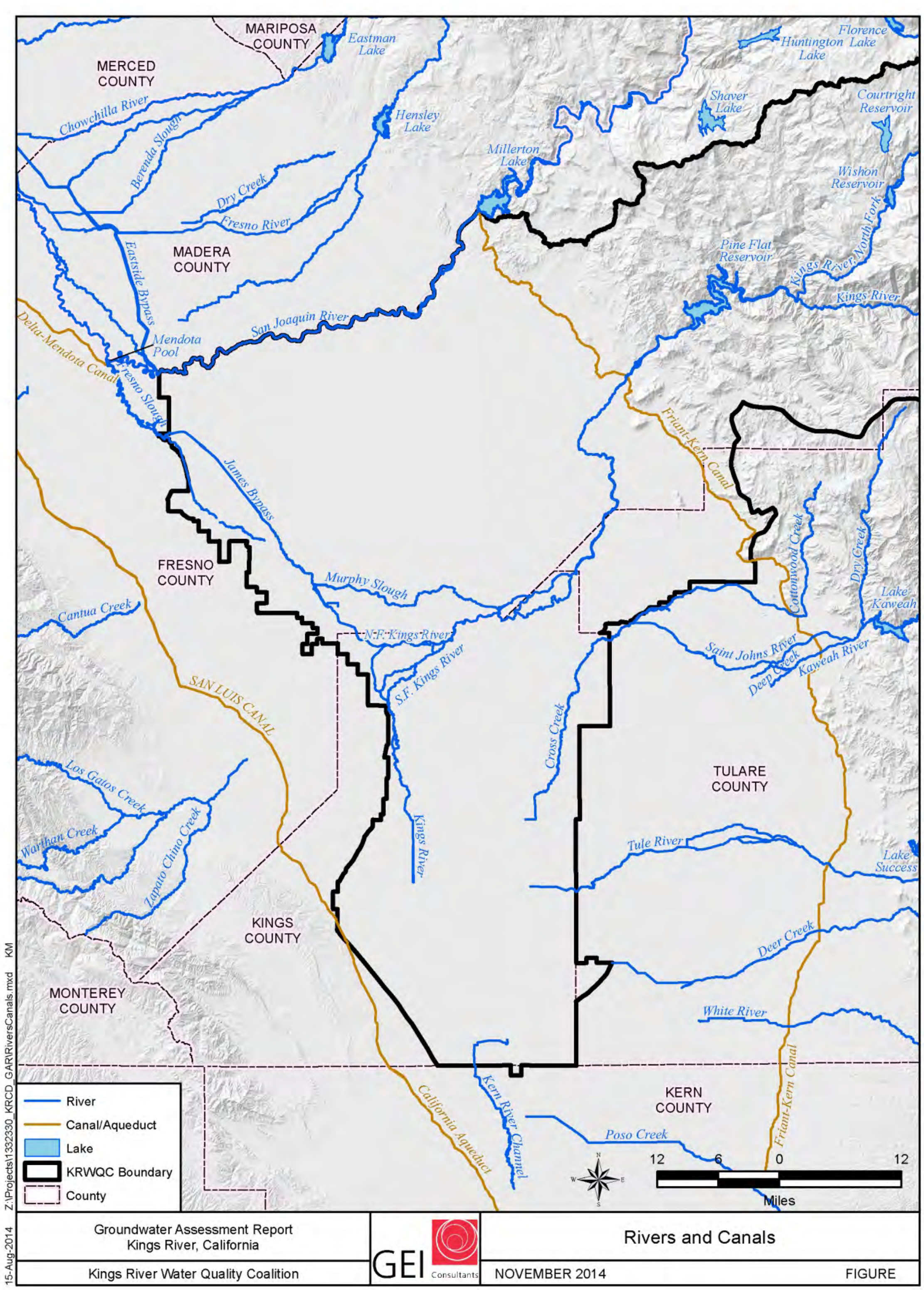


Figure 4-1. Regional Surface Water Sources and Conveyance

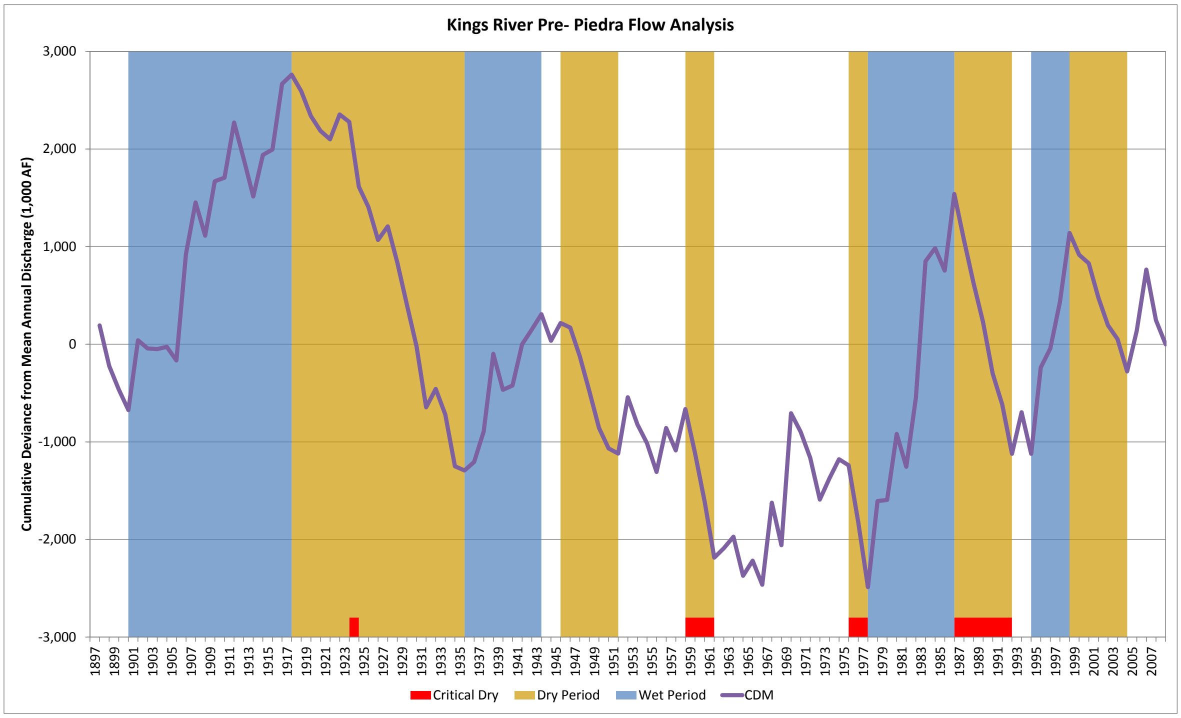


Figure 4-2. Wet, Dry and Critical Dry Periods and Cumulative Departure from the Mean for Unimpaired Kings River Flows (Pre-Piedra)

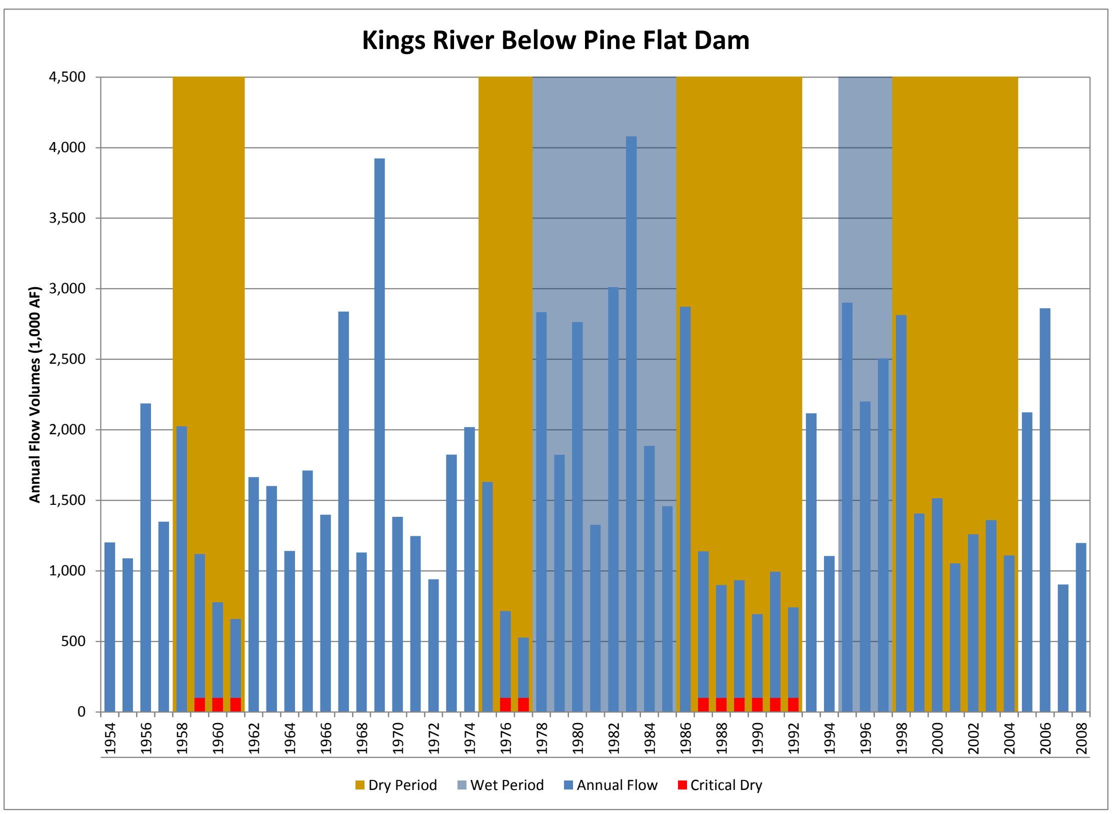


Figure 4-3. Regulated Kings River Flows Below Pine Flat

4.1.1.2 Precipitation and Evaporation

Monthly and daily precipitation data was exported from regional groundwater models and California Data Exchange Center (CDEC), listed by station. Combined averages are used in locations where stations and/or data are sparse for the time periods needed. To ensure consistency in the ET calculation, the years 1997, 1998, and 1999 are used for the three ET year types regardless of the crop inventory year. Stations are assigned to the four subareas of the study area. The calendar rainfall data for the four subareas are shown in **Figure 4-4**.

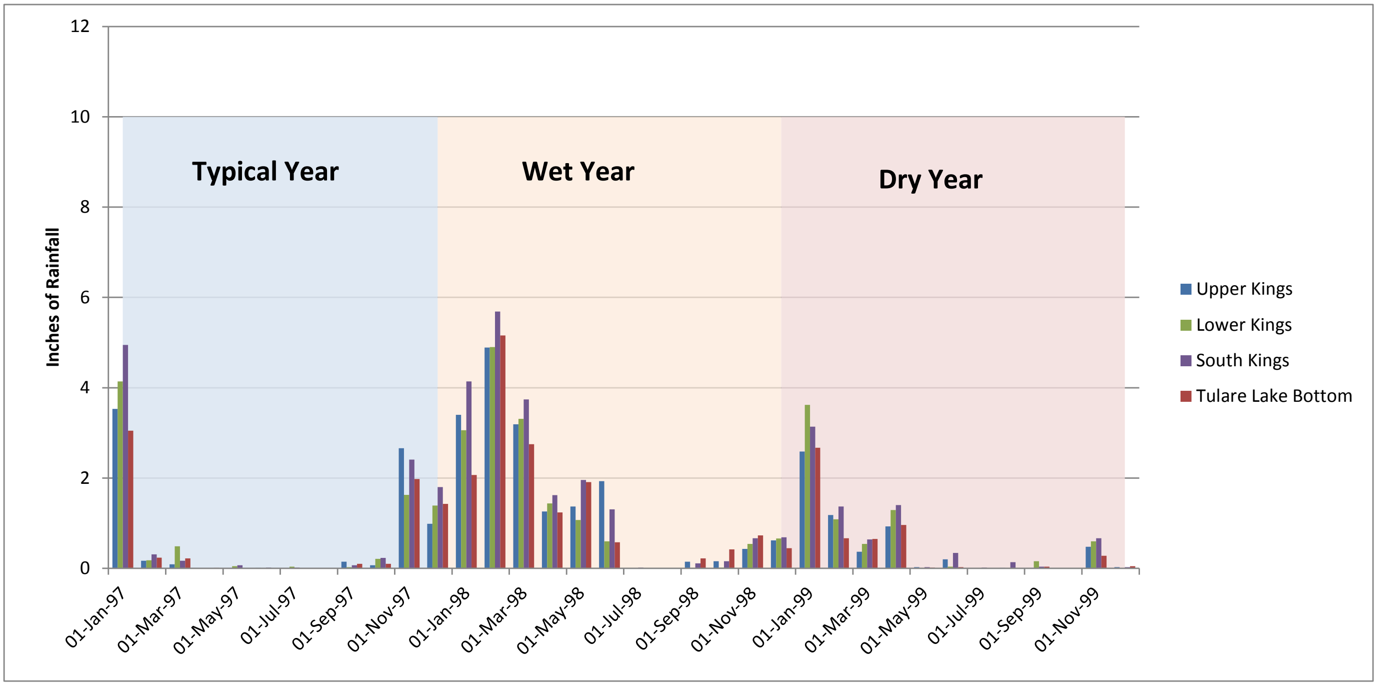


Figure 4-4. Rainfall Patterns According to Subarea on Calendar Year

Crop ET data for Typical, Wet, and Dry hydrologic years, 1997, 1998, and 1999 were obtained.. Data is listed by crop and irrigation method from the Irrigation Training and Research Center (ITRC) website http://www.itrc.org/etdata/waterbal.htm. The number of ET crop categories is approximately 35 with the actual total based on the three irrigation methods of flood, sprinkler, and micro/drip.

4.1.2 Water Management Agencies and Major Facilities

Water management organizations are shown in **Figure 4-6**. Water districts and private interests (e.g.; mutual water companies) operate through conjunctive use. These agencies divert the available local and imported surface water through an extensive network of canals for direct irrigation use, and/or intentional recharge to groundwater through dedicated percolation ponds and unlined canals. Maps of the distribution systems were obtained from available water management and agricultural water management plans and reviewed to identify water distributed from the local and imported sources.

4.1.3 Kings River Watershed Coalition Subareas

The subareas were designated based on the boundaries of the water management agencies, surface water sources, groundwater conditions and operational histories (**Figure 4-5**). The relative availability of surface water determines the degree of dependence on groundwater. In some areas there are no public water agencies and surface water is distributed to mutual water companies or private entities with rights or contracts.

4.1.4 Surface Water Supply Sources

In order to augment surface water supply in the basin, multipurpose reservoirs, were constructed on Sierra Nevada Rivers in order to store winter runoff for release and distribution during the irrigation season. SWP and CVP Contracts for Delta water were also negotiated. Reservoirs include Millerton Reservoir on the San Joaquin River, Pine Flat on the Kings River; Lake Kaweah on the Kaweah River and Success Reservoir on the Tule River.

The reservoirs on the Sierra Nevada Rivers provide a source of high quality water for the conjunctive use programs and for agriculture, recharge, municipal, fishery and other beneficial uses, including leaching of accumulated salts. The conjunctive use program provides for high regional water use efficiency and helps the Coalition area respond to hydrologic variability. At a basin scale, this means that water diverted or imported is beneficially used for irrigation or for groundwater recharge, and that little is returned to the stream system. There is very little flow out of the area through the James Bypass, and water only leaves the area in the wettest years.

In the wet years, water may be is intentionally recharged or applied in excess of the immediate irrigation demand (pre-irrigation) to increase soil moisture and recharge groundwater. A portion of the applied water migrates past the root zone and may also provide transport mechanism for nitrogen and salts leached below the soil zone, where they can then travel through the unsaturated zone to groundwater. The recharged water is stored in the groundwater basin and made available in years with low snowpack, reservoir storage, streamflow and surface water deliveries.

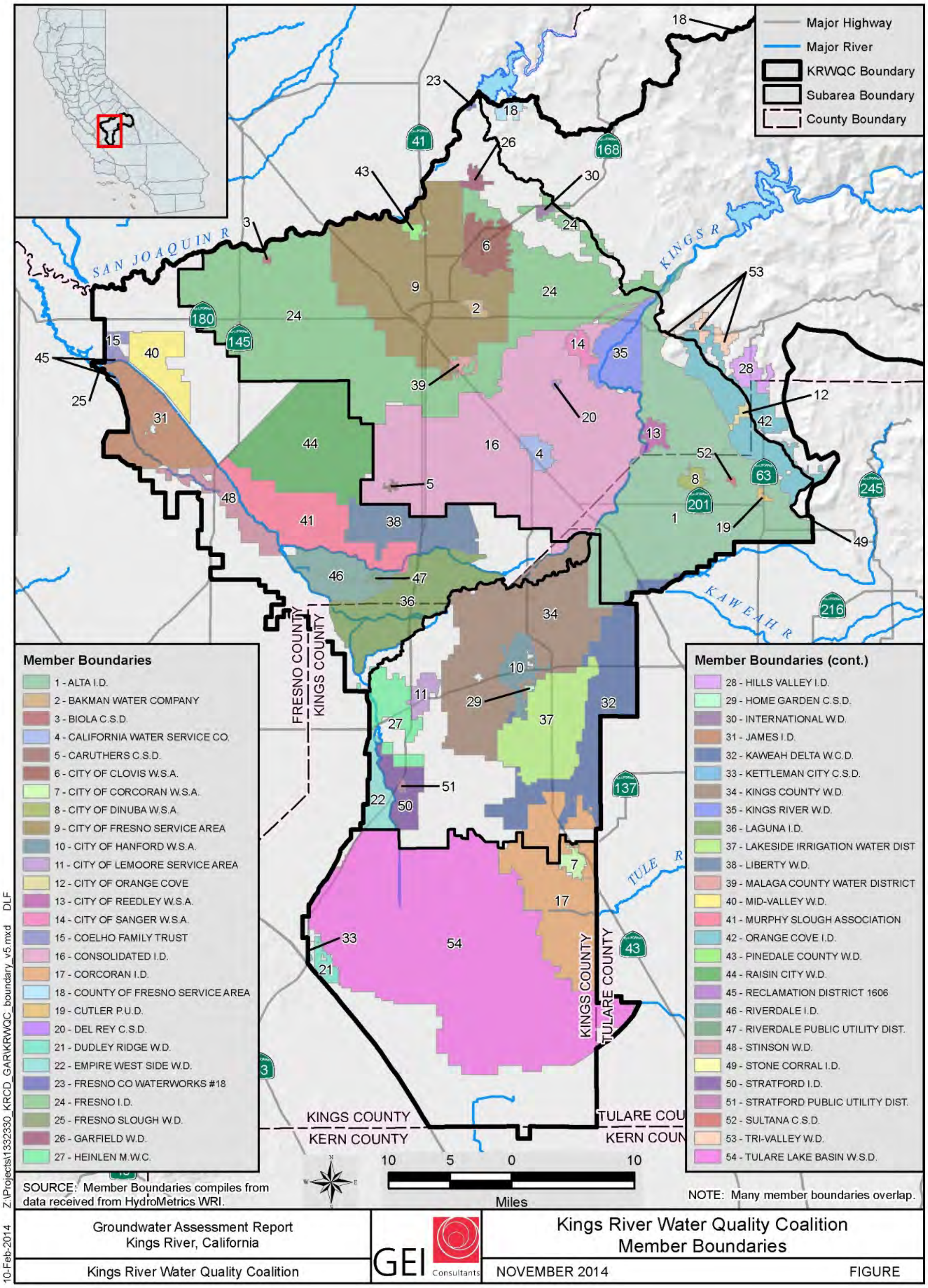


Figure 4-5. Coalition Area Water Management Agencies

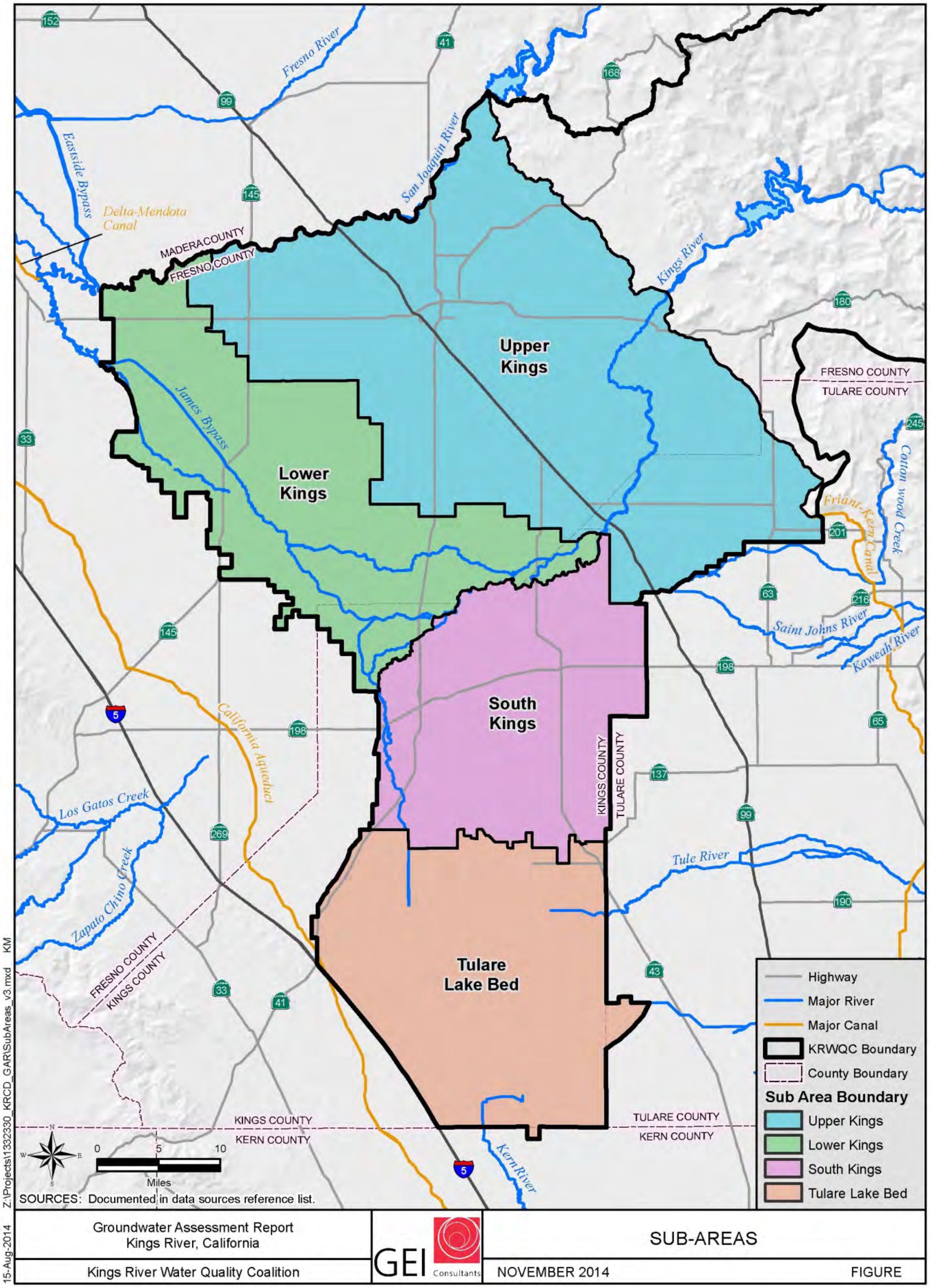


Figure 4-6. Kings River Watershed Coalition Sub Areas

Delta water is imported via the CVP DMC and the CVP Friant Unit from the San Joaquin River water via the Friant-Kern Canal. The water from the Delta is higher in TDS than the local surface water sources originating in the Sierra Nevada Mountains. The CVP DMC delivers Delta water to the terminus at the Mendota Pool where is can be diverted and distributed to areas in the Lower Kings along the North Fork of the Kings River. The Southern Kings and Tulare Lake Bed subareas south of the Kings River rely on multiple sources of surface water including the SWP, Kings River, Friant-Kern Canal and diversion of local rivers and streams including the Tule and Kaweah River.

The Southern Kings and Tulare Lake Bed subareas are a closed basin, meaning that it is internally drained and that there is very limited surface water or groundwater outflows from the subareas. The Tulare Lake bed area is the terminus for the South Fork of the Kings, Kaweah and Tule Rivers. The salt that originate in the runoff from both the Sierra Nevada and Coastal Ranges, and imported from the Delta, have no ability to be transported out of the basin, and salts become concentrated through evaporation over time, including the time prior to agricultural development. The sources of surface water, recharge and relative reliance on groundwater pumping for each subarea are discussed further below.

4.1.4.1 Upper Kings

The Kings Basin Integrated Groundwater/Surface Water Model (Kings IGSM) provides the most detailed water budget information for the Upper and Lower Kings Basin. The information below is excerpted from the “Kings Basin Integrated Groundwater and Surface water Model (Kings IGSM) Model Development and Calibration” report (WRIME, 2007a). The Kings IGSM is currently being updated by KRCD through 2012 using the DWR Integrated Water Flow Model. The model covers the Upper and Lower Kings subbasins but not the Southern Kings or Tulare Lake Bed. Diversions from the Kings River to the Southern Kings and Tulare Lake Bed subareas are also derived from the surface water budgets and diversion records used in the Kings IGSM as discussed further in the next sections.

The primary source of surface water in the Upper Kings Basin is the Kings River, including Pine Flat Reservoir releases, and stream inflows from Mills Creek, Hughes Creeks and other smaller local watershed. The Kings River Water Association (KRWA) is the water master for the Kings River. Based on streamflow data for water years from 1964 to 2004, the average annual total surface water inflow to the basin is approximately 1.85 million acre-feet (MAF). This is a relatively balanced hydrologic period and represents the time when the basin was operated under regulation by Pine Flat. Of the total inflow, the Kings River on the average contributes 1.78 MAF, with a low of 500 thousand acre-feet (TAF) in dry years, and a high of 4.25 MAF in wet years. Much like the rest of California, the Kings Region observes the “average conditions” on a relatively infrequent basis, and water management activities must respond to wet or dry conditions.

To meet their agricultural and urban water demand, the Upper Kings Basin water users divert an annual average of about 1.16 MAF of water, primarily for irrigated agriculture and groundwater recharge purposes. This water is applied primarily in the eastern part of the Coalition area on the alluvial fans. The major diverters in the Upper Basin – Alta Irrigation District (AID), Fresno Irrigation District (FID), and Consolidated Irrigation District (CID) - divert a total of 920 TAF (AID: 162 TAF, FID: 482 TAF, and CID: 275 TAF) through the canal distribution systems. All of these districts have developed and are developing groundwater recharge facilities. The balance (226 TAF) is diverted via Peoples and Lakeland Canals for water users further in the Southern Kings and Tulare Lakes Basin subareas by various water districts and others with entitlements (e.g.; mutual water districts).

Average annual import from the CVP Friant-Kern Canal is on the order of 78 TAF. FID and the City of Fresno have federal contracts for San Joaquin water delivered via the CVP Fraint-Kern Canal. This includes access to San Joaquin River flood releases, called Section 215 water. Kings River and imported San Joaquin water are beneficially used for irrigation, municipal and groundwater recharge. The City of Fresno has developed surface water treatment facilities to take Kings River water under contract with FID, and their CVP Friant-Kern water under contract with the USBR. Surface water treatment facilities using Kings River water are planned to service municipal areas which have been impacted by nitrates in the AID service.

As the Kings River flows through the Upper Kings Basin, it can either gain or lose water. In drier times, streamflow from the Kings River is lost through seepage to groundwater. In wetter periods, the Kings River may gain streamflow from the groundwater basin if groundwater levels are high enough and water can move from storage in the groundwater basin back to river. The average annual outflow from the Upper Kings Basin into the Lower Kings Basin is 734 TAF, with a low of about 200 TAF in driest years and a high of 3 MAF in wettest years.

4.1.4.2 Lower Kings

On an average annual basis, the Lower Kings Basin water users divert about 329 TAF to meet agricultural and urban water demands. The major diversions in the Lower Basin occur at Reynolds Weir (116 TAF), Lemoore Weir (81 TAF), and Last Chance Weir (67 TAF) and total of 264 TAF. The rest of the water is diverted at Crescent Weir, Stinson Weir, Island Weir, and James Weir. Similar to that in the Upper Kings Basin, the diversions are made through an extensive system of mostly unlined canals. There is a significant annual variability due to hydro-climatic variations, and the diversion ranges from a low of 60 TAF in dry years to a high of 500 TAF in wet years. The Kings River is unique in that it divides into a North Fork that flows to the

San Joaquin River via Fresno Slough, and a South Fork that allows flood water to flow into the Tulare Lake Basin in wet years.

As the Kings River flows through the Lower Kings Basin it loses water through seepage into groundwater, averaging about 189 TAF, or may gain water through surface and storm runoff, agricultural and urban return flows. The estimated annual gains and losses show that, with the exception of a very few wet years where there are gains to streamflow, the Kings River in this reach is mostly a losing stream.

James Irrigation District (JID) and Tranquility Irrigation District (TID) receive water from the Kings River and import Delta Water delivered down the DMC. The DMC is a source of salt load in the Lower Kings. Normal surface water supplies of the TID include Schedule 2 CVP Water and South of Delta Central Valley Project Water. Schedule 2 CVP Water (Riparian Water or Rights Water) is delivered as a settlement of the TID's water rights claims in Fresno Slough; the settlement amount is 20.2 TAF. Other water used by the District includes high flows from the Kings River, and unintentional spills from James Irrigation District. The District also diverts Kings River high flows from the Fresno Slough when it is available, typically during wet hydrologic years. This last occurred in 2005 and 2006. The District only receives Kings River water from high flows in about 45 percent of the years, or every 2 to 3 years on average. In the past, during wet years, the USBR has made surplus water available to TID, which is above its normal contract deliveries. The source of this water may be either imports from the Delta via the Delta Mendota Canal, or San Joaquin River flood releases (TID, 2011).

JID diversions are last on the Kings River and the supply is unreliable and available only in the wettest years. The Districts has a USBR contract for 35.3 TAF delivered and diverted at Mendota Pool. The District entered into agreements with the USBR and KRWA to establish the District's entitlements to surface water from both the San Joaquin River and the Kings River, called Schedule 2 water, for 9.7 TAF. Groundwater may also be pumped from wells both within and outside of the District (JID, 2011). Both JID and TID are actively developing additional groundwater recharge facilities.

After the diversions and stream losses in the Lower Basin and outflow through the South Fork, the average annual outflow through the North Fork of the Kings River (below James Weir) is 251 TAF, with a low of 0 TAF in dry years and a high of 2.00 MAF in the wettest year. However, only about 25% of the time, there is some flow below James Weir to the San Joaquin River. In most other dry and average years, the Kings Basin flows are diverted for beneficial use and there is no outflow through the North Fork past the James Bypass gaging station. This indicates high regional water use efficiency in both the Upper and Lower Kings subareas (WRIME, 2007a).

4.1.4.3 Southern Kings

The water diverted from the South Fork of the Kings River averages 410 TAF annually, including 184 TAF at Army Weir, 50 TAF at the KRWD diversion, and 176 TAF at Peoples Weir via the Peoples and Lakeland Canals. This water is low in salts and provides a clean source of irrigation and recharge water. The average annual outflow through the South Fork of the Kings River to the South Kings and Tulare Lake Sub areas (below Army Weir) is approximately 92 TAF (WRIME, 2007a).

The Southern Kings subarea extends from the Kings River down the South Fork of the Kings River to the City of Stratford, and includes part of the Kings County Water District (KCWD) and a number of smaller district and mutual water companies that operate through conjunctive use of surface water and groundwater. KCWD manages supplies for conjunctive use in the eastern part of the subarea and the areas east of the Coalition boundary. These programs have an effect on the groundwater conditions in the Southern Kings subarea (Fugro, 2007).

KCWD is the largest district in the subarea and uses surface water originating from the Kings River, Kaweah River and San Joaquin River. KCWD has no control over the timing and quantity of these surface water deliveries. In addition to the surface water distributed in the District from ditch companies, the District has purchased surplus CVP Friant water made available through short term contracts with the USBR. KCWD has also endeavored to divert and recharge as much flood water as possible from the San Joaquin, Kings, and Kaweah Rivers.

The KCWD and other districts in the subarea own and operate numerous intentional recharge basins. All of the imported supplies have either recharged the underground through percolation basins or diverted for direct surface irrigation. Kings River water is usually taken in high flows for short durations.

The other districts, including Lakeside Irrigation Water District and mutual water companies take the Kings River water under the entitlements coordinated through the KRWA. There are a complex array of transfers, water sales and facilities used to distribute Kings River water, local water and imported San Joaquin flood waters. Detailed accounting of flows to each of the Districts was beyond this scope of work, and the relative proportion and source of surface water and groundwater to the area was evaluated using the available water management plans and discussion with local agencies.

To the east of the Southern Kings and Tulare subareas, up on the alluvial fans of the Kaweah, Tule and local streams; there are a number of water districts with a mix of sources that include CVP Friant unit contracts. Intentional recharge and recharge of applied water in areas upgradient of the South Kings subarea influence the salt and nutrient balance in both the Southern Kings and Tulare subareas from downward flow gradients.

4.1.4.4 Tulare Lake Bed

The Tulare Lake Bed subarea includes Tulare Lake Water Storage District, Corcoran ID, City of Corcoran and Empire West Side WD, Stratford ID and part of the Kaweah Delta WCD, and Lakeside WD. There are other private mutual water companies and land holders with water rights. These water entities derive water from some mix of the Kings, Kaweah and Tule Rivers. All rely on groundwater to varying degrees, depending on the access and entitlement to surface water.

This area is also served by the Tulare Lake Drainage District which has developed drainage collection and disposal facilities for the management of agricultural sub-surface tile drain waters. Major streams that provide water supplies to agriculture include the South Fork of the Kings River, entering from the north; the Kaweah and Tule Rivers and distributaries, entering from the east; and the Kern River, entering from the south but proving little or no inflow. The only minor stream of significance is Deer Creek. The Tulare Lakebed is the natural terminus of these streams.

Flooding of cropland occurs on the average of one out of every seven years in the Tulare Lake Bed area. During extreme flooding periods, flood flows will enter the Tulare Lake Basin Water Storage District. Residual floodwaters in Tulare Lake Bed are used to the maximum extent possible for irrigation. In the Tulare Lake Bed, surface water supplies consist of water rights on the Kings and Tule Rivers, and contracted State Project Water (SPW). Between 1993 and 2006, SWP have accounted for about 39% (107 TAF) of the total average annual supply (277 TAF); with the balance of the average annual supplies from flood water (14.3%; 39.5 TAF), local rivers including the Kings (43%, 119 TAF), and other water transfers (3.7%; 142 TAF) (TLBWSD, et al., 2010).

The Tulare Lake Basin Water Storage District owns conveyance laterals A and B from the California Aqueduct to the exterior boundaries of the irrigated portion of the District in the Tulare Lakebed area, however, the District itself does not have an internal distribution system and is not involved in the distribution or administration of water within the boundaries of the District.

There is useable groundwater in limited portions of the Tulare Lake Bed area and groundwater accounts for roughly 20% of the total supply. The Corcoran Clay is extensive underlying the Tulare Lake Bed and groundwater supplies above the clay are limited and high in naturally occurring salts.

The Tulare Lake Drainage District (TLDD) formed in 1966, and the Tulare Lake Reclamation District No. 761 overlying the westerly portion of the Tulare Lakes Basin Water Storage District lands, managing subsurface drainage for about 15% of the lands. The drainage water is collected and conveyed to evaporation ponds. Water Users manage subsurface drainage on the remaining lands through careful irrigation management and crop rotation. Because the District is located within a closed basin, all tailwater is used and reused until consumed to irrigate croplands by the utilization of extensive tailwater recovery systems.

There is a risk of degradation of ground water in the Tulare Lake Bed without a plan for removing salts from the Basin. Evaporation basins are an acceptable interim disposal method for agricultural subsurface drainage and may be an acceptable permanent disposal method in the absence of a valley drains provided that water quality is protected and potential impacts to wildlife are adequately mitigated (RWQCB, 2004).

4.1.5 Surface Water and Groundwater Supply

The relative mix of surface water and groundwater supplies and conjunctive use operations has an influence on the salt and nutrient mass balance. Changes in annual groundwater supply and type of use may be related to a number of factors, such as changes in surface water availability, seniority and volume of water rights, urban and agricultural growth, market fluctuations, and water use efficiency practices.

DWR has studied each of the hydrologic regions in the State as part of the California Water Plan 2013 Update, including the Tulare Hydrologic Region. The Coalition area covers only part of the larger Tulare Lake Hydrologic Region. The annual water supply for the Tulare Lake Hydrologic Region has remained relatively stable between 2002 and 2010. The percent to which groundwater or surface water contributed to the total supply during this same period was widely variable. Periodic cutbacks in surface water deliveries to meet regulatory requirements have resulted in large fluctuations in the annual amount of groundwater pumping required to meet existing water uses. Between 2002 and 2010, annual groundwater supply fluctuated from about 3.5 MAF in 2005 to about 8.7 MAF in 2009 and provided between 35 and 70 percent of the total water supply for the region. The persistent fluctuation in groundwater water supply points to a limited surface water supply reliability for the region and highlights the value of applying conjunctive water management practices to meet local water use during times of reduced surface water supply. Groundwater pumping to meet urban water uses remained fairly stable during the 2002 to 2010 period - between 550 TAF and 650 TAF. The percentage of groundwater use was reported by DWR planning areas.

The Tulare Lake Hydrologic Region accounts for 38 percent of all the groundwater extraction in California — double the amount of the two hydrologic regions coming second and third in groundwater extraction — San Joaquin River Hydrologic Region with 19 percent, and

Sacramento River Hydrologic Region with 17 percent of the total. The estimated average annual 2005-2010 total water supply for the region is about 11.7 MAF. Out of the 11.7 MAF total supply, groundwater supply is 6.3 MAF and represents 54 percent of the region's total water supply; 82 percent (0.6 MAF) of the overall urban water use and 52 percent (5.7 MAF) of the overall agricultural water use being met by groundwater. Thus more than 90 percent of the groundwater supply in the region is used to meet agricultural water use and 10 percent is used to meet urban water use (5.7 MAF versus 0.6 MAF). Groundwater contributes to 37 percent (29 TAF) for managed wetland uses in the region. **Table 4-1** shows the total and percent of groundwater use by DWR planning areas that overlap with the Coalition. (DWR, 2013). Again, there are different boundaries that serve as accounting units within the Coalition and DWR planning areas.

Table 4-1. Tulare Lake Hydrologic Region Average Annual Groundwater Supply by DWR Planning Area

Planning Area Number and Names		Ag Use met by Groundwater		Urban Use Met by Groundwater		Managed Wet-lands Use Met by Ground-water		Total Use Met by Groundwater	
Planning Area #	Planning Area Name	TAF	%	TAF	%	TAF	%	TAF	%
703	Lower Kings-Tulare	1467	70%	45	100%	1	4%	1512	69%
705	Alta - Orange Cove	436	46%	59	97%	0	0%	495	49%
706	Kaweah Delta	1548	60%	113	97%	3	100%	1664	62%

Research was conducted to further evaluate the relative proportion of surface water and groundwater supplied to meet the agricultural water demand within the Coalition boundaries. There was a lot of information for the Upper and Lower Kings areas that was available from the Kings IGSM model (WRIME, 2007a). There was less information available for the Southern Kings and Tulare subareas. The total annual Kings River water diversions at specific canals diverting water to the Southern Kings and Tulare subareas were available, but the distribution of the diverted water to specific agencies was not readily available, or was reported for overlapping areas depending on the source data set consulted. The capture and distribution of flood waters and managed water from the Kaweah and Tule Rivers and the smaller local watersheds was obtained from local agencies where readily available. The groundwater, water management and agricultural water conservation plans were obtained and reviewed to develop the average annual surface water supplied and the Coalition areas receiving the water. There were good historical records on the volumes and area of delivery for DMC and SWP water. The area receives a lot of local and imported flood water from the San Joaquin, but this information was only available for some areas.

Where there was uncertainty, the numbers for the DWR planning areas and discussion with the local water managers were used to develop the relative percentages of surface water and groundwater use and the surface water sources. This is an area for improvement in the data GAR database. The relative percentages of surface water and groundwater supply, and the percentage of the surface water that is imported DMC or SWP water is shown in **Table 4-2**.

Table 4-2. Percentages of Surface Water and Groundwater Supply

				Percent of Each Surface Water/River Sources				
Water Use Area ID	**Area Name**	**Percent Ground-water**	**Percent Surface Water**	**Delta Mendota**	**State Water Project**	**Friant-Kern Canal**	**Kings River**	**Kaweah River**
1	AID	60%	40%				100%	
2	CID	44%	56%				100%	
3	Crescent Canal Service Area	86%	14%				100%	
4	East Side Well Field	100%	0%				100%	
5	FID	38%	62%			16%	84%	
6	Foothills North	33%	67%				100%	
7	Foothills South	46%	54%				100%	
8	James	14%	86%	55%			45%	
9	Laguna	53%	47%				100%	
10	Liberty	90%	10%				100%	
11	Mendota Pool Area	100%	0%				100%	
12	Mid-Valley	100%	0%				100%	
13	Murphy Slough	52%	48%				100%	
14	Private Pumpers East of Liberty	100%	0%				100%	
15	RCWD	100%	0%				100%	
16	Riverdale	91%	9%				100%	
17	Stinson	76%	24%				100%	
18	Tranquility	19%	81%				100%	
19	Kaweah Delta WCD	82%	18%					100%
20	Tulare Lake Basin WSD	19%	81%		39%		51%	10%
21	South Kings - Other	65%	35%				100%	

4.1.6 Surface Water Quality

The source and quality of imported water is important as it contributes to salt loading based on the amount of applied water and the concentration as shown in **Figure 4-7**. Salts are generally not consumed or exported from the Tulare Lake Basin. Nitrate concentrations in surface water sources are generally low (**Figure 4-8**). Surface water TDS information was used in combination with the annual surface water delivery information to estimate salt loading in the Coalition area.

4.1.6.1 Kings River

Water quality in the Kings River is measured by KRCD at various locations. **Figure 4-11** show the TDS concentrations at Pine Flat and Peoples weir. The figures show that the Kings River does gain salts between the two stations, likely due to runoff from irrigated lands below Pine Flat Dam, and that seasonal fluctuations at Peoples Weir and salt concentrations are relatively low.

4.1.6.2 San Joaquin, Friant-Kern Canal

San Joaquin River water delivered to FID and the City of Fresno through the Friant-Kern Canal has similarly low TDS concentrations and very little seasonal fluctuation as shown in **Figure 4-12** and **Figure 4-13**.

4.1.7 State Water Project – California Aqueduct

State Water Project (SWP) water is delivered through the California Aqueduct. Its TDS concentrations are considerably higher than water from the Kings River as shown in **Figure 4-14**. There is considerable fluctuation between about 100 and 400 mg/L depending on the nature of the water year and the season as shown in **Figure 4-15**.

4.1.7.1 Delta-Mendota Canal

The Delta-Mendota Canal (DMC) also brings water of relatively high salt concentrations into the Coalition area as shown in **Figure 4-16** and fluctuates greatly throughout the seasons as shown in **Figure 4-17**. Not a great deal of DMC water is used by Coalition members (only James ID), but use of this water would contribute to higher susceptibility to salt loading.

4.1.7.2 Tule and Kaweah Rivers

The Tule and Kaweah Rivers bring minimal salt into the southern portions of the Coalition area as shown in **Figure 4-18** and **Figure 4-19** with minimal seasonal fluctuations as shown in **Figure 4-20** and **Figure 4-21**.

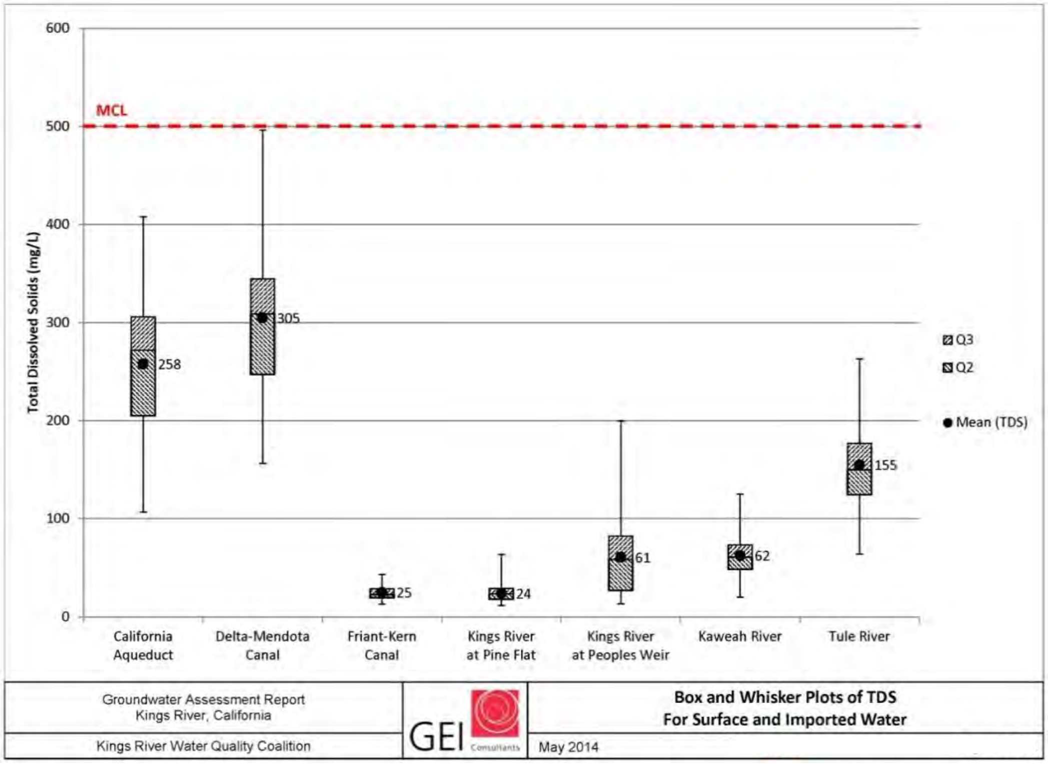


Figure 4-7. Box and Whisker Plots of TDS For Surface and Imported Water

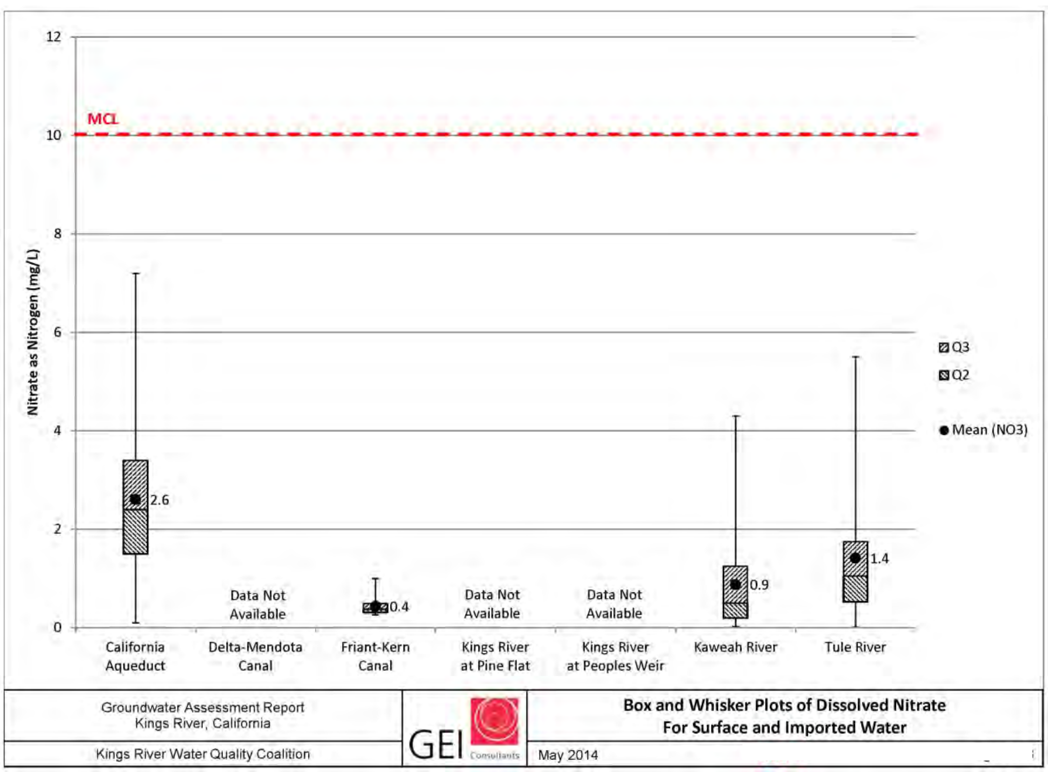


Figure 4-8. Box and Whisker Plots of Dissolved Nitrate For Surface and Imported Water

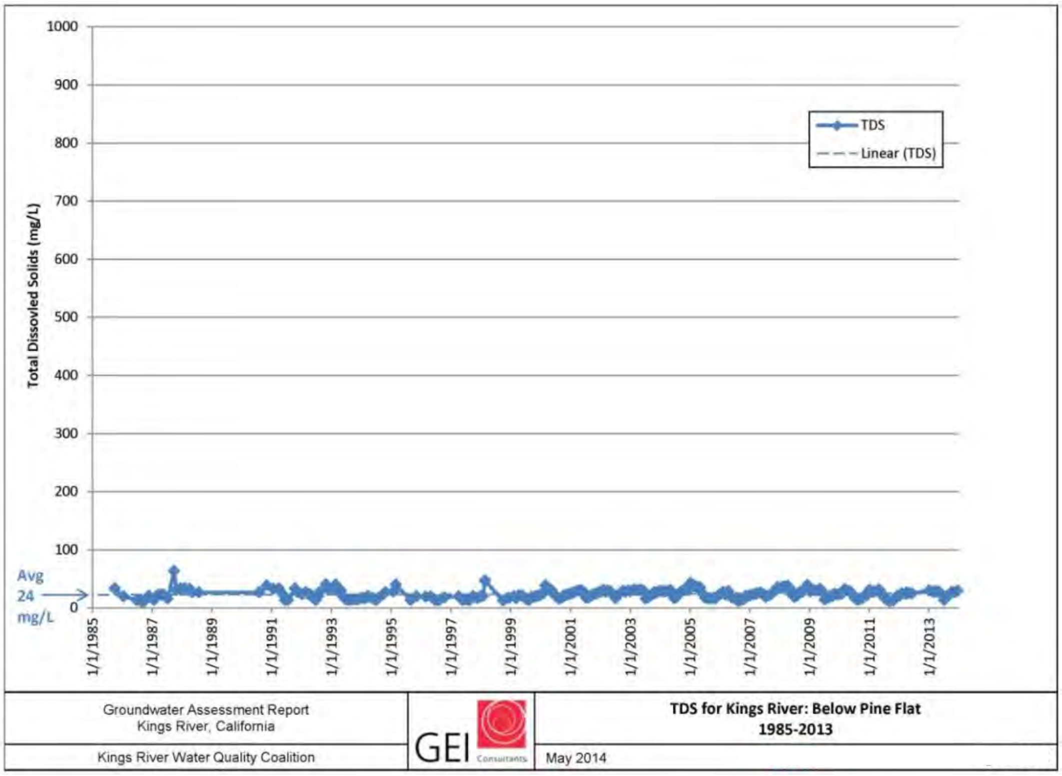


Figure 4-9. TDS for Kings River: Below Pine Flat

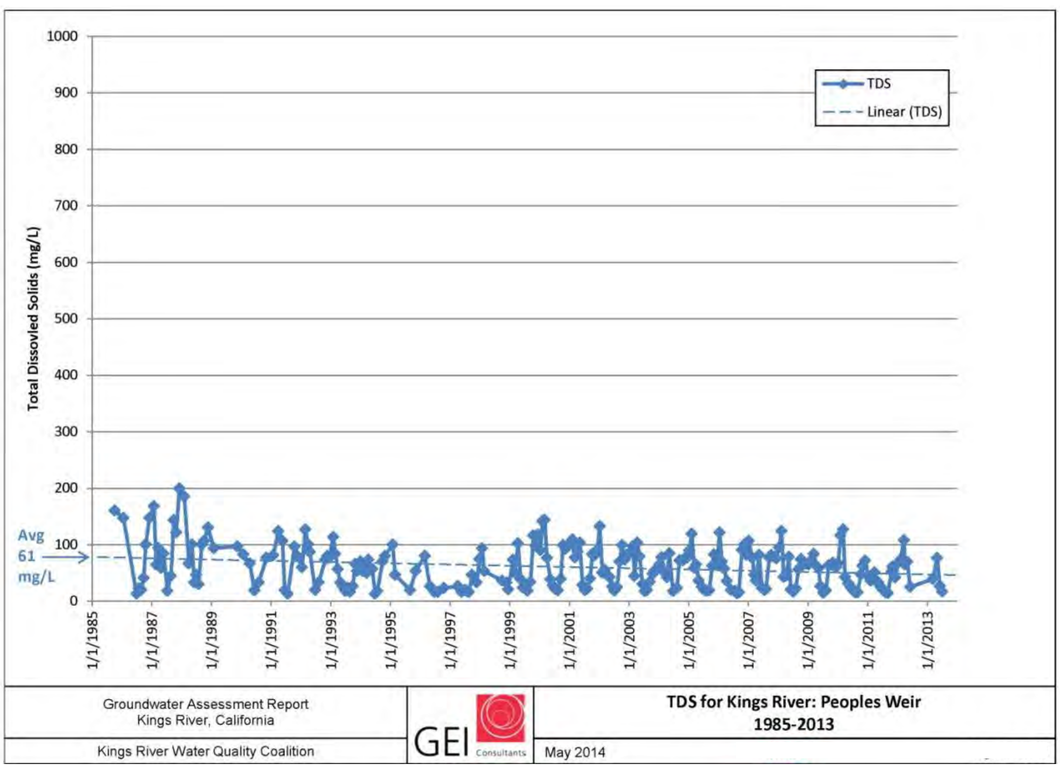


Figure 4-10. TDS for Kings River: Peoples Weir

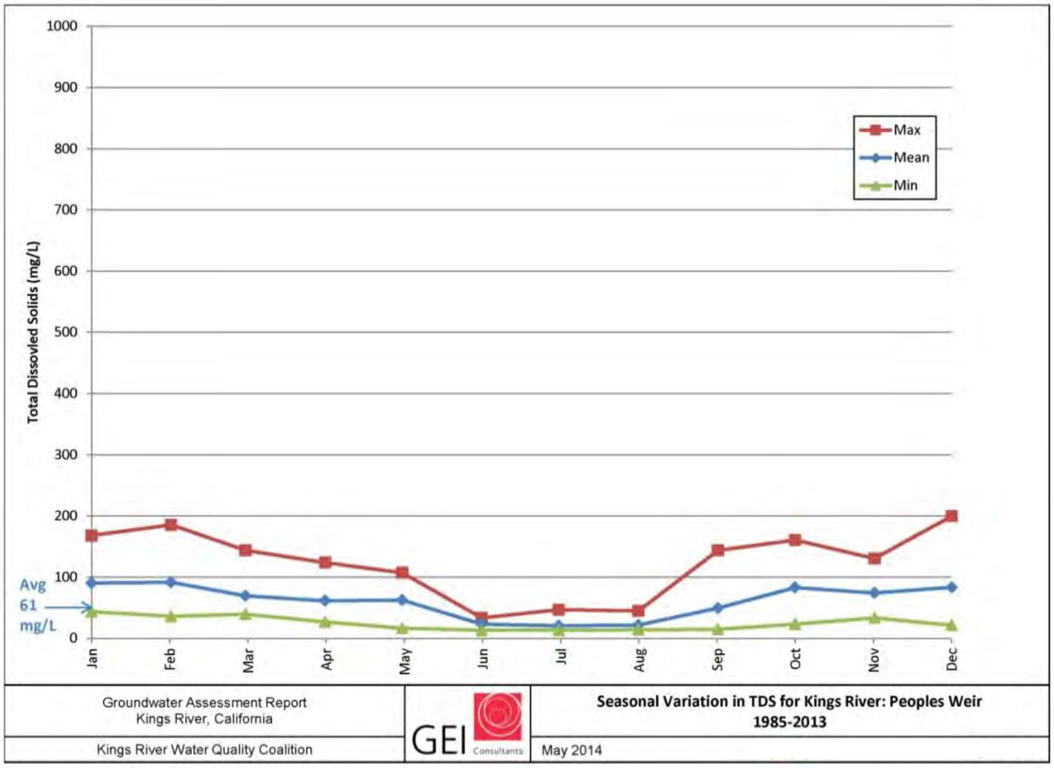


Figure 4-11. Seasonal Variation in TDS for Kings River: Peoples Weir

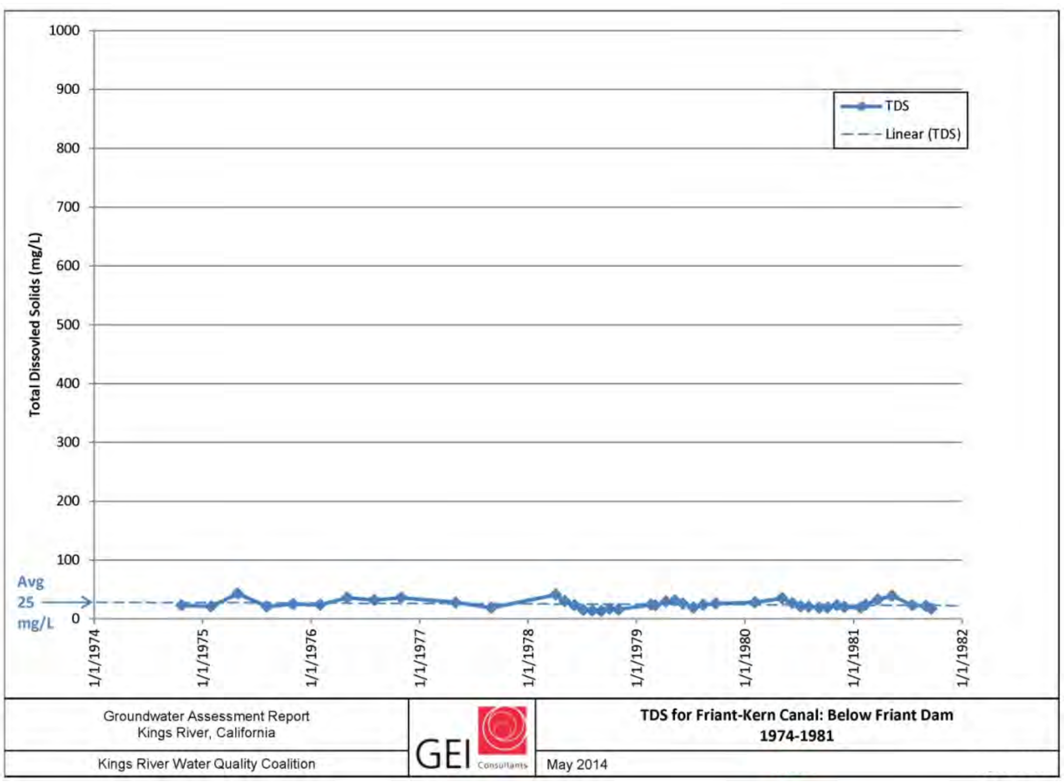


Figure 4-12. TDS for Friant-Kern Canal: Below Friant Dam

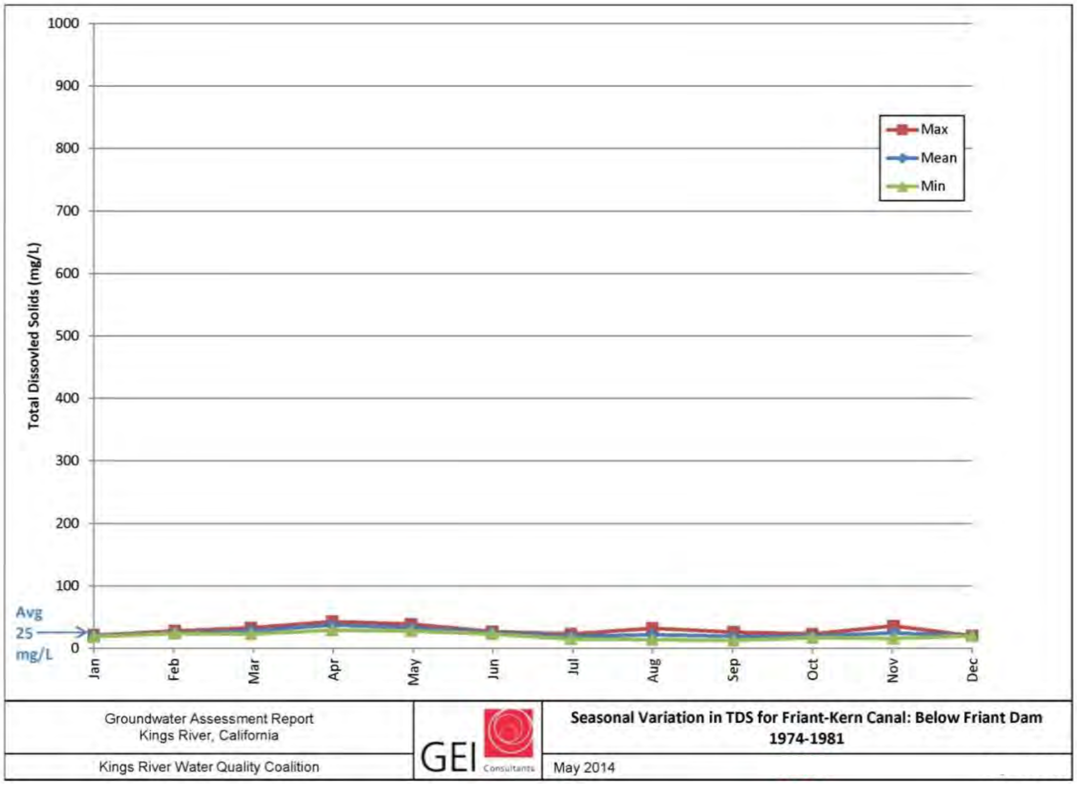


Figure 4-13. Seasonal Variation in TDS for Friant-Kern Canal: Below Friant Dam

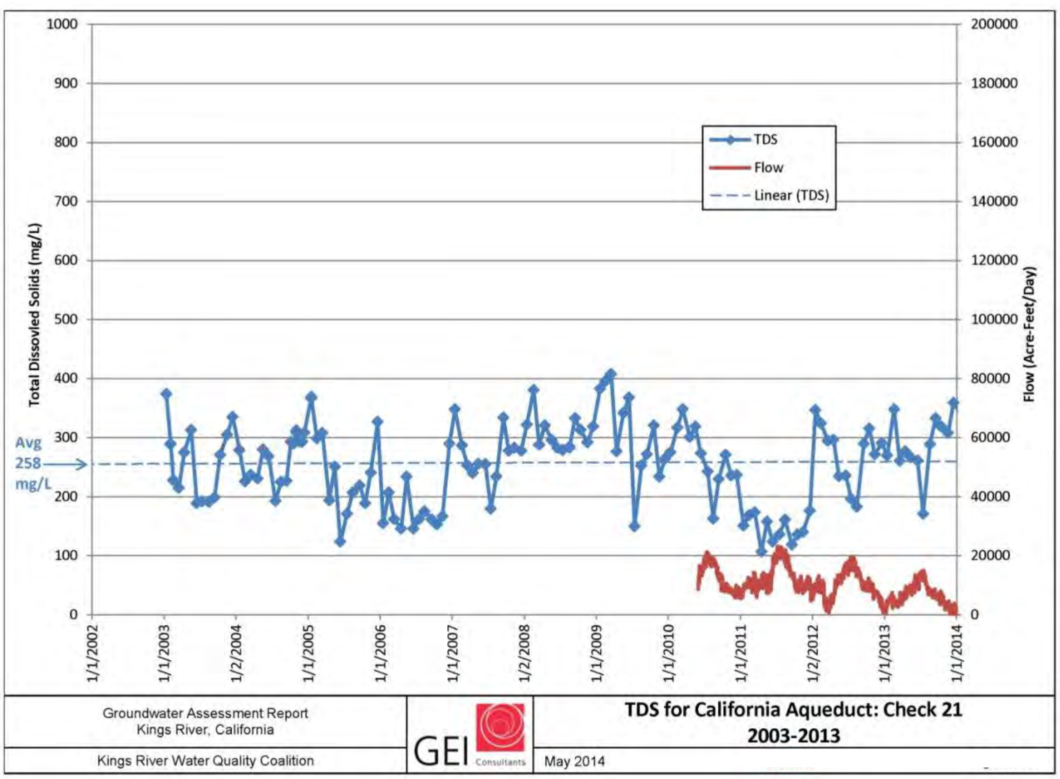


Figure 4-14. TDS for California Aqueduct: Check 21

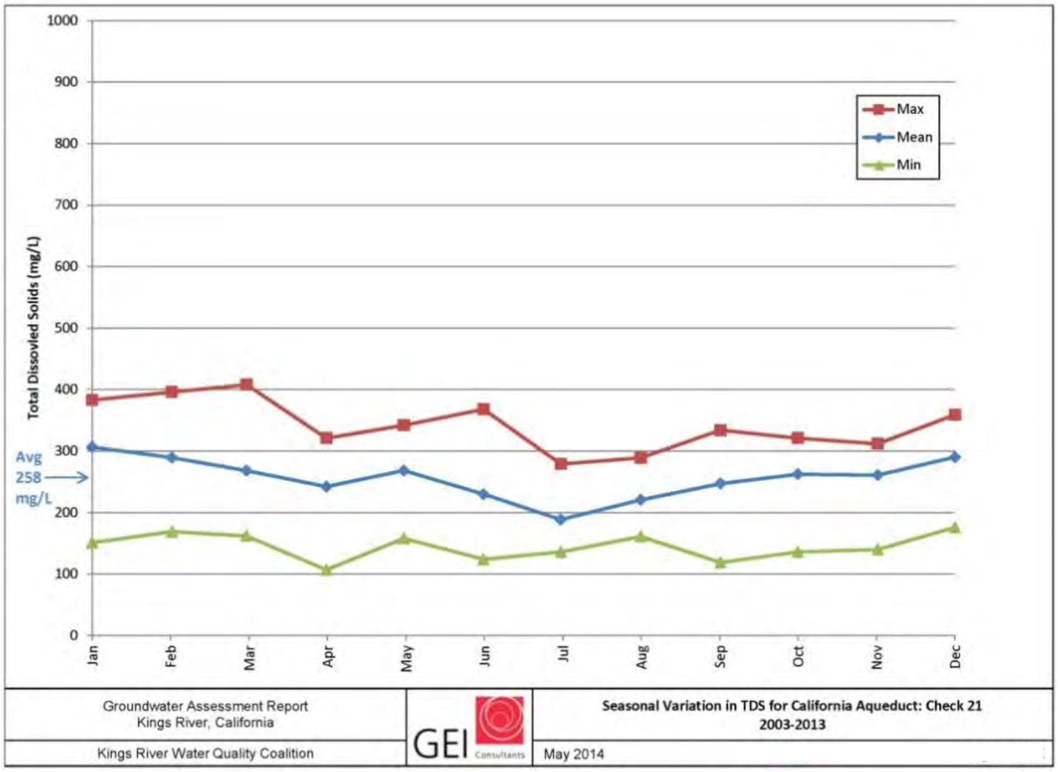


Figure 4-15. Seasonal Variation in TDS for California Aqueduct: Check 21

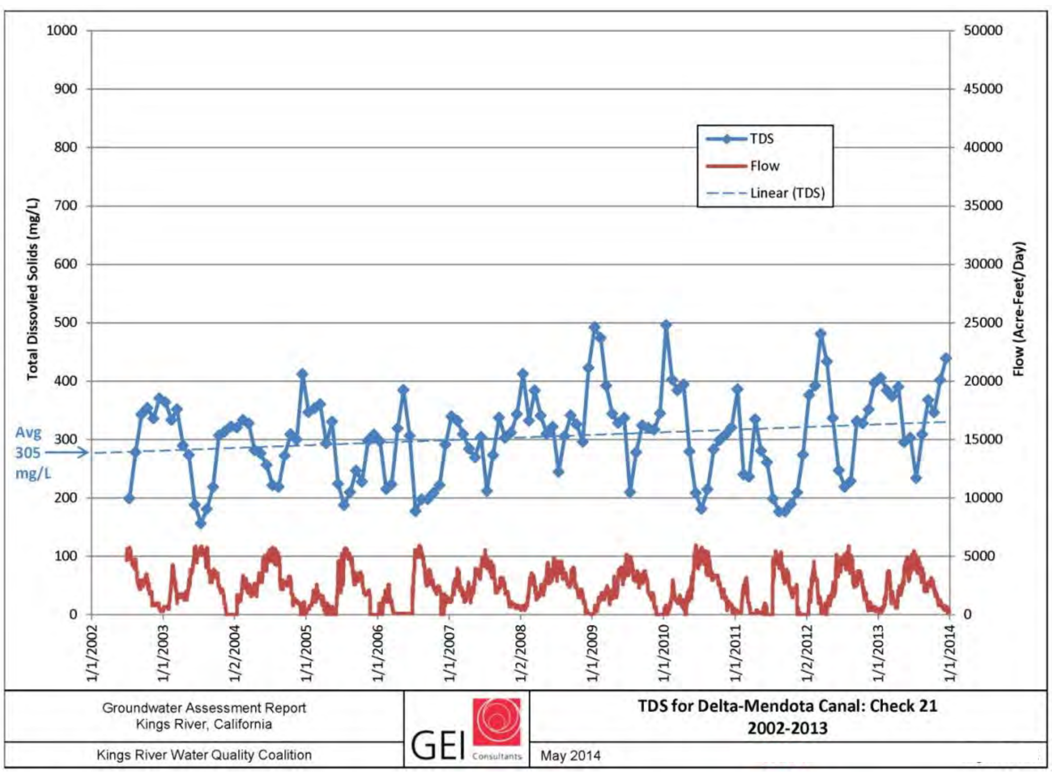


Figure 4-16. TDS for Delta-Mendota Canal: Check 21

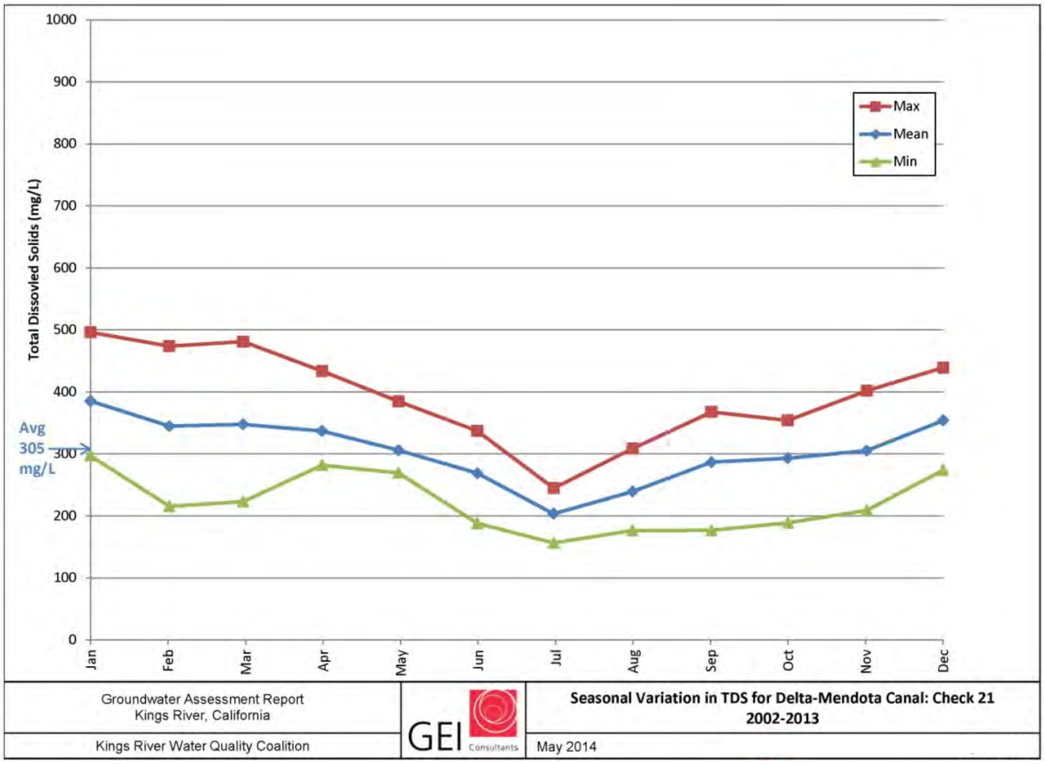


Figure 4-17. Seasonal Variation in TDS for Delta-Mendota Canal: Check 21

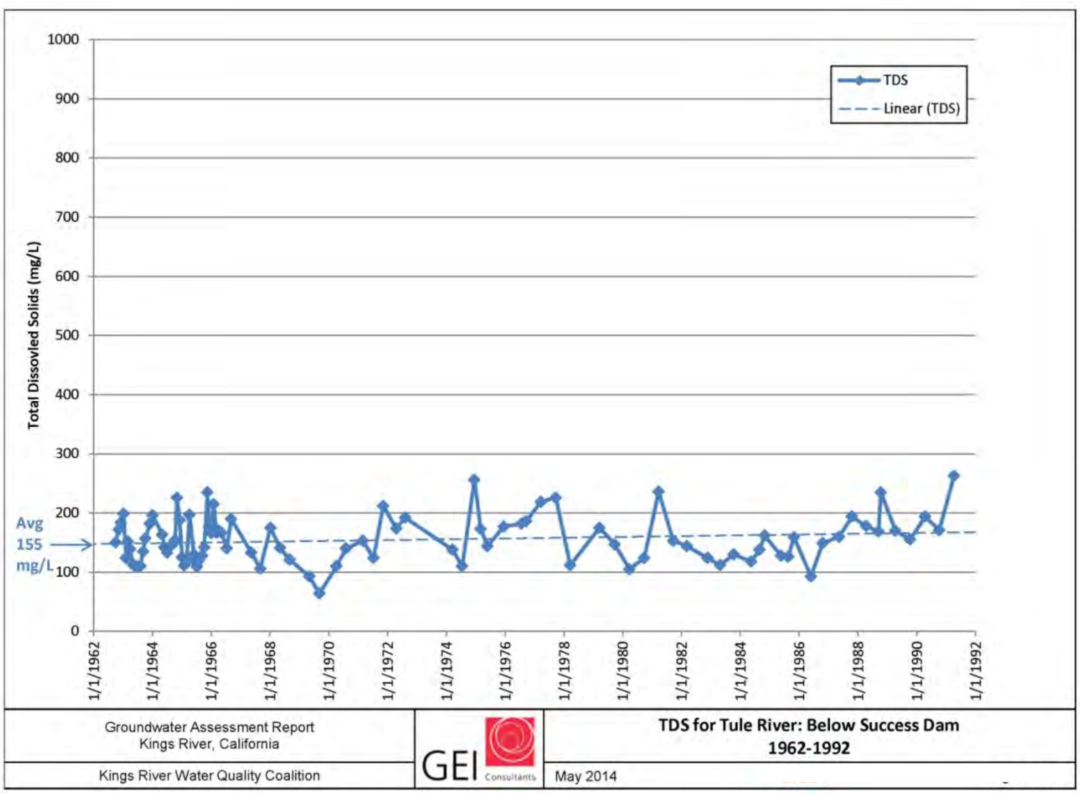


Figure 4-18. TDS for Tule River: Below Success Dam

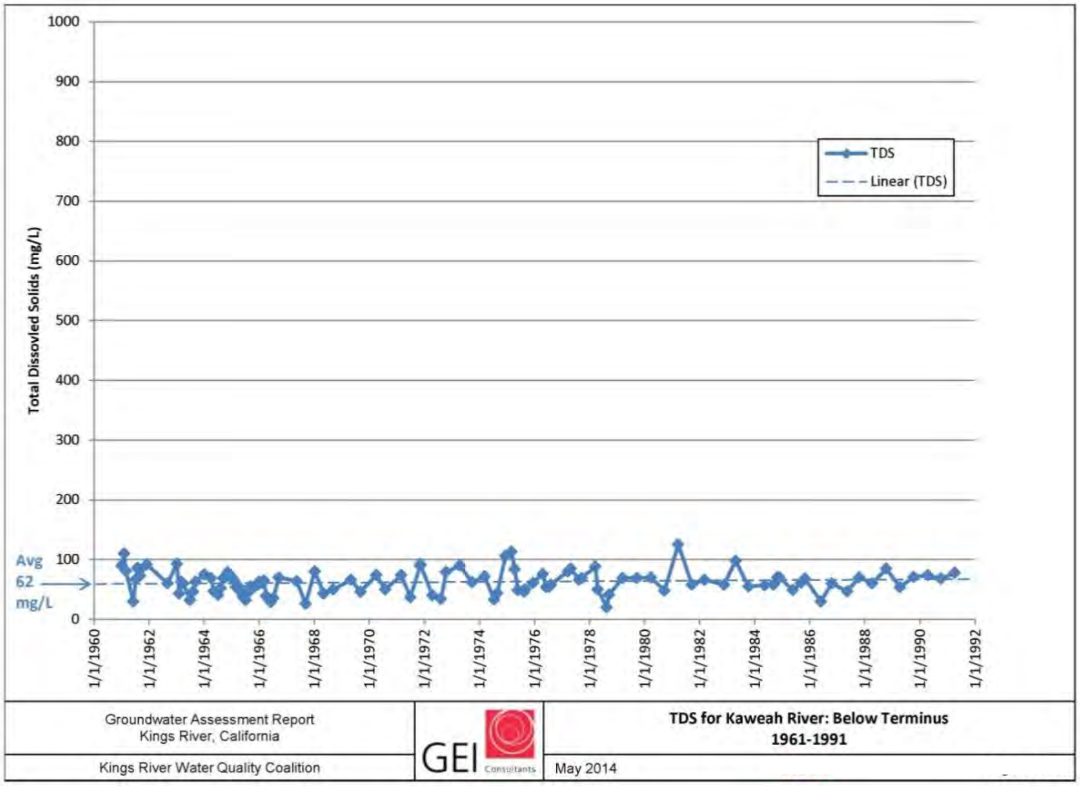


Figure 4-19. TDS for Kaweah River: Below Terminus

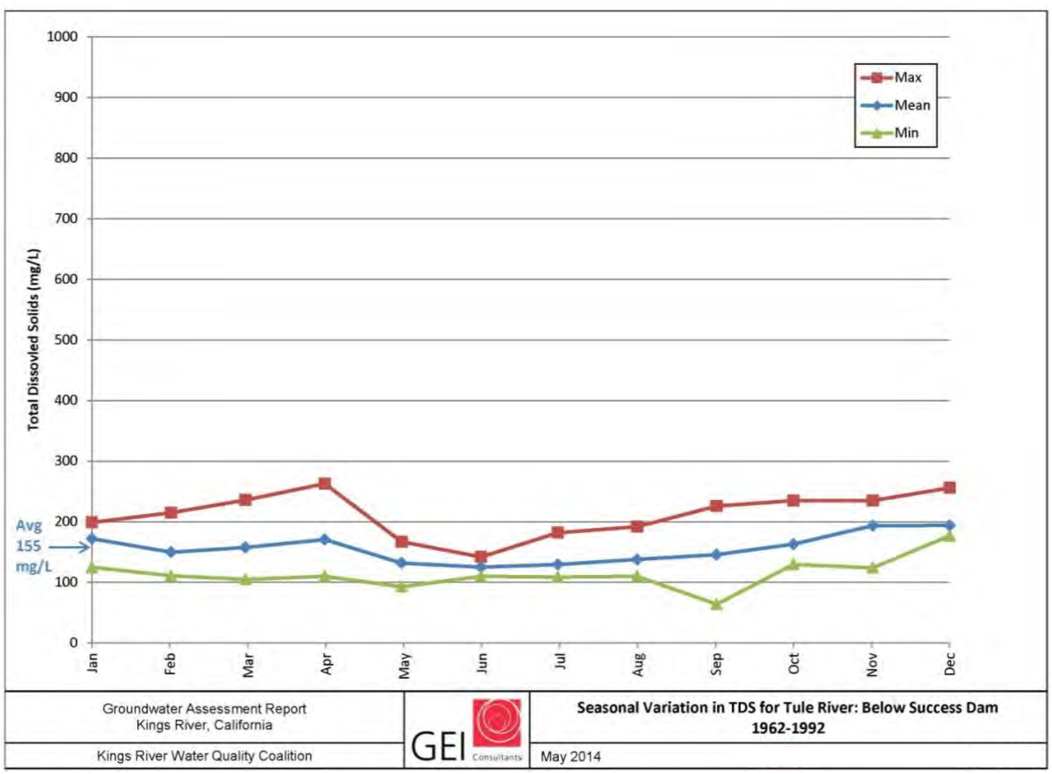


Figure 4-20. Seasonal Variation in TDS for Tule River: Below Success Dam

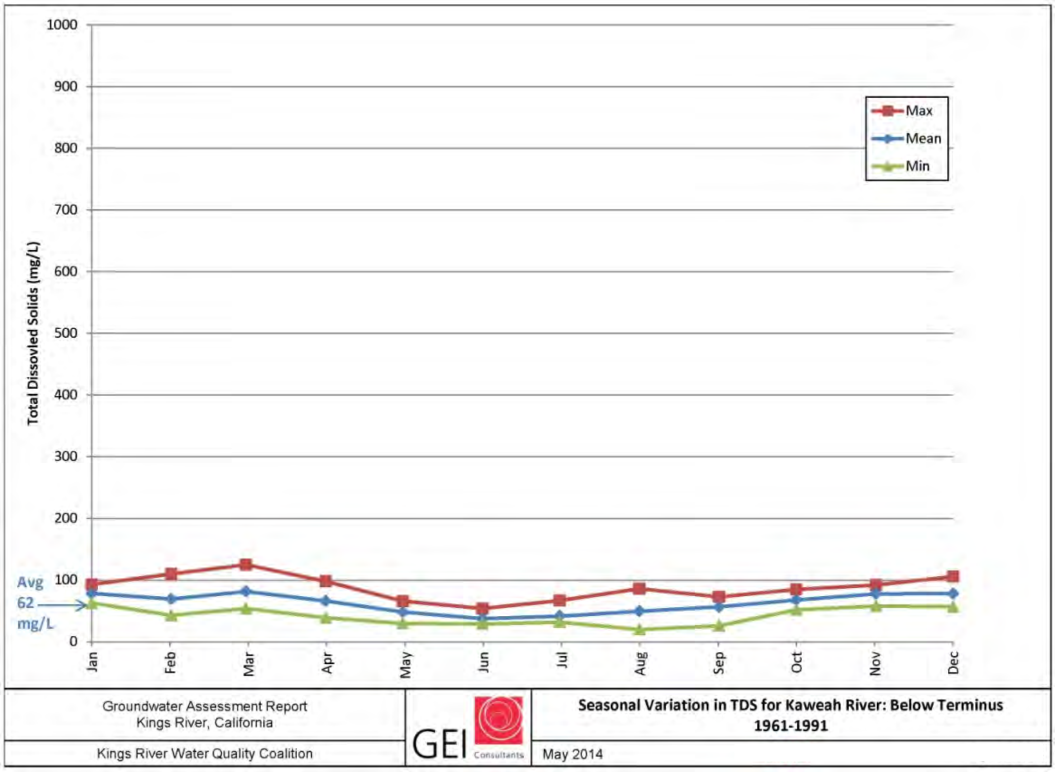


Figure 4-21. Seasonal Variation in TDS for Kaweah River: Below Terminus

4.1.8 Surface and Interceptor Drainage

Drainage water quality data is collected and reported by KRWQC as part of the ILRP. The location of drain outlets is shown in **Figure 4-22.** There was no readily available mapping of areas that are managed through use of drain tiles.

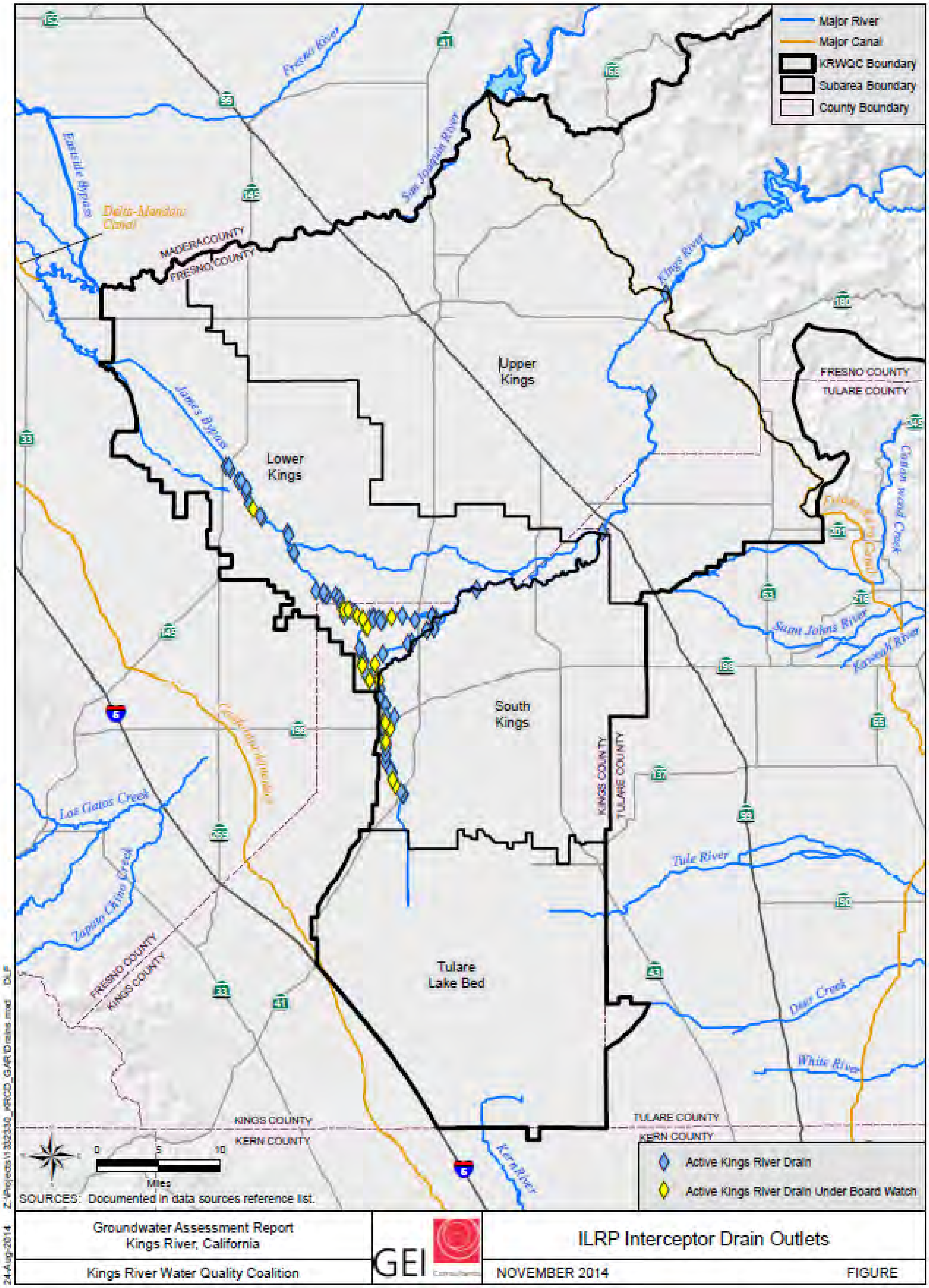


Figure 4-22. ILRP Interceptor Drain Outlets

4.2 GROUNDWATER SYSTEM

Intrinsic susceptibility is influenced by the spatial distribution of the physical parameters of the underlying groundwater aquifer and soil matrix that exist in the groundwater basin. These parameters are relatively time invariant. This includes the native aquifer materials (geochemistry), presence and extent of clay layers and degree of confinements, depositional environmental and permeability of materials. Time variant parameters include transport and time of travel in vadose and saturated zone, and preferential flow paths.

Regional water management and on- farm activities vary over space and time and influence the recharge and discharge relationships, water level contours, and rate of flow when affected by regional pumping regimes. Both the susceptibility and vulnerability factors are factored into the Kings GAR conceptual model.

This section discussed the groundwater levels, depth to water, aquifer characteristics, and the groundwater conditions in the subareas, including the flow, water budget, recharge discharge relationships, unique geologic features and basis for subarea boundaries. The interaction between the surface water, land use and groundwater happens first on the land surface in the soils zone.

4.2.1 Surface Soils

Surface soils represent the part of the earth's surface in direct contact with daily hydrologic, on-farm and other land use activities. Surface soils are a critical element in sustaining the natural processes for the growth of food crops, or providing natural foraging for livestock, and for land application of dairy or other wastes. The permeability and porosity of surface soils influence agronomic and wastewater disposal practices, and the rate which water, salt and nitrogen compounds move through and interact with the native soil, also creating the environmental for soil bacteria to process nutrients and affecting the availability of nitrogen for crop production. SSURGO (Soil Survey Geographic database) refers to digital soils data produced and distributed by the Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center (NCGC). The database assigns attribute values based on the soil properties at the 1 to 10 acre level of resolution. The Order requires Soil information for salinity, alkalinity and acidity. Soil salinity is shown **Figure 4-23** and Soils PH and alkalinity are shown in **Figure 4-24.** Soil permeability, as indicated by the hydrologic group, is shown in **Figure 4-25**

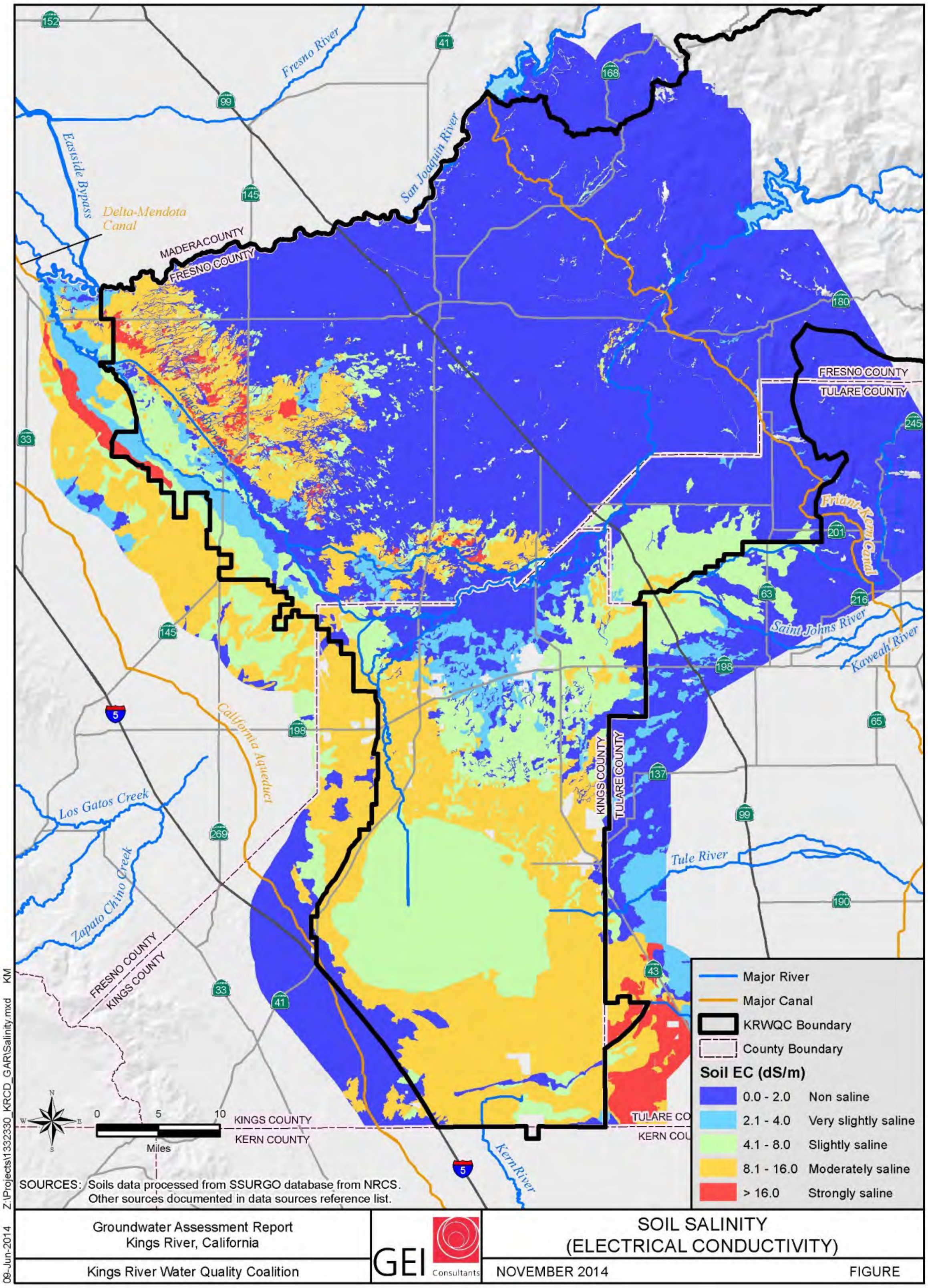


Figure 4-23. Soil Salinity Map

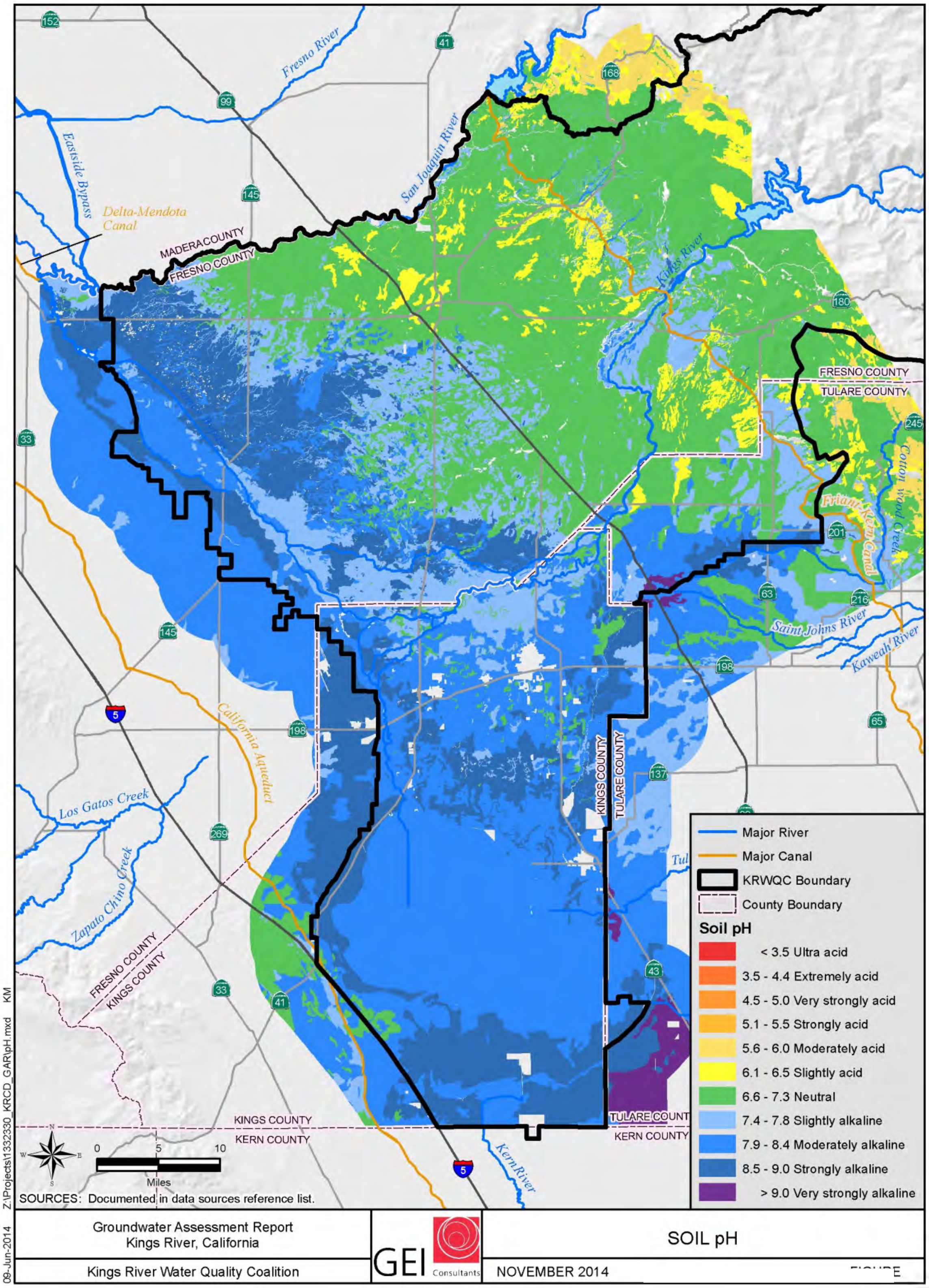


Figure 4-24. Soil PH and Alkalinity

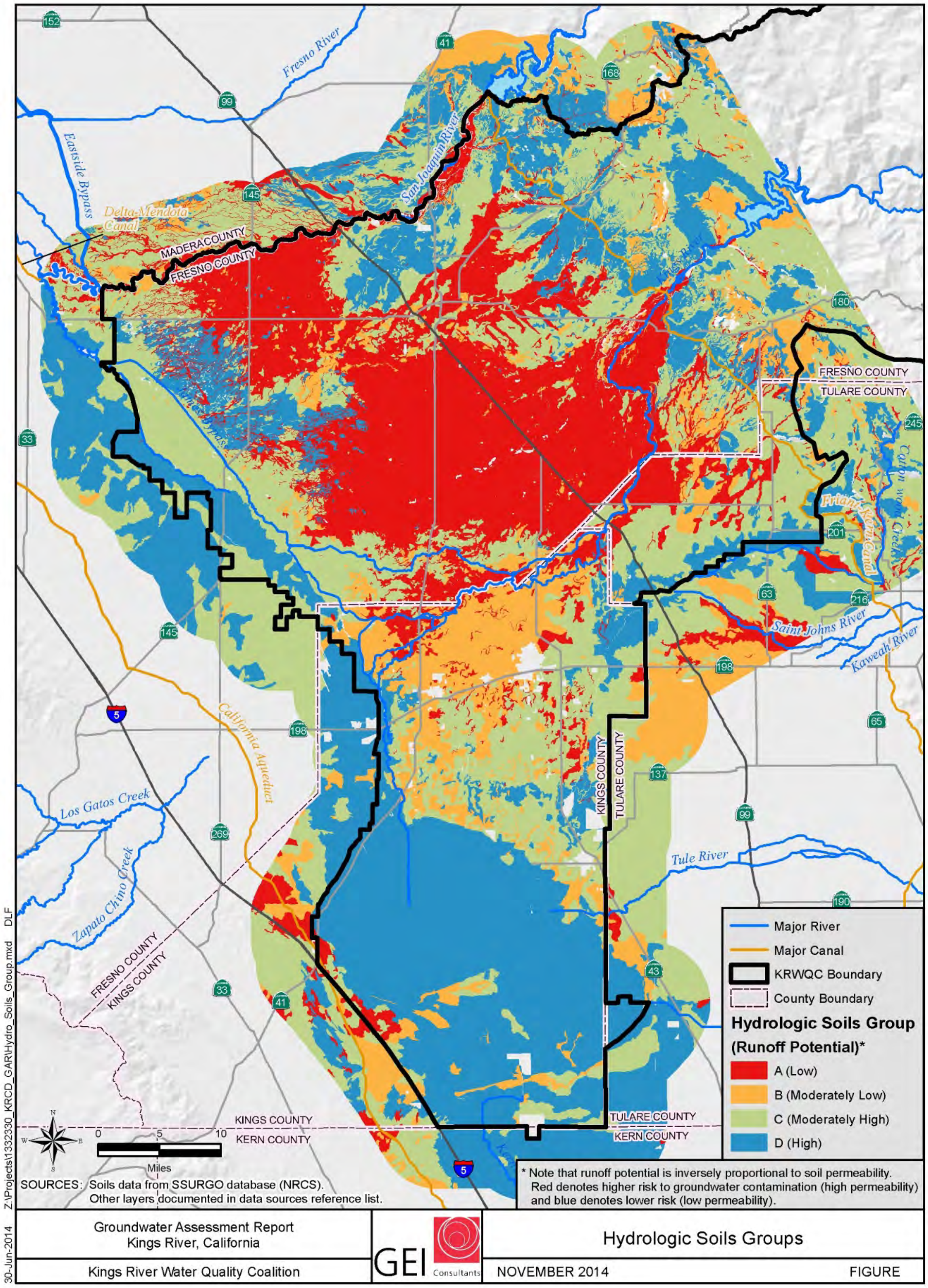


Figure 4-25. Hydrologic Soils Group

4.2.2 Regional Geologic Setting and Groundwater Basins

The Kings study area is in the Tulare Lake hydrologic region and includes the Kings and Tulare Lake subbasins (**Figure 4-27**) as designated in DWR's Bulletin 118 (DWR, 2003). The groundwater management plans referenced in Section 1.4.3 of **Chapter 1 – Introduction**, Bulletin 118, groundwater model documentation, other key references and USGS studies listed in the bibliography were reviewed to identify groundwater basin characteristics and aquifer properties. There are multiple groundwater management plans that mosaic the Coalition area, making data consolidation and extraction complicated. The Tulare Lake Basin geology is also described in detail in documents developed to support the RWQCB review of the municipal use (MUN) designation of areas within the Tulare Lakes Basin (Schmidt, 2013; Schmidt, et al., 2014).

A generalized surficial geology map is shown in **Figure 4-26** (USGS, 2006)[1] which also shows the extent of the Corcoran clay. Both the Kings and Tulare subbasins are filled with material originating from the Coastal Range to the west and the Sierra Nevada to the east. Sediments carried from the two ranges filled the valley trough between the mountain ranges is comprised of marine and continental sediments. To the east of the valley, the Sierra Nevada is composed primarily of pre-Tertiary granitic rocks and is separated from the valley by a foothill belt of Mesozoic and Paleozoic marine rocks and Mesozoic metavolcanic rocks along the northern one-third of the boundary. The Coast Ranges west of the valley have a core of Franciscan assemblage of late Jurassic to late Cretaceous or Paleocene age and Mesozoic ultramafic rocks. These rocks are overlain by marine and continental sediments of Cretaceous to Quaternary age and some Tertiary volcanic rocks. The alluvial deposits of the western part of the valley tend to be of finer texture relative to those of the eastern part of the valley because they are derived from the Coast Ranges and have a higher clay content (USGS, 1998) (USGS, 2006).

The sediments influence the geochemistry and resultant water quality; and time of travel through the vadose zone and in saturated portion of the aquifer. The course materials lie at the edges of the mountains along the alluvial fans in the east side of the valley and these areas contain more coarse and permeable materials originating from the Sierra Nevada Range than do the less well developed fans originating the Coastal Range. The San Joaquin, Kings, Tule and Kaweah Rivers have cut through the deposited materials and resulted in higher permeability zones that are able to more readily transmit water and any dissolved contaminants through preferential flow paths. The sediments in the Kings Study area are saturated with freshwater range in thickness from 100 to more than 4,000 ft. The Coastal Range is composed of marine sediments and water moving through these aquifer materials dissolve and transport salts. Saline water with a minimum dissolved-solids concentration of 2,000 mg/L occurs at depth.

[1] From Figure 3 of USGS Ground-Water Quality Data in the Southeast San Joaquin Valley, 2005–2006—Results from the California GAMA Program.

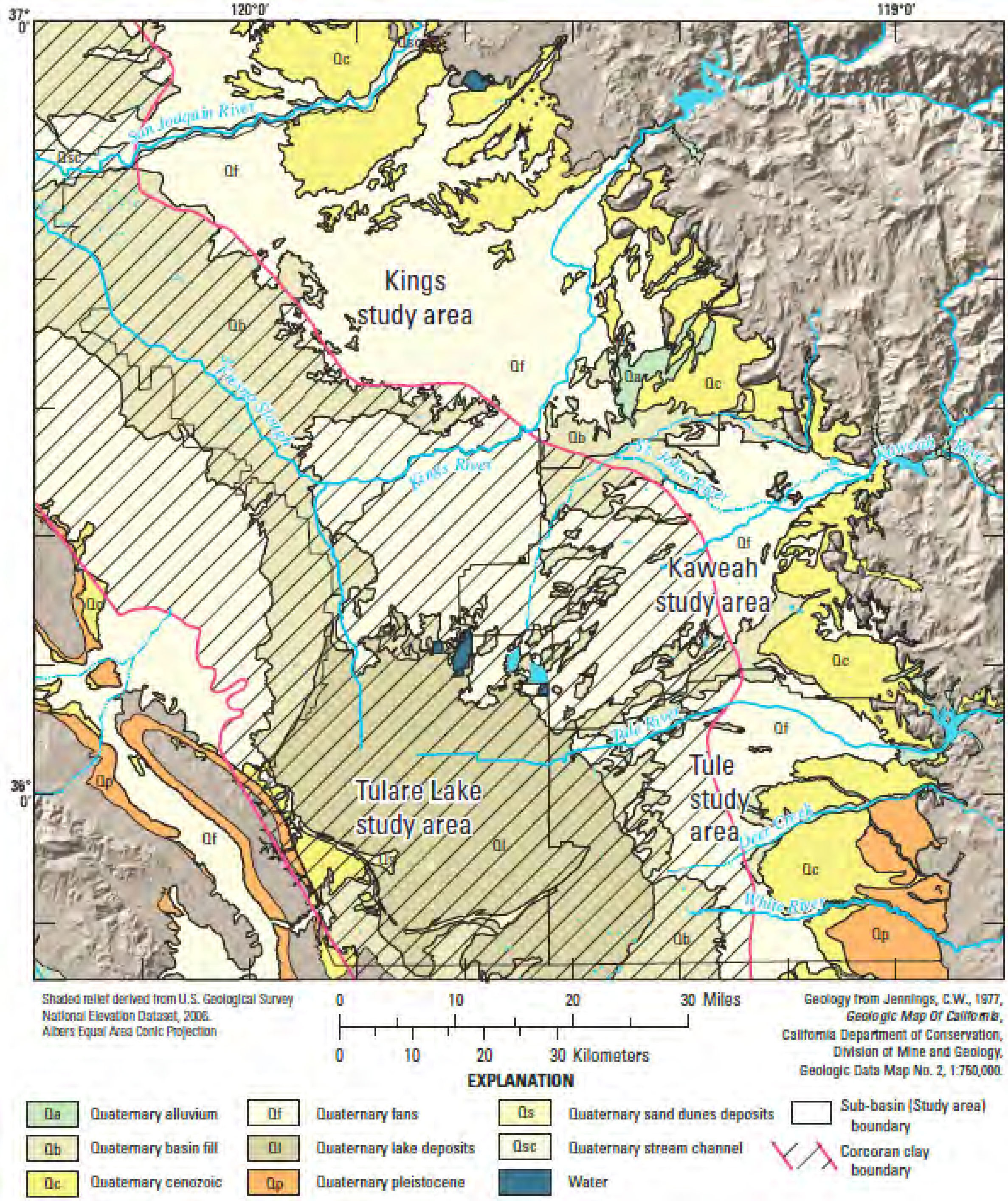


Figure 4-26. Surface Geology

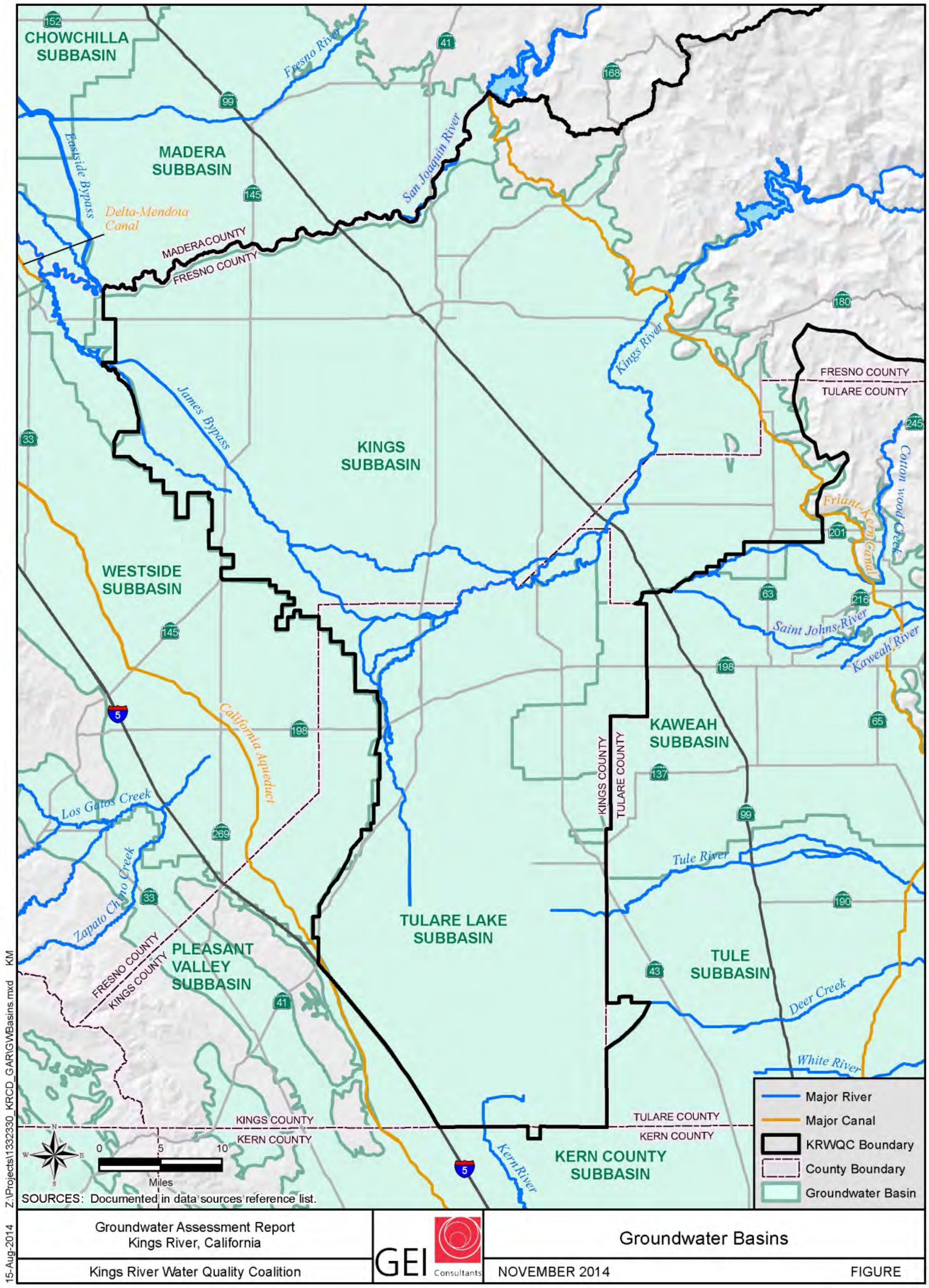


Figure 4-27. DWR Bulletin 118 Groundwater Basin Boundaries

4.2.2.1 Hydraulic Conductivity

Aquifer parameters vary greatly throughout the basin, and influence rates of infiltration and groundwater flow, which in turn control how rapidly water at the land surface move downward through the unsaturated vadose zone to the saturated part of the aquifer. These aquifer parameters are therefore a major factor in the susceptibility of groundwater to nitrate contamination.

One important parameter is the hydraulic conductivity (K). K is correlated to sediment texture (Russo and Bouton 1992), which is the fraction of sediments that are coarse-grained (sands and gravels) as opposed to fine-grained (clays and silts). A three-dimensional sediment texture model of the Central Valley was developed by the USGS (Faunt, et al., 2010) from geophysical data and information from drillers' logs. This texture model was used to develop the subsurface layering and aquifer characteristics for the Central Valley Hydrologic Model (CVHM) (USGS_PP1766; USGS, 2009).

For the GAR, the percent coarse sediments (to a depth of 125 feet) in the texture model was converted to K, using values for the end members (100% coarse and 0% coarse) and using a power mean averaging for values in between. The formula below was used to covert values for each CVHM cell:

Average K to 125 feet = $[P_c{*}K_c^{p}+(1-P_c){*}K_f^{p}]^{(1/p)}$

Where,

P_c is the percent coarse in decimal format (i.e., P_c = 0.20 or 20%) for each USGS CVHM cell.

K_c is the hydraulic conductivity of the coarse-grained end member (3,300 ft/day)

K_f is the hydraulic conductivity of the fine-grained end member (0.24 ft/day)

p is the averaging power-mean exponent (-0.8)

The end member and power mean values above were calibrated by USGS using data specific to the San Joaquin Valley. The variation of K values using various power mean exponents is shown in **Figure 4-28**. The resulting relative variation, using a p of -0.8, in hydraulic conductivities is shown in **Figure 4-29**.

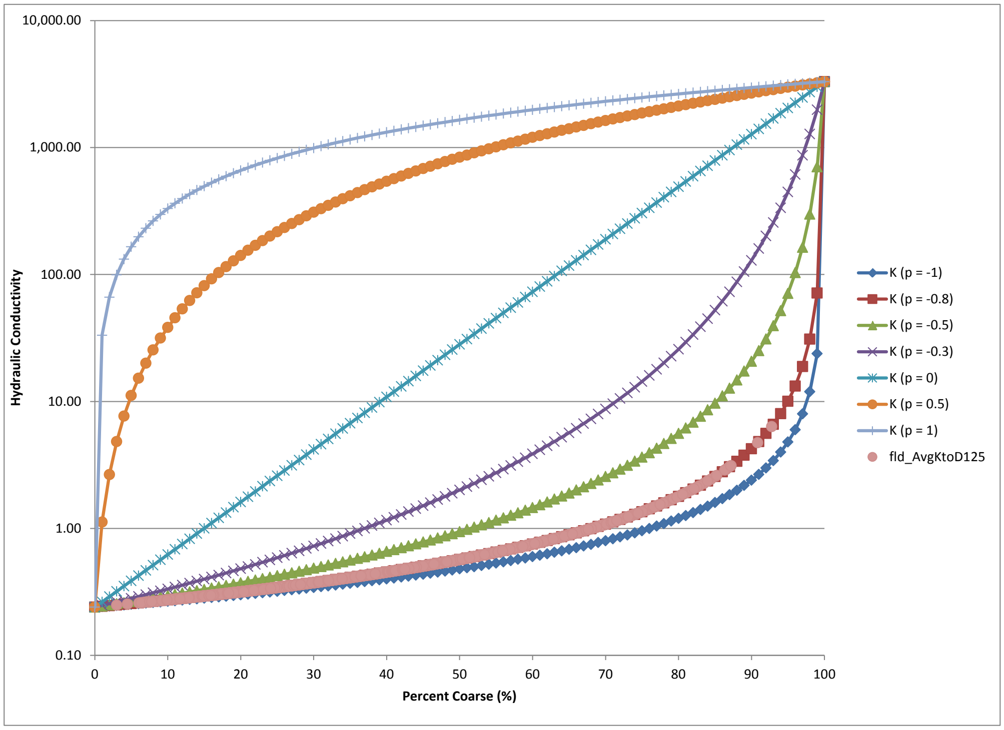


Figure 4-28. Hydraulic Conductivity Variation Using Power Mean Averaging

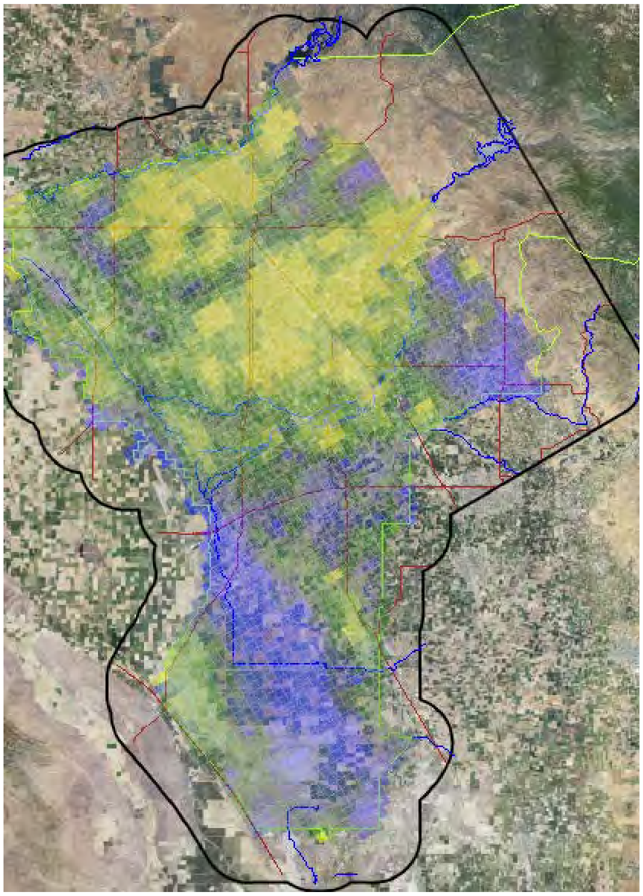


Figure 4-29. Hydraulic Conductivity from USGS Texture Model

4.2.2.2 Clay Layers and Confinement

Generally thin, discontinuous lenses of fine-grained sediments (clay, sandy clay, sandy silt, and silt) are distributed throughout the Coalition area, creating areas of perched water or confinement, and affecting the rate and direction of groundwater flow and contaminant transport. The clay layers offer some degree of protection from surface sources of contamination and constrain the time of travel for water and contaminants from the soils zone through the unsaturated zone. The large percentage of fine-grained sediments in the western San Joaquin Valley impedes the downward movement of groundwater and contributes to agricultural drainage problems and to land subsidence in the area.

The USGS (Croft, 1972) prepared several subsurface geologic cross sections extending through the Tulare Lake Bed. Six “clayey or silty clay tongues”, designated by letter symbols A to F are found in varying degrees and thickness in the Coalition areas. The most widespread of these are the A, C, and E Clays. The E-Clay is also known as the Corcoran Clay (**Figure 4-30**), and is the most laterally extensive confining bed in the San Joaquin and is a dominant influence on the hydrogeology. In addition to the Corcoran Clay, the other clay members provide semi- confined or confined aquifer conditions.

The presence or absence of the Corcoran and other clays have a major influence on how contaminants at the land surface reach groundwater, recharge areas and discharge relationships. The Corcoran Clay is thick and aerially extensive throughout the Coalition area, creating an upper aquifer in contact with the land surface and a lower aquifer that is under pressure. A number of studies have documented the difference in water quality in wells perforated below clay layers (Schmidt, 2004) (WRIME, 2007) (Fugro, 2007) (USGS, 2006).

Groundwater perched above the Corcoran Clay is more vulnerable to contamination due to naturally occurring salts and as a result of both the contact with the land surface and the overall volume of water available above the clay that can mix with potential contaminants. There is an observed difference in the groundwater elevations above (higher) and below the clay (lower) which provide the physical mechanism for flow between the aquifers through dual completion wells or other flow paths.

4.2.3 Regional Groundwater Contours and Depth to Water

Figure 4-32 presents a map of wells with water level data stemming from various public and private sources.

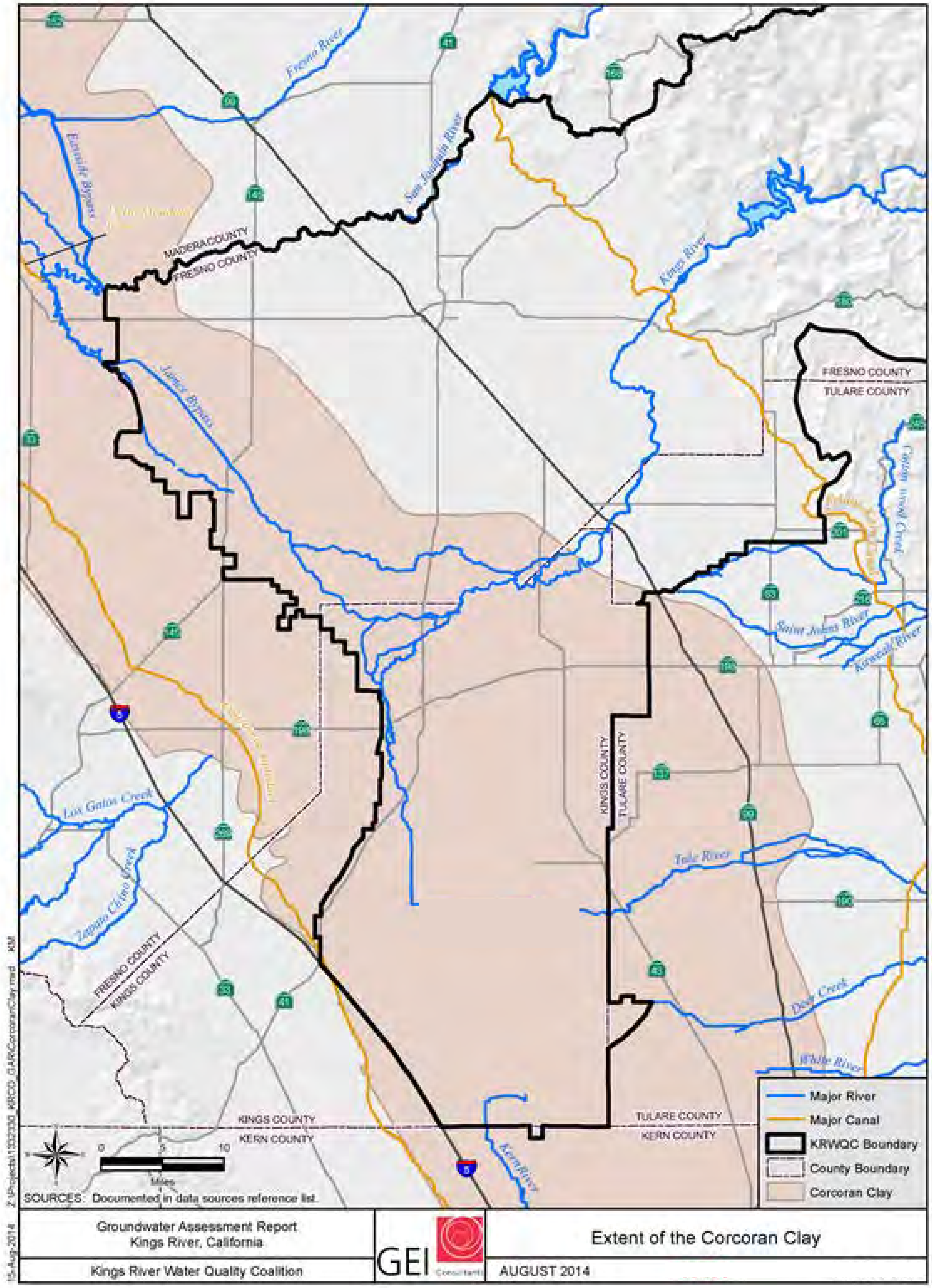


Figure 4-30. Extent of the Corcoran Clay

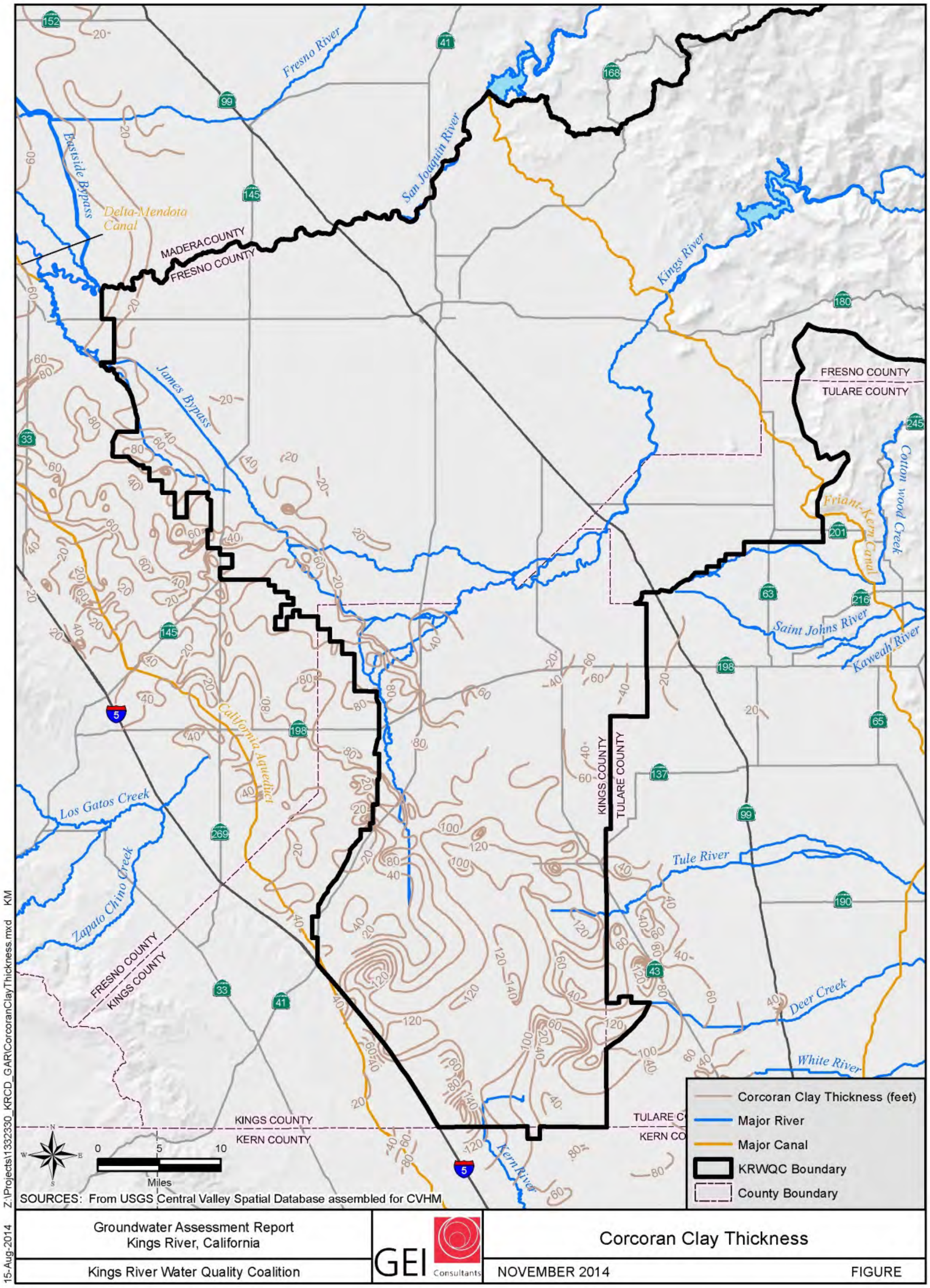


Figure 4-31. Corcoran Clay Thickness

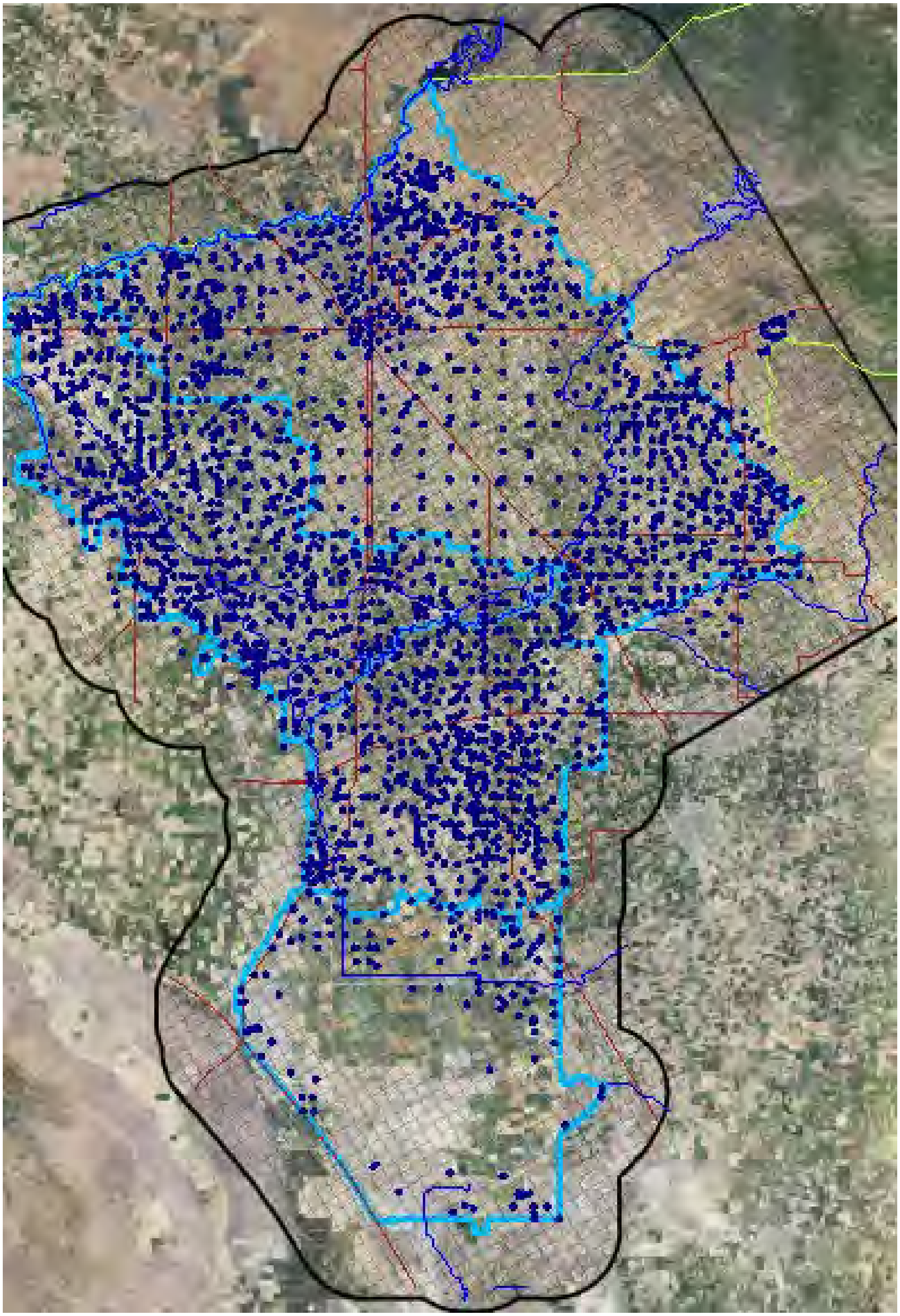


Figure 4-32. Depth to Groundwater Well Locations

There are multiple sources of data for groundwater levels and both local agencies and DWR map water elevation contours from this data. Statewide groundwater level data, including wells within the Kings study area, are available for download at DWR's Water Data Library website.[2] The data for some wells extend back to 1910. This data was accessed and downloaded for the Kings GAR. DWR also has groundwater basin contour maps for the Kings, Tulare Kaweah and Tulare Lake basins dating from 1958 through 2010, and depth to water maps for the same areas for 2000 and 2010.[3] DWR contours the entire San Joaquin River and Tulare Lake Region dating back to 1952. All of the maps are available in PDF and the underlying well data is in the Water Data Library. The local water agencies collect groundwater level data. Much, but not all of the data is provided to DWR.

Of the wells shown, a collection of model wells used for the Kings IGSM model calibration are used for purposes of understanding groundwater elevation changes over time in the Upper and Lower Kings subareas. On the map (**Figure 4-33)**, the IGSM wells are shaded a light blue with hydrographs for four wells shown to the right of the figure. The blue to yellow shading of the CVHM cells indicates relative depth to groundwater from ground surface with yellow being shallow and dark blue being deeper.

The hydrographs generally indicate a slight decline in groundwater elevations with declining elevations most prominent in the Lower Kings subarea towards the western region due to its higher use of groundwater. The map for areas outside of the Kings IGSM (i.e., South Kings and Tulare Lake Bed subareas), where the population of wells is much less, CVHM model data is used to ascertain the groundwater elevations to make a complete Kings study area groundwater elevation map. This was also done to minimize the effects of water level data gaps. To minimize the chance for error in the GAR analysis, modeled contours and the land surface elevations in the CVHM model were used to complete an annual average Kings study area groundwater elevation and general flow direction map (**Figure 4-34**).

The groundwater elevation contours shown in **Figure 4-34** reflect the maximum groundwater elevation in the period between 2000 and 2010 to be used for solely for the purpose of this study, as explained in **Appendix B – Description of Overlay Index Variables**. The maximum groundwater elevations are important to the potential proximity of groundwater elevations to contaminant sources near ground surface or in the vadose zone. If this map is compared to published groundwater contour maps (**Figure 4-39**), groundwater elevations are somewhat higher with less pronounced cones of depression as a result of taking the average of maximum values.

[2] http://www.water.ca.gov/waterdatalibrary/

[3] http://water.ca.gov/groundwater/data_and_monitoring/south_central_region/GroundwaterLevel/gw_level_monitoring.cfm

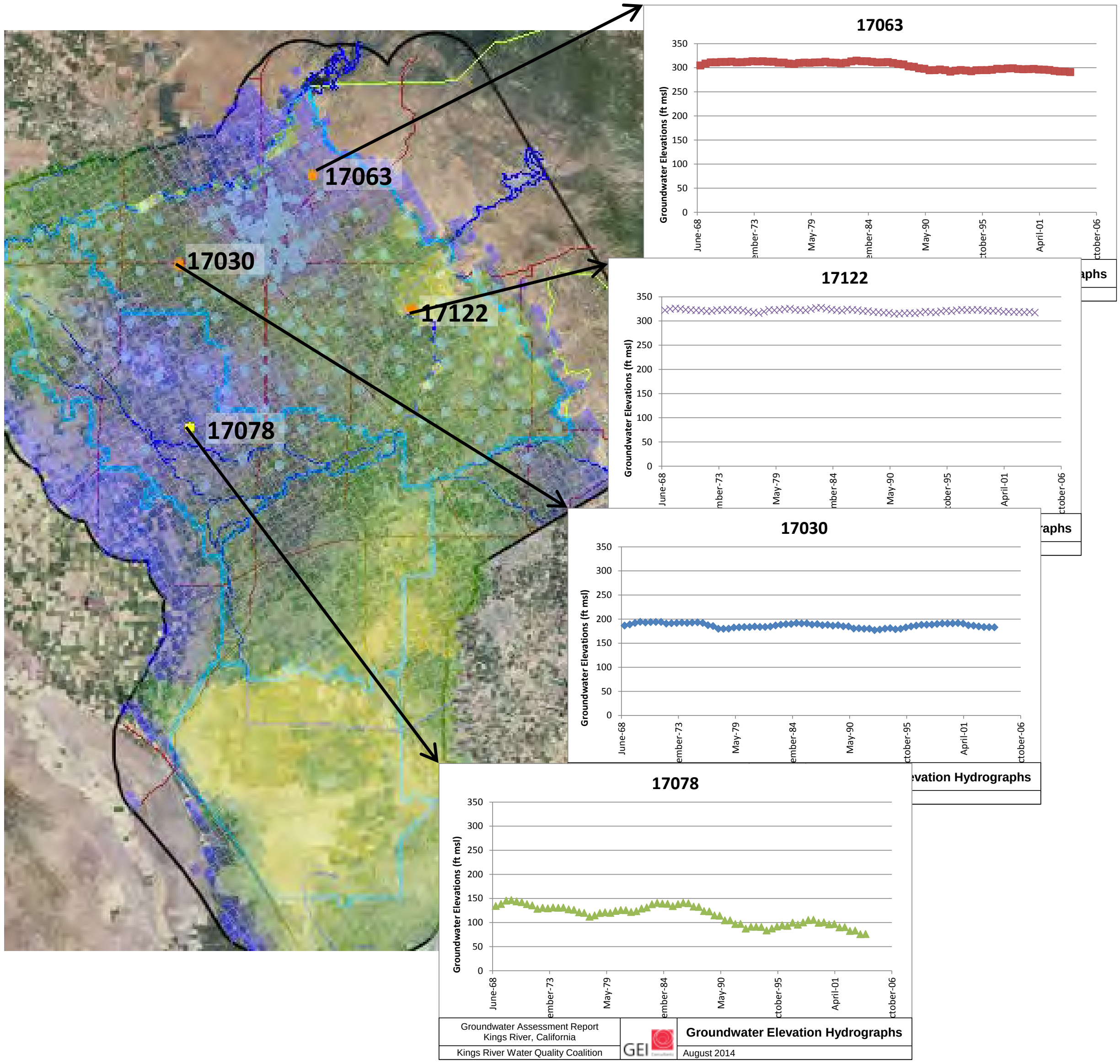


Figure 4-33. Upper and Lower Kings IGSM Well Hydrographs and Shaded Depth to Groundwater

4.2.3.1 Upper and Lower Kings

The Kings IGSM, the most recently published model of the Upper and Lower Kings Systems (WRIME, 2007a), provides the best source for aggregated information on the groundwater conditions and the surface water/groundwater budgets. The basis for the boundary between the Upper Kings and Lower Kings designation is locally defined based primarily on surface water management and water agency jurisdictional boundaries. The Upper Kings includes Alta Irrigation District, Consolidated Irrigation District, Fresno Irrigation District which have active conjunctive use/recharge programs and rights to 65% of the Kings River flows, resulting in a lower reliance on groundwater and relatively large volumes of surface water recharge as compared to the Lower Kings. This has higher permeability soils and aquifer materials associated with the alluvial fans, and intermittent clay layers.

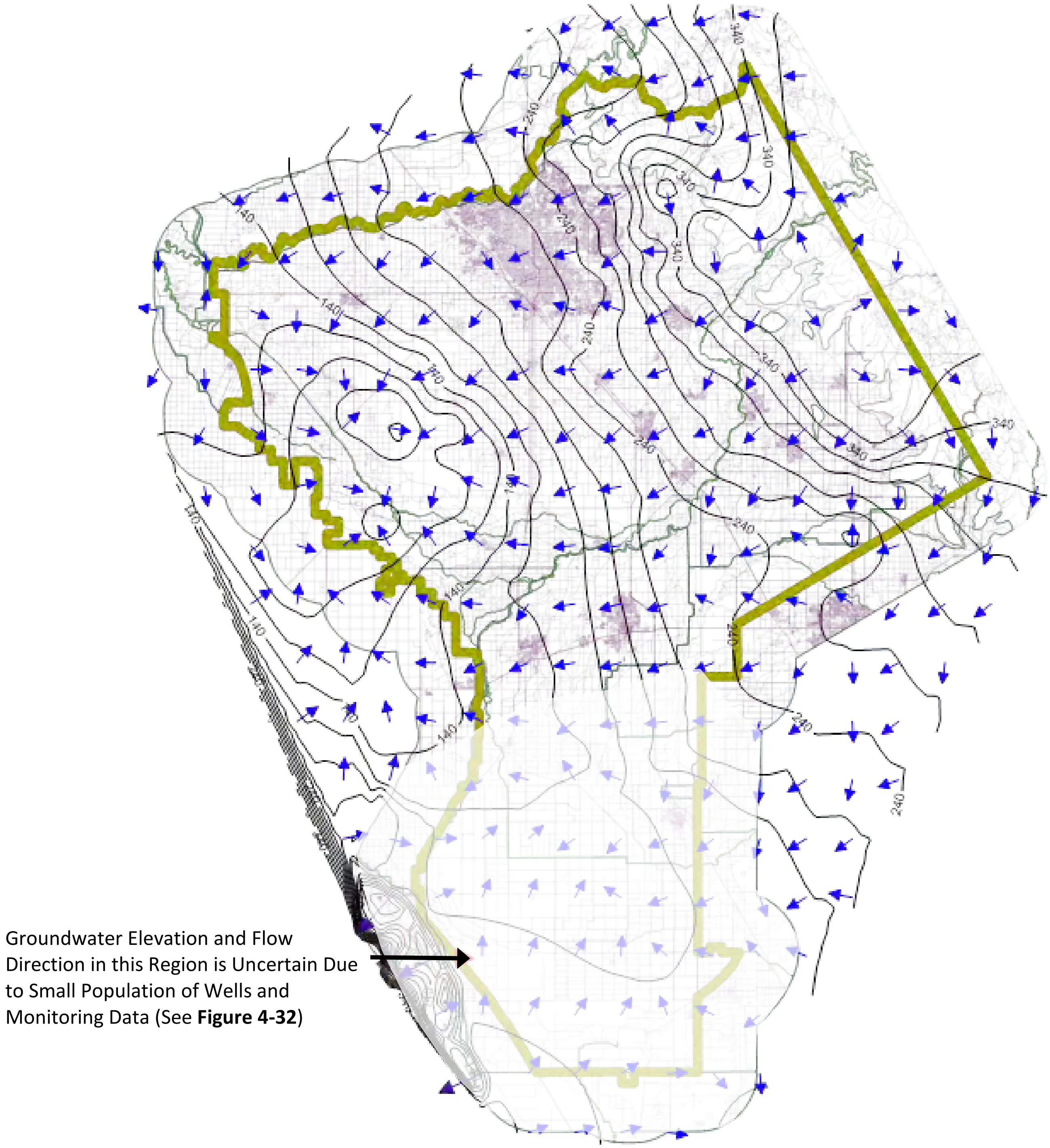


Figure 4-34. Regional Groundwater Elevation and Flow Directions

4.2.4 Groundwater Conditions in the Subareas

Recharge is from local runoff, deep percolation of applied water, canal leakage and intentional recharge operations using Kings and Friant-Kern water; and from the San Joaquin River. Improvements to ambient groundwater quality from recharge operations using Kings River water or Friant-Kern water improve groundwater quality over baseline conditions and reduce nitrate levels where recharge operations are conducted. The studies of the Leaky Acres recharge facility, which also applied Kings River water and local flood runoff, showed that after initial recharge there was some increase in groundwater TDS; but a new, low TDS was attained by the end of the recharge period and TDS levels were reduced further over the long term (Nightingale, 1977) (Nightingale, 1983). The results of the Leaky Acres studies also showed an initial increase in nitrates in groundwater due to leaching of nitrates from the soil and unsaturated zone, but that long term data documented that nitrate levels decreased over time as the cleaner Kings River surface water was recharged and blended with the ambient groundwater. Groundwater discharge is from pumping for agricultural and municipal uses.

With the exception of the City of Fresno, which has developed surface water treatment facilities, all the cities are reliant on groundwater. AID is also working to develop surface water treatment facilities.

The Lower Kings is primarily distinguished by the presence of the Corcoran Clay, creating a confined, semi-confined and unconfined conditions. There is higher reliance on groundwater pumping due to less reliable surface water delivery. The Upper Kings Basin has a total groundwater storage capacity of 35 million AF to an average depth of about 500 feet. The groundwater storage in the Lower Kings Basin is estimated to be about 44 million AF to an average depth of about 1,000 feet (WRIME, 2007b).

The largest groundwater level declines and greatest depletions in groundwater storage occur during the most severe drought periods and the Kings IGSM modeling and declining groundwater levels indicate overdraft. The overlying groundwater management plans and the Kings IRWMP recognize that the groundwater basin is in overdraft and that groundwater storage has been depleted in the modeled period from 1964 to 2004 (**Figure 4-35**). DWR has also classified the basin as being in a critical state of overdraft (DWR, 2003).

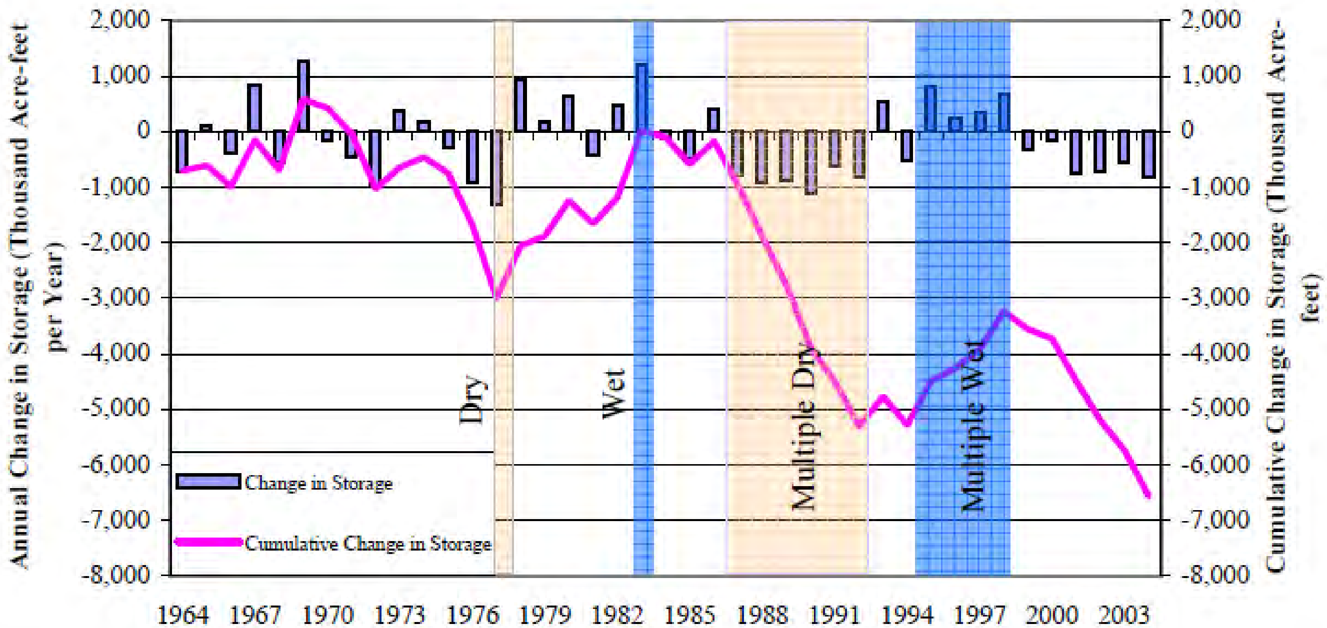


Figure 4-35. Change in Groundwater Storage in Kings Basin (From Figure 4-1B in WRIME 2007)

Figure 4-36, **Figure 4-37**, **Figure 4-40**, and **Figure 4-41** show representative historical groundwater level trends for all groundwater elevation wells in the Upper Kings, Lower Kings, South Kings, and Tulare Lakebed subareas, respectively. The box and whisker charts provide the maximum, minimum, average, count, mean and percentile ranking of the available data. The number of wells for each time period is on the right vertical axis while the groundwater elevations are indicated on the left vertical axis. The maximum high and minimum low groundwater elevation values are indicated by the lines (whiskers) on top and bottom, and the boxes indicate where the second and third quartile (i.e. 50% of wells located nearest the median (middle value or line between boxes). A close proximity between the average (black dot) and the median generally reflects a better dataset with less overall deviation and spread in the data over the range. The “X” with a value represents the number of wells in the total population used for the data shown. These charts will be used in both groundwater elevation and water quality cases where data is available but is sporadic with data gaps and/or wells are added or removed over time in the study subarea. They should be used with care and only for making generalized comments of each subarea.

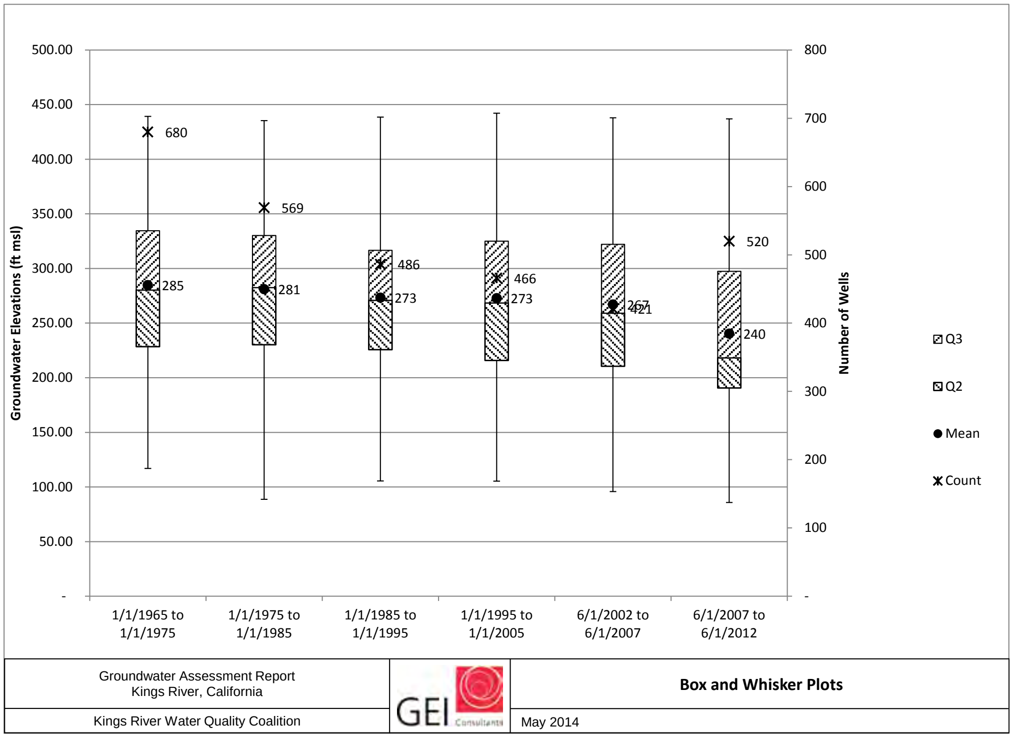


Figure 4-36. Upper Kings Representative Whisker Chart for Groundwater Elevations

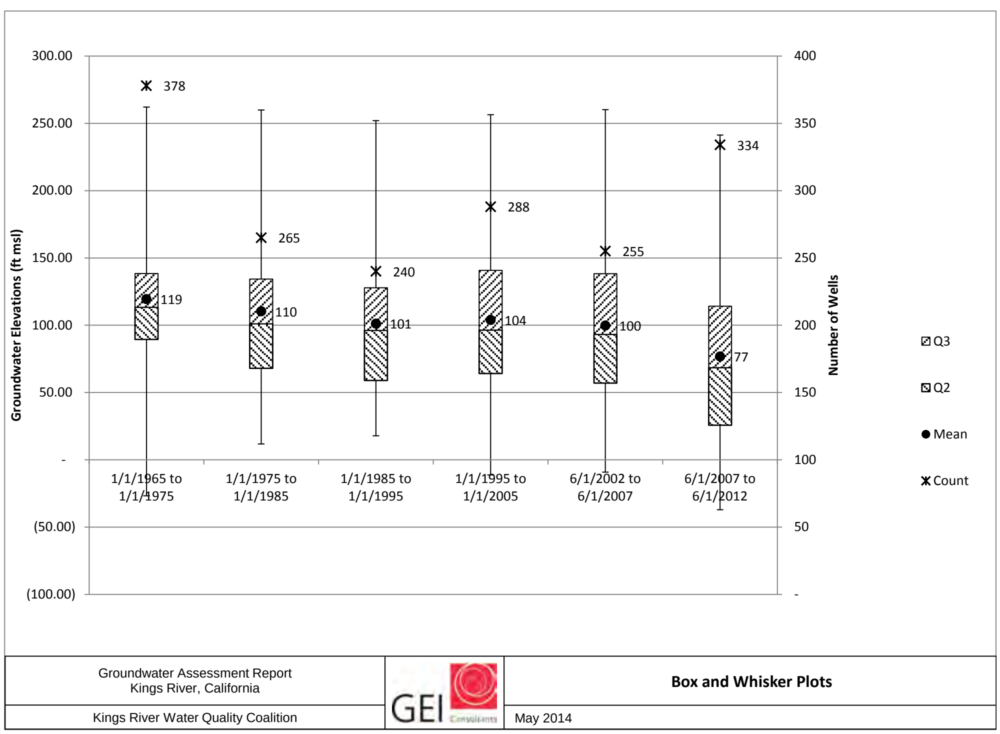


Figure 4-37. Lower Kings Representative Whisker Chart for Groundwater Elevations

Of the two whisker plots shown, the general trend line can be traced using the mean points (black dots) for each of the time intervals. As mentioned above in the continuous well hydrographs for the Upper and Lower Kings subareas (**Figure 4-33**), both subareas show to be in a somewhat steady state of decline over time with areas along the western region showing more change from year to year due to higher uses of groundwater.

Another point of mention is the differences in the data between wells screened either above or below the Corcoran Clay Member, screened near a river or recharge source, or screened in a perched aquifer. In most cases, the screen location of the monitoring wells is unknown. In the Lower Kings and South Kings subareas, this problem is more pronounced as shown in the group of well hydrographs shown in **Figure 4-38**. In this figure, monitoring data from the top (high elevation) well hydrograph is likely measuring a perched aquifer near the river, disconnected from the regional aquifer, and close to the ground surface; whereas, the bottom two well hydrographs are measuring the underlying regional aquifer approximately 100 feet below the top hydrograph. While not conclusive, the slight differences in the bottom two well hydrographs do indicate potential screening differences resulting in 50 foot differences in measurements taken in the same month.

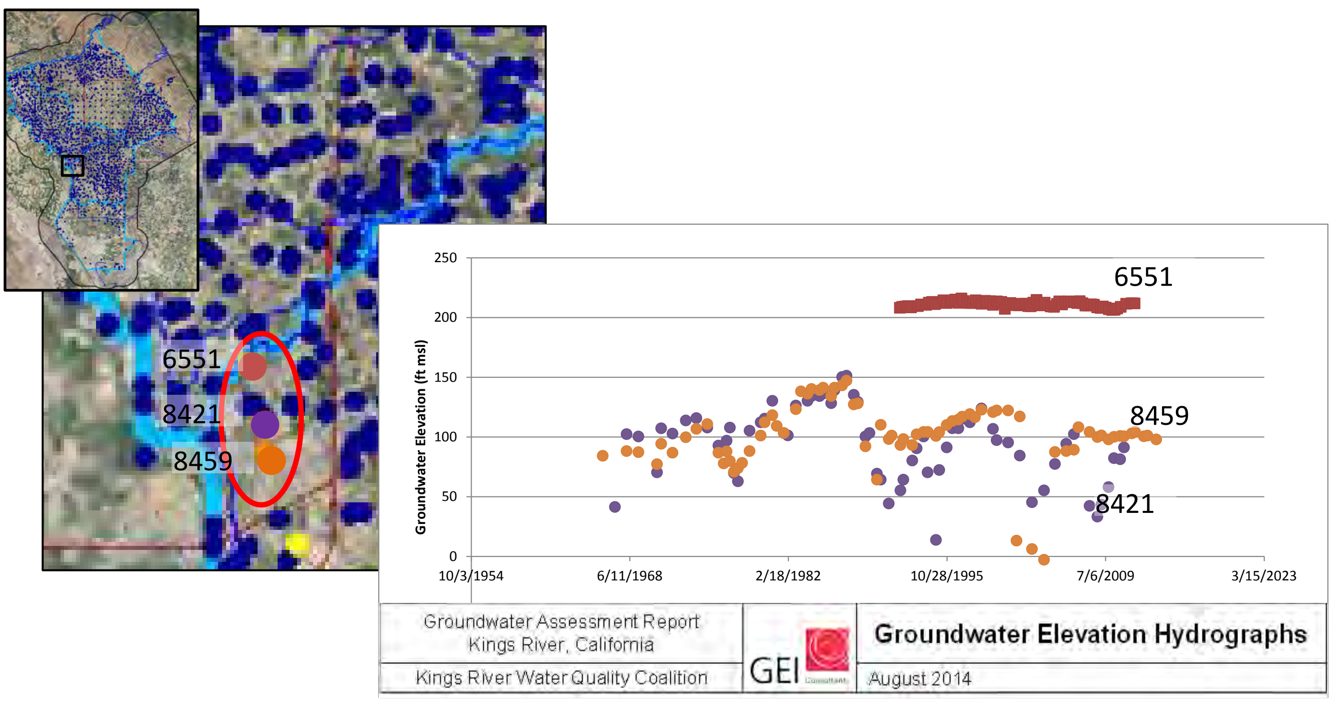


Figure 4-38. Problematic Well Data Due to Screen Location

The most recent 2013 fall groundwater level contour map produced by KRCD is presented in **Figure 4-39**. The groundwater levels are responsive to both seasonal and climatic variations that also influence water delivery and groundwater pumping. The general movement of groundwater is from the northeast to the southwest direction based on the water level contours. Two water level depressions are observed; one beneath the Fresno/Clovis metropolitan area in the Upper Kings Basin, and the second larger and deeper depression in the Lower Kings Basin generally in the area of the Raisin City Water District. The Raisin City area has a high reliance on groundwater since there is less access to surface water, and some areas that do not receive any surface water.

Groundwater declines and storage depletion continued in the Lower Kings though there is now a relative stability in groundwater levels as a result of a balance between inflows from the Upper Kings and surrounding area, and depletions from pumping and use of groundwater. In the area in the Lower Kings that does not receive surface; groundwater, salts and nutrients are cycled through the groundwater system with limited dilution provided by applied surface water.

4.2.4.1 Southern Kings

As with the areas to the north, the natural groundwater flow system has also been greatly altered by large-scale diversions and redistribution of surface water and conjunctive use programs. There are a number of groundwater and water management plans for the area that summarize conditions (Fugro, 2007) (Provost, 2011). This area underlain by the Corcoran Clay and received recharge from the areas to the east where the alluvial fans percolate streamflow and applied water from the Kaweah, St. Johns and Tule River. Some additional water from the CVP Friant unit is obtained when flood waters are available. The bulk of groundwater discharge is for agricultural use. The basis for the boundary to the North is the Kings River. The boundary to the East is the Coalition Area.

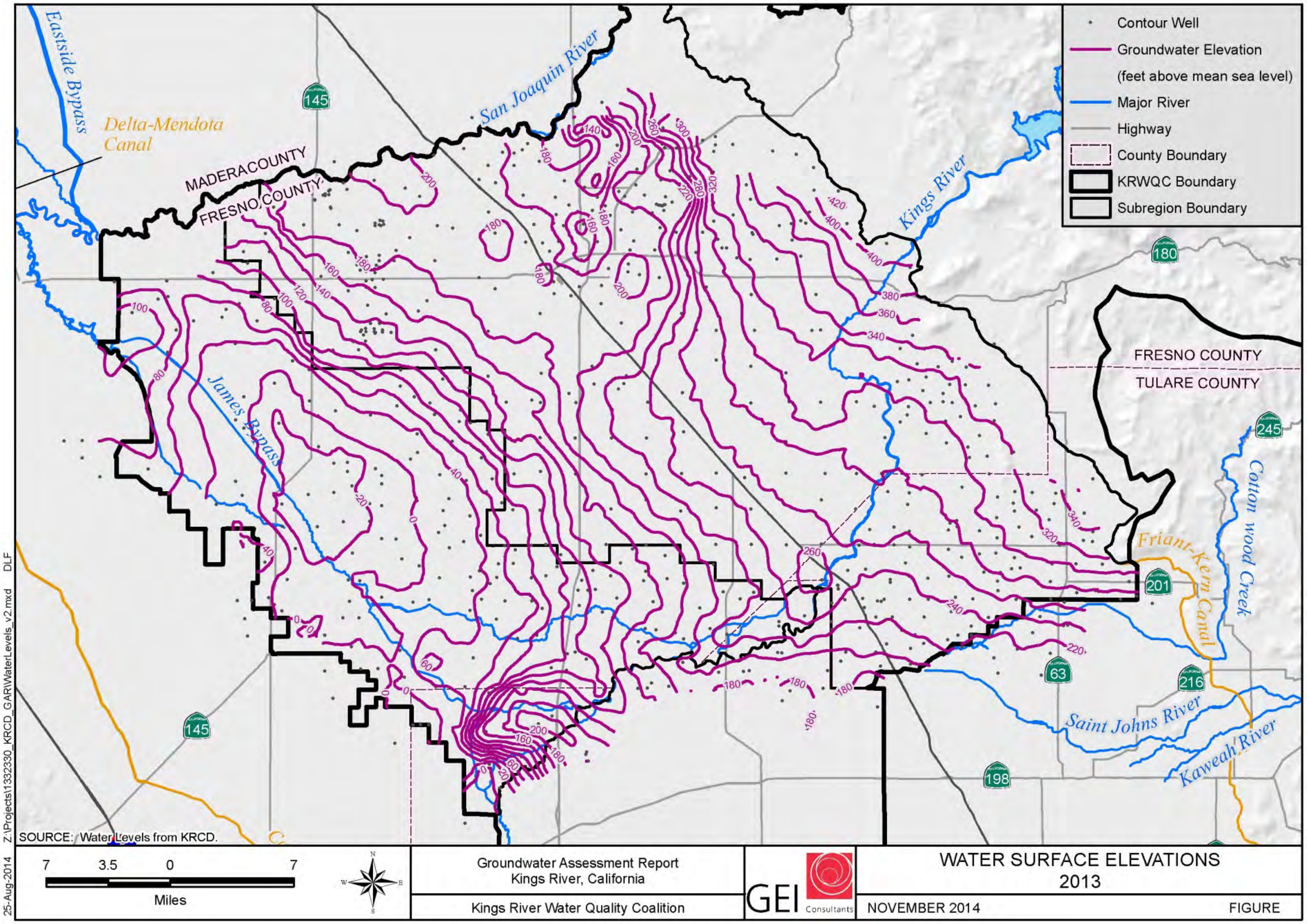


Figure 4-39. Upper and Lower Kings Water Level Contour for 2013

The alluvial fan/basins of the Kaweah, Tule and Kings are characterized by southwest to south flowing rivers, creeks, and irrigation canal systems that convey surface water from the Sierra Nevada to the west toward the Tulare Lake Bed. There is a transition from unconfined, to semi-confined to fully confined moving from east to west into the Coalition area. West of U.S. Highway 99, the area is primarily under confined and semiconfined groundwater conditions. The groundwater elevations in the confined aquifer (beneath the "E" clay or Corcoran clay) differs significantly from the unconfined water level surface; thought the ability to firmly discern the difference is masked by sampling in wells dually completed in both parts of the aquifer. Water is found both above and below the Corcoran clay.

DWR characterized the Kaweah Groundwater Basin as being in a critical state of overdraft in the 1980 version of Bulleting 118 and this designation was not re-evaluated in the 2003 update, but overdraft has been confirmed in a number of local studies. The water management practices east of the Coalition area influences the flow of groundwater into the South Kings and Tulare subarea. As described in the surface water section, the amount of imported water was reviewed, but the groundwater budget for this area was not intensively investigated since the data is widely distributed with each agency. Contouring based on multiple completion wells complicates development of a regional flow picture. Groundwater generally flows from the northeast to the southwest. The influence of water supply from the Kings River also occurs on lands where this water is delivered. The water levels have demonstrated an overall decline, indicating storage depletion in the areas that include Kings County Water District, Lakeside Irrigation Water District and smaller Districts. The average annual depletion is between 17 and 31 KAF in the parts of the area most recently studied (Fugro, 2007) (Provost, 2011).

Areas above the clay are recharged from applied water, canal leakance and recharge ponds, but contain limited storage capacity. Groundwater occurs at various depths within the shallow zone, since partially-confining clay layers or lenses occur throughout the area. Wells are often multiply completed making interpretation of hydrographs and contours challenging. Groundwater level contours vary throughout time based on hydrology and the availability of surface water, declining when groundwater pumping is increased to meet agricultural demands. Groundwater level hydrographs show annual and cyclical fluctuations in groundwater levels, reflecting climatic conditions and magnitude of replenishment, extractions of groundwater, and the hydraulic conductivity of the aquifer system or systems penetrated by each well.

The box and whisker chart (**Figure 4-40)** for the South Kings subarea on average behaves in a state of decline, with an approximate 45 foot change over time. Extreme low elevation values (i.e., bottom whiskers) likely indicate wells screened only in deeper aquifers.

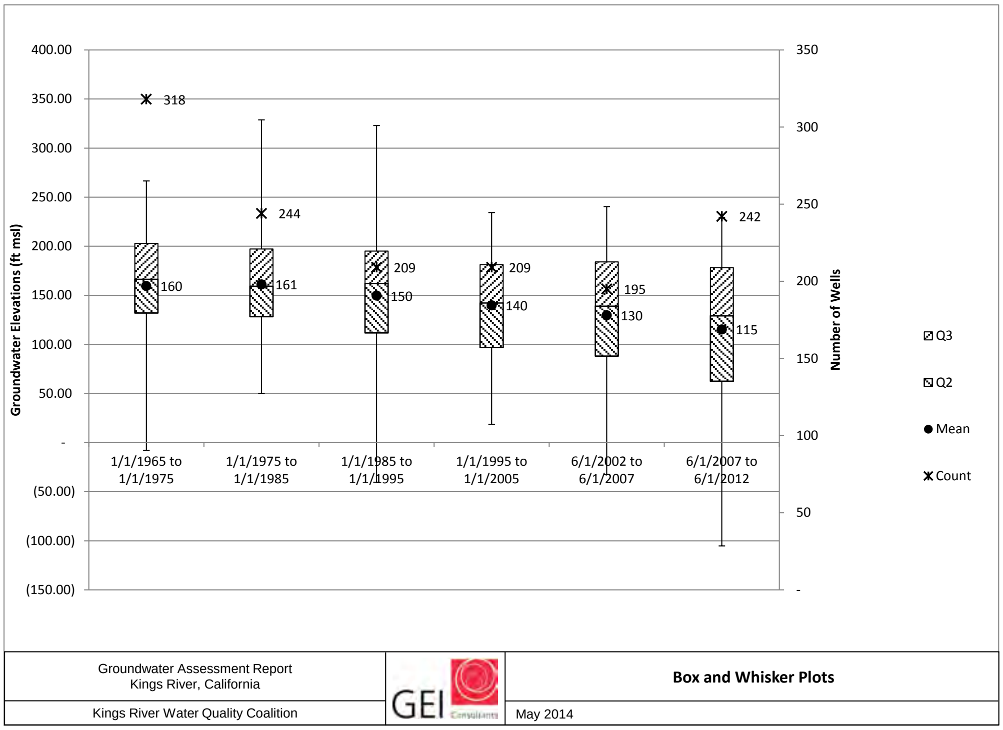


Figure 4-40. South Kings Representative Whisker Chart for Groundwater Elevations

4.2.4.2 Tulare Lake Bed

In Tulare Lake Bed area, the Corcoran Clay and other clay layers are extensive and thick, limiting the ability to produce economic quantities of water from wells, and thus there are few wells and limited pumping in the areas above the clay. Wells must be drilled below the clay formations to a depth of about 1,200 to 2,000 feet in the northern portion of the lake bed to find any useable groundwater. Groundwater conditions in and around the Tulare Lake area are described in a number of reports and studies by the USGS, DWR and others, and are substantiated from records of actual development and attempted development of groundwater resources. What is unique about the lakebed is the lack of usable groundwater resources. The USGS has identified three relatively shallow clay tongues around the margins of the Tulare Lake Bed. High salinity groundwater is present beneath most of the lakebed area above the A and B-Clays. In contrast, lower salinity groundwater is found below the deepest of these (the C-Clay). Recent study of the hydrogeology of the area in support of the de-designation of municipal uses provide the most recent and comprehensive analysis of the Lake Bed Area (Schmidt, et al., 2014). Of particular importance are clay and other fine-grained deposits within the uppermost several hundred feet of the subsurface.

There is shallow groundwater perched above the clays that is not useable and drainage is carefully managed to prevent high groundwater tables and impacts to agriculture. The shallowest groundwater in most of the lakebed area is less than 20 feet deep. Detailed maps showing the water-level elevations and direction of shallow groundwater flow are generally unavailable since there are few wells. The first subsurface waters encountered in the interior portion of the Tulare Lake Bed region have naturally high concentrations of salts. Historical data from farm operators indicate that the electrical conductivity is in the range of 5,000 to greater than 35,000 µS/cm, which is clearly unusable for municipal and agricultural use. Thus, there is no shallow water suitable for these purposes (Schmidt, et al., 2014).

With little exception of a few isolated privately owned wells of marginal quality, no ground water of satisfactory quality has been developed under the southwestern two-thirds of the Tulare Lakes Basin Water Storage District. In the northern one-third of the Tulare Lake Basin Water Storage District there is good quality ground water, but it is at such great depths that little water is pumped. Current ground water replenishment takes place directly through the natural recharge process and indirectly through use of SWP and other surface waters. Recent studies have shown that the area does not have municipal or agricultural groundwater beneficial uses and the area shown in **Figure 4-42** has been recommended for de-designated in the Basin Plan (Schmidt, et al., 2014) (Schmidt, 2013).

The box and whisker chart (**Figure 4-41**) for the Tulare Lakebed subarea on average shows generally increasing groundwater elevations because of very little pumping in the region, and the migration of groundwater towards the lower elevations in the Central Valley.

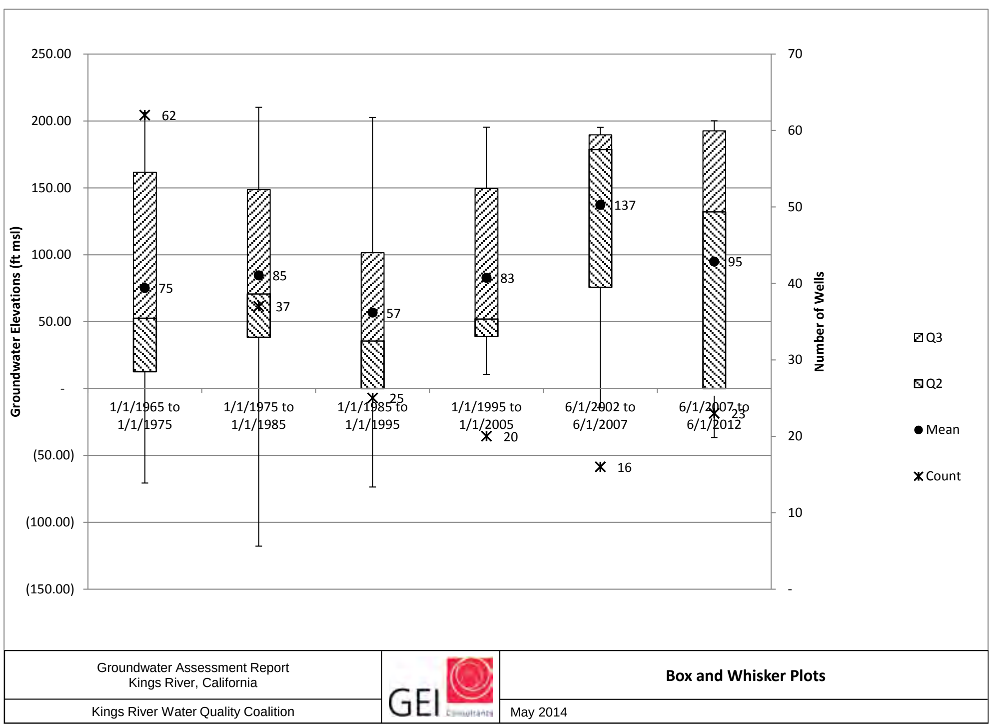


Figure 4-41. Tulare Lake Bed Representative Whisker Chart for Groundwater Elevations

4.3 LAND USE AND CROPPING

In order to accurately represent the Kings Study Area, the California Augmented Multisource Landcover (CAML) data was explored as the most recent and accurate source for land use and irrigation methods. To verify that CAML data was appropriate for reviewing agricultural land use in the Kings Study Area, the DWR Land Use Surveys data used in the 2010 CAML data were compared with the respective County Agricultural Commission Reports, as shown in **Table 4-3** below.

Table 4-3. Land Use Data Sources

DWR Land Use Survey	County Agricultural Commission Report
Tulare County, 1999	1999 Tulare County Agricultural Crop & Livestock Report
Fresno County, 2000	2000 Fresno County Agricultural Crop and Livestock Report
Kings County, 2003	Agricultural Crop Report 2003

This section compares the land uses and amounts, but not the geographic extents.

4.3.1 Sources of Data

4.3.1.1 California Augmented Multisource Landcover

The California Augmented Multisource Landcover data was obtained from UC Davis for 2010 and 1990. The data is available in GIS Raster format with each land use type, including crop types, urban uses, natural and riparian lands, and other agricultural land uses. The CAML data was developed by the Center for Watershed Sciences, University of California Davis, using data from four different sources:

- Department of Water Resources Land Use Survey (DWR LU Survey)
- Pesticide Use Reports (PUR), California Department of Pesticide Regulation
- Farmland Mapping and Monitoring Program (FMMP), California Department of Conservation
- Multi-Source Land Cover (MSCL), California Department of Forestry and Fire Protection

Additional information about this process can be found in Technical Report 2: Nitrogen Sources and Loading to Groundwater for the California Nitrate Project (UCDAVIS, 2012).

Agricultural land use in the CAML data relied primarily on DWR LU Survey values, supplemented by information from the California Department of Pesticide Regulation.

4.3.1.2 DWR Land Use Survey

The DWR Land Use Surveys focus on mapping over 70 different crop types or categories, as well as irrigation methods and water sources, when available. The surveys used in this analysis were

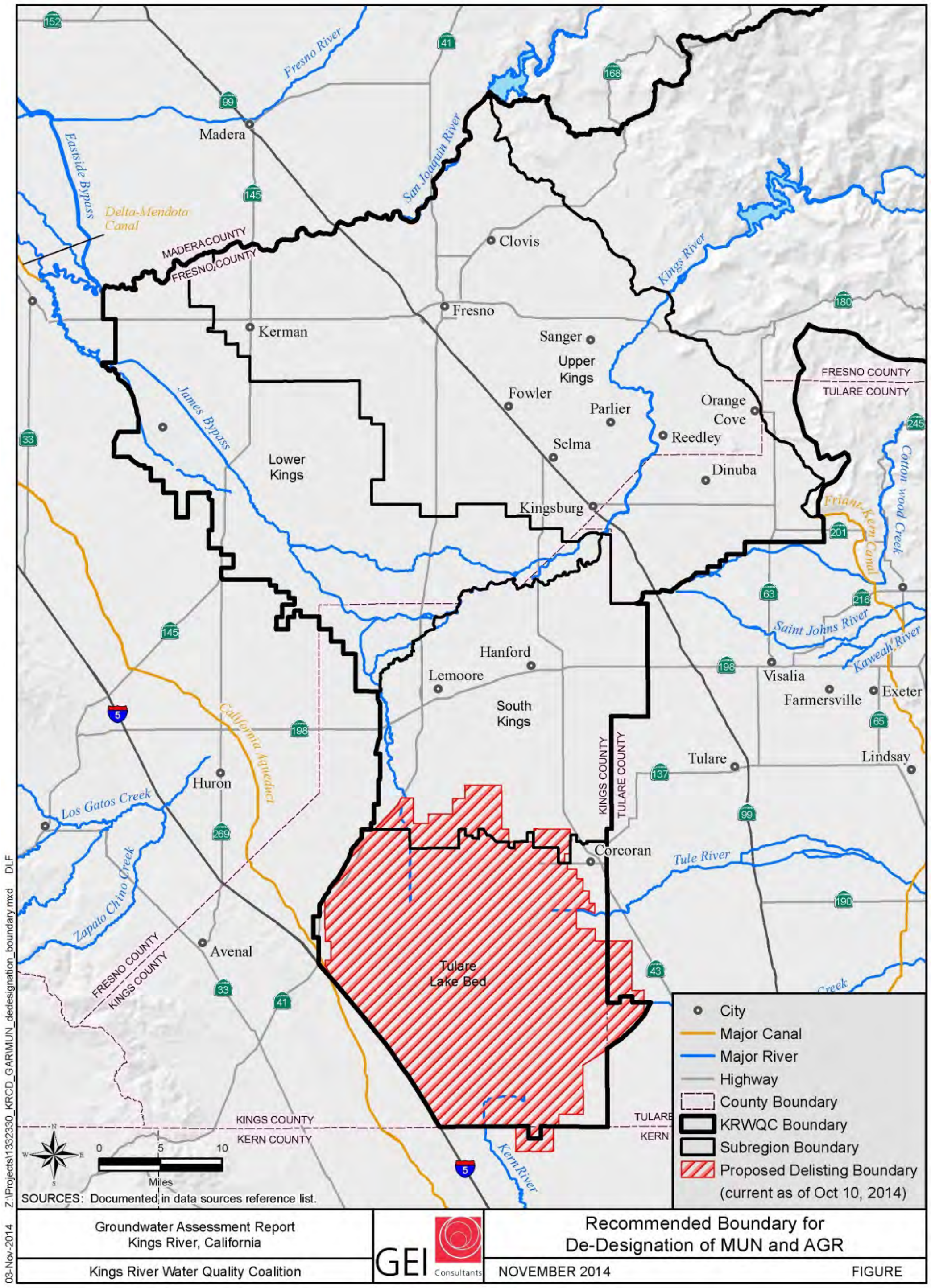


Figure 4-42. Recommended Boundary for De-Designation of MUN and AGR

conducted using aerial photos and satellite imagery to define boundaries, which were entered directly into a digital map for a GIS system. DWR conducted field visits to visually identify land uses for over 95 percent of the agricultural areas in each survey. Land Use Surveys for each county are rotational, about once every seven years (DWR, 2014).

4.3.1.3 County Agricultural Commission Reports

These reports are produced annually and contain statistical information on the acreage, yield, and gross values in accordance with Sections 2272 and 2279 of the California Food and Agricultural Code. Crop acreage is available in a tabular format (Fresno County, 2000), (Kings County, 2004), (Tulare County, 2000).

4.3.2 Data Comparison

The Cal Poly Irrigation Training and Research Center (ITRC) crop types were used to group the land use types for the DWR Land Use Surveys and the County Agricultural Commission reports (ITRC, 2014). The tables and charts below present the results of the land use reporting by DWR and the County Agricultural Commission.

Table 4-4. Source Comparison, Tulare County Crop Land Use, 1999

Crop Class	DWR LU Survey		County Agricultural Commission	
	Acres	% of Total	Acres	% of Total
Alfalfa Hay and Clover	97,833	12.94	103,000	6.35
Almonds	17,053	2.26	16,009	0.99
Apple, Pear, Cherry, Plum and Prune	48,145	6.37	49,823	3.07
Avocado	431	0.06	646	0.04
Citrus (no ground cover)	116,384	15.40	130,989	8.07
Corn and Grain Sorghum	110,174	14.58	196,425	12.10
Cotton	70,553	9.33	67,200	4.14
Flowers, Nursery and Christmas Tree	2,407	0.32		
Grain and Grain Hay	72,292	9.56	61,940	3.82
Grape Vines with 80% canopy	85,670	11.33	81,334	5.01
Melons, Squash, and Cucumbers	1,060	0.14	133	0.01
Misc Subtropical	1,822	0.24	4,304	0.27
Misc. Deciduous	3,451	0.46	1,140	0.07
Misc. field crops	37,642	4.98	58,792	3.62
Onions and Garlic	477	0.06		
Pasture and Misc. Grasses	6,120	0.81	769,100	47.39
Peach, Nectarine and Apricots	30,723	4.06	31,812	1.96
Pistachio	10,175	1.35	9,674	0.60
Potatoes, Sugar beets, Turnip etc.	4,064	0.54	4,500	0.28
Rice	1,171	0.15		
Safflower and Sunflower	1,395	0.18	5,471	0.34
Small Vegetables	64	0.01		
Strawberries	2,393	0.32	486	0.03
Tomatoes and Peppers	3	0.00		
Turf	34,403	4.55	30,086	1.85
Walnuts	97,833	12.94	103,000	6.35
Total	**755,905**		**1,622,864**	

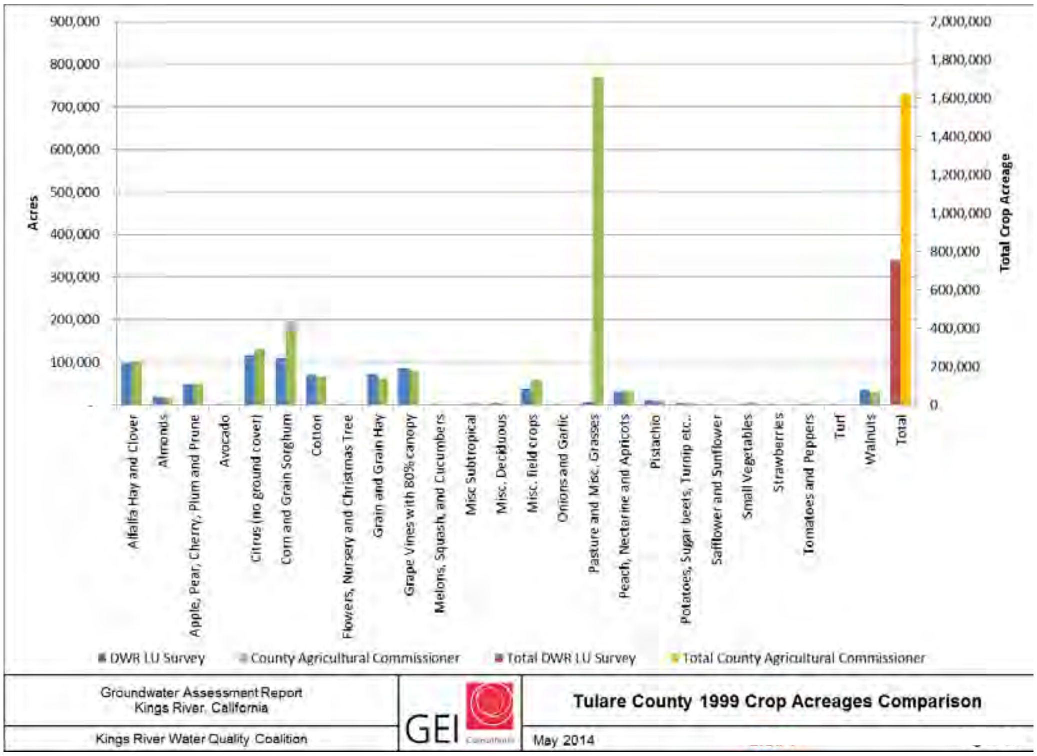


Figure 4-43. Tulare County 1999 Crop Acreages Comparison

Table 4-5. Source Comparison, Fresno County Crop Land Use, 2000

Crop Class	DWR LU Survey		County Agricultural Commission	
	Acres	% of Total	Acres	% of Total
Alfalfa Hay and Clover	99,380	7.61	95,200	7.74
Almonds	88,883	6.81	60,555	4.92
Apple, Pear, Cherry, Plum and Prune	31,322	2.40	22,072	1.79
Avocado	10	0.00		
Citrus (no ground cover)	34,222	2.62	27,081	2.20
Corn and Grain Sorghum	32,991	2.53	30,170	2.45
Cotton	304,007	23.28	302,700	24.61
Flowers, Nursery and Christmas Tree	1,279	0.10		
Grain and Grain Hay	73,813	5.65	84,300	6.85
Grape Vines with 80% canopy	258,450	19.79	225,276	18.32
Melons, Squash, and Cucumbers	36,244	2.77	36,680	2.98
Misc Subtropical	1,144	0.09	3,120	0.25
Misc. Deciduous	4,048	0.31	4,070	0.33
Misc. field crops	92,674	7.10	43,020	3.50
Onions and Garlic	28,465	2.18	32,430	2.64
Pasture and Misc. Grasses	11,326	0.87	40,000	3.25
Peach, Nectarine and Apricots	40,853	3.13	29,038	2.36
Pistachio	12,665	0.97	4,541	0.37
Potatoes, Sugar beets, Turnip etc.	19,056	1.46	19,100	1.55
Rice	6,522	0.50	6,160	0.50
Safflower and Sunflower	3,328	0.25	3,070	0.25
Small Vegetables	2,649	0.20	33,810	2.75
Strawberries	89	0.01	494	0.04
Tomatoes and Peppers	116,407	8.91	123,900	10.07
Turf	411	0.03		
Walnuts	5,881	0.45	3,122	0.25
Total	**1,306,122**		**1,229,909**	

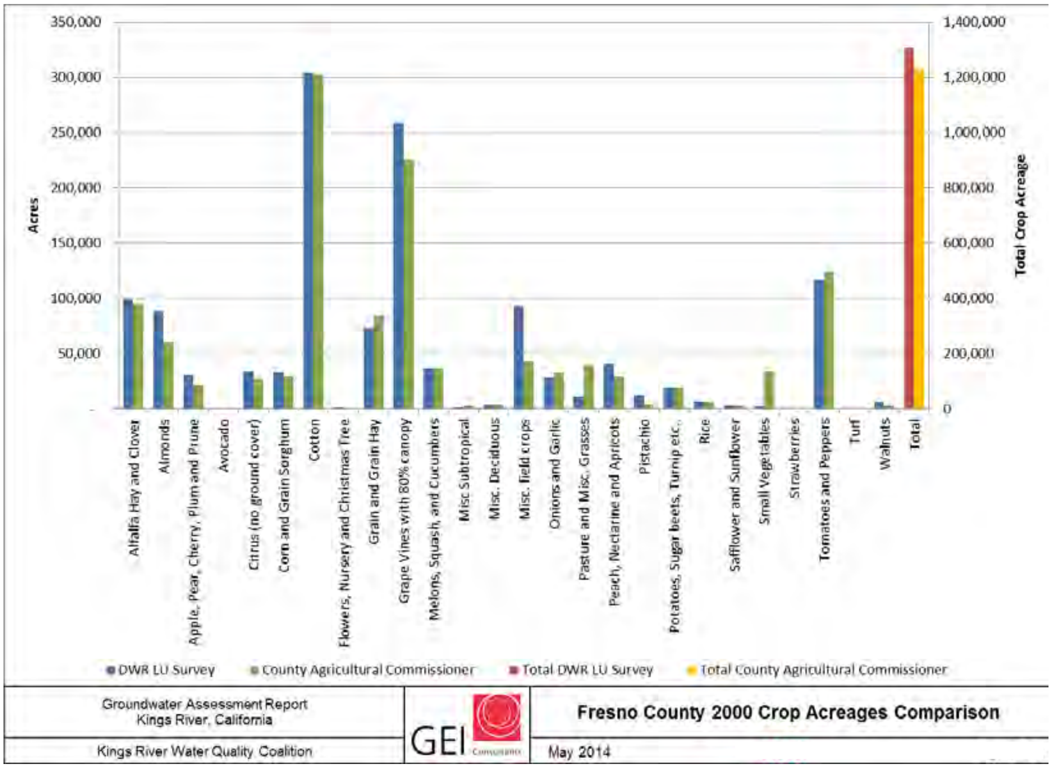


Figure 4-44. Fresno County 2000 Crop Acreages Comparison

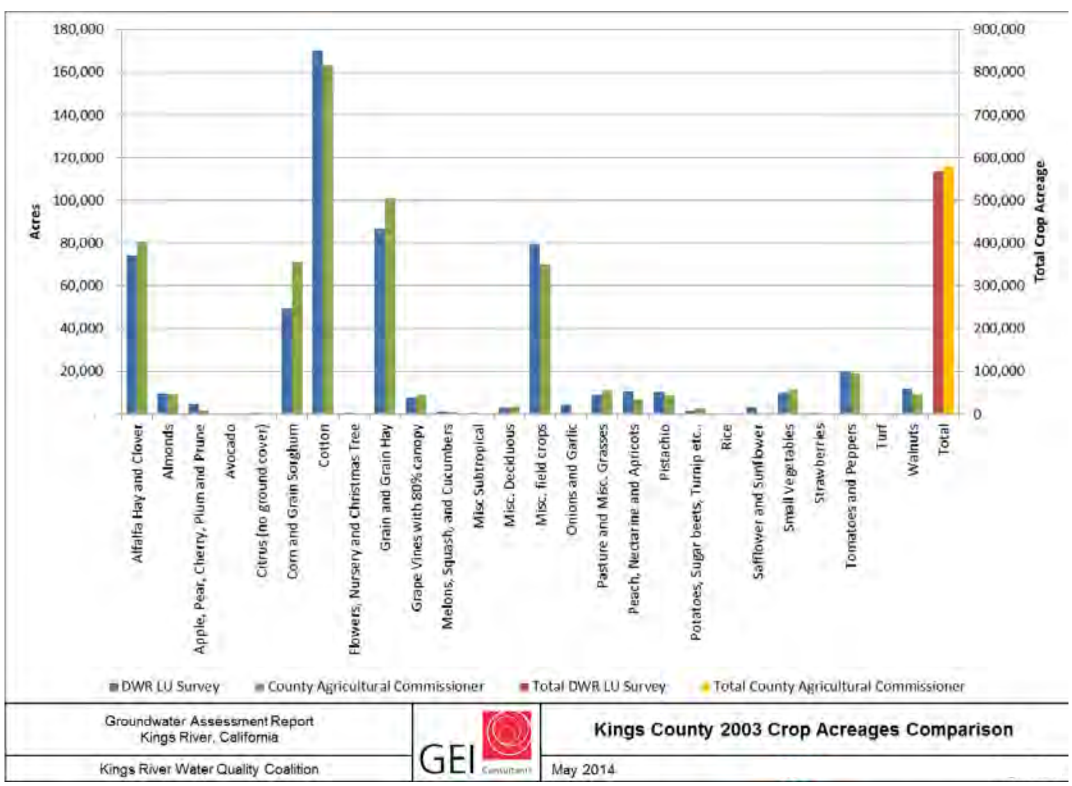


Figure 4-45. Kings County 2003 Crop Acreages Comparison

Table 4-6. Source Comparison, Kings County Crop Land Use, 2003

Crop Class	DWR LU Survey		County Agricultural Commission	
	Acres	**% of Total**	**Acres**	**% of Total**
Alfalfa Hay and Clover	74,435	13.10	80,722	13.92
Almonds	9,657	1.70	9,365	1.61
Apple, Pear, Cherry, Plum and Prune	4,731	0.83	1,752	0.30
Avocado		-		-
Citrus (no ground cover)	136	0.02		-
Corn and Grain Sorghum	49,500	8.71	71,086	12.26
Cotton	170,337	29.97	163,400	28.17
Flowers, Nursery and Christmas Tree	5	0.00		-
Grain and Grain Hay	86,903	15.29	100,931	17.40
Grape Vines with 80% canopy	7,757	1.36	9,009	1.55
Melons, Squash, and Cucumbers	1,355	0.24	687	0.12
Misc Subtropical	610	0.11	-	-
Misc. Deciduous	2,926	0.51	3,735	0.64
Misc. field crops	79,071	13.91	70,213	12.11
Onions and Garlic	4,323	0.76		-
Pasture and Misc. Grasses	8,759	1.54	11,000	1.90
Peach, Nectarine and Apricots	10,591	1.86	6,922	1.19
Pistachio	10,230	1.80	8,600	1.48
Potatoes, Sugar beets, Turnip etc.	1,712	0.30	2,667	0.46
Rice		-		-
Safflower and Sunflower	3,326	0.59		-
Small Vegetables	10,049	1.77	11,369	1.96
Strawberries	5	0.00		-
Tomatoes and Peppers	19,956	3.51	19,131	3.30
Turf		-		-
Walnuts	11,929	2.10	9,368	1.62
Total	**568,303**		**579,957**	

4.3.3 Analysis and Results

As can be seen by the tables and figures, the DWR Land Use Surveys used in the 2010 CAML data sets compare well with the County Agricultural Commission Reports. The greatest discrepancy can be seen in Tulare County, most noticeably in pasture acreages. If pasture is excluded from the Tulare County comparison, the correlation can be seen among the rest of the crop categories, including the total acreages (see **Figure 4-46** below). Removing pasture from Tulare County, total acreage in all three counties differs by at most 13% for all the counties, and in general, the breakdown of crop types compare well. It also appears that minor errors exist in the identification of Corn and Grain Sorghum and Misc. field crops across all three counties.

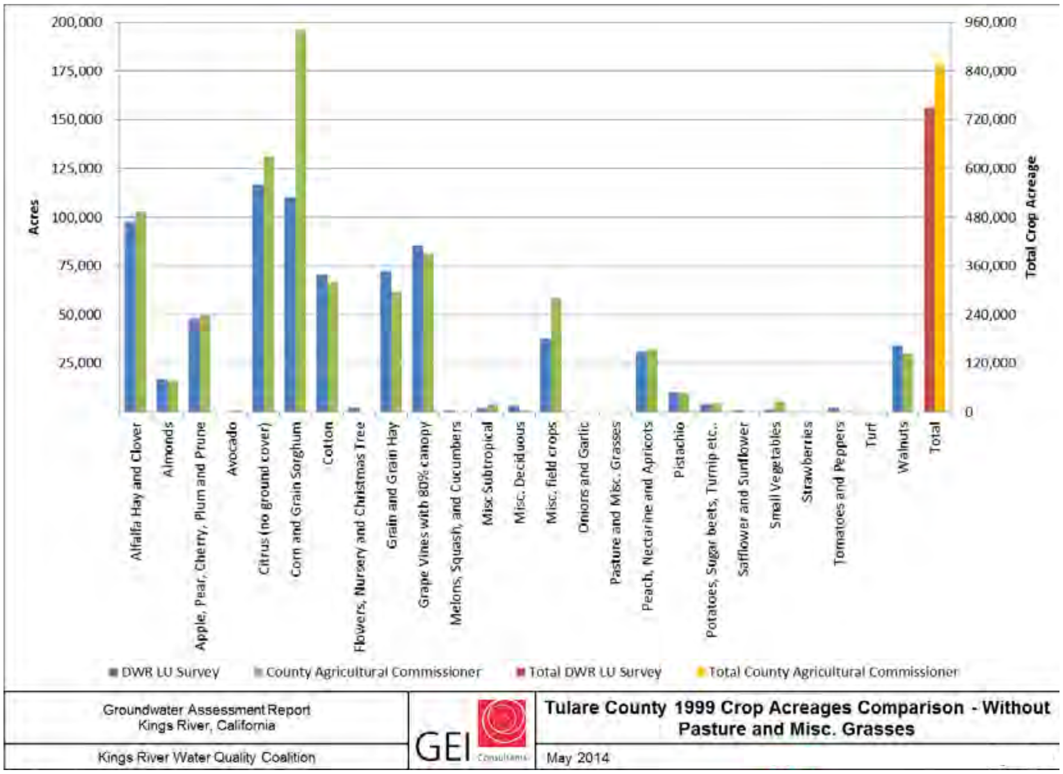


Figure 4-46. Tulare County 1999 Crop Acreages Comparison – Without Pasture and Misc. Grasses

The review of the crop acreage comparison, especially for Tulare County, should include these considerations:

1. Best available data. Although satellite imagery is currently used by DWR to conduct these Land Use Surveys, aerial imagery was the more commonly available source of data in prior years. It is possible that due to the granularity of aerial imagery, crops that may look similar were misidentified. It is not known in what year DWR switched to satellite imagery.

2. Differences in terminology. The DWR Land Use Surveys use standard categorizing of crop types; types of pastureland, for example, includes alfalfa, clover, and native pasture. The County Agricultural Reports all independently separate out specific crops (i.e., corn and corn silage), while also combining crops into 'other'. Finally, the ITRC uses another grouping of crop types, based on the metric of grass ETo.

3. Temporal differences. The DWR LU Surveys are a snapshot in time of the land usage, while the County Agricultural Reports summarize the year past. Therefore, crop changes that occur during the year may not be captured in the DWR LU Surveys (DWR, 2014).

4.3.3.4 2010 CAML and DWR Land Use

As discussed above, CAML agricultural data was developed using two different sources: DWR Land Use Surveys and Pesticide Use Reports (PUR). The DWR Land Use Data, consisting of county data for Tulare (1999), Fresno (2003), and Kings (2003), was supplemented with PUR land use for areas where there was no DWR Land Use data present. This section compares the 2010 CAML and the DWR Land Use Surveys (UCDAVIS, 2012).

The 2010 CAML data was originally provided in raster data format representing 1 meter x 1 meter areas. This data was processed and a table was created with the values (land uses) for each raster. To compare the two data sources, both the CAML data and the DWR Land Use Surveys were clipped to the Kings GAR Boundary within Fresno, Kings, and Tulare Counties. Similar to the County Agricultural Commission data, the CAML crop types were grouped into the ITRC crop types. As seen below in **Figure 4-47** and **Table 4-7** below the 2010 CAML and DWR Land Use Survey crop acreages agree in proportion, although not in total acreage. This relative difference in acreage between the 2010 CAML data and the DWR LU Survey data, about 39%, is most likely due to the supplement of PUR data to the DWR LU Surveys data.

Table 4-7. 2010 CAML and DWR Land Use Survey Comparison

	2010 CAML		DWR LU Survey	
Crop Class	**Acres**	**% of Total**	**Acres**	**% of Total**
Alfalfa Hay and Clover	137,719	11.18	129,953	10.75
Almonds	61,989	5.03	54,841	4.54
Apple, Pear, Cherry, Plum and Prune	46,533	3.78	44,318	3.67
Avocado	90	0.01	95	0.01
Citrus (no ground cover)	60,205	4.89	52,168	4.32
Corn and Grain Sorghum	85,145	6.91	81,245	6.72
Cotton	204,577	16.60	213,275	17.64
Flowers, Nursery and Christmas Tree	950	0.08	1,012	0.08
Grain and Grain Hay	105,921	8.60	94,128	7.79
Grape Vines with 80% canopy	280,128	22.73	268,859	22.24
Melons, Squash, and Cucumbers	1,322	0.11	1,423	0.12
Misc Subtropical	2,604	0.21	1,945	0.16
Misc. Deciduous	2,238	0.18	3,917	0.32
Misc. field crops	87,914	7.13	99,876	8.26
Onions and Garlic	2,034	0.17	1,619	0.13
Pasture and Misc. Grasses	19,569	1.59	16,047	1.33
Peach, Nectarine and Apricots	77,778	6.31	90,941	7.52
Pistachio	5,076	0.41	5,232	0.43
Potatoes, Sugar beets, Turnip etc.	5,194	0.42	5,565	0.46
Rice	14	0.00	14	0.00
Safflower and Sunflower	3,791	0.31	3,377	0.28
Small Vegetables	684	0.06	777	0.06
Strawberries	174	0.01	103	0.01
Tomatoes and Peppers	20,976	1.70	20,354	1.68
Turf	410	0.03	414	0.03
Walnuts	19,235	1.56	17,500	1.45
Total	**1,232,269**		**1,208,996**	

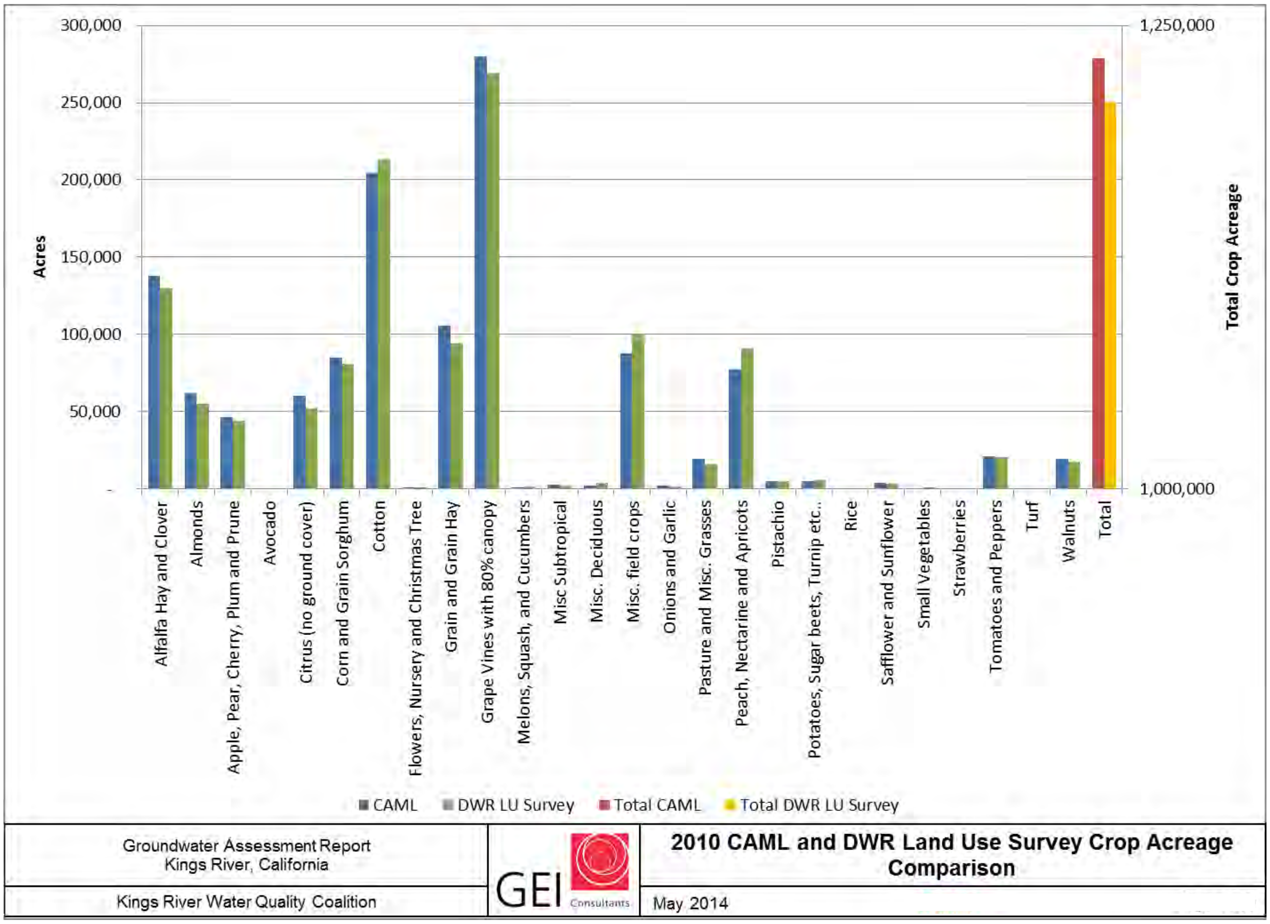


Figure 4-47. 2010 CAML and DWR Land Use Survey Crop Acreage Comparison

4.3.3.5 Conclusions to Data Used

With the considerations discussed above and the correlation of DWR Land Use Surveys and CAML data to County Agricultural Commission reports, the DWR LU Surveys, and thus the 2010 CAML data, provide an accurate representation of crop land use in the project area in terms of gross acreage. Therefore, both the 1990 and 2010 CAML data will be used as the best available geographic data for the Kings Groundwater Assessment Report, 2014.

4.3.4 Use of CAML Land Use and Crop Data

The 1990 and 2010 CAML land uses were used to characterize the agricultural land uses within the Kings Project Area. Chapter 3, Data Source and Needs to Support Analysis presents more details on CAML data and its uses. The CAML data represents a point in time, and since cropping can change from year to year due to multiple outside forces such as market demand, water availability, capital costs, and policy changes, this data is not a true indicator of cropping trends. However, this data is valuable for understanding the context for the Kings Project.

In 2010, irrigated agricultural land uses made up 67% of the total land uses within the Kings Project area. Nonagricultural or unirrigated land uses include urban areas, native vegetation and water features, and dairy farms. The predominant irrigated agricultural land use consists of vineyards (19%), cotton (19%), alfalfa hay and clover (11%), and grain and grain hay (10%). **Table 4-8** below presents the current irrigational agricultural land uses and the top crop types in the Kings Project Area.

Table 4-8. 2010 Kings Project Area Irrigated Agricultural Land Uses

Crop Type	2010 Acreage	% of Total	Cumulative %	Top 80%
Grape Vines with 80% Canopy	337,184	18.74	18.74	Yes
Cotton	335,398	18.64	37.38	Yes
Alfalfa Hay and Clover	199,713	11.10	48.47	Yes
Grain and Grain Hay	171,671	9.54	58.01	Yes
Misc. Field Crops[a]	123,786	6.88	64.89	Yes
Corn and Grain Sorghum	122,846	6.83	71.72	Yes
Citrus (no ground cover)	93,977	5.22	76.94	Yes
Peach, Nectarine and Apricots	83,749	4.65	81.60	Yes
Almonds	78,432	4.36	85.95	No
Apple, Pear, Cherry, Plum and Prune	68,072	3.78	89.74	No
Tomatoes and Peppers	44,195	2.46	92.19	No
Pasture and Misc. Grasses[b]	35,595	1.98	94.17	No
Walnuts	26,649	1.48	95.65	No
Pistachio	25,047	1.39	97.04	No
Potatoes, Sugar Beets, Turnip etc.	13,149	0.73	97.77	No
Misc. Deciduous[c]	13,126	0.73	98.50	No
Onions and Garlic	9,253	0.51	99.02	No
Safflower and Sunflower	7,363	0.41	99.43	No
Melons, Squash, and Cucumbers	4,006	0.22	99.65	No
Small Vegetables[d]	2,464	0.14	99.79	No
Misc. Subtropical[e]	1,948	0.11	99.90	No
Flowers, Nursery and Christmas Tree	1,078	0.06	99.96	No
Turf	410	0.02	99.98	No
Strawberries	211	0.01	99.99	No
Avocado	168	0.01	100.00	No
Rice	14	0.00	100.00	No
Total	**1,799,506**	**100**	**100**	

a – includes other truck and field crops not in the table such as asparagus, green beans, and hops.
b – includes grassed such as Bermuda grass, klein grass, and millet.
c – includes other deciduous fruit and nut trees not in the table such as cashews, persimmons, and pomegranates.
d – includes vegetables such as carrots, lettuce, and spinach.
e – includes fruit such as bananas and guavas.

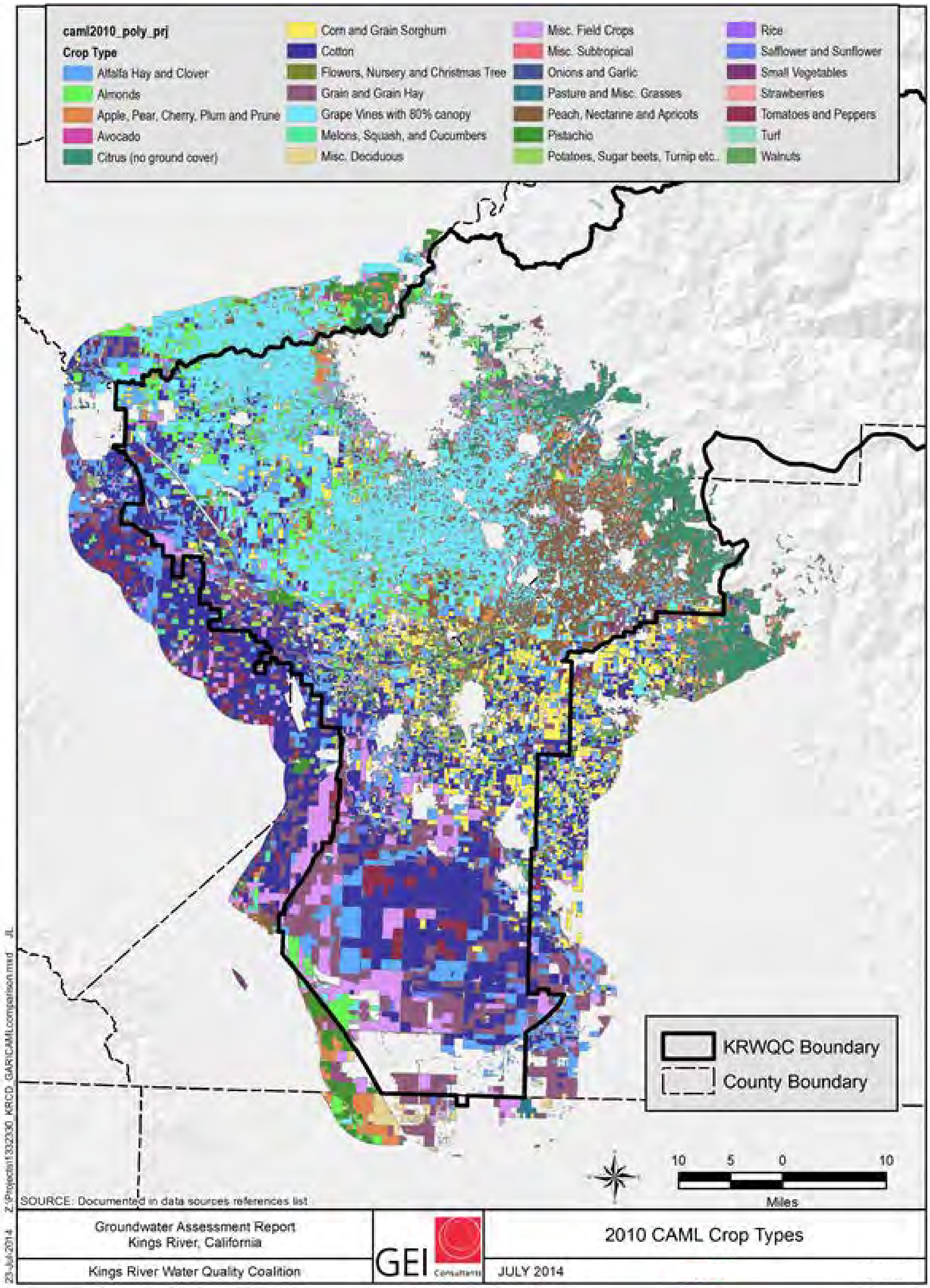


Figure 4-48. 2010 CAML Crop Types

The light blue area in the table represents the crop commodities compromising 80% of the acreage in the Coalition area.

Irrigated agricultural land uses within the Kings Project area has not changed significantly in the past 20 years, making up 63% of total land uses. Using 1990 CAML data, the significant crops were also cotton (28%), vineyards (18%), alfalfa hay and clover (10%), and grain and grain hay (7%). **Table 4-9** and **Figure 4-49** present the irrigated agricultural land uses in 1990.

Table 4-9. 1990 Kings Project Area Irrigated Agricultural Land Uses

Crop Type	1990 Acreage	% of Total	Cumulative %	Top 80%
Cotton	449,329	27.60	27.60	Yes
Grape Vines with 80% canopy	290,862	17.87	45.47	Yes
Alfalfa Hay and Clover	159,254	9.78	55.25	Yes
Grain and Grain Hay	110,641	6.80	62.05	Yes
Misc. Field Crops	89,815	5.52	67.57	Yes
Citrus (no ground cover)	74,248	4.56	72.13	Yes
Corn and Grain Sorghum	74,056	4.55	76.68	Yes
Peach, Nectarine and Apricots	68,103	4.18	80.86	Yes
Apple, Pear, Cherry, Plum and Prune	66,578	4.09	84.95	No
Safflower and Sunflower	53,401	3.28	88.23	No
Almonds	51,803	3.18	91.42	No
Pasture and Misc. Grasses	39,061	2.40	93.82	No
Tomatoes and Peppers	32,859	2.02	95.83	No
Pistachio	15,057	0.92	96.76	No
Potatoes, Sugar Beets, Turnip etc.	14,709	0.90	97.66	No
Walnuts	14,402	0.88	98.55	No
Onions and Garlic	11,019	0.68	99.22	No
Melons, Squash, and Cucumbers	5,595	0.34	99.57	No
Flowers, Nursery and Christmas Tree	1,965	0.12	99.69	No
Small Vegetables	1,741	0.11	99.80	No
Misc. Subtropical	1,588	0.10	99.89	No
Misc. Deciduous	550	0.03	99.93	No
Strawberries	485	0.03	99.96	No
Turf	353	0.02	99.98	No
Avocado	194	0.01	99.99	No
Rice	149	0.01	100.00	No
Total	**1,627,819**	**100**	**100**	

a – includes other truck and field crops not in the table such as asparagus, green beans, and hops.
b – includes grassed such as Bermuda grass, klein grass, and millet.
c – includes other deciduous fruit and nut trees not in the table such as cashews, persimmons, and pomegranates.
d – includes vegetables such as carrots, lettuce, and spinach.
e – includes fruit such as bananas and guavas.

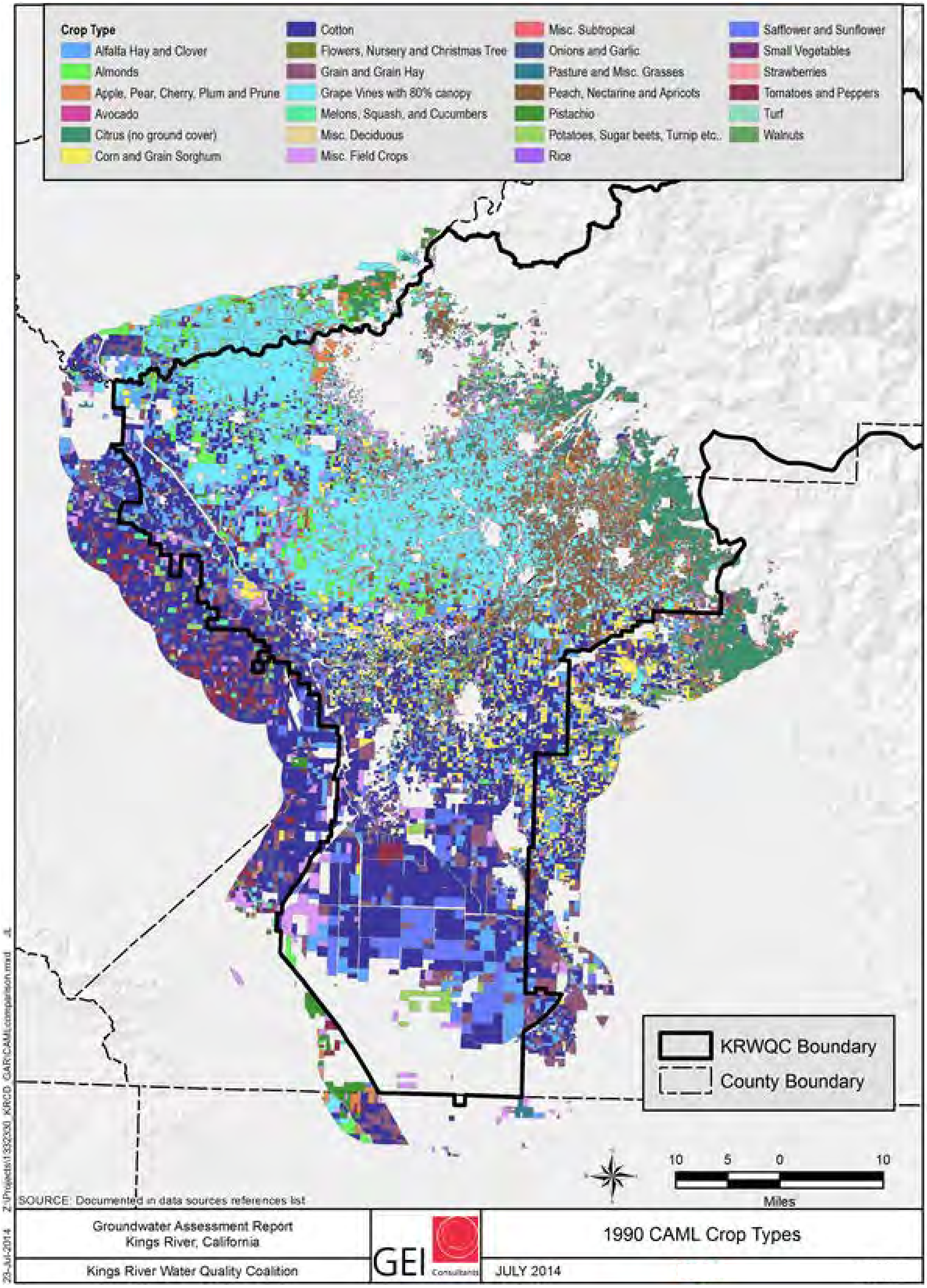


Figure 4-49. 1990 CAML Crop Types

Since 1990, land acreage for cotton has decreased by more than 100,000 acres, while grain and hay, corn and grain sorghum, vineyards, and alfalfa hay and clover acreages have significantly increased. Moreover miscellaneous deciduous crop acreage, which includes nut trees (excluding almonds and walnut) and fruits such as persimmon, has nearly tripled since 1990, while rice, safflower and sunflower crop acreage have reduced each by as much. **Figure 4-50** illustrates the changes in crop acreage for the period from 1990 to 2010. It is worth noting that in 2010, idled cropland is about 11,000 acres and about 77,000 acres in 1990.

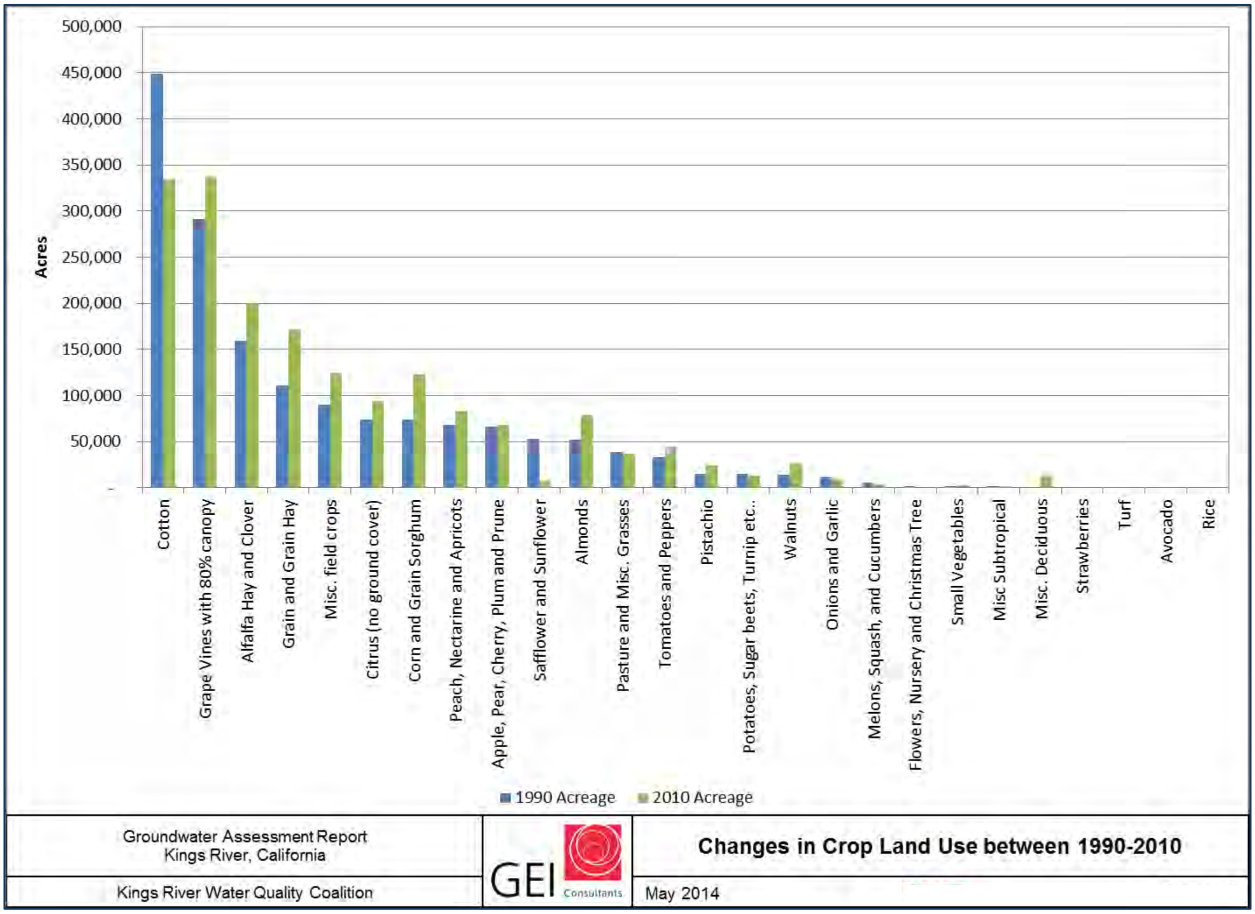


Figure 4-50. Changes in Crop Land Use 1990-2010 for the Kings Project Area

4.3.5 Irrigation Methods

Irrigation methods can be divided into two general categories, unpressurized surface (gravity) systems including furrows and border strips and pressurized systems such as sprinklers, micro-sprinklers and drip. Both categories of systems are widely used within the study area.

One parameter that differentiates these two categories is their relative irrigation efficiency. As described below, efficiencies associated with pressurized systems are generally higher than those attributed to gravity systems. In applying this distinction, it is essential to understand that efficiency numbers refer to the proportion of the water applied to an irrigated area that is available for consumption by a crop and that the relevant frame of reference for these values is the irrigated area. While the irrigated field is a useful frame of reference for capturing irrigation and fertilizer application practices that drive leaching of contaminants to groundwater, a larger more fundamental frame of reference is the groundwater basin. Within a basin-wide context, deep percolation lowers the efficiency of a gravity irrigation system. This may be viewed as a benefit because deep percolation lost from a field may become recharged groundwater gained and a key component of the regional water budget.

Therefore, while the following discussion of agricultural practices focuses on the field-level frame of reference is it important to recognize how irrigation and fertility management practices fit within a basin-wide context. In particular, the factors that cause gravity irrigation to have low on-farm irrigation efficiencies may support conjunctive management within the basin.

(Note: One of the values of the GAR tool developed for this analysis is its capacity to bring together data from both the field-level and basin-level frames of reference. In particular, the tool enables presentation of information and analyses performed at the field-level frame of reference within a basin-wide context. This allows users to better understand the implications of field-level parameters, such as irrigation efficiency, on basin-wide groundwater management.)

4.3.5.1 Gravity Irrigation Systems

Gravity systems are used on fields that have been graded to provide sufficient slope for a stream of water released at the upper end of the field to flow down the length of the field. Advantages of this type of irrigation are that the hardware is simple and the energy needed to move water across the field comes from gravity. From an agronomic standpoint, the primary disadvantage of these systems is that because an irrigation application begins with water being released at the top of the field and ends after water has reached the bottom, the opportunity time for water to infiltrate into the root zone varies across the field (distribution uniformity). In addition to the differences in opportunity times, the infiltration rates of soils vary within a field. The differences in infiltration opportunity times and infiltration rates can lead to significant lack of distribution uniformity in the volumes of water infiltrating at various points in a field.

Lack of distribution uniformity of infiltration within a field is important when considering deep percolation and leaching of contaminants because the typical approach to compensating for lack of uniformity is to apply sufficient water to meet the irrigation requirements of areas having short opportunity times. This strategy tends to apply more water than is required to areas having long opportunity times resulting in deep percolation from these areas. In addition to the lack of uniformity inherent to surface irrigation, a compounding factor is that surface irrigation applications are made less frequently than applications with pressurized systems, and, therefore, distribute large volumes of water needed to replenish soil moisture depleted during the period since the previous application. In the GAR tool, the lack of uniformity is expressed in the irrigation efficiency values that range from 68 percent for furrow irrigation to 83 percent for basins. As discussed earlier, the relatively low irrigation efficiencies associated with gravity irrigation can be of value in conjunctively managed basins where recharge of surplus surface water can be essential to a strategy of maintaining groundwater storage for use during water short years.

4.3.5.2 Pressurized Irrigation Systems

In contrast to gravity systems, pressurized systems convey water in tubes or pipes for release at or near the points where the water is targeted to infiltrate. When properly designed and operated, pressurized systems have the potential to increase the distribution uniformity and irrigation efficiency. As a result, at the field level, the proportion of applied water available for crop consumption is typically greater for pressurized systems than for gravity systems. The major drawbacks to pressurized systems are the costs of purchasing and installing the hardware, the cost of energy required for pressurizing water, and the management required to maintain pumps, valves, filters, pipes and sprinklers or drip emitters. Efficiencies associated with pressurized systems range from 68 percent for hand-move and side-roll sprinklers to 86 percent for drip.

4.3.6 Influence of Irrigation Systems on Deep Percolation

Deep percolation generated by irrigation can be a beneficial source of groundwater recharge in areas, such as much of the study area, which receive high quality water for irrigation. However, deep percolation is also the mechanism that conveys nitrates and other agricultural chemicals from the soil surface to groundwater. By reducing deep percolation, one of the outcomes of growers' adoption of advanced irrigation practices is a reduction in leaching of nitrates and other water quality constituents. Therefore, while deep percolation that recharges groundwater can be of value from a basin-wide perspective, deep percolation's transport of contaminants is problematic from both the on-farm and the basin-wide frames of reference.

Although intrinsic properties, such as soil type, influence infiltration, the effects of soil types can often be compensated by adjustments to management, particularly when using pressurized systems. Deep percolation of precipitation, however, remains heavily influenced by soil type with sandy soils typically having higher rates of percolation than more finely textured soils.

Intrinsic and management variables affecting the rate and volume of deep percolation include soil type, crop and irrigation method. Therefore, information available in the GAR analytical tool on the spatial and temporal distribution of these factors provides insights into the distribution of deep percolation over the study area and how that distribution is changing. These variables were among the inputs used in the tool's deep percolation algorithm to generate the temporal and spatial rankings of vulnerability to deep percolation that result from combinations of intrinsic and management variables found over the study area. These representations of historical, current and possible future patterns of deep percolation offer insights into nitrate leaching.

As growers improve their management of gravity irrigation systems and shift to use of pressurized systems, the resulting reduction in deep percolation from farm fields reduces transport of salts and nitrates to groundwater. To compensate for the reduction in groundwater recharge provided by deep percolation, districts in the Kings River area have implemented an extensive program of managed groundwater recharge basins as well as taking advantage of seepage from conveyance facilities. Measures implemented by growers that reduce deep percolation from fields and by districts that increase groundwater recharge from managed basins are both represented by coverages in the GAR and illustrate the progression in conjunctive management from primary reliance on deep percolation of applied water as a recharge mechanism to increasing reliance on recharge generated from dedicated recharge basins. The GAR coverages also illustrate the quality of the source water being released into recharge basins or applied to irrigated fields to demonstrate how the characteristics of the source water influence the quality of water recharged in the basin.

4.3.7 Changes in Irrigation Practices

Current irrigation practices for the Kings Project Area were reviewed using DWR Land Use Survey data. Although the Land Use Surveys have included whether lands were irrigated or not, irrigation methods data are a relatively recent inclusion in the DWR Land Use Survey, available for the counties within the Kings Project Area back to 1999 (DWR, 2014). DWR Land Use Survey data does not indicate if acreages or crops are irrigated using multiple methods, therefore this section serves to provide a basic characterization of irrigation practices and trends in the Area, rather than an in-depth analysis. Similar to cropping land uses, irrigation methods can change from year to year due to forces external to crop needs such as water availability and pricing, policy changes, crop commodity pricing and equipment technologies and costs.

Current agricultural irrigation methods in the Kings Project Area primarily consist of border strip irrigation and furrow irrigation, which together make up more than 66% of total irrigation, followed by surface drip (11%) and micro sprinkler (8%). **Table 4-10** below lists the current irrigation methods used and their acreages for the Kings Project Area.

Table 4-10. Current Kings Project Area Irrigation Methods

Irrigation Method	Acres	% of Total
Border Strip Irrigation	389,995	34
Furrow Irrigation	361,190	32
Surface Drip Irrigation	129,356	11
Micro Sprinkler	88,956	8
Buried Drip Irrigation	12,252	1
Permanent Sprinkler	5,708	<1
Hand Move Sprinkler	4,404	<1
Linear Move Sprinkler	4,265	<1
Center Pivot Sprinkler	2,262	<1
Side Roll Sprinkler	1,562	<1
Basin Irrigation	1,124	<1
Subirrigation	903	<1
Wild Flooding	6	<1
Solid Set Sprinkler	5	<1
Unknown or not mapped	128,903	11
Total	**1,130,887**	
Source: **(DWR Land Use Survey, 2009)**, **(DWR Land Use Survey, 2007)**, and **(DWR Land Use Survey, 2003)**		

The DWR Land Use Surveys provide a County-specific look (within the Kings Project Area) at irrigation changes between 2001 and 2010. In Fresno County, border strip irrigation and furrow irrigation are the predominant irrigation methods in 2001 and 2010, but looking at the DWR Land Use Surveys, both methods show a significant change in use by about -30% to -40% since 2001. In addition low volume irrigation methods have changed by about +45%. **Table 4-11** and **Figure 4-51** illustrate the irrigation method changes in Fresno County.

Table 4-11. Changes in Irrigation Methods in Fresno County within the Kings Project Area

Irrigation Method	2000 Acres	2009 Acres	% Change
Basin Irrigation	273	157	-54.03
Border Strip Irrigation	238,824	172,857	-32.05
Buried Drip Irrigation	4,051	8,942	75.28
Center Pivot Sprinkler	-	613	200.00
Furrow Irrigation	226,960	152,523	-39.23
Hand Move Sprinkler	4,728	3,182	-39.10
Linear Move Sprinkler	-	-	-
Micro Sprinkler	47,874	63,266	27.70
Permanent Sprinkler	1,736	4,615	90.68
Side Roll Sprinkler	-	1,562	200.00
Solid Set Sprinkler	-	5	200.00
Subirrigation	12	903	194.58
Surface Drip Irrigation	81,554	119,864	38.04
Wild Flooding	-	-	-
Unknown or not mapped	30,953	65,871	72.13
Total	**636,965**	**594,362**	**-6.92**
Source: **(DWR, 2000)**, **(DWR Land Use Survey, 2009)**			

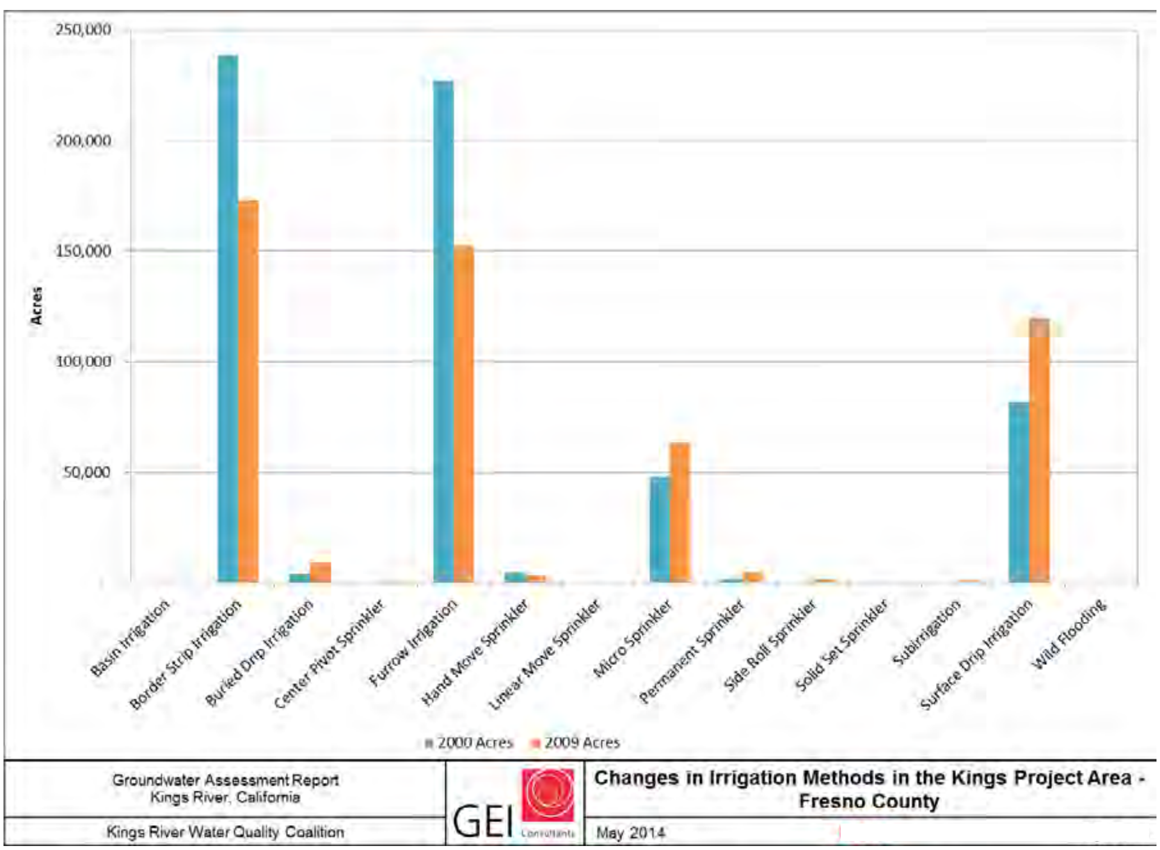


Figure 4-51. Changes in Irrigation Methods in the Kings Project Area – Fresno County

In Tulare County, furrow irrigation made up the majority of irrigation methods in 2001 (61%), but has since decreased in usage in 2010 to less than half the acreage. Border strip irrigation has increased in usage by about 32%. It should be noted, that while the DWR Land Use Surveys show total irrigated acreage in 2010 have decreased by about 24% since 2001, the Tulare County Crop Report shows about a 5% increase. **Table 4-12** and **Figure 4-52** illustrate the irrigation method changes in Tulare County.

Table 4-12. Changes in Irrigation Methods in Tulare County within the Kings Project Area

Irrigation Method	1999 Acres	2007 Acres	% Change
Basin Irrigation	-	-	-
Border Strip Irrigation	18,711	25,852	32.05
Buried Drip Irrigation	78	56	-33.08
Center Pivot Sprinkler	-	73	200.00
Furrow Irrigation	75,840	32,850	-79.11
Hand Move Sprinkler	62	-	-200.00
Linear Move Sprinkler	-	-	-
Micro Sprinkler	19,467	20,676	6.02
Permanent Sprinkler	42	600	173.59
Side Roll Sprinkler	-	-	-
Solid Set Sprinkler	-	-	-
Subirrigation	-	-	-
Surface Drip Irrigation	3,526	3,444	-2.34
Wild Flooding	61	-	-
Unknown or not mapped	6,250	13,973	76.37
Total	**124,037**	**97,523**	**-23.93**
Source: **(DWR, 1999)**, **(DWR Land Use Survey, 2007)**			

As a region, the Tulare Lake Hydrologic Region, which includes Fresno County, Kings County, Tulare County, and Kern County, has not changed drastically in irrigation methods between 2001 and 2010. The results of the 2010 and 2001 Statewide Irrigation Methods Surveys for the Tulare Lake Region show that the primary irrigation method for both years was gravity irrigation followed by low volume irrigation methods (DWR, 2011). Gravity irrigation, which includes border strip irrigation, furrow irrigation, and flood irrigation, has reduced in proportion of irrigated acreage by 10% since 2001 but remains the more prevalent method of use. Low volume irrigation, which includes drip irrigation, micro sprinkler, and sub-irrigation, is used more in 2010 than in 2001, with an increase in about 6%. **Figure 4-53** below compares the irrigation methods surveyed for the Tulare Lake Hydrologic Region for 2001 and 2010.

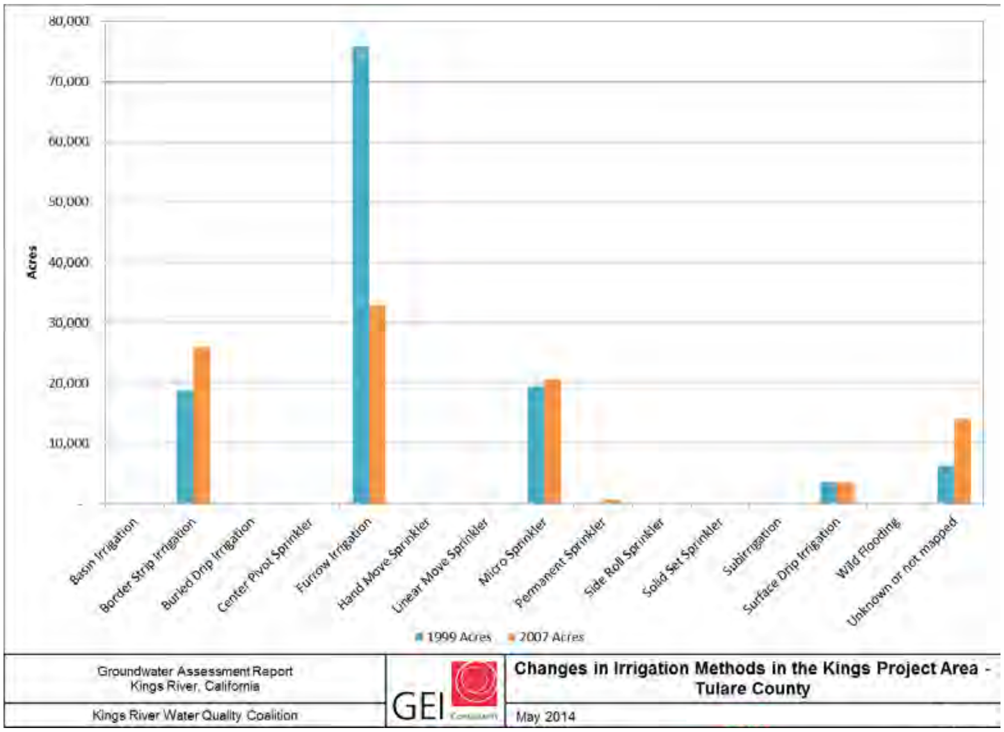
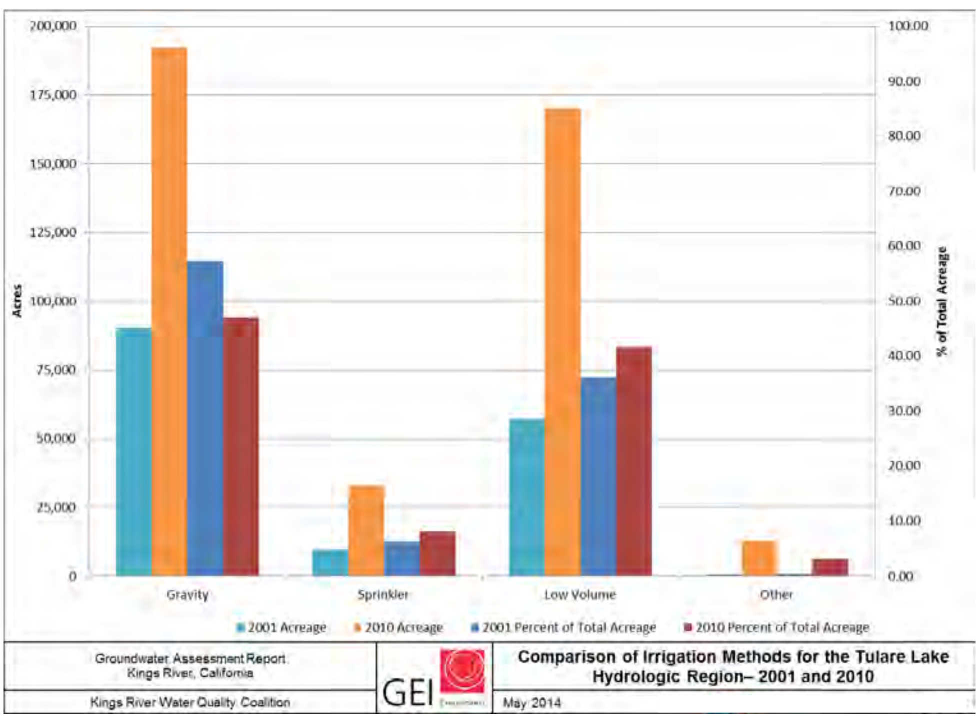


Figure 4-52. Changes in Irrigation Methods in the Kings Project Area – Tulare County



Note: 2001 and 2010 Historic irrigation method information is not available for Kings County through the DWR Land Use Surveys.

Figure 4-53. Comparison of Irrigation Methods for the Tulare Lake Hydrologic Region

A number of grower surveys and studies demonstrate changing irrigation practices that improve irrigation efficiency, and reduce deep percolation and associated nitrate leaching. Surveys conducted in 2001 for California and 2002 for the San Joaquin Valley found that from 1972 to 2002, acreage for orchards and vineyards increased, while field crops have decreased, corresponding to the increase in low-volume irrigation and the decrease in surface/gravity irrigation, respectively (Orang, et al., 2008), (CIT, 2002). In addition, a 2013 UC Davis Research Report on spatial analysis of irrigation efficiency in California shows a slight increased efficiency overall for all crops in the Tulare Lake Hydrologic Region between 2001 and 2010, with the greatest improvement in tomatoes of about +4.67% between 2001 and 2010 (Sandoval-Solis, et al., 2013). **Table 4-13** presents the UC Davis calculated mean irrigation efficiencies for the Tulare Lake Hydrologic Region and statewide, as well as the changes in selected crop irrigation efficiencies between 2001 and 2010.

Table 4-13. Summary of Crop Irrigation Efficiencies for the Kings Project Area

	Mean Irrigation Efficiency, %		Changes in Crop Irrigation Efficiency (2001-2010), %					
	2001	**2010**	**Corn**	**Cotton**	**Pasture**	**Tomatoes (Fresh)**	**Almonds & Pistachios**	**Vineyard**
California	74.5	77.5	+0.4	+3.0	-0.5	+2.6	+4.3	+3.3
Tulare Lake HR	85.5	87.8	+0.4	+3.5	+1.5	+8.1	+0.8	+2.1
Source: **(Sandoval-Solis, et al., 2013)**								

Comparison between current and prior irrigation practices demonstrates that growers in the Coalition area are implementing irrigation systems and on-farm water management practices to improve irrigation efficiency. Irrigation management systems have been discussed through multiple surveys and reports looking at the relationship between irrigation methods, irrigation efficiency, fertilizer application, and nitrate loading of groundwater (Sandoval-Solis, et al., 2013) (UCDAVIS, 2012) (CIT, 2002) (Dillon J., Edinger-Marshal S., Letey J., 1999) (USGS, 2012) (USGS, 2006).

There has been a pronounced shift in irrigation methods throughout the study area as growers have been converting from gravity to pressurized systems, particularly for irrigation of tree crops and processing tomatoes. A further shift is evident as growers further improve the distribution uniformity and application efficiency of their systems by moving from high pressure, high volume sprinkler systems to low pressure, low volume drip and micro-sprinkler systems. As well as being identified in the land use data presented in this groundwater assessment, these shifts in irrigation methods has been documented in studies including the *San Joaquin Valley Grower Irrigation Survey* (CIT, 2002)and Irrigation Shifts Toward Sprinklers, Drip and Micro-sprinklers (Dillon J., Edinger-Marshal S., Letey J., 1999).

The shift from surface methods to pressurized methods and from sprinklers to micro-sprinklers and drip is driven by improvements in technology; changes in land use from annual to permanent crops; availability of workers trained to manage more sophisticated, less labor intensive systems; and improvements in cultural and agronomic practices. Important implications of these shifts have been that more of the applied water is consumed by crops (increased irrigation efficiency) and less is available for deep percolation. Although the changes in irrigation technology and management have conserved water and reduced deep percolation, growers have adopted these improvements largely due to their potential to improve crop yields, quality and profitability.

4.3.8 Fertilization

With respect to this groundwater assessment, the nutrient of greatest interest is the nitrate form of nitrogen, a species that is valuable as a nutrient but problematic when found in aquifers that are sources of drinking water. Because of its importance, this section of the report will focus on nitrates.

4.3.8.1 Summary of Nitrogen Cycle

Understanding of the processes that make nitrate nitrogen available both as a nutrient and as a groundwater contaminant begins with a basic understanding of the nitrogen cycle. Nitrogen gas, N_2, is our atmosphere's predominant component and is a stable gas that does not interact readily with plants and animals. In the natural nitrogen cycle, nitrogen becomes accessible in the environment through the process of fixation which is mostly performed by bacteria in the roots of leguminous plants. These bacteria convert atmospheric nitrogen into ammonia, NH_3, which then is rapidly converted to the forms of nitrogen needed for plant growth where it is a key ingredient of proteins, amino acids and nucleic acids.

Because nitrogen fixation is performed only by specialized microbes associated with leguminous plants, under natural conditions the availability of reactive nitrogen is governed by the presence or absence of these plants. Other organisms cannot use atmospheric nitrogen directly but obtain nitrogen from accumulated soil organic matter, plants, animals and microbial communities. However, humans have reduced dependence on leguminous plants by application of manure to augment soil fertility and by developing processes to synthetically convert N_2 into biologically usable compounds. Among these compounds are forms of fertilizer which, when applied at adequate rates, sustain the vigorous plant growth needed to achieve consistently high yields and profitability.

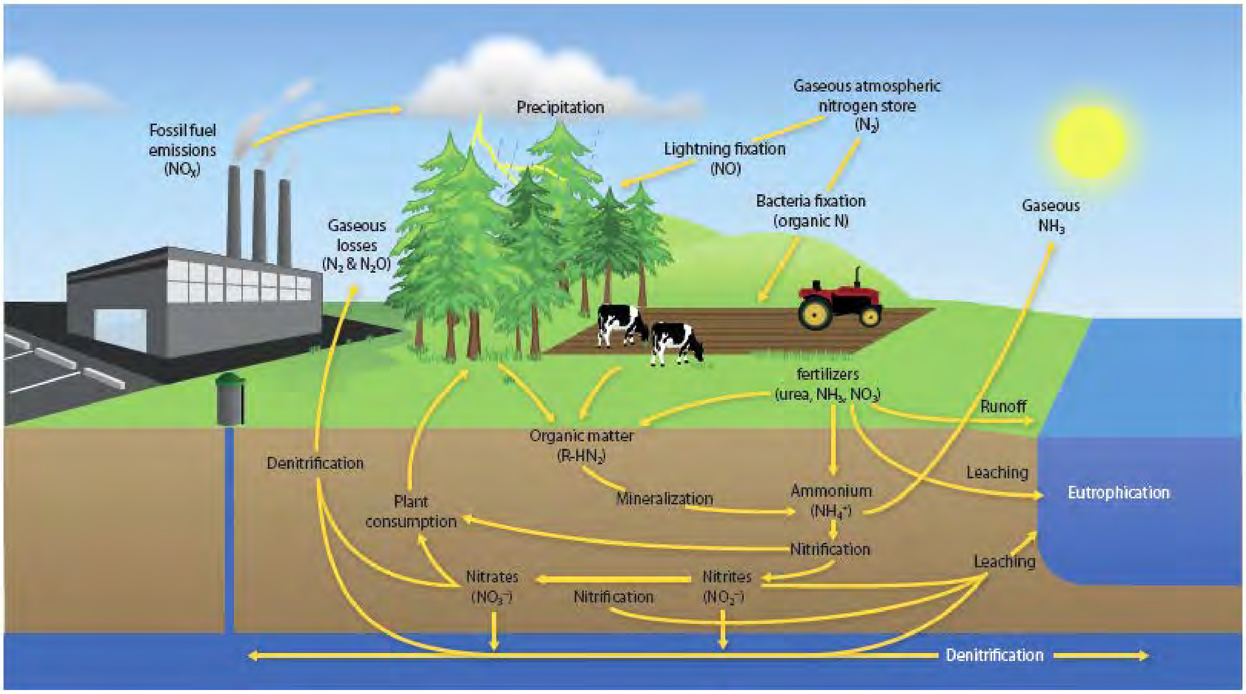


Figure 4-54. Nitrogen Cycle (Source: UC Davis SB 2X Report to the Legislature)

Soil nitrogen is most abundant in the organic form but is subject to mineralization, a suite of processes performed by soil microbes that converts organic nitrogen to various inorganic forms. The rates of mineralization depend on environmental conditions such as temperature, moisture, pH, and oxygen content, as well as the type of organic matter available. The first product of mineralization is ammonium, NH_4^+, but under aerobic conditions, microbes can convert ammonium first to nitrites, NO_2^-, and then to nitrate, NO_3^-. Most plants use nitrate or ammonium as their preferred source of nitrogen. Plants preference for nitrate is one reason management of this species is important. The second reason is that because of its negative charge, nitrate tends to resist bonding to soil particles and readily leaches to groundwater where, as noted above, its presence raises concerns. While, use of manure and synthetic fertilizer has had a profound impact on agricultural productivity, application of these materials has also increased the quantity of nitrate available to be transported by deep percolation to groundwater.

The ultimate fate of "reactive" forms of nitrogen such as organic nitrogen, ammonium, nitrate, ammonia, and nitrous oxide is completion of the nitrogen cycle by returning back to the atmosphere as N_2. Although nitrate in groundwater exists in the anoxic condition required for denitrification, it is largely insulated from the necessary microbial activity. Therefore, nitrate in groundwater is relatively stable and converts to N_2 at a slower rate than nitrate in anoxic conditions closer to the soil surface.

The preceding brief description of the nitrogen cycle, drawn largely from information presented in the California Nitrogen Assessment and from Assessing Nitrate in California's Drinking Water – Technical Report 2, illustrates that whether natural or introduced, reactive nitrogen moves through the environment in response to a variety of processes. The complexity of these processes, particularly the conversion between organic forms of nitrogen to nitrates and the rates at which available forms of nitrogen may be taken up by crops, makes tracking nitrogen by mass balance much more difficult that tracking a constituent such as salt which is conservative and is not consumed to a significant degree by crops.

Growers are aware of the activity of the nitrogen cycle from having observed how nitrogen levels in the soil can quickly drop as plants consume applied nitrogen that has been converted first to nitrite and then to nitrate, however application of this awareness is challenging. Incomplete understanding of how much nitrogen crops require at various stages in their life cycles and constraints in the techniques available to apply nitrogen limit growers' ability to schedule fertilizer applications that exactly match their crops' needs. While similar limitations constrain the effectiveness of irrigation practices, the constraints on nitrogen applications are more severe largely due to the complexities of the nitrogen cycle. The outcome of these constraints is that in order to introduce sufficient fertilizer to promote vigorous crop growth over an entire field, nitrogen is often applied at rates that target the requirements of nutrient deficient areas within a field. Therefore, although growers are frequently observed to apply more nitrogen than is recommended by research organizations, field research is often conducted on plots that are too small to capture the variability inherent in larger fields.

Although not evaluated in this GAR, a primary driver behind the development and adoption of precision farming techniques is to better target fertilizer applications to crop and soil conditions at differing points in a field. As with drip irrigation and other more targeted forms of irrigation, an outcome of adoption of precision farming may be to improve farm profitability while reducing leaching of nitrates.

4.3.8.2 Influence of irrigation practices on leaching of nitrates

One of the key insights that results from understanding factors influencing nitrate concentrations now observed in groundwater is that the mass of nitrate leached to groundwater is a function of volume of deep percolation that drained from the root zone and the concentrations of nitrate in the soil at the time leaching occurred. Research suggests that the irrigation management has been and continues to be at least equal to, and possibly of greater importance than, fertilizer application in affecting and controlling the leaching of nitrate (Letey, et al., 2013).

A second insight is that just as the concentrations of nitrates now observed in groundwater are a legacy of past fertilizer and irrigation management practices, the rates at which nitrates are now migrating to groundwater, or may migrate to groundwater in the future, are reflections of more recent or future approaches to managing both fertilizer and irrigation. The decades-long feedback cycle between farming practices that cause leaching of nitrates and measurement of nitrate levels in groundwater keeps monitoring of current groundwater conditions from being a reliable indicator of the effectiveness of present-day fertilizer and irrigation management practices in controlling nitrate loadings to groundwater.

As well as the direct linkages between deep percolation and leaching described above, there are other, more subtle connections between irrigation and fertilizer management and leaching of nitrates. For example, simply reducing applications of water and nitrogen may have less impact on nitrate leaching than anticipated. This is because reductions in loadings to the soil may hinder crop development reducing uptake of water and nitrogen and lowering crop yield. The resulting effect is that while less water and nitrogen may have been applied to the soil, a greater proportion of the applied nitrogen remains available for leaching and a greater proportion of the applied water is available as a vehicle for nitrate transport. As a consequence, practices intended to reduce groundwater contamination need to be carefully designed to attain the desired results.

In spite of gaps in data and understanding, information provided in the GAR illustrates the dynamic nature of farming practices in the study area and suggests the impact that improvements in irrigation practices and management of fertilizer may have on reducing nitrate leaching. Information presented in the GAR also illustrates the spatial variability of intrinsic conditions that influence susceptibility and vulnerability to nitrate contamination, show the impact of crop types and irrigation practices on deep percolation rates and suggest the degree to which adoption of advanced irrigation and fertilizer management techniques may be able to counteract intrinsic conditions that render an areas groundwater susceptible to nitrate contamination.

The overlay coverages presented in the GAR provide valuable snapshots of land use practices across the study area at different points in time. As a result, the representations in the GAR of shifts in land use from seasonal to permanent crops such as trees and vineyards and of the often parallel conversion to drip or micro-spray irrigation are highly instructive. However, for fields remaining in seasonal crops these snapshots do not directly depict continuous agronomic practices such as crop rotations and the changes in irrigation and fertilizer management practices that take place in a single field through the progression of a crop rotation. One of the benefits of the square mile resolution of the GAR coverages is that this resolution creates a pool of fields spanning several crops which reduces the distortions that could result from displaying data at a single field level of resolution. The agronomic value of each crop in a rotation is one reason why the concept of targeting individual crops as sources of groundwater contamination should be used with caution.

The complexity of the nitrogen cycle reduces the value of a mass balance analysis of nitrogen as compared with mass balance computations of water and of TDS. Research indicates that the amount of nitrogen leached is more closely related to the amount of water percolating beyond the root zone than the amount of nitrogen applied (Letey, et al., 2013). Because leaching numbers are affected primarily by the volume of percolation rather than by constituent concentration, limiting percolation of water beyond the root zone is the most effective way to reduce nitrate loading to groundwater.

4.3.8.3 Fertilizer Rates

Data for on-farm and non-farm nitrogen fertilizer use in the study area from 1987 through 2006 were compiled by the USGS from county fertilizer sales in the area (Gronberg and Spahr, 2012). These data show non–farm usage representing a negligible proportion of total nitrogen use in the area averaging only 0.3% of on-farm usage. On-farm usage varied over the period with total applications peaking at the beginning and near the middle of the period, with lower levels of nitrogen applied in the early 1990's and early 2000's. Nitrogen usage at the end of the period, 2006, was very near the average usage over the 20-year period. The year with the peak nitrogen application was 1996 when the nitrogen usage was 121% of the average, while in 1993 and 2001, the years with the lowest usage, applications were 84% of the average.

Table 4-14 shows the range of typical recommendations for applied nitrogen by crop in pounds per acre per year based on data from the referenced UC Davis sources. These data indicate that vegetables generally have the highest recommended nitrogen application rates, particularly fresh market tomatoes (237.5 lbs/ac/year), an important crop in the study area. Grains/cotton and nut trees also have high recommended nitrogen application rates with typical rates in the range of 150 to 175 lbs/ac/year. Crop categories with the lowest recommended nitrogen application rates include grapes (40 lbs/ac/year) and, due to its ability to fix atmospheric nitrogen, alfalfa (25 lbs/ac/year).

Table 4-15 shows reported nitrogen application rates, by crop, from survey data collected throughout California in 1973 and 2005 (Rosenstock et al., 2013). **Table 4-15** also compares application rates reported in the grower surveys with the average of the recommended application rates shown above in **Table 4-14**. The reported nitrogen rates vary considerably on a crop-by-crop basis from the recommended rates. In addition, there is a considerable spread been the maximum and minimum recommendations and among the rates reported by growers

Table 4-14. Minimum, Maximum and Average Recommendations of Nitrogen Application (lbs/ac/year)

Crop	Minimum	Maximum	Average	Source
Alfalfa	0	50	25	Meyer et al. 2007. Pub 3512
Almond	100	200	150	Weinbaum 1996. Pub. 3364
Avocado	67	100	83.5	Faber 2005. CE Ventura Avocado Handbook and Pub. 3436
Bean, dry	86	116	101	Long et al. 2010. Pub 8402
Broccoli	100	200	150	Le Strange et al. 2010 Pub. 7226
Carrot	200	250	225	Nunez et al. 2008. Pub. 7211
Celery	150	275	212.5	Daugovish et al. 2008. Pub. 7220
Corn	100	275	187.5	http://agri.ucdavis.edu
Corn, sweet	100	200	150	Smith et al. 1997. Pub. 7223
Cotton	100	200	150	Hake et al. 1996 Pub. 3352
Grape, raisin	20	60	40	Christensen et al. 2000. Pub. 3393
Lettuce	170	220	195	Jackson et al. 1996. Pubs. 7215 and 7216
Melon, cantaloupe	80	150	115	Hartz et al. 2008. Pub. 7218
Melon, watermelon	*	160	160	Baameur et al. 2009. Bub. 7213
Melons (mixed)	100	150	125	Mayberry et al. 1996. Pub. 7209
Nectarine	100	150	125	Pub. 3389
Oats	50	120	85	Munier et al. 2006. Pub. 8167
Onion	100	400	250	Voss et al. 1999. Pub. 7242
Peach, cling	50	100	75	Norton et al. 2007. Pub. 8276
Peach, free	50	100	75	Norton et al. 2007. Pub. 9358
Pepper, bell	180	240	210	Hartz et al. 2008. Pub. 7217
Pepper, chili	150	200	175	Smith et al. 1997. Pub. 7244
Pistachios	100	225	162.5	Beed et al. 2005. In Fereguson et al. 2009
Plums, dried (prunes)	*	100	100	Norton et al. 2007. Pub. 8264
Plums, fresh	110	150	130	Johnson and Uriu 1989. Pub. 3331
Rice	110	145	127.5	Mutters et al. 2009. Pub. 3514
Safflower	100	150	125	Kafka and Kearney 1998. Pub. 21565
Strawberry	150	300	225	Strand et al. 2008. Pub. 3351
Tomatoes, fresh market	125	350	237.5	Le Strange et al. 2000 Pub. 3351
Tomatoes, processing	100	150	125	Hartz et al. 2008. Pub. 7228
Walnuts	150	200	175	Anderson et al. 2006 Pub. 21623. Weinbaum et al. 1998. Pub. 3373
Wheat	100	240	170	Munier et al. 2006. Pub. 8167

[1] Nitrogen application rate estimates from Rauschkolb and Mikklesen (1978), UC ARE Cost and Return Studies and USDA Agricultural Chemical Use Program reports

who responded to the surveys. Nevertheless, when the data are pooled, the average reported application rates across all crops match the recommended rates relatively closely with the average reported applications in 1973 being 95% of the recommended rates and the average reported rates in 2005 being 115% of the recommended rates. These data also indicate that while growers reduced nitrogen application to a few crops, such as grapes, peaches, corn and avocados, between 1973 and 2005, the general trend was an increase in applications over this period.

Table 4-15. Reported Nitrogen Applications[1, 2]

Crop	1973	2005	1973/avg[3]	2005/avg[3]
Almond	127	179	85%	119%
Avocado	125	112	150%	134%
Bean, dry	51	91	50%	90%
Broccoli	182	190	121%	127%
Carrot	120	216	53%	96%
Celery	183	238	86%	112%
Corn	287	259	153%	138%
Corn, sweet	145	213	97%	142%
Cotton	109	174	73%	116%
Grape, raisin	57	44	143%	110%
Lettuce	159	193	82%	99%
Melon, cantaloupe	95	163	83%	142%
Melon, watermelon	159	151	99%	94%
Nectarine	131	104	105%	83%
Onion	146	212	58%	85%
Peach, cling	133	102	177%	136%
Peach, free	133	113	177%	151%
Pepper, bell	162	346	77%	165%
Pepper, chili	162	300	93%	171%
Pistachios	148	159	91%	98%
Plums, dried (prunes)	95	130	95%	130%
Plums, fresh	110	104	85%	80%
Rice	86	130	67%	102%
Strawberry	159	193	71%	86%
Tomatoes, fresh market	142	177	60%	75%
Tomatoes, processing	142	182	114%	146%
Walnuts	120	138	69%	79%
Wheat	88	177	52%	104%
Average across all crops	**134.1**	**171.0**	**95%**	**115%**

[1] Table provides reported applications and a comparison with average recommendations presented in **Table 4-14**.
[2] Nitrogen rates are estimated from Rauschkolb and Mikklesen (1978). UC ARE Cost and Return Studies and USDA Agricultural Chemical Use Program reports
[3] Percentage of nitrogen application rate to average of maximum and minimum recommended

4.3.9 Other Potential Sources of Contamination

This study seeks to identify the vulnerability of groundwater from sources which may originate from irrigated agriculture, primarily salts and nitrates. However, there are naturally occurring sources of salt and nitrates, or other non-agronomic land uses that could also contribute to the impairment of groundwater quality.

4.3.9.1 Natural Occurrence

While salts and nitrates may occur naturally, the mechanisms for their occurrence in groundwater are different and are addressed separately. Pesticides typically do not occur naturally and their occurrence in groundwater is assumed to be of an anthropogenic origin.

Salts

In natural systems, salts can become concentrated in groundwater in several ways:

- **Dissolution**. As water travels across and through natural materials (soil, rock, organic material), it picks up salts. Water sources emerging from the Sierra Nevada Mountains (the major recharge source to the Coalition area) typically have TDS concentrations well below 100 mg/L as was shown in **Figure 4-7**. Naturally occurring saline soils within the basin could also contribute the salinity of groundwater. **Figure 4-23** showed a map of saline soils as documented in the in the SSURGO geodatabase (NRCS, 2014). There is a limited amount of moderately to strongly saline soils in the Coalition area found mostly in the Lower Kings and Tulare Lakes subareas. Much of the geologic formations on the Coastal Range are of marine deposits and sediments originating from this area have a higher degree of salts such that water moving from and through these formations has higher TDS. As such, naturally occurring salt concentrations are higher in the Western part of the Coalition and lower in the East.

- **Evaporation of applied water**. As water evaporates or is consumed by plants, salts in the remaining water become concentrated. Prior to irrigated agriculture, the major area of evaporative concentration in the Coalition area were in the Tulare Lake bed. High TDS levels are a persistent problem in the shallow groundwater perched above the clay layers (Schmidt, 2013). Salt from irrigation water is managed on- farm by factoring in the leaching fraction when scheduling irrigation to maintain high levels of crop productivity.

- **Ancient marine deposits**. The marine deposits are found at depth below the freshwater-bearing continental deposits. The thickness of the fresh water aquifer is generally greater than 2000 feet in the Coalition area (USGS, 1995) and therefore the ancient saline water should not affect the shallower production zones.

Nitrates

Low levels of nitrate may be natural in origin; however, high concentrations of nitrate are generally related to fertilizer production and application, septic systems, agricultural and animal waste ponds, leaking sewer lines, sludge or manure application. Natural groundwater nitrate concentrations in areas unaffected by human activity are generally below 3 mg/L (Nitrate as N) (Spalding, et al., 1993). In isolated cases, there can be nitrogen present in native geologic materials (Holloway, et al., 2002) and it is also deposited on surface soils from airborne pollutants originating from fossil fuel combustion and animal feeding operations (UCDAVIS, 2012). However, nitrogen generally cycles between the atmosphere, surface water, and groundwater systems by a complex set of biological processes. There have been no geologic or atmospheric deposition sources of nitrogen that have been attributed to elevated groundwater nitrogen levels in the study area (UCDAVIS, 2012). Nitrogen in groundwater from natural sources is generally considered insignificant compared to the magnitude of human sources (UCDAVIS, 2012).

Imported Water

Nitrate concentrations in imported water sources are generally low as shown in the available data on **Figure 4-55**. Nitrogen from surface and imported water sources it is not considered significant.

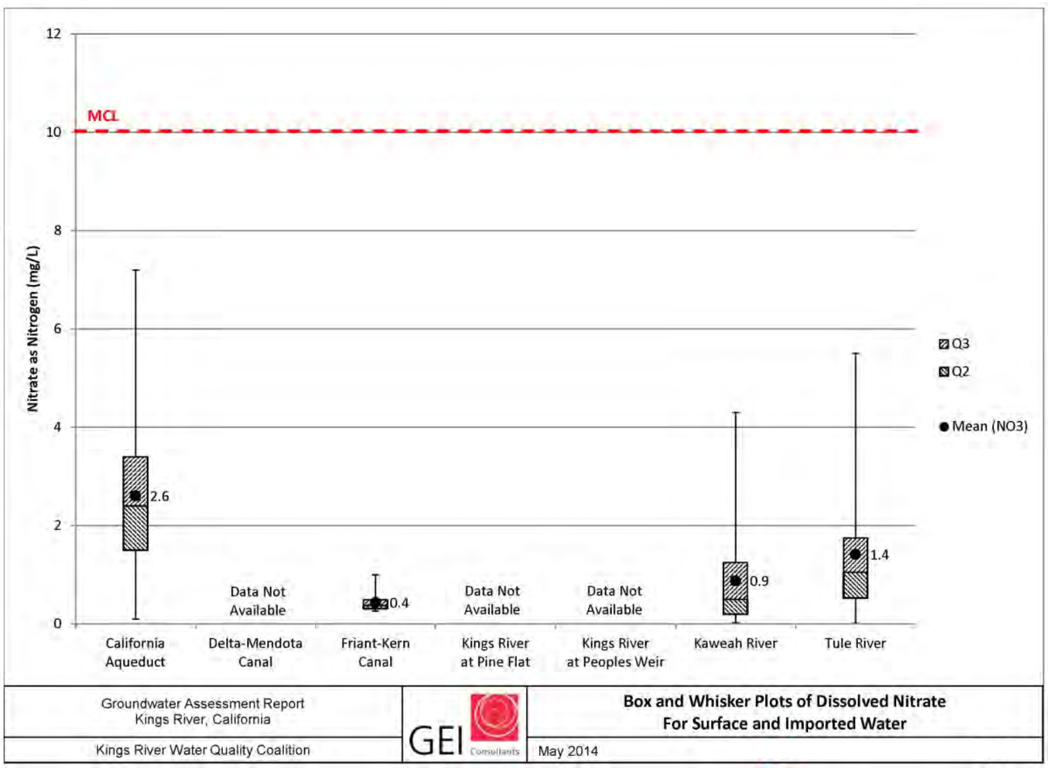


Figure 4-55. Box and Whisker Plots of Dissolved Nitrate for Surface and Imported Water

4.3.9.2 Land Uses - Other Potentially Contaminating Activities

Alternative sources could be contributing to exceedance of drinking water standards and this is an area of uncertainty. The purpose of the Kings GAR is not to conduct a loading analysis from potential sources or to explain specific observed exceedance. The Kings GAR does identify potential non-agricultural sources of salt and nitrogen that could be contributing to observed exceedance at a well. It is not be appropriate to presume an exceedance is always from an agricultural source. In areas where there is an exceedance, but the GAR analysis results in low vulnerability designation, an alternative source could be a contributing factor to explain this condition.

To identify potential land uses (other than irrigated agriculture) that could be sources of contamination, information about all sites regulated by the RWQCB was collected. The locations of the 974 active sites identified by the RWQCB are shown in **Figure 4-56**. About 402 facilities associated with construction, industrial and manufacturing (other than food processing), dredging, energy, and transportation were assumed to have a low potential to release nitrates or salts to the environment and are symbolized with small dots. Of the remaining 572 facilities, 130 have WDR permits, and six have NPDES permits. The only regulated sites for which effluent monitoring data was readily available were the NPDES sites which typically discharge to surface water bodies. U.C. Davis identified wastewater treatment and food processing facilities and data as reported to the RWQCB, documenting nitrate loading from these facilities (UCDAVIS, 2012)[4]. KRCD provided maps of dairy locations.

The vast majority of the 572 regulated sites fell into three categories: Animal Feeding/Dairy, Food Processing, and Wastewater Treatment Plants. Other regulated site types include Recycled Water Use areas, Composting Facilities, and Municipal Collection Systems (which are regulated separately from WWTPs because of the possibility of system overflows or leaks).

There are methods that seek to identify the sources of nitrates in groundwater. Studies have used the isotopic composition of nitrate and oxygen (δ15N, δ18O) to determine source(s) of nitrate in groundwater. Mineral fertilizer, animal manure, and wastewater are anthropogenic sources of nitrate with characteristic ranges of δ15N and δ18O values. Fertilizer is different than animal or human waste sources. The nitrate isotopic composition in animal manure and wastewater largely overlap, making them difficult to distinguish. In addition, denitrification causes isotopic fractionation that can make it difficult to determine the isotopic composition of the original source. Using nitrate nitrogen and oxygen isotopic compositions alone can lead to ambiguous nitrate source attributions for areas where animal manure and wastewater sources

[4] See Appendix, Table 8. This presents both wastewater and industrial food processor nitrate wastewater stream concentrations an the amount applied for irrigation or percolated.

are co-located, but the approach can still work to discriminate these sources from fertilizer (Eppich, 2012). N isotope ratios were evaluated in the Salinas Valley and found to be useful (Rolston, 2002).

The Lawrence Livermore National Laboratory (LLNL) performed specialized analyses of domestic well groundwater for the SWRCB as part of the GAMA Domestic Well Project in Tulare County (LLNL, 2013).

LLNL analyzed 151 of the 181 domestic well water samples collected by the SWRCB for stable isotopes of oxygen and hydrogen in water; and analyzed 29 samples for stable isotopes of nitrogen and oxygen in dissolved nitrate. These isotopic data constrain the source of water recharging the groundwater produced by the domestic wells in this survey, and help to constrain the source of nitrate in these wells. The water isotopic evidence shows that domestic wells in the foothills (with elevations above 400 feet) receive recharge derived from local precipitation that has experienced some evaporation. In contrast, valley domestic wells below 400 feet surface elevation draw on groundwater heavily impacted by irrigation with Kings and Kaweah River water, as indicated by water isotopic composition. A preliminary investigation of the correlation between land use and nitrate isotopic composition was conducted. The sparse nitrate isotopic data sets, and the cursory approach to assigning land use limit conclusions, but patterns observed are suggestive of multiple anthropogenic sources, including dairy wastewater, septic effluent and synthetic fertilizer. Significant findings of the study include:

- Nitrate isotopic composition appears to vary with land use
    - Dairy, agricultural/residential, and wild-land sites are isotopically distinct
    - Dairy site nitrate-N isotopic data are isotopically consistent with a manure source
    - Nitrate-O isotopic data are isotopically consistent with local nitrification of ammonium (from manure, septic effluent, or synthetic ammonium fertilizer)
- The isotopic evidence is consistent with more than one nitrate source
    - Domestic wells located close to dairies frequently have a different nitrate isotopic composition than wells not close to dairies in similar hydrogeologic settings.
    - The isotopic compositions measured are consistent with the suspected sources of nitrate to these wells (soil, fertilizer, manure, septic or community wastewater).
    - High concentrations of nitrate occur in all developed land use categories.

These methods potentially could be used to determine the sources and relative contribution of nitrogen in groundwater from various sources when there is questions about which source is contributing to an exceedance.

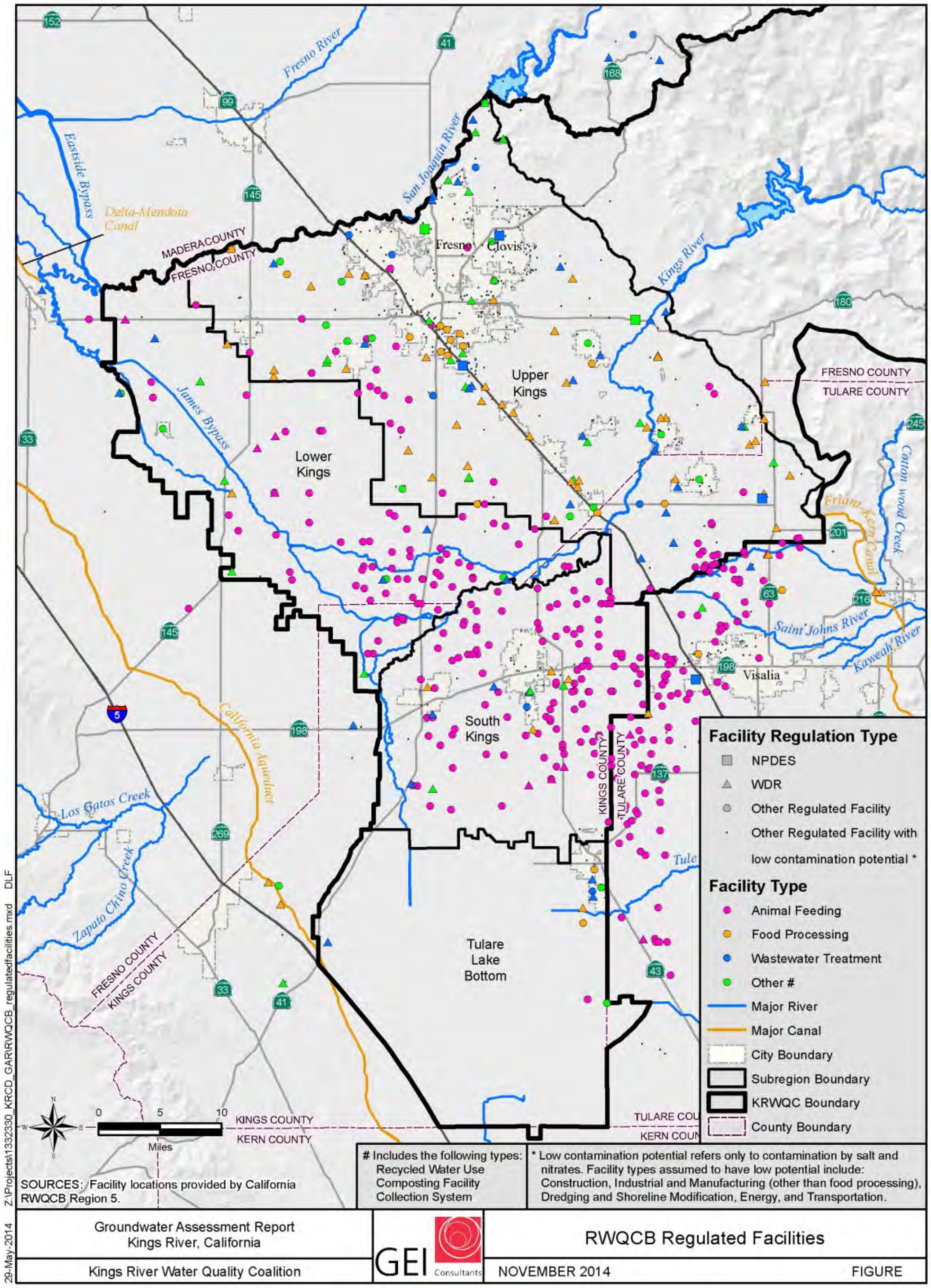


Figure 4-56. RWQCB Regulated Facilities

4.3.9.3 Animal Feeding/Dairy Facilities

The RWQCB identifies 392 animal feeding facilities and dairies in the study area; ten of these facilities have WDR permits. The facilities are distributed throughout the Coalition area, with the highest density near the Kings River in the Lower Kings and South Kings subareas.

4.3.9.4 Food Processing Facilities (excluding Dairies)

The RWQCB identifies 78 food processing facilities (excluding dairies, which are included in the previous section) in the study area; 57 of these facilities have WDR permits. Many facilities are clustered along the Highway 99 corridor.

4.3.9.5 Municipal Wastewater Systems

The RWQCB identifies 51 wastewater treatment facilities in the study area; 38 of these facilities have WDR permits and four have NPDES permits. The facilities are distributed throughout the Coalition area, servicing all of the major urban areas and some small communities.

4.3.10 Domestic Wastewater Systems

Septic systems could also contribute significant amounts of contaminants to groundwater. These are regulated at the county level and the counties do not have aggregated or easily accessible information to determine the number and location of septic systems. The City of Fresno Nitrate Management Plan (Boyle, 2006) (Schmidt, 2004)documented the effects of unsewered areas and Industrial wastewater disposal on groundwater in the Fresno metropolitan area, also demonstrating how sewering these areas resulted in reductions in nitrate contamination of groundwater. This report also showed the benefits of intentional recharge from the Leaky Acres on the reducing in nitrate contamination.

In order to identify where septic systems may be concentrated, parcel data was used in conjunction with information about known sewer systems. The red areas shown in **Figure 4-57** are parcel clusters which potentially have high-density septic systems. They were developed by identifying parcel clusters with all the following conditions:

- Individual parcels are less than 2 acres.
- The cluster of adjacent parcels exceeds a total of 5 acres.
- The cluster is outside of a known sewer service area identified by county LAFCO records.

It should be noted that the red areas identify locations that could *potentially* have a high density of septic systems and that the identified parcels may not have septic systems at all or may have sewered systems not recorded in the LAFCO records. In particular, the areas on the interior of the greater Fresno area metropolitan area likely have a sewer system or are connected to the City’s system.

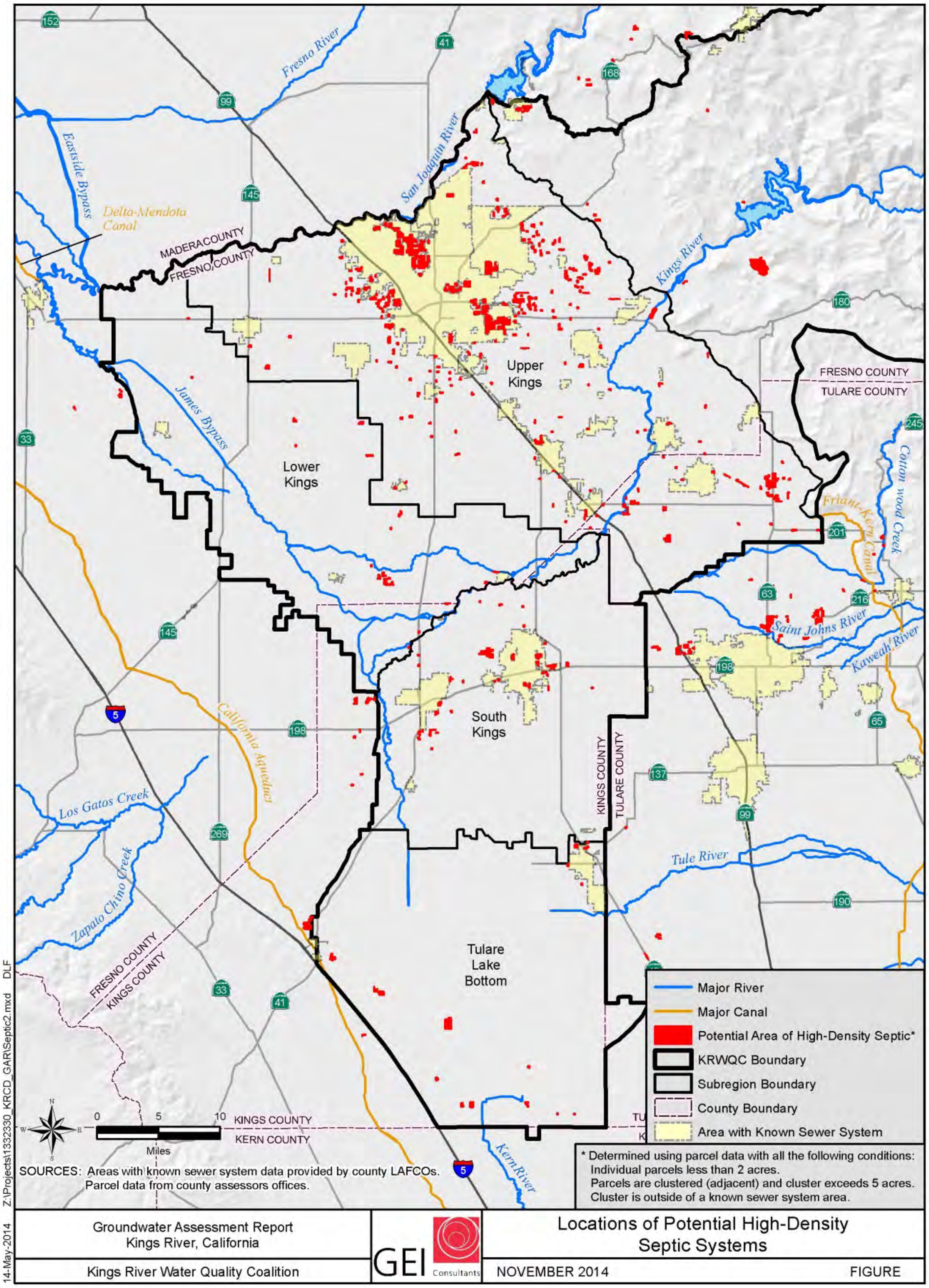


Figure 4-57. Locations of Potential High-Density Septic Systems

Chapter 5. Groundwater Quality

Chapter 5. Groundwater Quality

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Chapter 5. Groundwater Quality

5.1 INTRODUCTION

Maintaining groundwater quality that preserves beneficial uses is the goal of the Order. This chapter reviews water quality objectives, identifies the sources of groundwater quality information, and discusses the spatial and temporal trends for constituents of concern. This information will assist with interpretation of the GAR analyst vulnerability in **Chapter 8**.

5.2 WATER QUALITY STANDARDS AND OBJECTIVES

5.2.1 Nitrate and Salinity

Drinking water and agricultural beneficial uses are to be protected by the Order. Goals for nitrate and salinity are set by various agencies as shown in **Table 5-1**. The enforceable drinking water limits are indicated with an asterisk and these levels are used as exceedance thresholds for the GAR.

Table 5-1. Water Quality Goals

	Nitrate as N (mg/L)	TDS (mg/L)	Notes
California Department of Public Health			
Primary MCL [1]	10*	--	CDPH measures nitrate levels with units of mg/L as Nitrate. For consistency, the MCL has been converted to mg/L as Nitrogen.
Secondary MCL [2]	--	1000*	CDPH has established a range of maximum levels between 500 and 1000 mg/L. Short-term exceedances can be up to 1500 mg/L
U.S. Environmental Protection Agency (USEPA)			
Primary MCL [1]	10*	--	USEPA measures nitrate levels with units of mg/L as Nitrogen.
Secondary MCL [2]	--	500	USEPA secondary standards are not enforceable in California.
MCL Goal [3]	10	--	
Cal/EPA, OEHHA			
California Public Health Goal	10	--	
Food & Ag. Org. of United Nations			
Agricultural Water Quality Goals	--	450	

[1] Primary MCLs (Maximum Contaminant Levels) are based on health, technology, and economic considerations for drinking water.
[2] Secondary MCLs are based on taste, odor, or welfare considerations.
[3] Level established for no adverse health effects. Typically lower than the enforceable MCLs.
-- Indicates that no contaminant level has been established
* Indicates an enforceable MCL.
Source: California Department of Public Health

5.2.2 Maximum Contaminant Levels for Pesticides

Maximum contaminant levels for pesticides are shown in **Table 5-2.** Because not all pesticides have an MCL, the California Department of Public Health (DPH) MCL having the highest priority, the Environmental Protection Agency (EPA) MCL having the second priority. If neither of these MCLs has been established, the DPH notification level was used.

Table 5-2. Pesticide Maximum Contaminant Levels

Pesticide	California DPH MCL (ug/l)	EPA MCL (ug/l)	California DPH Notification level (ug/l)
Alachlor	2	2	--
Aldicarb	--	3	7
Aldicarb sulfone	--	3	--
Aldicarb sulfoxide	--	4	--
Atrazine	1	3	--
Azinphos methyl	--	--	--
gamma-BHC (Lindane)	0.2	0.2	--
Bromomethane	--	--	--
Bromacil	--	--	--
Bentazon	18	--	--
Chlordane	0.1	2	--
Carbofuran	18	40	--
Cyanazine	--	--	--
Cypermethrin	--	--	--
1,2-Dibromo-3-chloropropane	0.2	0.2	--
1,2-Dichlorobenzene	600	600	--
1,3-Dichloropropene	0.5	--	--
1,2-Dichloropropane	5	5	--
DDD	--	--	--
DDE	--	--	--
DDT	--	--	--
Diethanolamine (DEA)	--	--	--
Diazinon	--	--	1.2
Dicamba	--	--	--
Dichlorvos	--	--	--
Dicofol	--	--	--
Dimethoate	--	--	1
Diuron	--	--	--
1,2-Dibromoethane	0.05	0.05	--
S-Ethyl dipropylthiocarbamate	--	--	--

Table 5-2. Pesticide Maximum Contaminant Levels, Continued

Pesticide	California DPH MCL (ug/l)	EPA MCL (ug/l)	California DPH Notification level (ug/l)
Fenamiphos	--	--	--
Heptachlor	0.01	4	--
Heptachlor epoxide	0.01	0.2	--
Hexazinone	--	--	--
Linuron	--	--	--
Metalaxyl	--	--	--
Metolachlor	--	--	--
Metribuzin	--	--	--
Molinate	20	--	--
Methoxychlor	30	40	--
Naled	--	--	--
Naphthalene	--	--	17
Napropamide	--	--	--
Norflurazon	--	--	--
Methyl parathion	--	--	2
Prometon	--	--	--
Prometryn	--	--	--
Propargite	--	--	--
Simazine	4	4	--
Thiobencarb	70	--	--
Toxaphene	3	3	--
Xylene(s)	1,750	10,000	--

-- Indicates value not available.

Sources: Pesticides are those with measurements in the GAR area.

5.3 Sources of Data

Groundwater quality data is available from a variety of programs and sources, including the California DPH’s Drinking Water Program, DWR’s Water Data Library, USGS’s National Water Information System (NWIS), SWRCB’s GAMA program, RWQCB’s Dairy program, and the Department of Pesticide Regulation (DPR). Much of this data is available using the SWRCB’s data management system, GeoTracker. However, locations for many of the wells have a low accuracy (including the DPH wells which have locations obscured to within a mile for security reasons), and much of the raw data has not been reviewed to remove outliers and erroneous data. The UC Davis SB-2X study developed the CASTING database for their nitrate study and CV-SALTS developed a water quality database as part of Phase II Conceptual Model - Task 3 of their program.

5.3.1 Review of Nitrates and Salinity Datasets

Both the UC Davis and CVSALTS data sets were reviewed for use in the Kings GAR. The CV-SALTS dataset contains both TDS and nitrate measurements, went through an appropriate QA/QC process, and is current to 2014. CVSALTS data was selected for use in the GAR due to the more extensive QA/QC of the available data and the availability of both TDS and Nitrate data. **Figure 5-1** shows the distribution of CV-SALTS data from various primary datasets.

Table 5-3 shows a summary of the data available from CV-SALTS. The GAMA-EDF portion of the dataset contains primarily monitoring data from environmental cleanup sites and other facilities regulated by the Water Boards. Monitoring at these facilities is likely to contain anomalously high values that are representative of localized contamination where the potentially responsible party is already identified. The GAMA-EDF dataset would therefore only be useful if it could be filtered for wells at the facilities that do represent ambient, baseline conditions where irrigated agriculture may be contributing source. The information needed for this filtering was not readily available. Therefore, the GAMA-EDF statistics are shown in **0**, but was removed for the purposes of the GAR analysis.

The program which provides the most data in recent decades is the CDPH drinking water program, which started in the early 1980's as shown in **Figure 5-2** and **Figure 5-3**. Before this program, most of the groundwater quality monitoring was done by DWR and USGS. The nature of CDPH data is likely to be different from these earlier sources, since individual drinking water wells that exceed the MCL are likely to be taken off-line and monitoring discontinued when exceedence is observed. Therefore, in interpreting spatial and temporal trends that involve statistical summaries of the data should be interpreted in light of this difference.

5.3.2 Review of Pesticide Datasets

For pesticides, the GeoTracker GAMA dataset was used and filtered only for constituents that came from DPR. A summary of the pesticide monitoring is shown in **Table 5-4**.

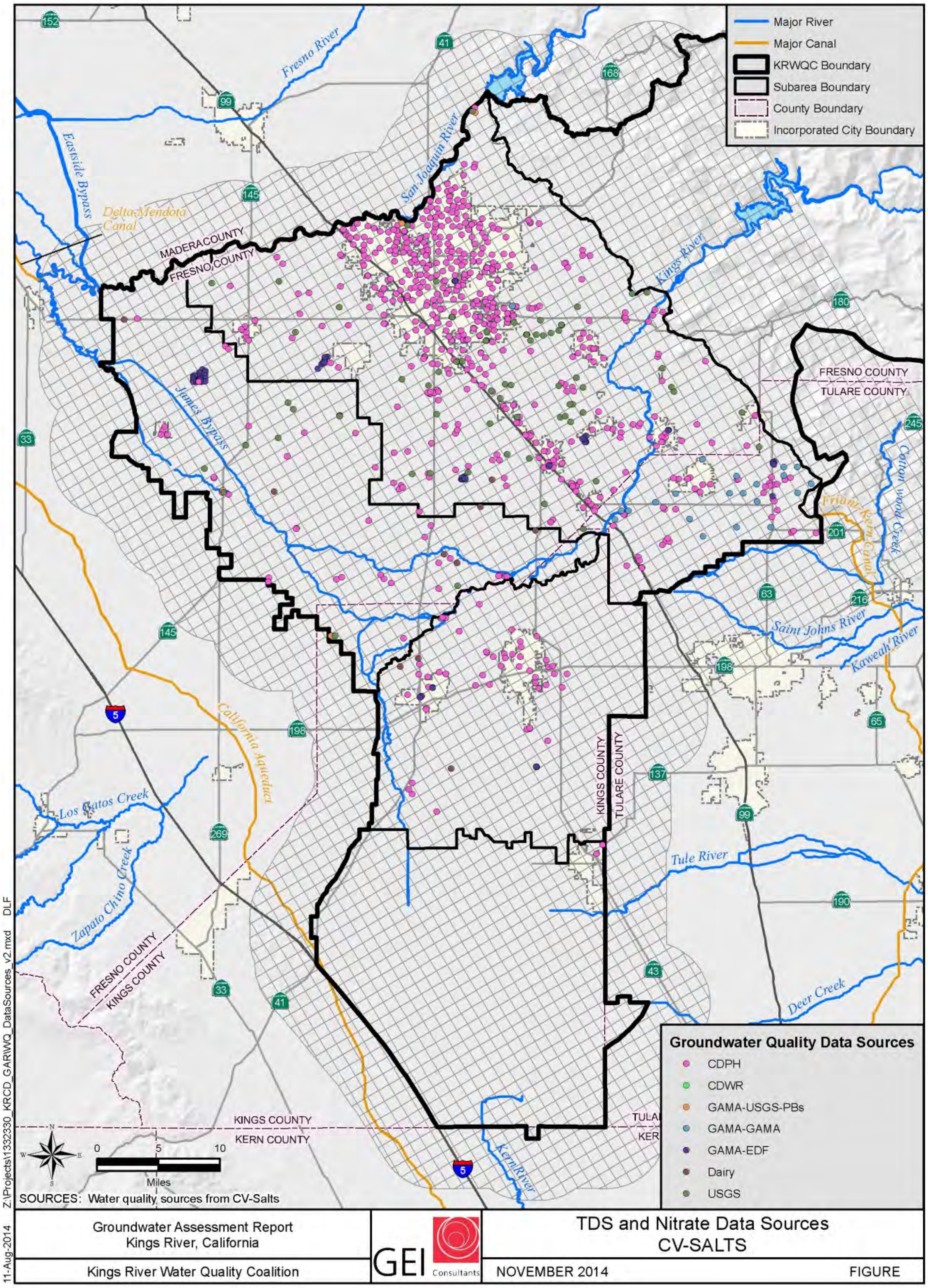

Figure 5-1. Nitrate and TDS Data Sources – CVSALTS

Table 5-3. Summary of Nitrate and TDS data from CV-SALTS

Nitrate as Nitrogen (NO_3 - N)

Monitoring Entity	Number of Wells	Number of Samples	Wells in Shallow Zone	Wells in Deep Zone	Wells in Unknown Zone	Wells with Results over 5mg/L (as N)	Wells with Results over 10mg/L (as N)	Wells with Results over 20mg/L (as N)	T0 (pre-1976)		T1 (1976-1985)		T2 (1986-1995)		T3 (1996-2005)		T4 (2006-2014)	
									Wells	Samples	Wells	Samples	Wells	Samples	Wells	Samples	Wells	Samples
CDPH	920	29,279	0	920	0	314	126	36	0	0	161	164	337	1,101	667	10,235	848	17,779
CDWR	1,200	1,983	0	52	1,148	509	243	111	950	1,471	298	415	52	96	1	1	0	0
GAMA-USGS-PBs	38	38	0	38	0	7	2	1	0	0	0	0	0	0	34	34	4	4
GAMA-GAMA	22	22	0	22	0	1	0	0	0	0	0	0	0	0	0	0	22	22
GAMA-EDF	172	916	172	0	0	71	48	30	0	0	0	0	0	0	101	323	115	593
Dairy	533	1,089	310	223	0	223	137	55	0	0	0	0	10	10	104	359	473	720
USGS	265	443	118	130	17	78	51	23	11	11	19	19	182	211	81	119	60	83
Total	**3,150**	**33,770**	**600**	**1,385**	**1,165**	**1,203**	**607**	**256**	**961**	**1,482**	**478**	**598**	**581**	**1,418**	**988**	**11,071**	**1,522**	**19,201**

Total Dissolved Solids (TDS)

Monitoring Entity	Number of Wells	Number of Samples	Wells in Shallow Zone	Wells in Deep Zone	Wells in Unknown Zone	Wells with Results over 500 mg/L	Wells with Results over 1000 mg/L	Wells with Results over 2000 mg/L	T0 (pre-1976)		T1 (1976-1985)		T2 (1986-1995)		T3 (1996-2005)		T4 (2006-2014)	
									Wells	Samples	Wells	Samples	Wells	Samples	Wells	Samples	Wells	Samples
CDPH	793	5,789	0	793	0	145	32	18	0	0	166	167	325	782	526	2,178	714	2,662
CDWR	1,399	2,374	0	52	1,347	233	96	60	1,123	1,806	309	424	98	143	1	1	0	0
GAMA-USGS-PBs	64	66	0	64	0	9	7	5	0	0	0	0	0	0	61	62	4	4
GAMA-GAMA	22	22	0	22	0	5	1	0	0	0	0	0	0	0	0	0	22	22
GAMA-EDF	85	604	85	0	0	20	3	2	0	0	0	0	0	0	45	81	74	523
Dairy	96	423	96	0	0	36	15	10	0	0	0	0	0	0	95	343	42	80
USGS	371	609	140	203	28	95	44	34	15	15	24	34	187	232	153	207	86	121
Total	**2,830**	**9,887**	**321**	**1,134**	**1,375**	**543**	**198**	**129**	**1,138**	**1,821**	**499**	**625**	**610**	**1,157**	**881**	**2,872**	**942**	**3,412**

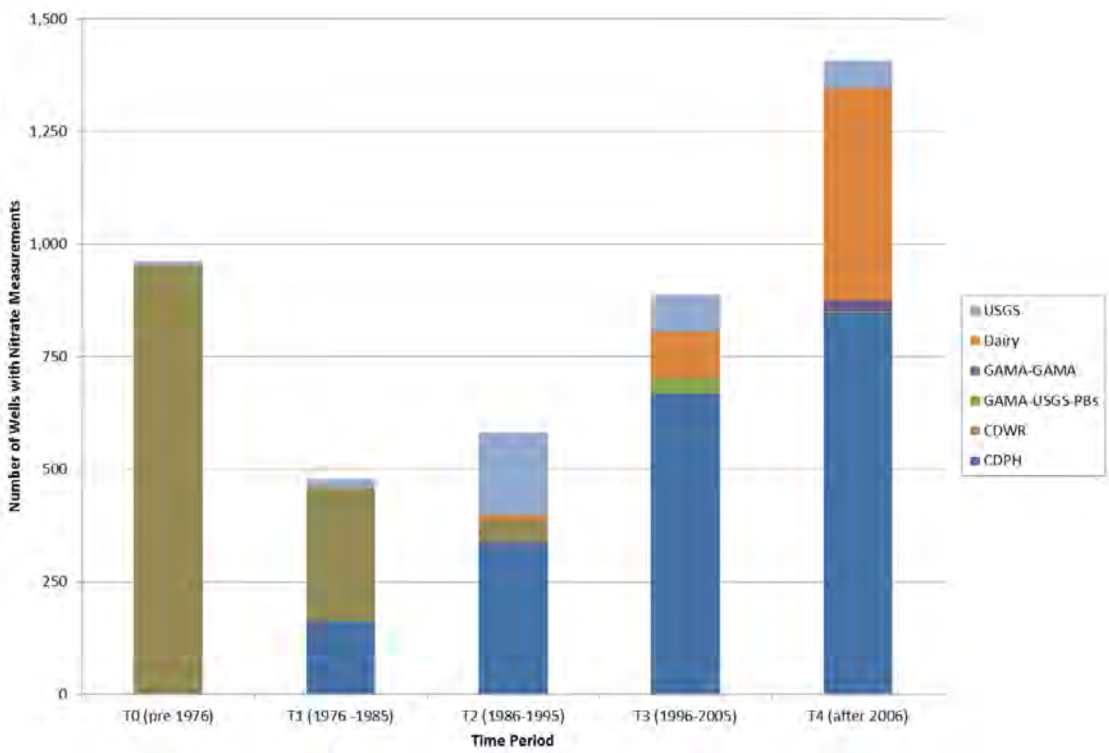

Figure 5-2. Well Inventory - NO_3

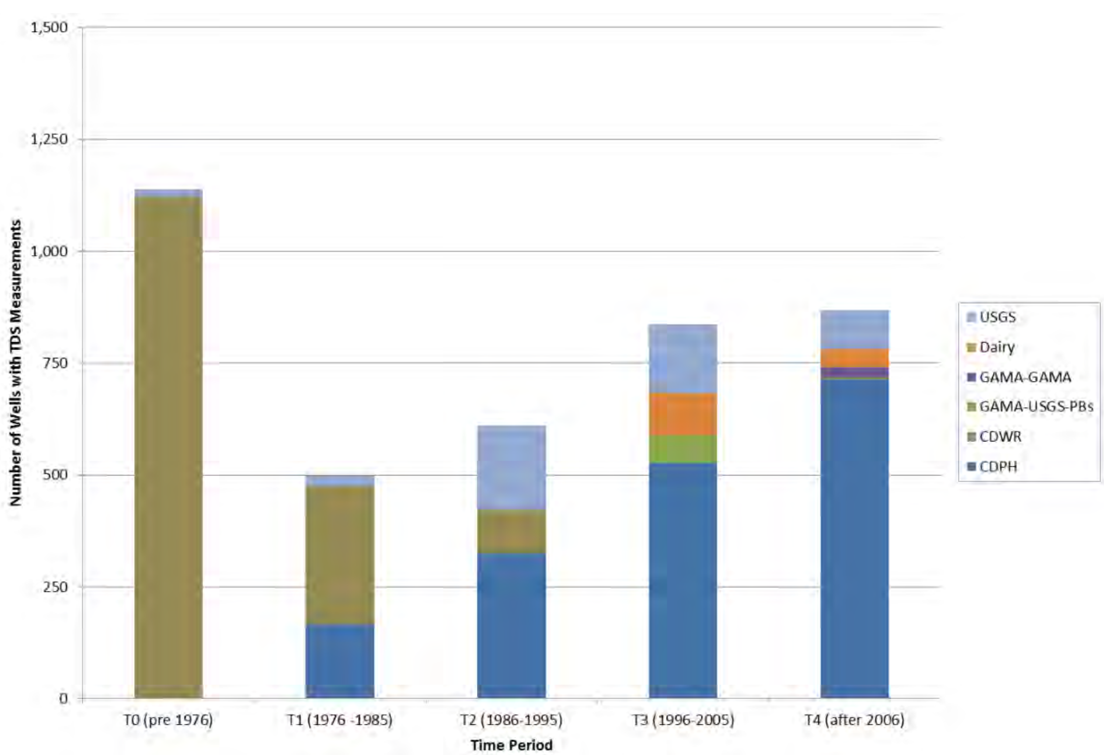

Figure 5-3. Well Inventory - TDS

Table 5-4. Summary of Pesticide Results

Pesticide	Total Number of Samples	Total Number of Detections[1]	Total Number of Exceedances[2]	Number of Wells Sampled	Number of Wells With Detections[1]	Number of Wells With Exceedances[2]
Alachlor	2,555	381	2	645	259	2
Aldicarb	897	147	30	484	136	23
Aldicarb sulfone	793	64	23	427	56	18
Aldicarb sulfoxide	792	63	1	426	55	1
Atrazine	4,703	873	497	1,477	472	265
Azinphos methyl	89	86	0	88	85	0
gamma-BHC (Lindane)	1,059	292	120	438	243	89
Bromomethane	10,582	605	0	692	363	0
Bromacil	3,779	624	0	1,386	239	0
Bentazon	1,092	431	0	405	245	0
Chlordane	1,042	141	137	409	109	106
Carbofuran	1,109	221	12	484	173	12
Cyanazine	645	64	0	436	63	0
Cypermethrin	64	62	0	63	61	0
1,2-Dibromo-3-chloropropane	18,822	15,089	5,545	762	633	242
1,2-Dichlorobenzene	10,762	614	0	721	357	0
1,3-Dichloropropene	10,577	464	338	662	232	171
1,2-Dichloropropane	10,716	665	6	706	349	3
DDD	39	34	0	38	33	0
DDE	517	501	0	292	279	0
DDT	41	36	0	40	35	0
Diethanolamine (DEA)	1,190	65	0	418	22	0
Diazinon	1,735	620	0	576	443	0
Dicamba	632	64	0	394	58	0
Dichlorvos	66	62	0	65	61	0
Dicofol	73	66	0	73	66	0
Dimethoate	2,043	706	0	597	486	0
Diuron	2,107	872	0	1,020	300	0
1,2-Dibromoethane	16,308	3,490	621	762	523	103
S-Ethyl dipropylthiocarbamate	636	553	0	388	343	0
Fenamiphos	127	81	0	125	80	0
Heptachlor	1,045	143	135	410	111	105
Heptachlor epoxide	1,044	142	134	409	110	104
Hexazinone	1,324	71	0	539	68	0
Linuron	52	35	0	48	35	0
Metalaxyl	100	97	0	66	63	0
Metolachlor	1,949	1,356	0	583	539	0
Metribuzin	2,389	1,354	0	932	538	0
Molinate	2,570	308	0	574	200	0
Methoxychlor	1,072	306	0	439	249	0
Naled	29	25	0	29	25	0
Naphthalene	10,372	685	0	638	263	0
Napropamide	35	13	0	35	13	0
Norflurazon	1,053	213	0	301	76	0
Methyl parathion	78	72	0	78	72	0
Prometon	1,819	149	0	969	119	0
Prometryn	2,043	277	0	919	181	0
Propargite	70	66	0	69	65	0
Simazine	5,011	1,984	0	1,522	726	0
Thiobencarb	2,092	310	0	572	202	0
Toxaphene	1,070	309	14	432	243	14
Xylene(s)	10,692	2,092	0	715	590	0
Total	**151,501**	**38,043**	**7,615**	**25,778**	**11,347**	**1,258**

[1] Measurements greater than 0.
[2] Measurements above the DPH or EPA Maximum Contaminant Level

5.4 NITRATES

5.4.1 Indicators

The Kings GAR uses the CVSALTS protocols for data conversion and reporting. Samples originally reported as Nitrate as Nitrate were converted to Nitrate as Nitrogen by dividing by 4.4268. All data used in the GAR analysis used Nitrate as Nitrogen in mg/L. The primary drinking water standard (MCL) of 10 mg/L was used as an indicator.

5.4.2 Natural Occurrence

Nitrate occurs naturally in many groundwater basins but at levels far below the regulatory maximum contaminant level (MCL) for drinking water. Natural or "background" nitrate concentrations below 2 mg/L (as nitrogen) are generally considered background (Mueller, 1996). The main potential sources of naturally occurring nitrate are bedrock nitrogen and nitrogen leached from natural soils. Surface water nitrate concentrations can be elevated in areas with significant bedrock nitrogen (Holloway, (1998), but they are not high enough to be a drinking water concern (UCDAVIS, 2012).

5.4.3 Spatial Distribution

Figure 5-4 shows Nitrate exceedances in the GAR area. An exceedance is any well with at least one measurement at or above the MCL of 10 mg/L. Nitrate exceedances are concentrated in areas outside of urban areas. The municipals wells for the cities tend to be screened at greater depths in the aquifer and any wells with exceedances are likely to cease operations unless the water is treated or blended to meet standards. Noticeably, the Fresno urban area has few exceedances except for around the perimeter of the city limits. These perimeter areas have had higher concentration of septic systems as shown in **Figure 4-57**. Other areas where exceedances are concentrated are in the Dinuba area and extending westward toward where the Kings River splits with branches toward the Delta-Mendota Canal and Tulare Lake. There are few wells in the Tulare Lake Bottom subarea.

Figure 5-5 shows Box and Whisker Plots by subarea for the period 2006-2014. Nitrate values tend to be lower and less variable in the Upper Kings Subarea. There are few wells in the Tulare Lake Bottom subarea, and no municipal wells. Based on the available data, only the South Kings subarea has a mean near the drinking water standard (10.0 mg/l) as identified by data from available wells (301 wells) for the period from 2006-2014.

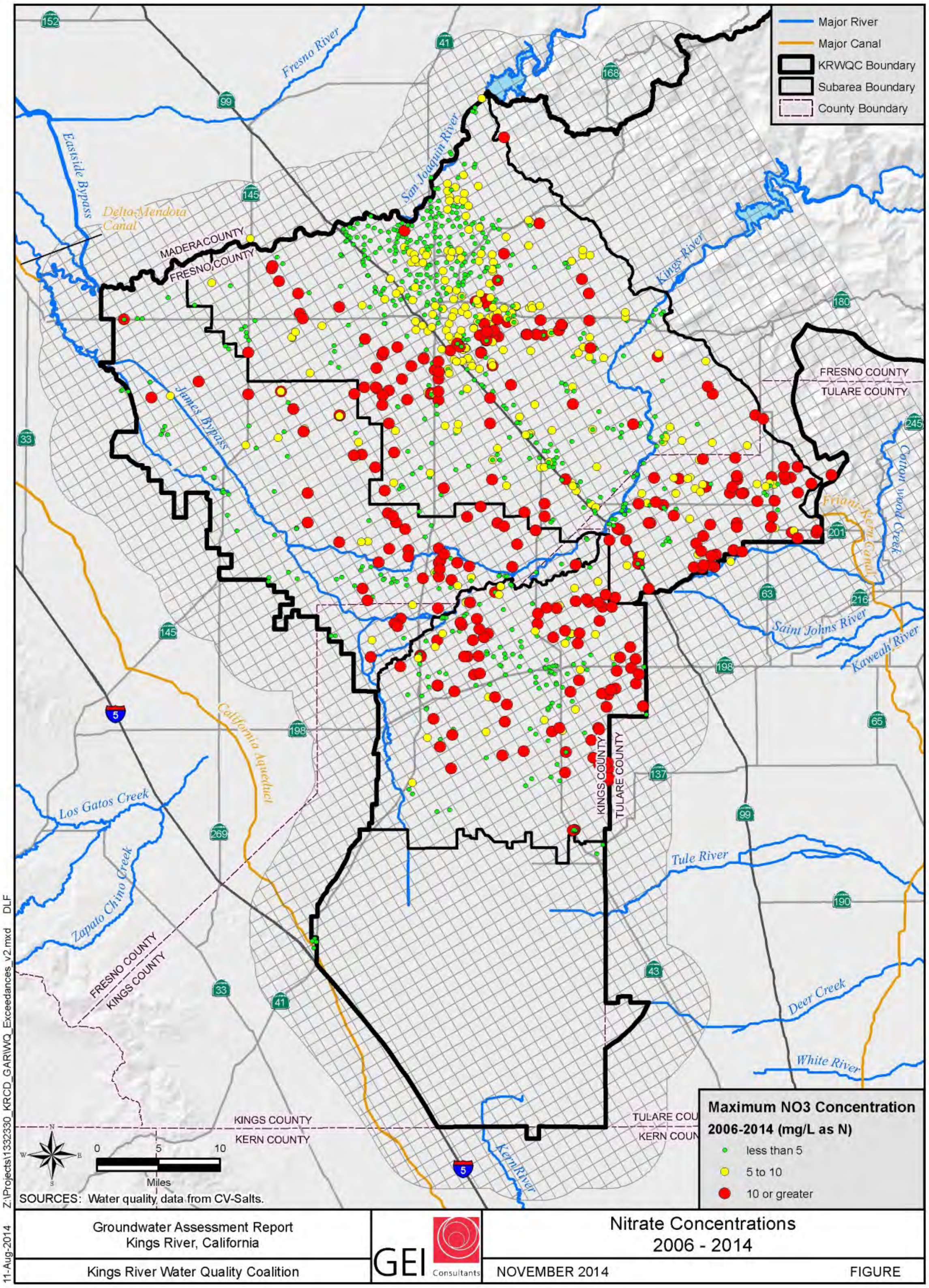

Figure 5-4. Nitrate Concentrations 2006-2014

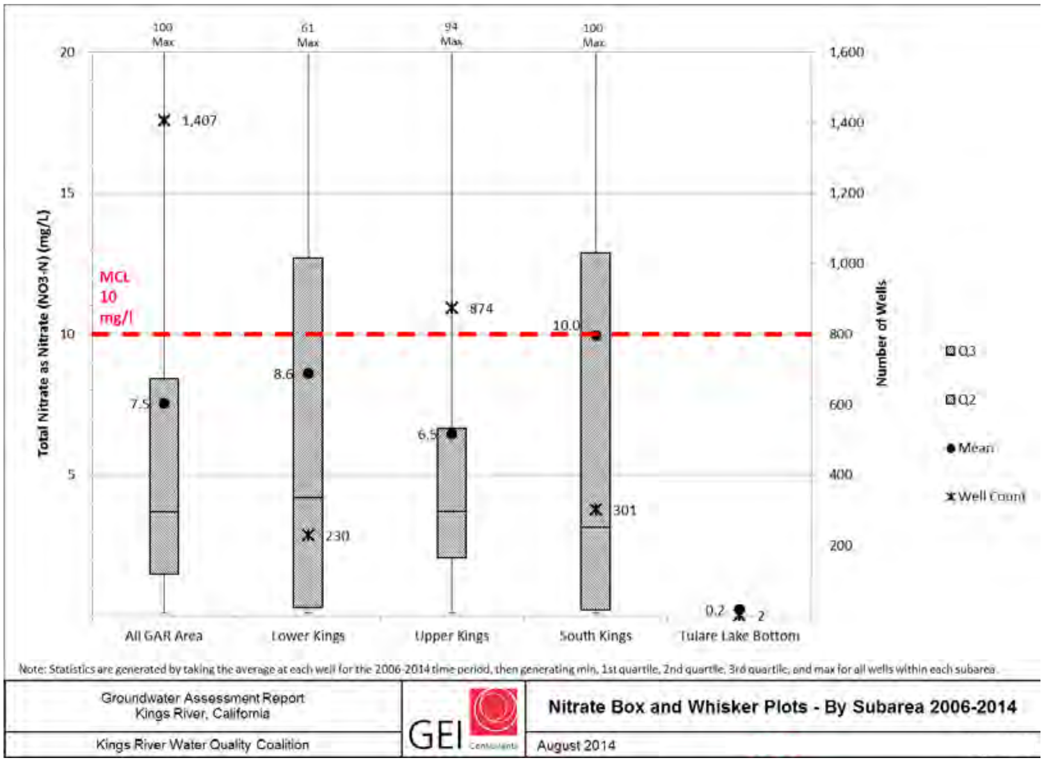

Figure 5-5. Nitrate Box and Whisker Plots - By Subarea 2006-2014

5.4.4 Temporal Trends

Figure 5-6 shows wells within the coalition that had long-term records dating back to the 1980's. Wells within the Upper Kings subarea tend to indicate increasing trends of Nitrate as shown by the blue line in the chemographs of wells 91, 657, and 984. However, no change and decreasing trends over time exist within the City of Fresno as shown at wells 72 and 289. The chemographs for the Lower Kings and South Kings have much lower Nitrate levels which remain constant with time. However, the depth designations assigned by CVSALTS is not sufficient to determine if the wells are above or below the Corcoran Clay. Well logs showing construction detail are not readily available and are not in the public domain. Wells above the Corcoran may have a different trend than shown in **Figure 5-6**.

When the data is aggregated in time periods and statistically analyzed the regional trends are less apparent than at individual wells. **Figure 5-7**, **Figure 5-8**, and **Figure 5-9** show box and whisker plots for different time periods in the Upper Kings, Lower Kings, and South Kings, respectively. The mean for the time periods shown does not indicate a consistent upward trend for nitrates based on the aggregated data.

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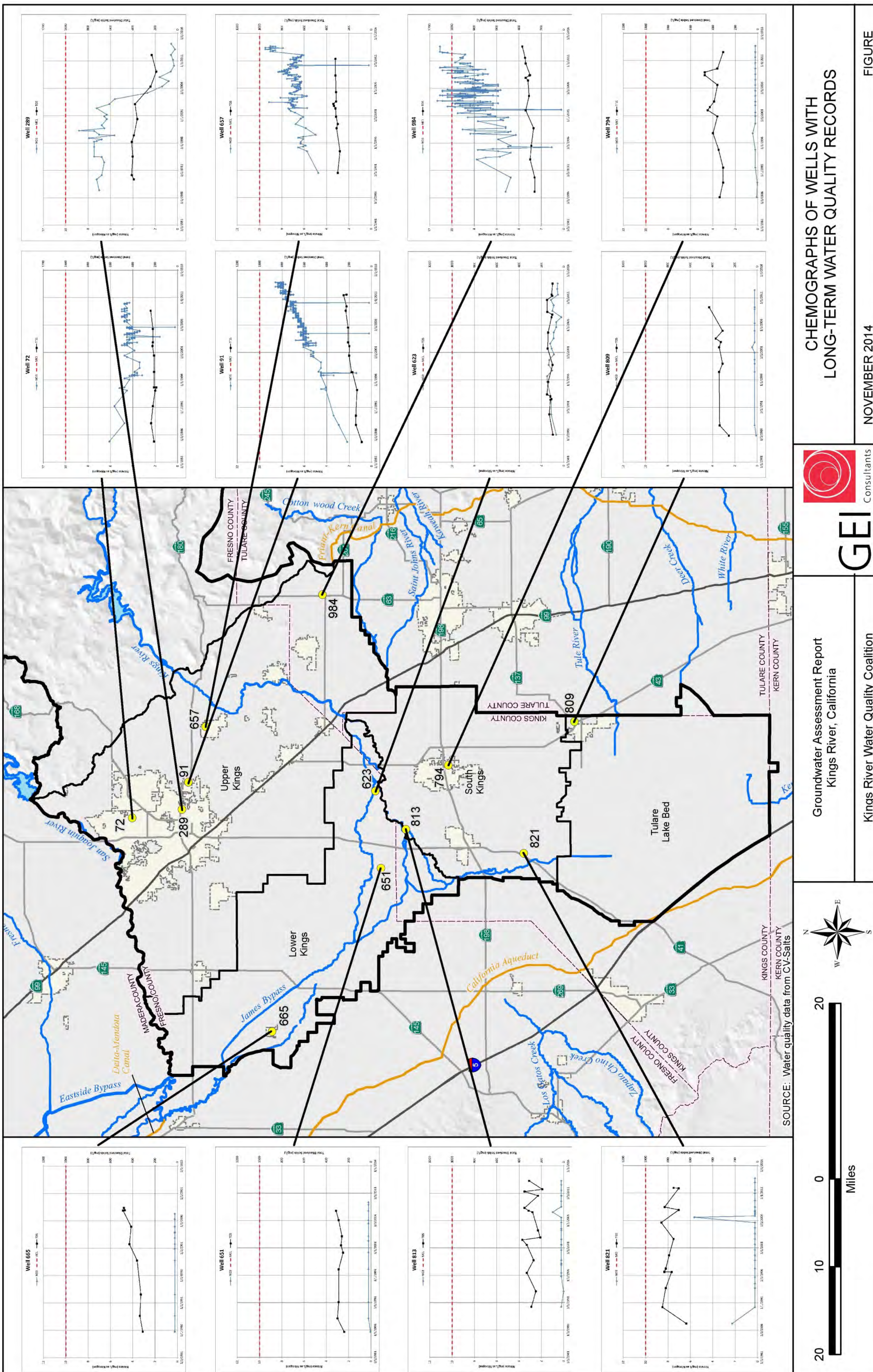

Figure 5-6. Wells with Long-term Water Quality ecords

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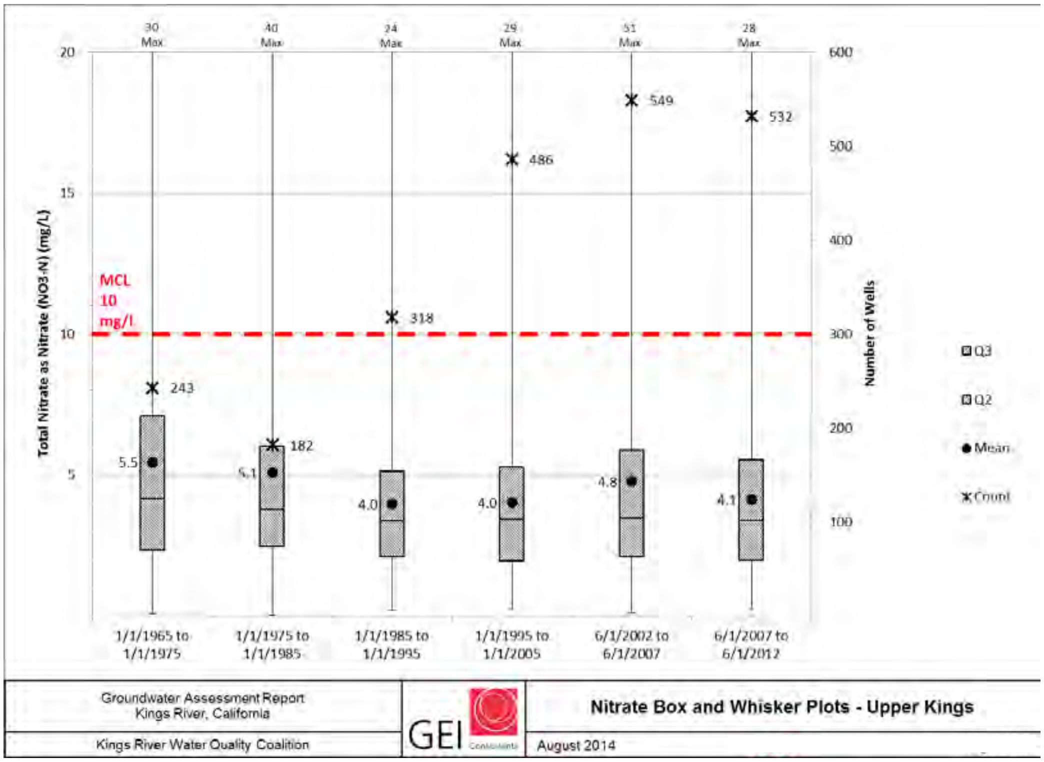

Figure 5-7. Nitrate Box and Whisker Plot for Upper Kings

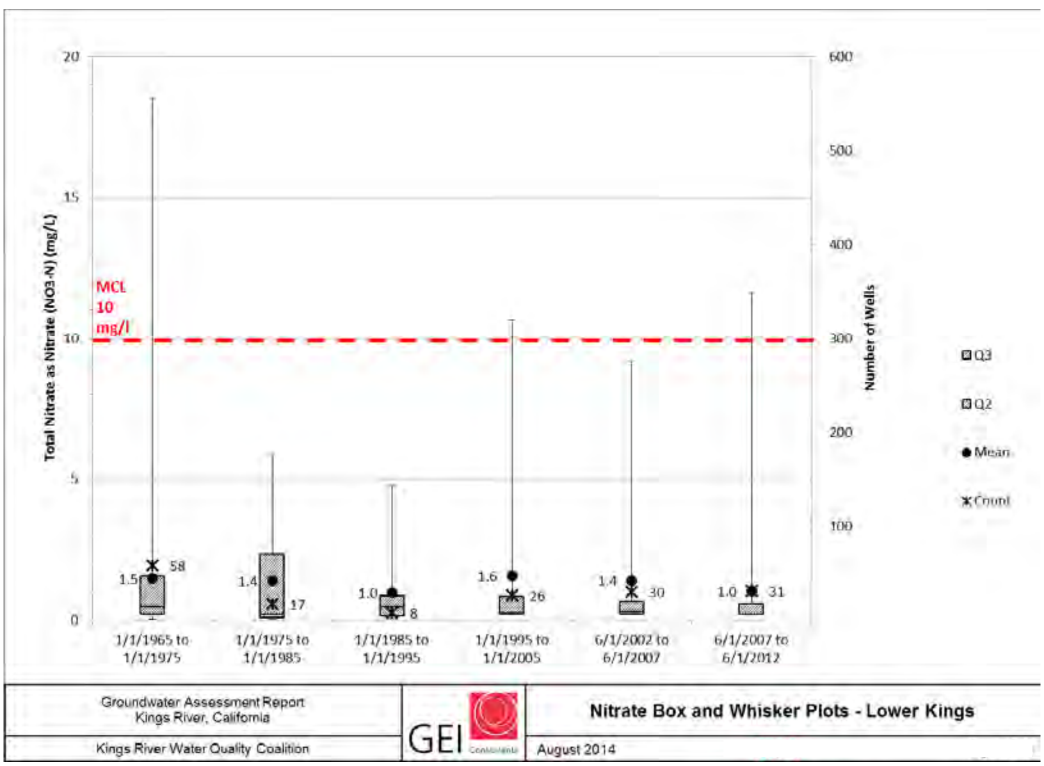

Figure 5-8. Nitrate Box and Whisker Plot for Lower Kings

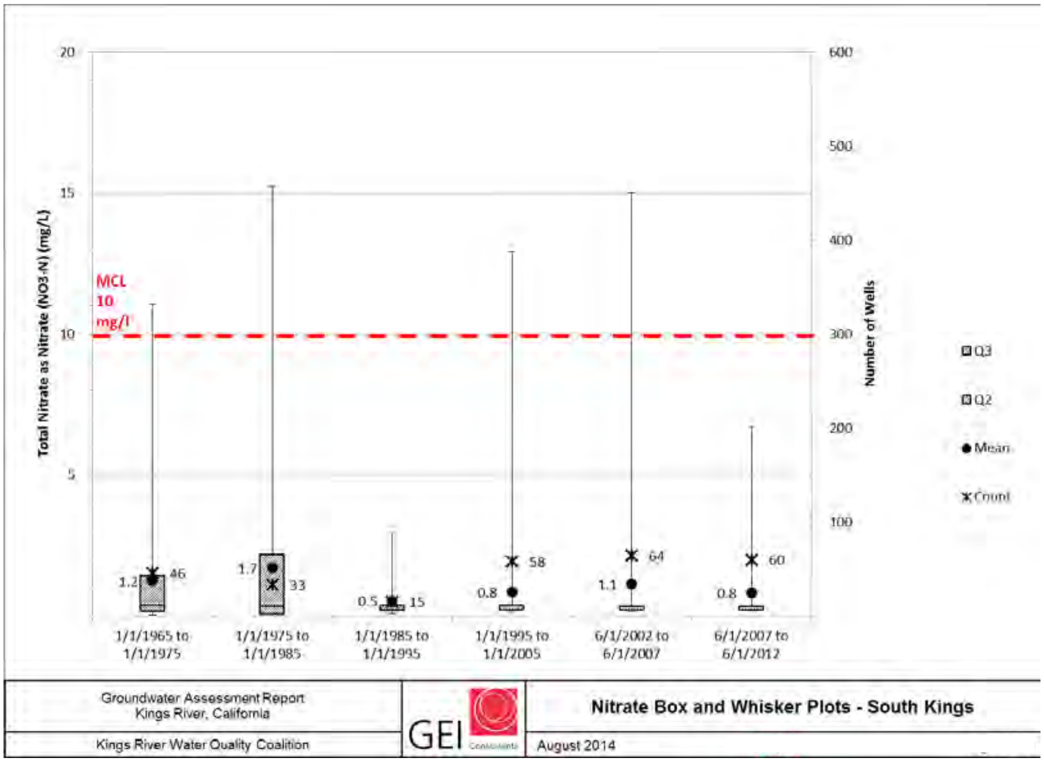

Figure 5-9. Nitrate Box and Whisker Plot for South Kings

Average nitrate concentrations were also aggregated for wells that had measurements in both T3 (1995-2005) and T4 (2006-2014). **Figure 5-10** shows the change in average concentrations between these two timeframes and indicates that increases are consistently occurring in the Upper Kings subarea, especially in the eastern part of the subarea. Wells in the City of Fresno tend to be more variable, but this could be related to the variability in the depth of wells. Wells in the Lower Kings and South Kings subareas generally show no significant change, or show both increases and decreases in the same area. **Table 5-5** shows a summary of the results and confirms that a higher percentage of wells are increasing in the Upper Kings, where increases and decreases are about equal in the other subareas.

Table 5-5. Summary of changes in average Nitrate concentrations between T3 and T4

Change	Overall GAR Area		Lower Kings		Upper Kings		South Kings		Tulare Lake Bottom	
(mg/L as N)	# wells	% wells	# wells	% wells	# wells	% wells	# wells	% wells	# wells	% wells
Increase >0.5	230	33%	16	28%	204	36%	10	12%	0	0%
Decrease >0.5	119	17%	14	25%	95	17%	10	12%	0	0%
No Change	357	51%	27	47%	266	47%	63	76%	1	100%
Total	**706**	**100%**	**57**	**100%**	**565**	**100%**	**83**	**100%**	**1**	**100%**

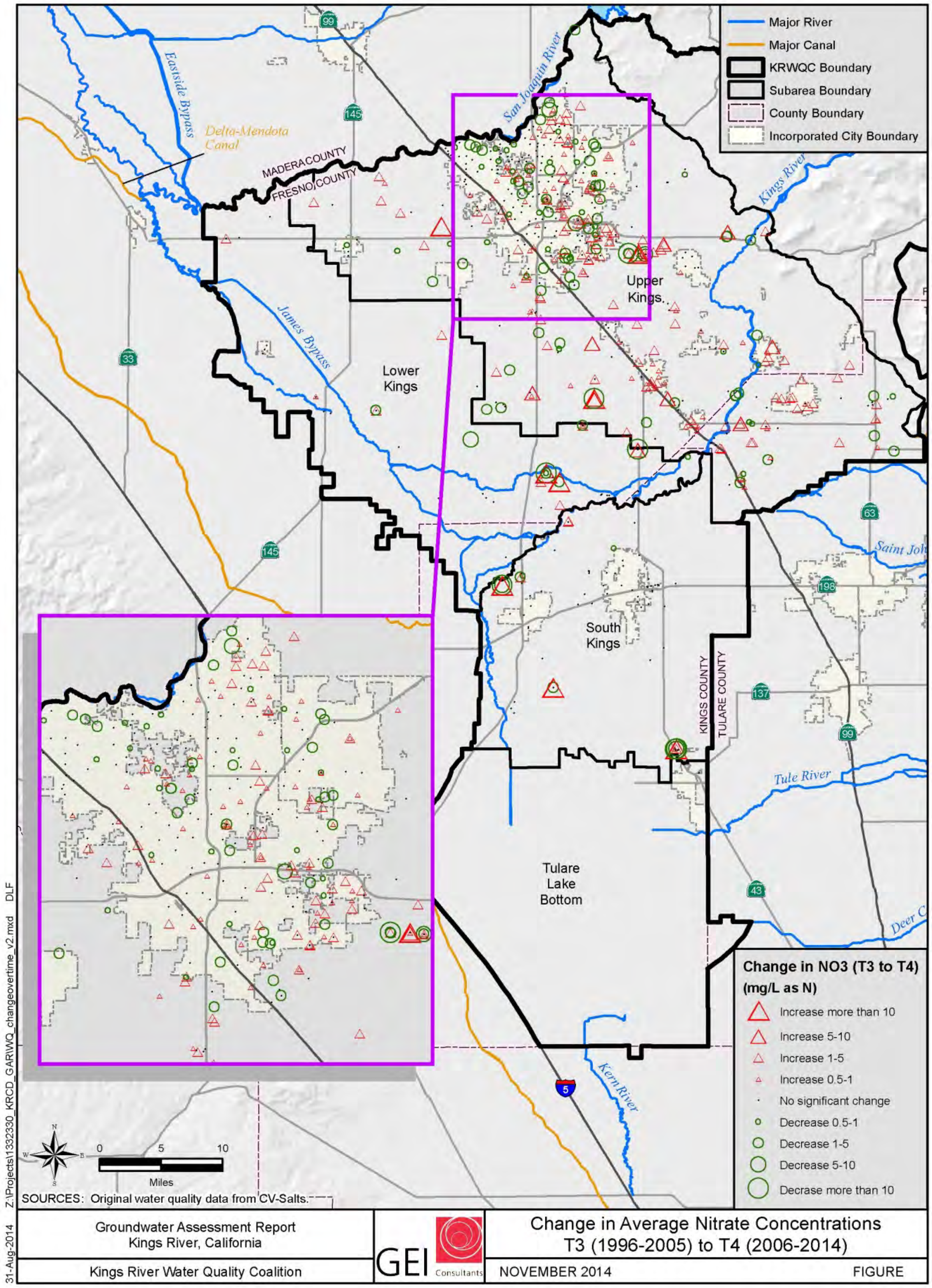

Figure 5-10. Change in average nitrate concentrations T3 to T4

5.5 Salinity

5.5.1 Indicators

The Kings GAR uses the CV-SALTS protocols for data conversion and reporting. Original data that was reported as Electrical Conductivity (EC) or Specific Conductance (SC) were converted to TDS by multiplying by 0.64. All water quality data used in the GAR analysis used the equivalent measurement in TDS in mg/L.

Fresh water suitable for water supply needs is defined as having a TDS measurement of less than 1,000 mg/L. Higher levels are defined as brackish and saline. The primary drinking water standard of 1,000 mg/L is used as an indicator.

5.5.2 Natural Occurrence

Saline and connate water can be found within the fresh water-bearing continental deposits; most saline and connate water is below the fresh water. This saline water comes from a variety of potential sources, including upward migration of old marine water (present during the deposition of the marine sediments) or through the process of evaporative concentration. The marine sediments that make up the Coastal Ranges naturally contain a variety of constituents that are of concern in surface and groundwater within the Central Valley. Through dissolution of the marine sediments, minerals and ions are released, and water flowing through such sediments increases in TDS (UCDAVIS, 2012). This has consequentially led to elevated TDS levels in much of the western side of the Coalition area.

5.5.3 Spatial Distribution

Figure 5-11 shows that overall there are relatively few TDS exceedances in the GAR area. There are few exceedances are in the Upper Kings subarea, with most of the TDS exceedances occurring in the Lower Kings and South Kings subareas. Both of these areas tend to have saline soils as shown in **Figure 4-23** of **Chapter 4**.

Figure 5-12 shows TDS Box and Whisker Plots for each subarea during the period from 2006-2014, indicating a clear distinction in TDS concentrations between the Upper Kings subarea and the Lower Kings and South Kings subareas, with the Upper Kings having lower TDS. The Lower Kings and South Kings have higher TDS for the time period shown and are likely as a result of the naturally occurring TDS found in the central part of the Coalition area in the Valley bottom.

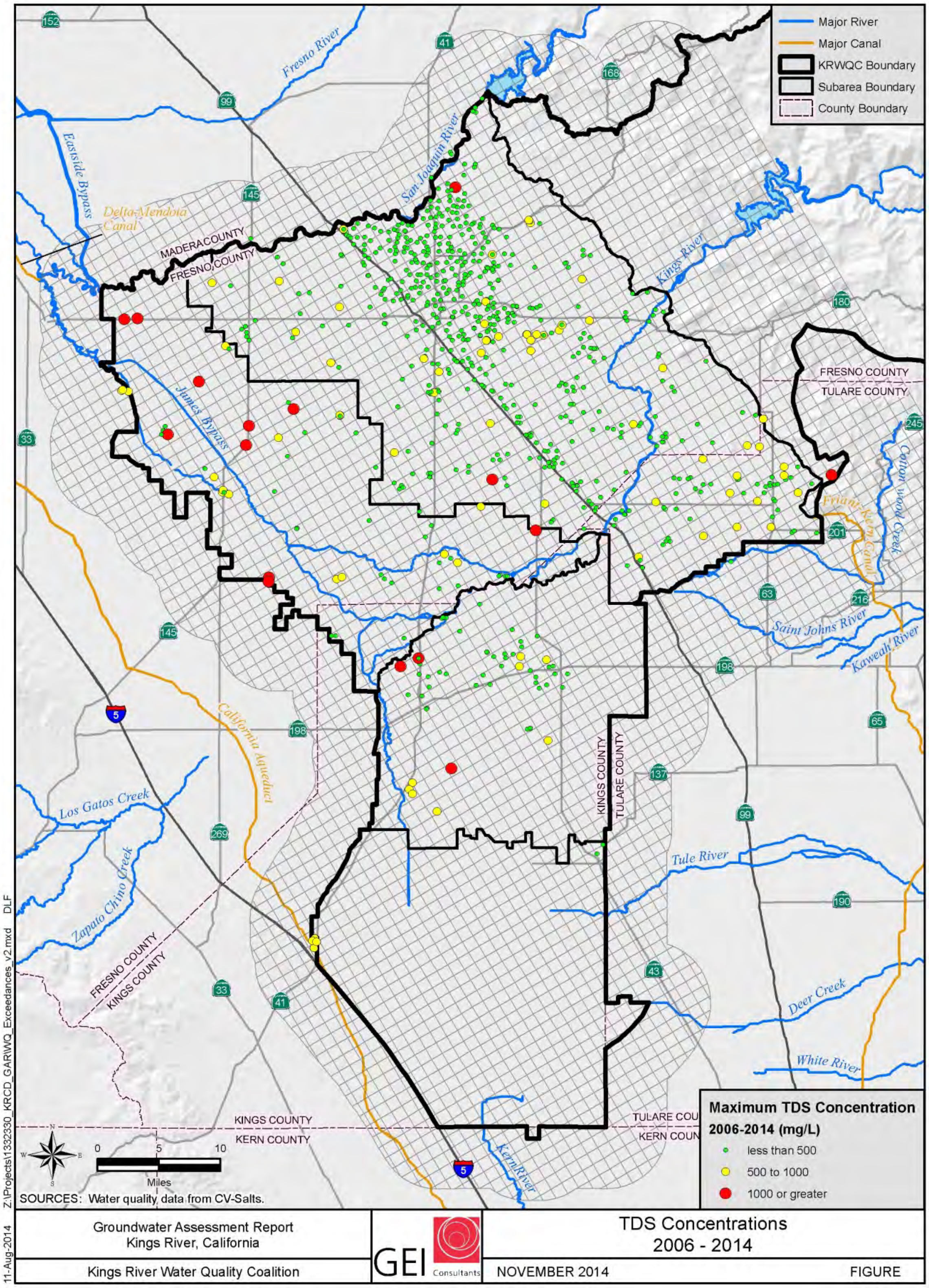

Figure 5-11. TDS Exceedances 2006-2014

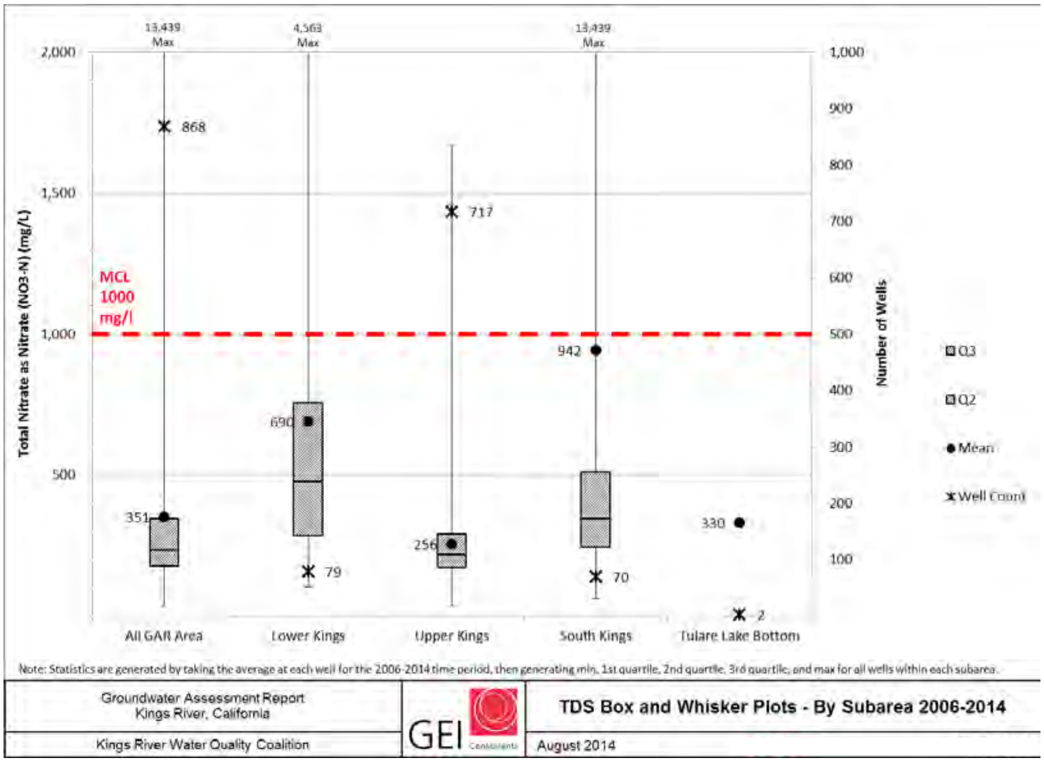

Figure 5-12. TDS Box and Whisker Plots – By Subarea 2006-2014

5.5.4 Temporal Trends

Figure 5-6 shows wells within the coalition that had long-term records dating back to the 1980's. Wells within the Upper Kings subarea tend to show similar TDS trends (shown by the black line on chemographs) as the nitrate trends discussed in **Section 5.4.4**. The chemographs for the Lower Kings and South Kings have TDS levels which are relatively constant with time, except at well 665 near James Bypass, which is trending upwards. But again, the depths of the wells in relation to the Corcoran Clay are not known and the upper parts of the aquifer may have different trends than shown in **Figure 5-6**.

Figure 5-13, **Figure 5-14**, and **Figure 5-15** present the box and whisker plots for the Upper Kings, Lower Kings and South Kings, respectively, with data aggregated for different time periods to evaluate temporal trends. For the Upper Kings and South Kings, there are no consistent trends in the mean concentration over time. The number of samples in the Upper Kings has increased over time but there is relative stability in the mean TDS. The Lower Kings shows a recent increase in mean TDS concentrations from the 1995-2005 timeframe to the 2007-2012 timeframe. However, the sample size was not large enough (14-55 wells) to make statistically meaningful interpretations.

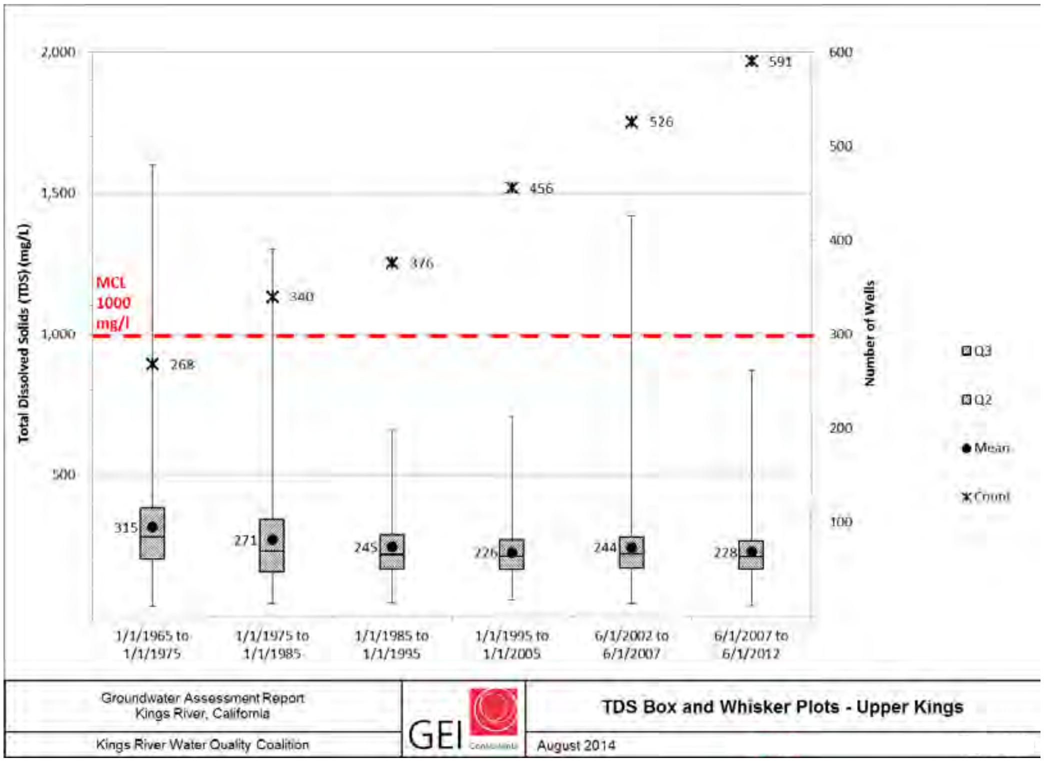

Figure 5-13. TDS Box and Whisker Plots for Upper Kings

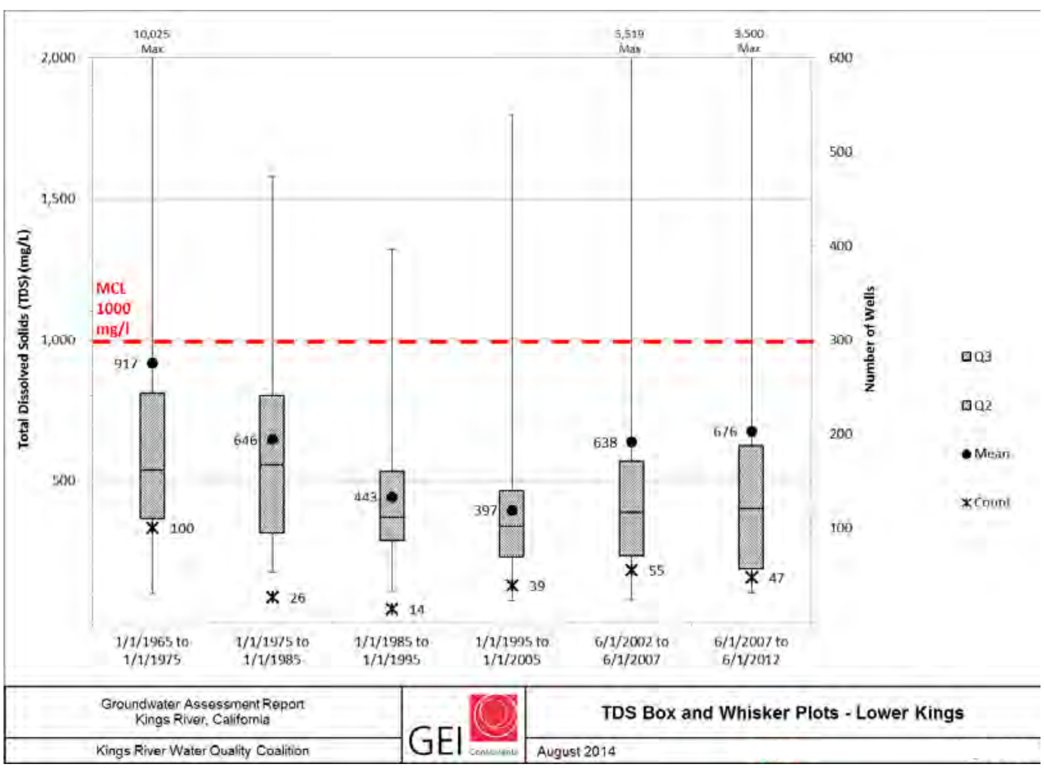

Figure 5-14. TDS Box and Whisker Plots for Lower Kings

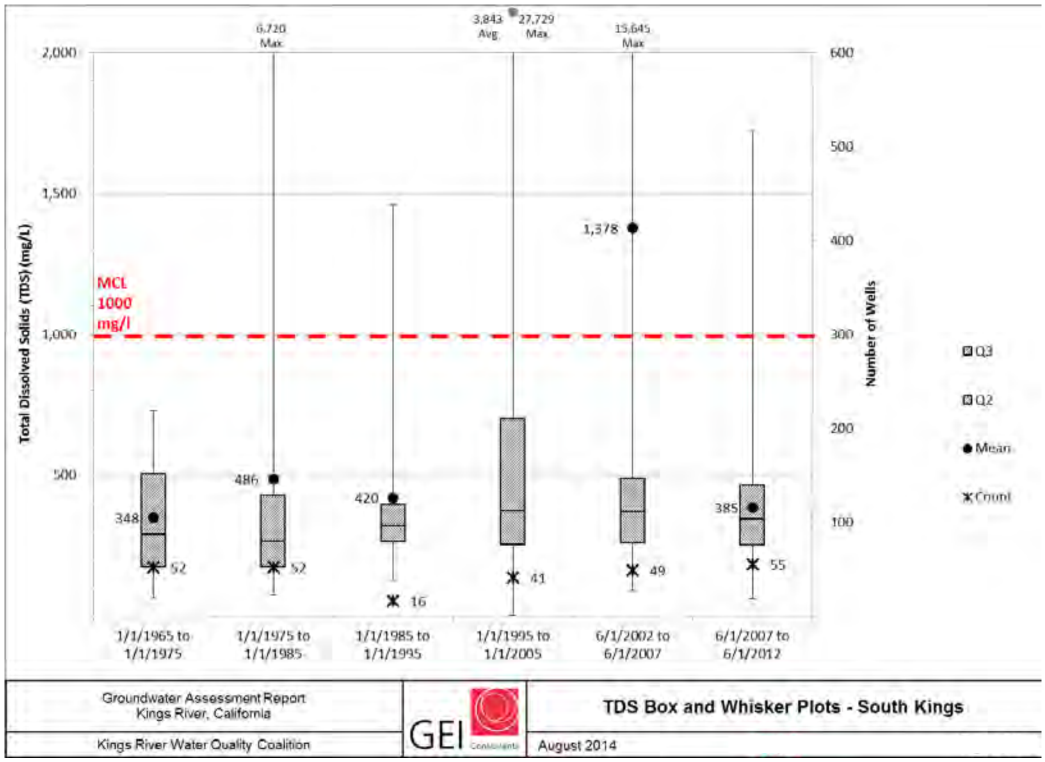

Figure 5-15. TDS Box and Whisker Plots for South Kings

Average TDS concentrations were also aggregated for wells that had measurements in both T3 (1995-2005) and T4 (2006-2014). **Figure 5-16** shows the change in average concentrations between these two timeframes and indicates that there is a great amount of variability in TDS changes in each subareas. **Table 5-6** shows a summary of the results and shows more clearly that a higher percentage of wells are increasing in the Upper Kings and Lower Kings, where the difference between increasing and decreasing trends is not significant in the South Kings where only 42 wells had data from the two timeframes.

Table 5-6. Summary of changes in average TDS concentrations between T3 and T4

Change	Overall GAR Area		Lower Kings		Upper Kings		South Kings		Tulare Lake Bottom	
(mg/L)	# wells	% wells	# wells	% wells	# wells	% wells	# wells	% wells	# wells	% wells
Increase >25	157	28%	19	43%	125	27%	12	29%	1	100%
Decrease >25	99	18%	14	32%	74	16%	11	26%	0	0%
No Change	296	54%	11	25%	266	57%	19	45%	0	0%
Total	**552**	**100%**	**44**	**100%**	**465**	**100%**	**42**	**100%**	**1**	**100%**

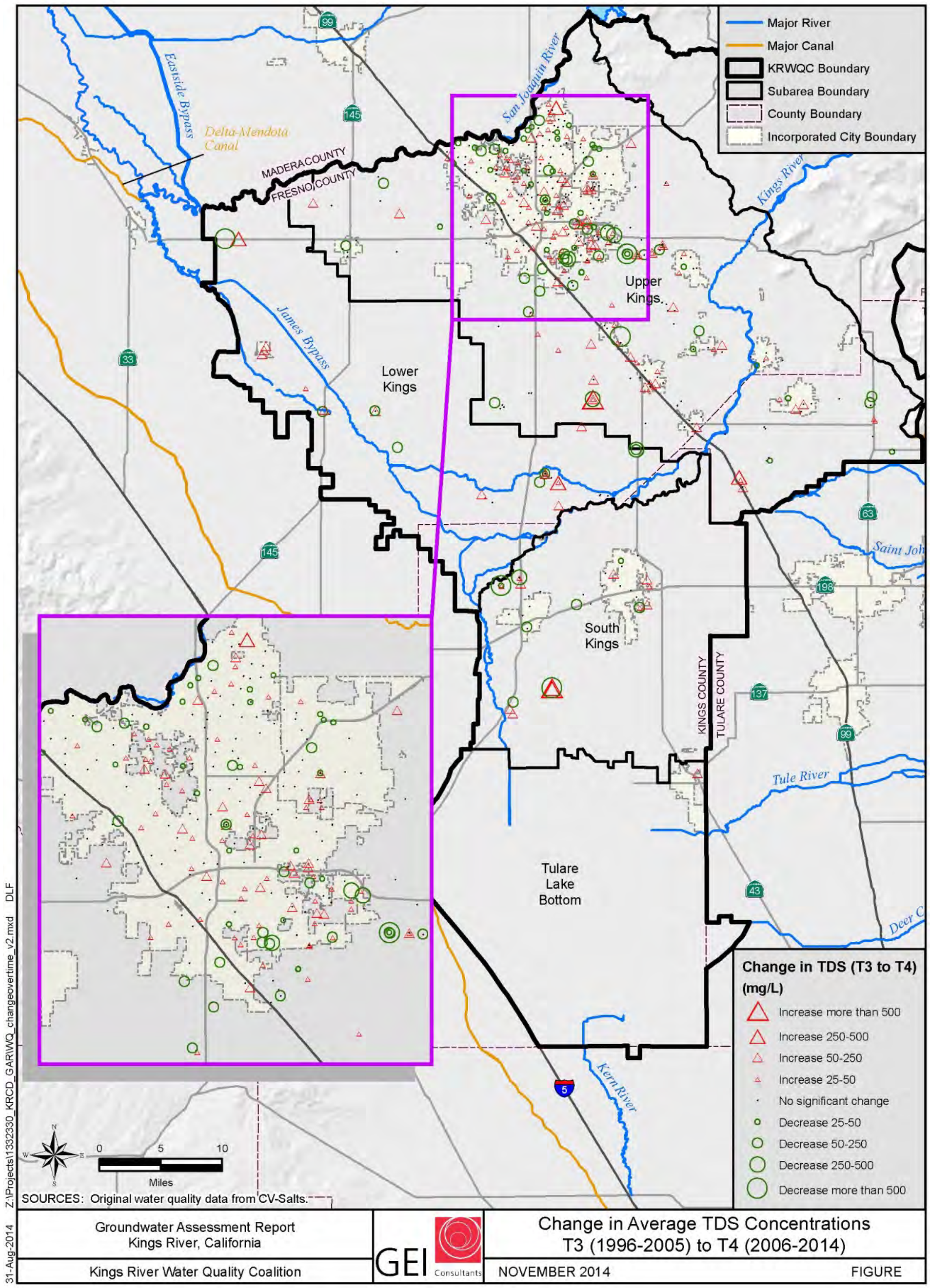

Figure 5-16. Change in average TDS concentrations T3 to T4

5.6 PESTICIDES

5.6.1 Indicators

The exceedance thresholds were shown in **Table 5-2**. All pesticide water quality data used in the GAR analysis was measured in micrograms per liter (ug/L).

5.6.2 Natural Occurrence

Pesticides are generally not found in nature in high detectable concentrations. Therefore, it is assumed that all occurrences of pesticides have an anthropogenic source.

5.6.3 Spatial Distribution

Figure 5-17 shows the Pesticide exceedances. Most of these exceedances are concentrated in the Upper Kings subarea and correspond largely to the areas designated by the Department of Pesticide Regulation as groundwater protection areas.

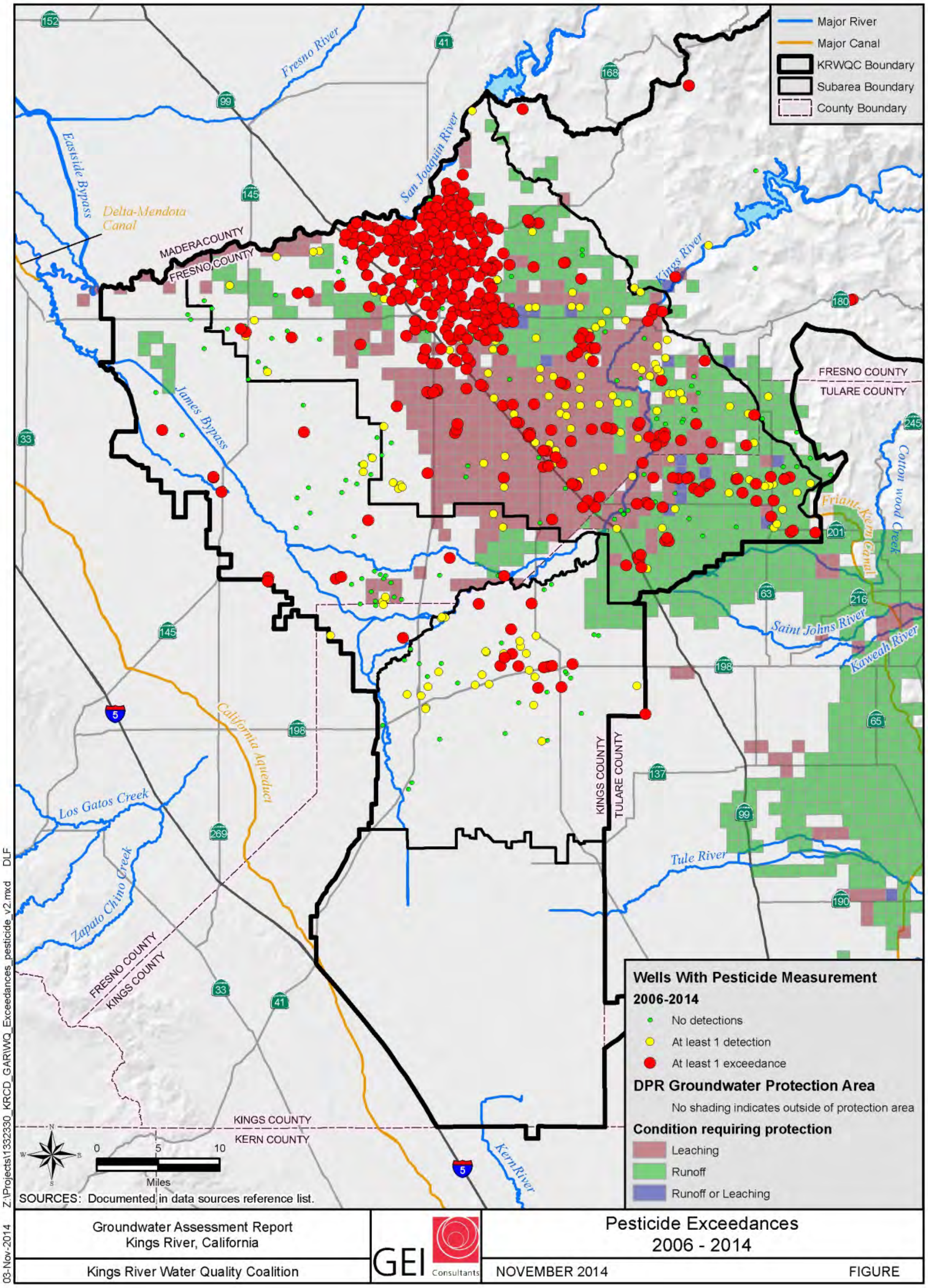

Figure 5-17. Pesticide Exceedances 2006-2014

Chapter 6. Groundwater Vulnerability Analysis

Chapter 6. Groundwater Vulnerability Analysis

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Chapter 6. Groundwater Vulnerability Analysis

6.1 INTRODUCTION

As noted in **Chapter 1 – Introduction**, a defensible groundwater vulnerability assessment follows proven scientific methods and includes adequate documentation of data, observations, and method of investigation to allow for independently reproducible results. In **Chapter 2 – Conceptual Model & Approach**, Section 2.4, alternative methods of analysis were described along with a brief description of the selected approach used in the vulnerability analysis presented in this chapter.

The purpose of this chapter is to provide the results from the analysis using a data management and analyst tool for assessing relative risk.

6.2 OVERLAY TOOL AND GAR ANALYSIS

The GAR Analyst is not a model, but rather, a tool for numerically, statistically and visually interpreting available data, whether from external modeling or derived from primary data sets. Routines and various utilities are available to convert raw data to Overlay Index Factors. Over time, the database and GAR Analyst can continue to be used by the Coalition to refine the analysis as improved datasets grow over time. Much of the data is also shared with the data used for running more complex deterministic groundwater surface water quality process models, or in deriving probabilistic statistical relationships.

In working with the Coalition, the listed preferences in a data management tool (GAR Analyst) include the following:

- Relational data management system for primary, secondary data sets (map and time series)
- Hybrid computational engine for contouring, calculating applied water and deep percolation, performing grid math
- Open and changeable set of assumptions, ability to weight risk factors
- Compatible with other programs in data sharing and automation
- No licensing requirements
- Data and tool are the clients to use

The Index Overlay tool was developed to;

- Manage the volumes of spatial and time series data (groundwater levels and quality)
- Provide transparency in the data and methods used
- Review primary and secondary datasets for quality and completeness
- Conduct basic statistical operations to ascertain a percentile level of risk associated with each of the overlay risk variables used in the indices

- Incorporate GIS coverage and export GIS coverages
- Support visual presentations of basic time series, interim and final results
- Aggregate data to the CVHM grid
- Provide sequential analysis of risk categories
- Evaluate alternative risk scenarios
- Evaluate the relative risk contributed by each of the risk variables and the cumulative risk
- Conduct overlay analysis

6.2.1 Assignment of Risk and Statistical Analysis Tool

Each set of data goes through a statistical evaluation to establish the overlay risk indices. In addition, statistical information about the data from the datasets is queried to ensure the user of the quality of the data, and correctness in the application of the data as the basis for an overlay.

At the level of review of data quality and coverage, the GAR Analyst is used to conduct basic statistical analysis on the datasets used as index variables and to assign risk values, including calculation of mean, median, mode, min/max and generation of histograms and percentile/exceedance graphs. The Percentile Ranking Method described in this section is used as the basis for minimizing bias in ranking of risk values amongst many index variables. The ranking becomes the degree to which a certain data point is important relative to all of the other data points in a given dataset. By grouping the ranking numbers based on the percentile range in the dataset, the relative difference between the ranking values is maintained for each dataset.

6.2.1.1 Percentile Ranking Method

Histograms are used to evaluate the distribution of the data, or the frequency with which certain values fall between pre-set bins of specified sizes; and are used to understand and characterize the index variable datasets. A bin is simply a set range in values (e.g., 1-3, 4-6, 7-9, etc.) across the domain of values. The selection of bins is a variable, but is set at a constant 100 bins for this analysis. The exceedance graph is a cumulative plot of the histogram values across the number of bins used. The term percentile implies a graph showing a single line which spans across 100 percent (x-axis) of the data range (y-axis). This plot becomes useful in setting the ranking of importance to the study by assigning a indices value to the different percentiles using 10% ranges for each index variable (e.g., the 90% to 100% range is the top 10% and can be assigned a high index value of 10, the 80% to 90% can be assigned an index value of 9, and so on). **Figure 6-1** shows an example histogram and frequency curve for relative amount of nitrogen (no units) at each IOG cell after running the applied water utility in the GAR Analyst.

The Percentile Ranking Method was used as the basis for minimizing bias in the data as a result of assigning of ranking values. A ranking value becomes the degree to which a certain data point is important relative to all of the other data points. By grouping the ranking numbers based on the percentile range in the dataset, the relative difference between the ranking values is maintained for each dataset. This becomes important as a means of comparing and grouping overlays with each having the same degree of weighting.

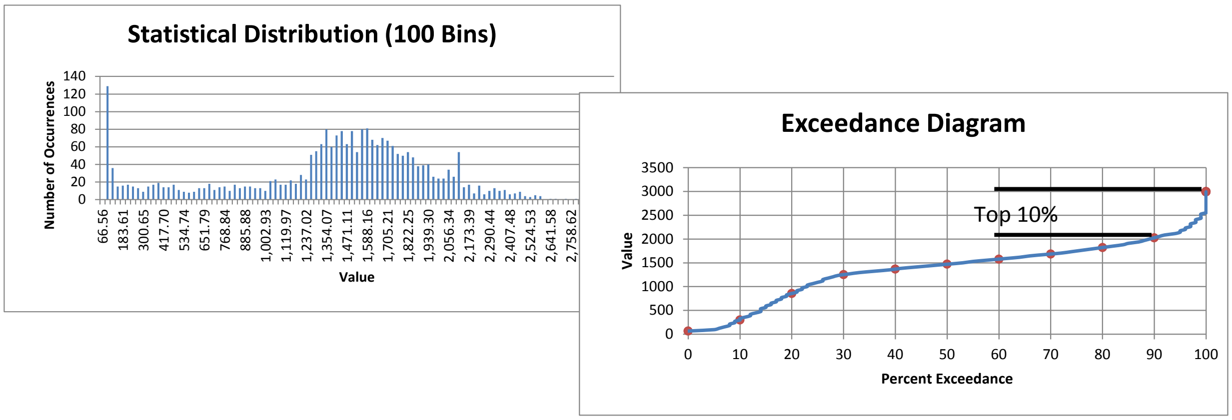


Figure 6-1. Factors Represented and Index Variable Definitions

The highest risk values are considered to be in the top 10 percent of each dataset and are assigned a value of 10. In this case the risk is considered to be proportional to the data values. As the values increase, the risk increases. If the risk is inversely proportional, meaning the risk goes down as the values increase, the top 10 percent of the values are assigned the lowest value of 1. Negative risk values may be assigned where risk is significantly reduced by a given index variable, such as intentional groundwater recharge using clean surface water provides an example of inverse proportionality using depth to groundwater where deeper groundwater is less susceptible and less vulnerable than shallow groundwater. The higher depth values are ranked low and the shallow depth values are ranked high.

Any ranking value greater than zero adds to the level of vulnerability risk, a zero implies no risk, and any value less than zero takes away risk. Further adjustments in the ranking values take place if certain ranges are known to have little or no impact either way to increasing vulnerability. In these documented cases, a zero value is used to turn off the ranking for the specified range in values. The remaining non-zero values retain their original percentile ranking to establish consistency, and to remove arbitrary value setting.

Table 6-1. Example of Inverse Percentile Ranking (Depth to Groundwater)

Index Value	Ranking Range	Ranking Value
1.024	1.024 to 14.721	10
14.721	14.721 to 23.853	9
23.853	23.853 to 36.029	8
36.029	36.029 to 46.683	7
46.683	46.683 to 57.641	6
57.641	57.641 to 66.772	5
66.772	66.772 to 78.644	4
78.644	78.644 to 99.951	3
99.951	99.951 to 128.869	2
128.869	128.869 to 457.613	1
457.6129	End Point	1

6.2.2 Basic Steps to Calculating an Overlay Index on a Dataset

The process to generate the index overlays for the specific variables is described in detail in **Appendix D.** The basic steps to calculating an overlay index on a given dataset (or index variable) are listed below. The systematic approach taken for each dataset is done to arrive at the final overlay indexing.

1. Obtain and Document Raw Geospatial Datasets in GIS
2. Conduct GIS Mapping and dissolve to the 1 sq.mi. grid of Index Overlay Grid, a subset of the CVHM grid.
3. Populate MS Access Raw Data Table
4. Decide on the need to manipulate the data to calculate a preferred value for purposes of ranking vulnerability
5. If needed, conduct additional calculations using built-in utilities (i.e., all raw data manipulations are done within the GAR Analyst to provide repeatable calculations on any given dataset, past, present, and future)
6. Map raw (or calculated) dataset in GAR Analyst to visualize relative variation of raw data
7. Understand and remove outlier or fill-in missing data, if found
8. Develop histogram distribution curve to understand its distribution (compared to but not tested for normality)
9. Create an exceedance curve to identify the percentile ranking of the dataset
10. Create index dataset by applying the real data to the index ranges, arriving at a ranking value of 0 through 10 for each cell, with 0 being no value and 10 being the highest level of vulnerability
11. Complete above steps for each dataset, resulting in a set of index variable overlays

12. Group overlays into four categories looking at Intrinsic, Regional Management, On-Farm, and Drinking Water Vulnerability overlays individually prior to grouping with each other
13. Compare the categorical overlays to the ambient exceedance mapping of nitrogen and salinity (TDS).
14. Present overlays using alternative themes centered around hydrologic conditions, and level of risk
15. Set weighting values using best expert judgment
16. Make comparisons in differences between agricultural irrigation practices in 2001 to those of 2010
17. Develop the narrative to support the delineation of high risk areas over the study area
18. Create a final index layer of the resulting map to highlight areas of a given percentile of risk, say the top 10 percent

6.3 Results of the Overlay Analysis

This section outlines the results of the GAR analysis.

Once the risk indices are assigned using the methods discussed above, the overlay analysis of the four risk categories is conducted using the GAR Analyst. **Figure 6-2** provides the three step overview of the process. Step 1 develops the intrinsic and on-farm vulnerabilities to make a comparison with areas of known high nitrate concentrations. At this step, weighting of specific variables is done using GAR Analyst utilities to reflect variables influencing average nitrate concentrations using CV-SALTS' dataset. The result of Step 1 is a weighting schema reflective of the intrinsic or on-farm activities of today, that may have the potential to create exceedances in the future. In some cases, other uses, such as livestock activities, industrial discharges, or past landfill or septic system disposal are the source of nitrate and, in some cases, are identified as a primary or contributing causes. Step 2 determines priorities for Coalition monitoring and reporting actions based on potential impacts to drinking water. Step 3, which takes place in **Chapter 8 - Summary of Results and Observations** applies the Groundwater Vulnerability Solution in Step 1, and the Drinking Water Priority in Step 2 to result in the Overall Priority of the GAR.

6.3.1 How to Read GAR Analyst Overlays

The figures contained within this section are a series of colorized figures with a blue to yellow spectrum representing low to high priority ranking, respectively, of the given index variable (or distribution of index variables). A blue cell (or low ranking cell) should be viewed as receiving a lower risk value relative to the yellow cells. A blue cell, in some cases, still represents a risk, but is associated as being an acceptable risk when considered statistically in its ranking relative to other cells in the study area.

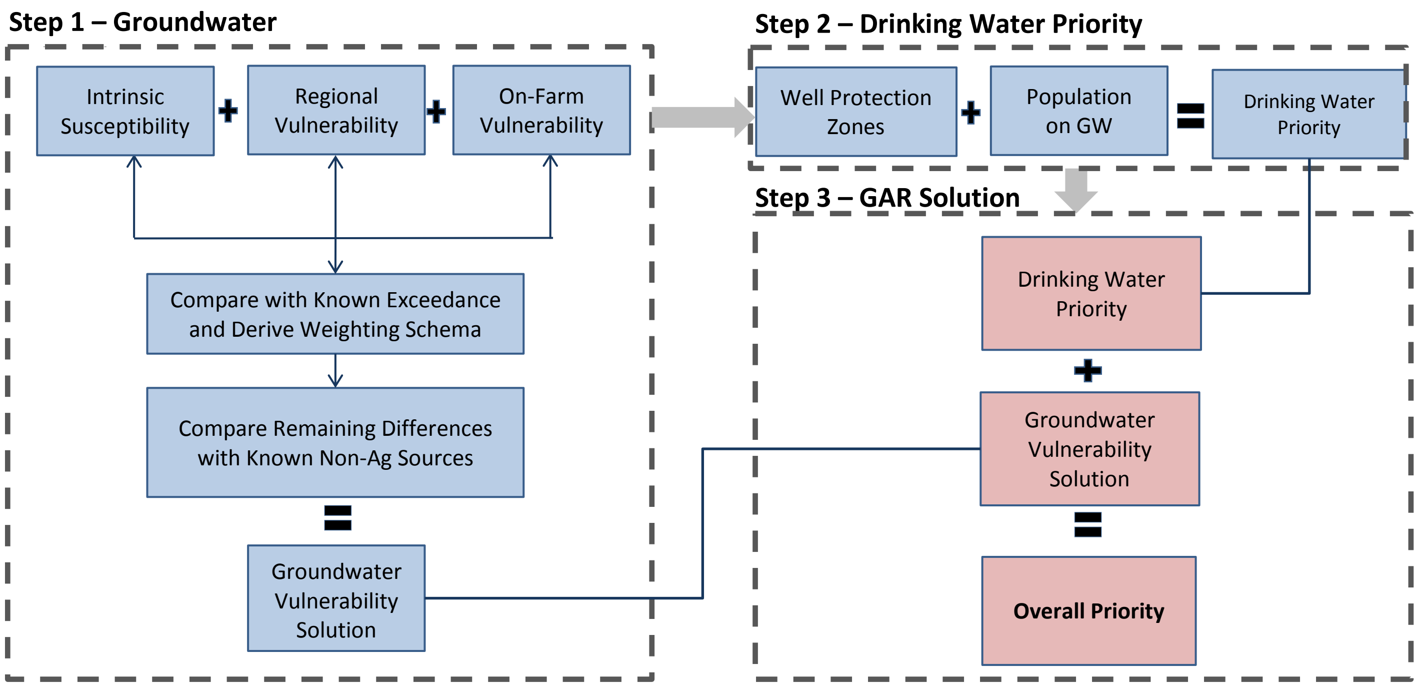


Figure 6-2. Overlay Process and Getting to GAR Priorities

A blank cell carries no ranking and is therefore ignored in the given overlay. To remove a cell from the overlay calculation (e.g., cells not overlying the Corcoran Clay in the clay thickness index variable), the ranking score of zero is applied. This means the cell area has no significant contribution to the overlay in question. Whereas, if a cell has a low ranking on one overlay and high ranking on another, the total of the two would tend to ameliorate the high ranking to make it somewhere in between the two ranked values. If a cell has no ranking (i.e., a zero value), the high ranking cell it is added to will remain high as part of the redistribution calculation. For this reason, a zero value cell has to be justified within the context of the index variable.

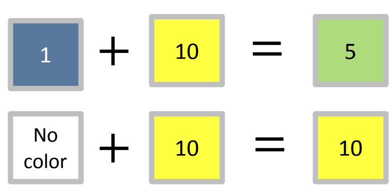


Figure 6-3. Understanding Cell Color Values and Addition of Cells

When viewing the overlay figures, also recognize the differences and additional areas included in the buffer area surrounding the study area. In some cases, the cells located outside the study area are included in the analysis to capture boundary conditions associated with activities outside the Coalition area; especially, when well data is contoured to include nearby public wells and population areas reliant on groundwater.

6.3.2 Deriving Overlay Index Categories

For the intrinsic susceptibility and regional categories in Step 1 of **Figure 6-2**, each is presented based on the weighted average of the occurrence of the specific index variables within each of the IOG cells (e.g., the shallow soil index applied to each cell is based on the area of intersecting soil-type polygons and their soil indices). The color ramp is used to present either the relative differences based on this weighted average, or the relative differences based on the assigned risk values using the cell ranking methodology.

The GAR Analyst is designed to be an interactive tool to view the actual data, test different datasets, evaluate each of the categories and ranked index variables, and present the interim analysis results for each of the four categories using the same color ramp, with ranking values normalized from 0 to 10.[1] This process allows for evaluation and comparison with the observed ambient contaminant concentrations, completed at the end of the Chapter.

The weighting schema described above in Step 1 of **Figure 6-2** is illustrated in the GAR Analyst screenshot (**Figure 6-4**) of the "Run" page. Each of the overlay categories is assigned a weighting based on the user's understanding of the data, comparisons with measured exceedances, and on-the-ground management of water within the study area. Adjustments in weighting are made by moving the slider up or down. As one variable is weighted more or less, the aerial distribution of high vulnerability (e.g., high risk cells) will change accordingly. The initial weighting is set at a constant value of five (5), to first consider a uniformly weighted dataset in making comparisons with measured and derived values of risk to groundwater from outside or other sources.

After each category is fully developed, meaning that the individual index variables have been aggregated within the category and resolved to a category solution layer, the category solutions are then aggregated and weighted based on the desired weighting schema. The final Groundwater Vulnerability Solution overlay is used for identification of assigned risk using the Drinking Water Priority overlay applied over the Coalition study area. The purpose of the steps taken below is to stop and understand each layer and the resulting outcome when layers are combined.

6.3.2.1 Intrinsic Susceptibility Category Overlays

The Intrinsic Susceptibility Category is comprised of four index variables: Surface Soil Permeability, Underlying Clay Layer Thickness, Depth to Groundwater, and Rate of Groundwater Movement. Intrinsic attributes are embedded in the natural hydrogeologic makeup of the region. Surface soils and the underlying geology are static properties of the region, not easily managed, and best understood using field science. Soil types govern the Shallow Soil Permeability, and geology governs the vertical and horizontal transmissivity, affecting the Rate of Groundwater Movement. The presence of the Corcoran Clay Member is also static, and is quantified using exploratory and drinking water well drilling logs.

[1] Negative values (0 to -10) are also used in cases where benefit is accounted for in current management practices.

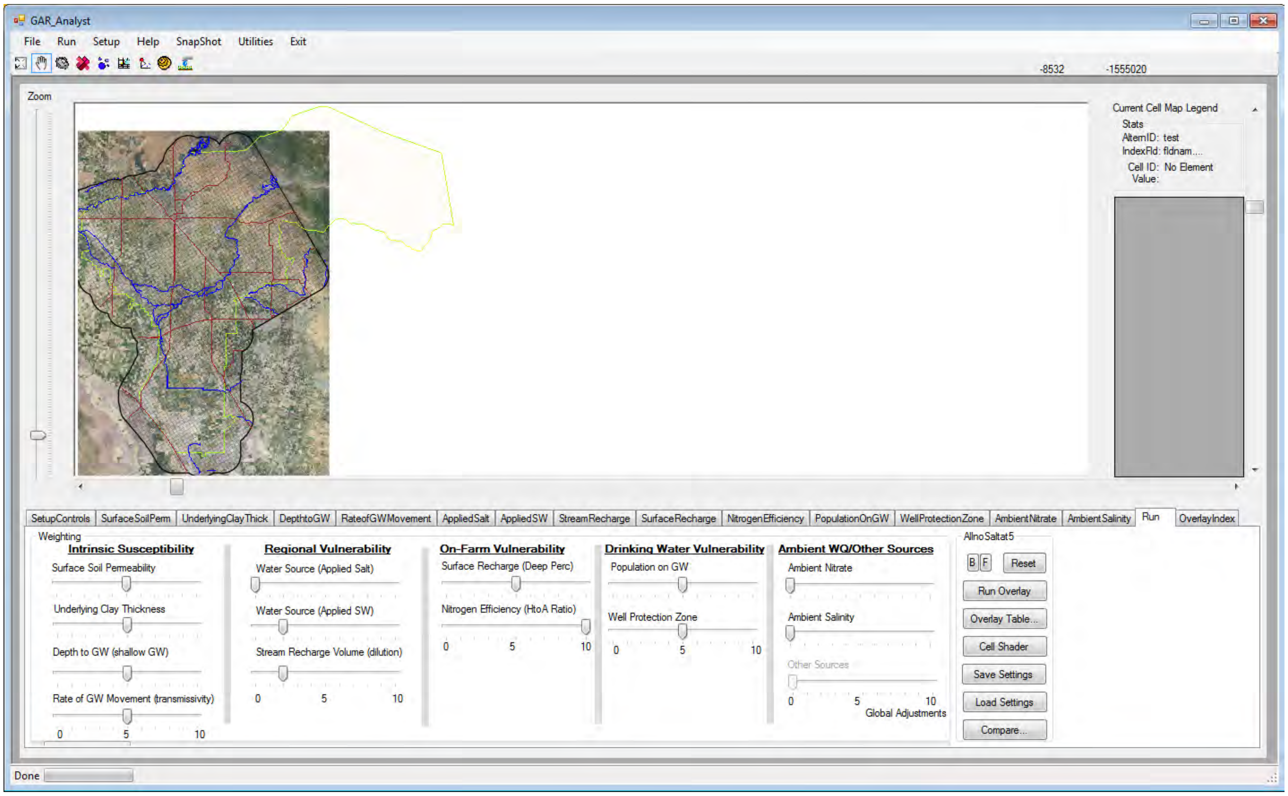


Figure 6-4. GAR Analyst Screenshot Showing Categories Containing Index Variables

Dynamic properties of intrinsic susceptibility are included in Depth to Groundwater where attributes are governed mostly by aquifer properties and the location of groundwater recharge and discharge points. Depth to Groundwater is also dynamic and is influenced by hydrologic variations, making it more or less susceptible in any given hydrologic year type (i.e., typical, wet, and dry).

Referring to **Figure 6-5,** (a)[2] Surface Soil Permeability, indicates areas in the Upper and Lower Kings Subregions where water and contaminants can penetrate the surface soils and root zones to travel through the unsaturated geologic strata of the vadose zone. From the yellow colored cells shown in the figure, high permeability soils are found in the midsection along the San Joaquin River and along the Kings River.

The additional risk of contamination from the presence of an Underlying Clay Thickness affects only cells where the Corcoran Clay Member is present, as shown in **Figure 6-5** (b). Lands overlying the clay layer have an inherent risk of contaminants migrating through the vadose zone to the saturated aquifer which sits atop the clay layer in an unconfined state. Areas along the eastern fringe of the clay layer are at highest risk, representing areas of relatively thin aquifer thickness and thin clay thickness, producing the risk of moving high concentration contaminated water below the protective clay layer where many of the drinking water wells are screened. Circulation of the shallow groundwater for agricultural

[2] Parenthetical lettering refers to collection of maps within a cited figure.

irrigation occurs unless surface water is imported to dilute and move high nitrogen concentration groundwater down gradient.

The third intrinsic overlay shown in **Figure 6-5,** (c) Depth to Groundwater, represents areas where the groundwater is close to the ground surface and therefore, susceptible to surface sources of contamination. Depth to groundwater is a surrogate for risk associated with contaminants coming into rapid contact with the groundwater. While depth to groundwater changes over time, once contaminants trapped in the vadose come into contact with the aquifer, the transport mechanism is created to move the contaminants and potentially degrade drinking water supplies down gradient. The values used to represent shallow groundwater are based on the behavior of the aquifer over the past 20 years and existing high groundwater elevation points of equilibrium.

The (d) Rate of Groundwater Movement is considered a surrogate for time of travel of waterborne contaminants moving through the unsaturated vadose zone to the saturated zone, as well as through the saturated aquifer. The color values assigned to this index variable are based strictly on the calculated vertical transmissivity based on the CVHM Texture Model of the region. Highly transmissive soils allow water to move faster and pose a higher risk to the groundwater system because of the vulnerability when nitrogen (or other chemical) is applied as part of the on-farm practices in food production. The highest transmissivity values logically follow the alluvial fan deposits of the San Joaquin River and Kings River systems. The rate of groundwater movement index variable is meant to acknowledge that farming practices over highly transmissive aquifer materials are more susceptible and can create higher vulnerability, and, in turn, higher risk.

From **Figure 6-5,** the South Kings and Tulare Lake Bed are most susceptible due to the shallow groundwater and depth of the clay layer along the old lakebed. Intrinsically the region is at risk of high concentrations of contaminants in the shallow groundwater. It is noted that the Tulare Lake Bed has shallow groundwater which is perched above extensive clay layers, and is not currently used as a source of municipal or agricultural supplies. There are few wells in this area because of the clays which preclude development of an economically viable groundwater supply or for municipal or agricultural purposes. Useable groundwater can be found, however, at depths below the extensive thick clay layer. The shallow groundwater above the clay layer is also intrinsically high in TDS, typically exceeding the current MCL and water quality objectives. The area is currently being considered by the RWQCB for de-designation as a municipal use because of these conditions (Schmidt, 2013).

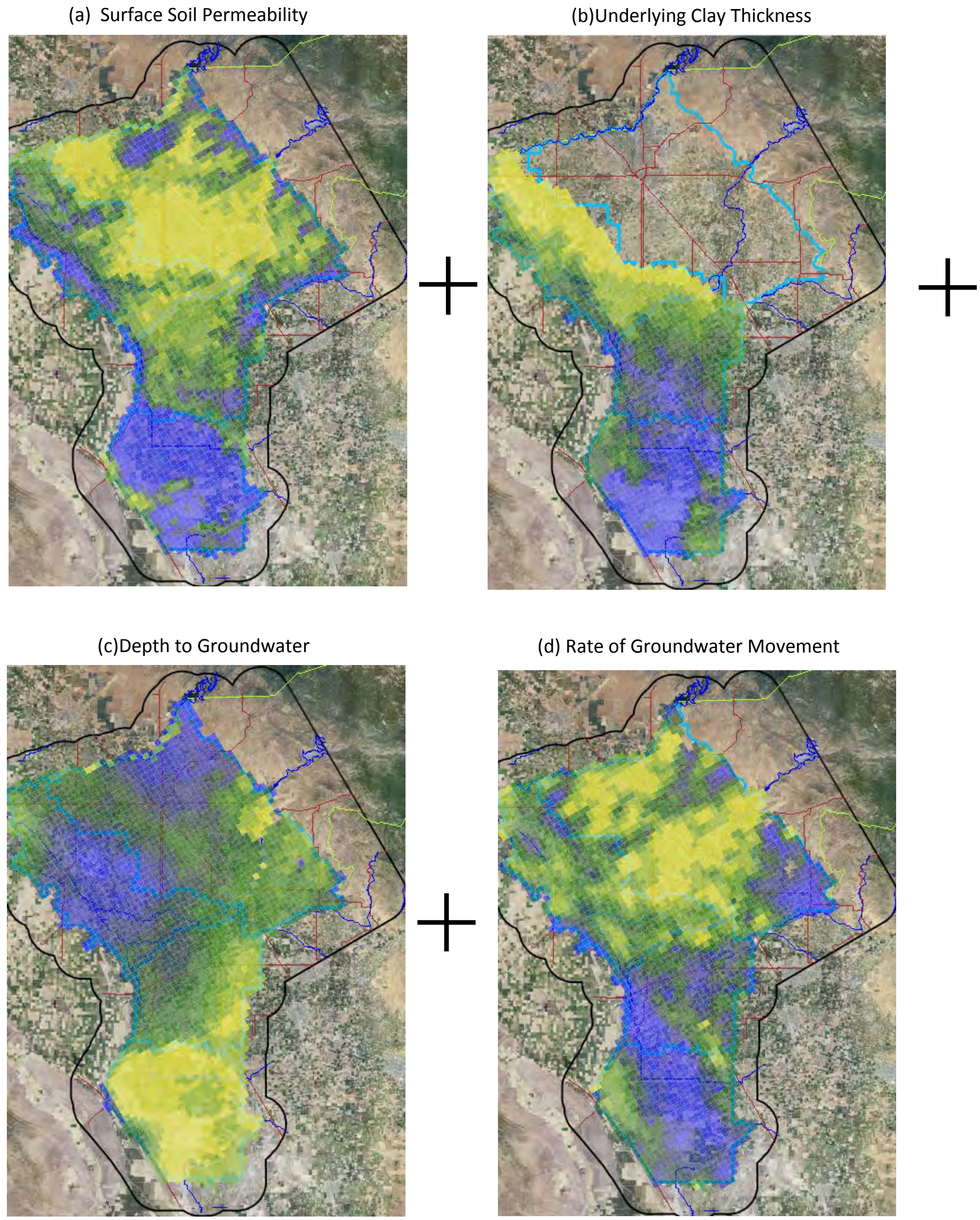


Figure 6-5. Intrinsic Overlay Index Layers

The resulting (a) Distribution of Intrinsic Values (see **Figure 6-6**) identifies by yellow colored cells, a higher susceptibility to groundwater contamination due to irrigated lands to be most prominent in the Upper and Lower Kings Regions. This overlay is used as the starting point to defining risk by identifying areas of high intrinsic susceptibility. The (b) Top 20 Percent of high ranking cells are highlighted to begin focusing on where the index variables are going to influence the final identification of high risk areas.

(a)Distribution of Intrinsic Values (b)Highlighting Top 20 Percent

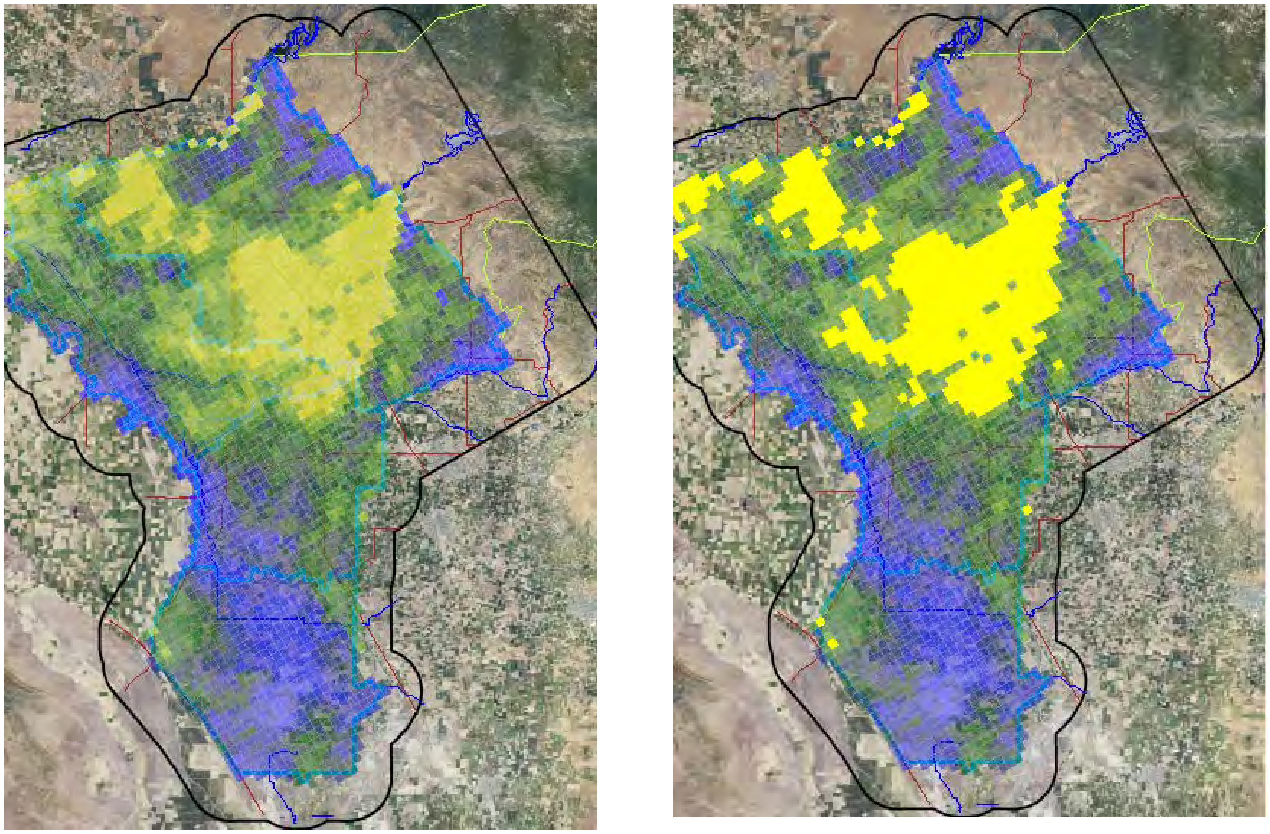


Figure 6-6. Intrinsic Overlay

6.3.2.2 Regional Vulnerability Category Overlays

Regional Vulnerability index variables are those which can be controlled on a regional-scale with the introduction of management programs such as intentional recharge and use of clean surface water supplies for irrigation and along rivers, unlined canals, and dedicated basins. The three index variables are Water Source (Applied Salt), Water Source (Applied Surface Water), and Stream Recharge.

The (**Figure 6-7**) (a) Stream Recharge figure only shows the cells which benefit based on the flow amount and alignment of the various streams, rivers, and canals. The blue in this case is the most negative value (or positive benefit). Areas with no shaded cells do not receive the benefit from recharge. The same benefit can be argued for agricultural areas importing and (c) applying surface water for irrigation of farmlands. In this case, the volume of surface water as deep percolation is the index variable and is treated as a negative value to offset risk associated with intrinsic susceptibility.

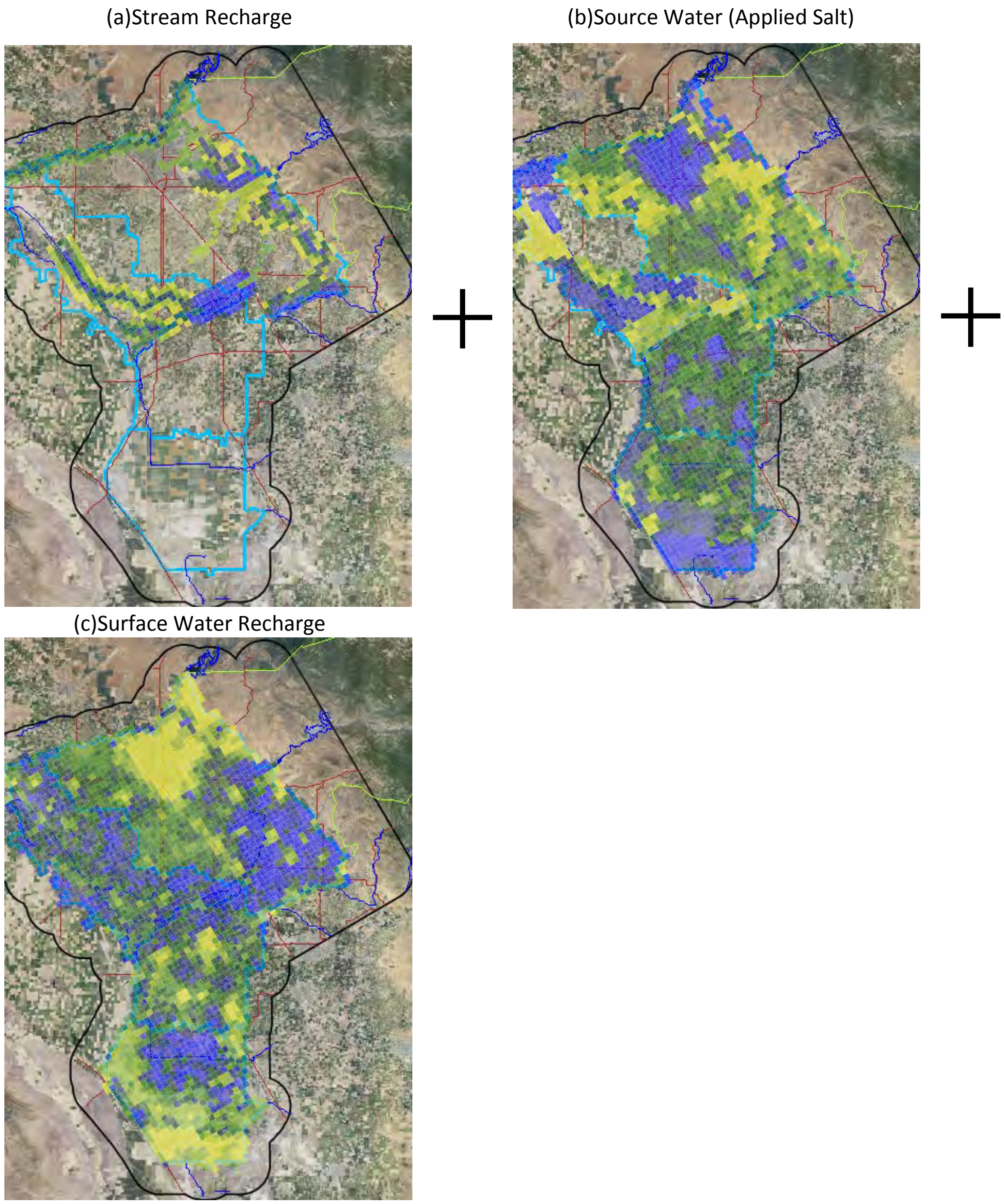


Figure 6-7. Regional Vulnerability Overlay Index Layers

The (b) Applied Salt figure is separated from the nitrogen assessment, understanding that salinity has been shown to contribute to higher nitrate leaching (Letey, et al., 2013) due to reduced plant growth using less nitrogen and flushing of soils, both allowing nitrogen to pass through the root zone and deep percolate to groundwater. For purposes of this report, the (b) Applied Salt layer is not considered a significant contributor to the assessment of nitrogen contamination in groundwater. **Section 6.3.2.3** provides a separate overlay solution for contamination due to importing salts from outside surface water sources. The Applied Salt may be brought back with a reduced weighting if the final overlay solution warrants.

To offset the above risk in areas overlying highly transmissive river deposits, the (a) Stream Recharge index variable and (c) Applied Surface Water for irrigation are applied as credits where actively managed recharge programs are already taking place, and to factor in natural recharge along clean water streams and rivers flowing out of the Sierra Nevada. In this case, a negative risk value is scored to fully realize the benefits of regional conjunctive use and active recharge programs. Risk is reduced through the benefits realized through dilution of any ambient contamination of groundwater.

The Regional Vulnerability solution is comprised of two beneficial layers resulting in an overall negative risk value when added and ranked. The blue cells represent values closer to -10 and the red, closer to -1. Regardless, this solution layer can only benefit the overall risk of high nitrogen concentrations in groundwater.

Distribution of Regional Vulnerability Overlay

Highlighting Top 20 Percent

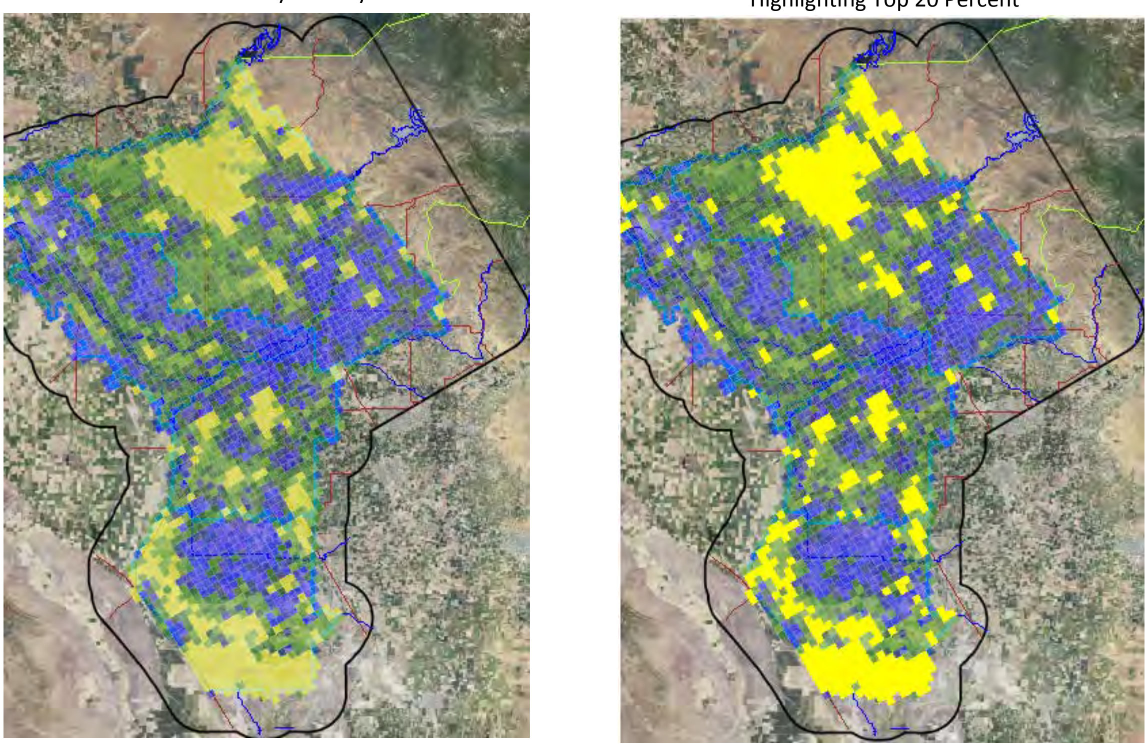
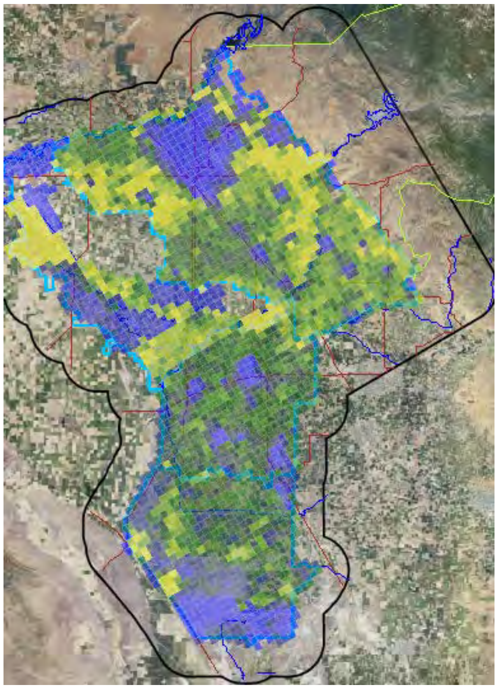


Figure 6-8. Regional Vulnerability Overlay (no Salt Load)

6.3.2.3 TDS Vulnerability

The groundwater vulnerability to salt contamination is based on the estimated amount of salt imported from outside surface water supplies high in salinity and salt loads from local supplies. This overlay captures the amount of surface water used in meeting crop demands and applies a monthly TDS concentration based on the source of supply (e.g., CVP, SWP, Friant Kern Canal, Kings River, etc.). The Tulare Lake Bed Region shows as having the highest susceptibility to salts based on the use of SWP and CVP water sources though natural conditions are the predominant factor. Areas in the Lower Kings are also more vulnerable (Tranquility) as a result of import of CVP water. This overlay is considered to be unique to salt and is not weighted highly in the general assessment of nitrogen.

Distribution of Salinity (TDS) Concentration



Highlighting Top 20 Percent

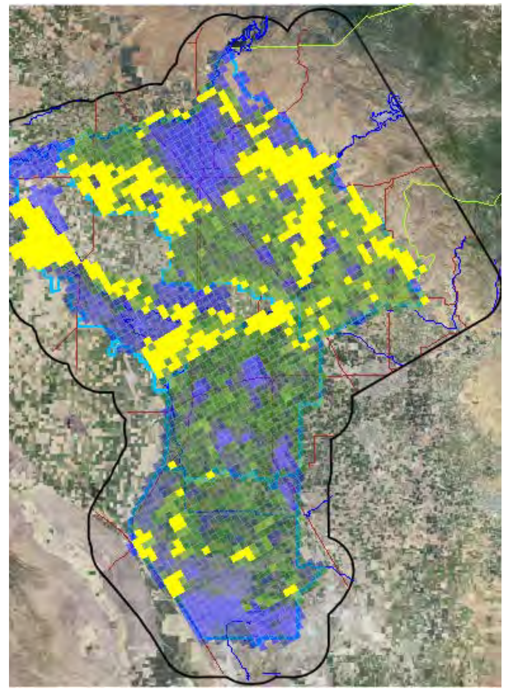


Figure 6-9. High TDS Vulnerability Overlay

6.3.2.4 On-Farm Category Overlays

Perhaps the most important of the three categories, the On-Farm Category represents activities taking place at the farm level where management actions can influence the amount of applied chemicals finding transport systems and reaching the groundwater system. Examples of this include improved management of applied irrigation where irrigation is inextricably linked to the amount of free nitrogen leaving the root zone as deep percolation, or through improved irrigation efficiencies by use of micro/drip irrigation methods, if applicable, and improved drainage and return flow practices. The two index variables in this category are Deep Percolation and Nitrogen Efficiency.

The (**Figure 6-10)** (a) Surface Recharge (Deep Percolation) is the product of water percolating from the surface, via the groundwater transport system, stemming from applied water and rainfall which travels beneath the root zone and is released to the unsaturated vadose zone where it is transported to the underlying aquifer. The amount of deep percolation is directly related to the irrigation efficiency, irrigation method, soil type, crop type, and precipitation. Areas of high deep percolation are considered to be more susceptible to contamination due to larger and more frequent volumes of water becoming available as a transport mechanism for contaminants. Higher surface recharge (from both applied water and natural precipitation) through deep percolation creates a higher vulnerability from all waterborne contaminants.

(a)Surface Recharge (Deep Percolation) (b)Nitrogen Efficiency

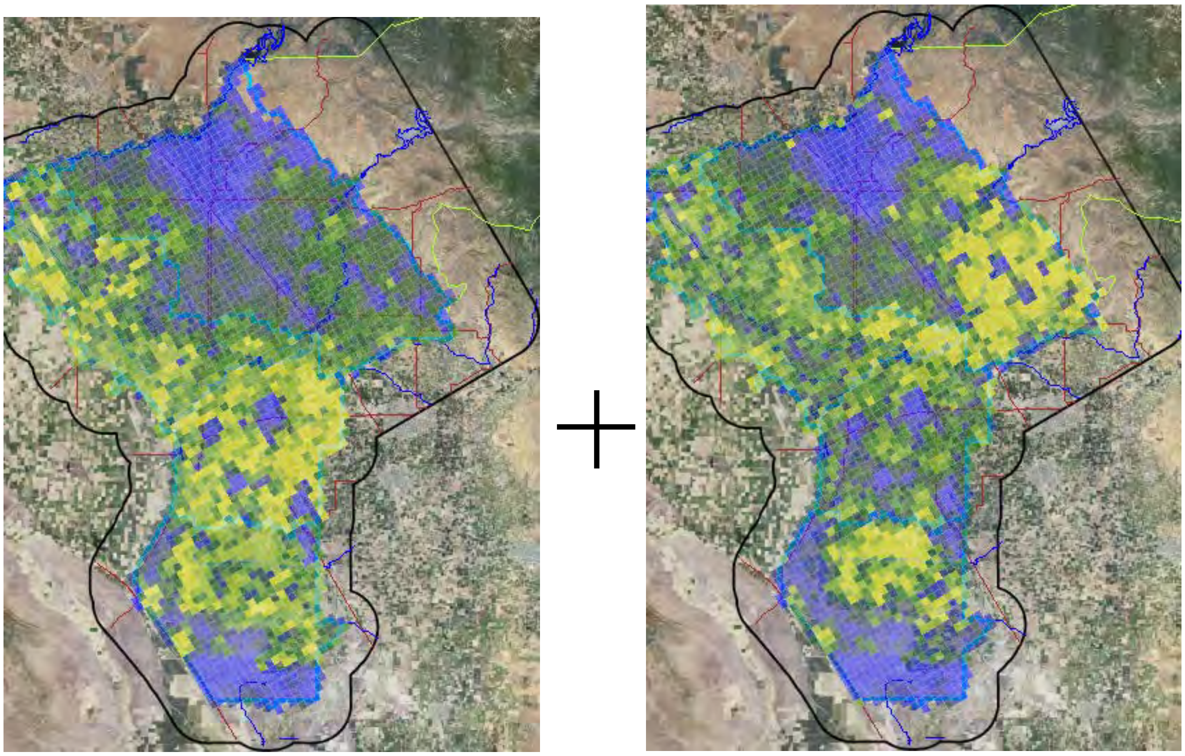


Figure 6-10. On-Farm Overlay Index Layers

The (b) Nitrogen Efficiency layer is representative of the amount of nitrogen available which can be transported through the vadose zone and contributes to contamination of groundwater supplies. Applied nitrogen is also subject to other loss processes, including loss in runoff, by ammonia volatilization, or denitrification. It may also be temporarily immobilized in organic compounds and microbial biomass, or retained as nitrate or (mainly adsorbed) ammonium in the root zone for use by subsequent crops. Also, growers may add nitrogen to soils with irrigation water when irrigating with waters high in nitrate, in which case fertilizer requirements may be reduced.

One aspect of nitrogen management involves prediction of an "expected crop yield," which is heavily influenced by the season's nitrogen demand. Such predictions are by nature approximate, which can at times result in the need to supplement nitrogen at rates in excess of forecasted expectations. There is also the need to manage residual nitrogen in the root zone when yields are less than expected.

Being very complex by nature, nitrogen mass balances cannot be reduced to one or two numbers making nitrogen management planning a very important process. Nevertheless, the outcome of sound plans is the retention and beneficial use of nitrogen by crops, in such a way that leaching to groundwater is reasonably minimized and risk is reduced. Over time, greater consideration of this aspect of management will need to be factored into the GAR Analyst and similar tools. However, the means to do this are not yet fully developed.

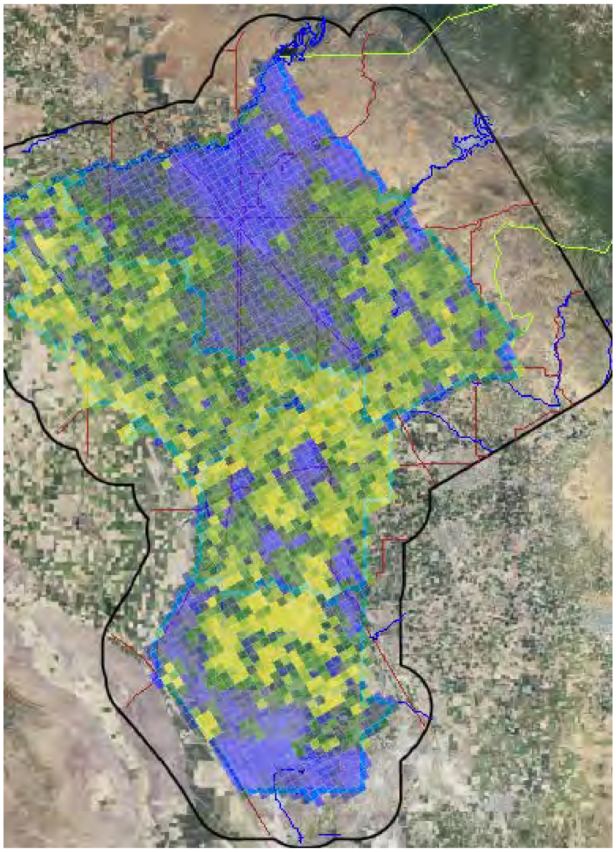
The methodology explained in detail in **Appendix B** and illustrated herein is based on the ratio of harvested to applied nitrogen[3] and the amount of deep percolation. The combination of these two factors satisfy the basic understanding of the nitrogen cycle published in the research article, *Soil Type, Crop and Irrigation Technique Affect Nitrogen Leaching to Groundwater* (Letey, et al., 2013).

From **Figure 6-10**, the combination of both deep percolation and nitrogen efficiency results in a relatively high vulnerability in all subregions with farming practices taking place. This is the only overlay where the northeast corner of the study area is identified as being of high vulnerability. This becomes important when comparing with ambient nitrogen conditions in **Section 6.5**. Given this solution's connection with nitrogen and groundwater, a higher weighting may be considered as part of the final report, taking into consideration the weighting of all layers based on well-documented discussions.

Isolating the top 20 percent of areas as shown in **Figure 6-11**, provides a similar conclusion of a broad disbursement of vulnerability across the study area with a bimodal distribution (see **Table 6-2**) containing a low and a high distribution of occurrences. This is the difference between agriculture, native, and urban lands, and associated applied water requirements and use of nitrogen.

[3] See source: *Nitrogen Source and Loading to Groundwater - Technical Report 2 Assessing Nitrate in California's Drinking Water*. Center for Watershed Sciences. UC Davis. March 2012

Distribution of On-Farm Overlay



Highlighting Top 20 Percent

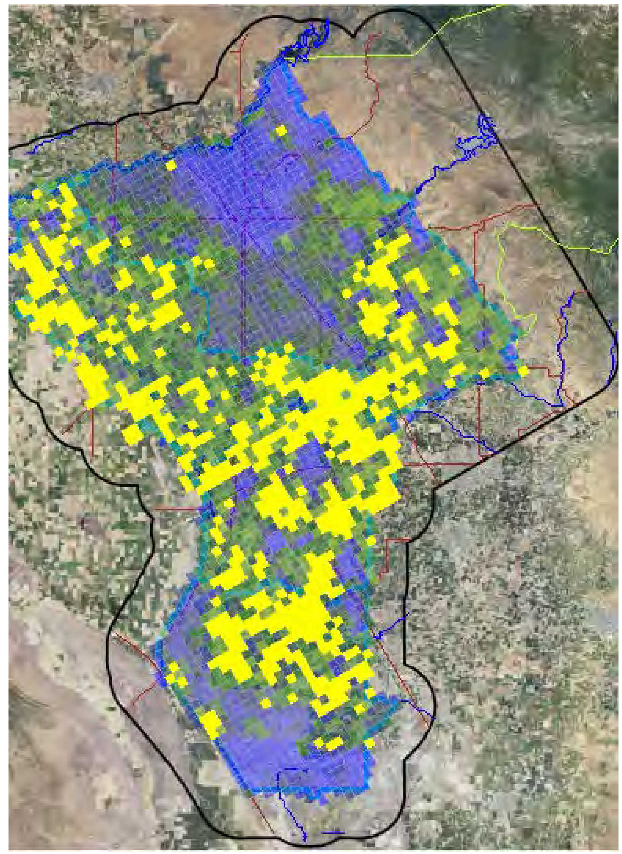
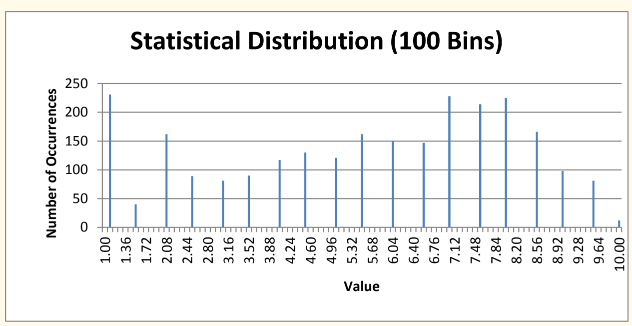


Figure 6-11. On-Farm Vulnerability Overlay

Table 6-2. On-Farm Overlay Statistics

****

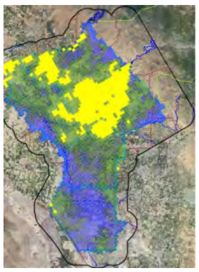
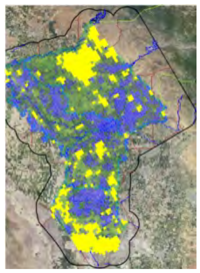
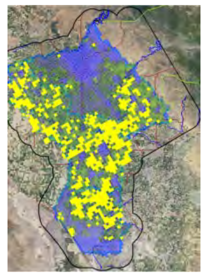
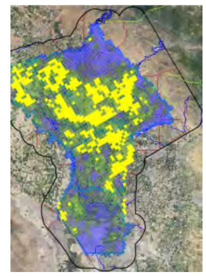
Database Field: fld_TotalIndexVal
Number of non-zero data points: 2544
Average: 5.497
Mode (most frequent): 1.000
Number of times: 231.000
Median1 (even middle value): 8.000
Median2 (even middle value): 7.000
Maximum: 10.000
Minimum: 1.000
Midrange (average of max and min): 5.500



6.4 COMBINING OVERLAY SOLUTIONS

Combining the overlay solutions from above is the next step in the overlay assessment process. The order is illustrated below, with the Overlay Solution being an example of the integrated layers based on a weighting schema:

Intrinsic + Regional + On-Farm = **Overlay Solution**

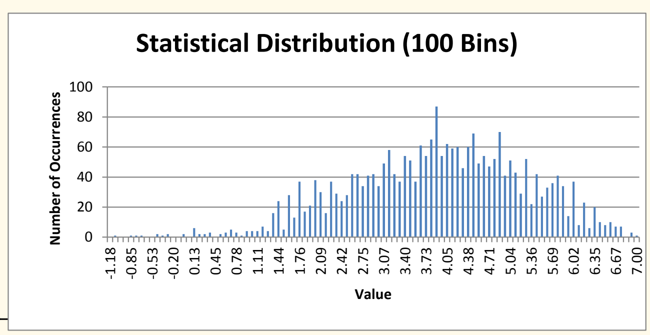
6.4.1 Intrinsic and Regional Category

The first comparative evaluation using the GAR Analyst solution engine is made between the categories of Intrinsic Susceptibility and Regional Vulnerability Overlay Solutions from the previous section (turning off Applied Salt by setting weighting value to zero (0)). The overlay initially assumes an even weighting schema (currently set at a value of five (5)) for each of the index variables. There is also a slight reduction in weighting for Underlying Clay Thickness to a value of three (3) to reduce the penalty of lands overlying the Corcoran Clay member (i.e., this was done to account for the level of uncertainty in groundwater extractions and movement in this area). The engine re-distributes the assigned values from -10 to 10. Areas outside the study area are removed from the overlay solution in this phase of the analysis. The normally distributed solution of the averaging is expected due to the ranking and normalization of the data prior to averaging.

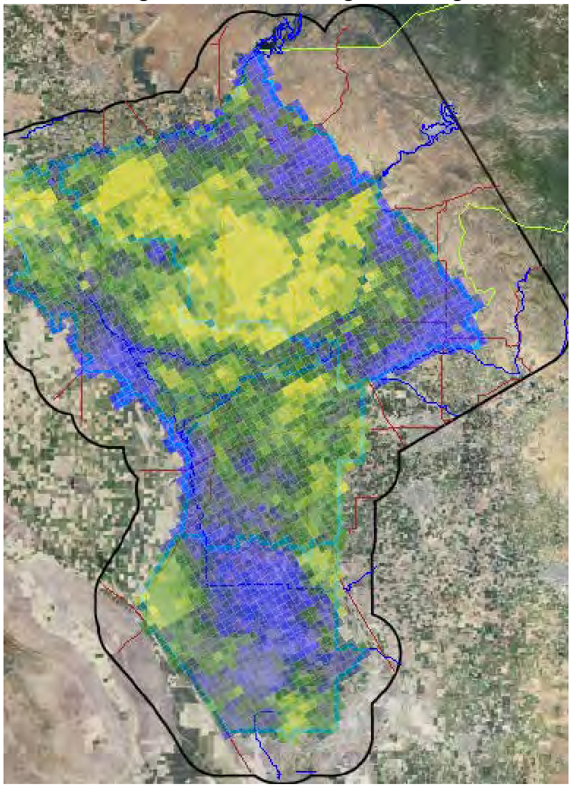
Table 6-3. Combining Intrinsic and Region Overlays

****

Database Field: fld_TotalIndexVal
Number of non-zero data points: 2541
Average: 3.860
Mode (most frequent): 4.000
Number of times: 44.000
Median (odd middle value): 2.952
Maximum: 7.000
Minimum: -1.182
Midrange (average of max and min): 2.909



Average of Intrinsic and Regional Categories



Highlighting Top 20 Percent of Area

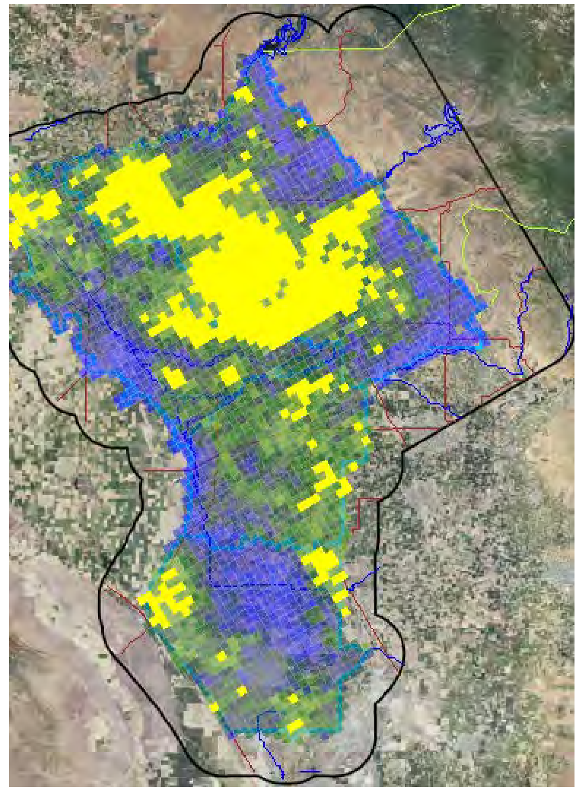


Figure 6-12. Average Susceptibility Overlay Solution from Intrinsic and Regional Overlay Categories

The solution overlay in this case shows large contiguous regions of high intrinsic susceptibility, likely due to both the shallow soil and shallow groundwater conditions.

6.4.2 Combining Average Susceptibility Overlay with On-Farm Overlay Category

Adding the On-Farm category to the susceptibility increases the understanding of the effects of farming practices on the level of risk and vulnerability to nitrate contamination. Weighted with the other categories[4], the combined overlay figure is shown below.

The addition and weighting schema for the On-Farm category appreciablly changes the distribution of the data and location of highest susceptability, vulnerability, and risk. There is a slight decrease in the relative risk, removing some of the contiguous areas and making those already considered high even higher (i.e., fewer areas in the top 20 percent). The

[4] Weighting of variables is done by assigning a 0 to 10 scale to each of the overlays. Initially, all overlays start with a value of 5. Changes up and own are made based on the results and an iterative comparison with measured values. The weighting to produce the combined overlay: Surface Soil Perm – 5; Underyling Clay – 3; Depth to GW – 5; Rate of GW – 5; Applied SW – 3; Stream Recharge – 3; Deep Perc – 6; Nitrogen Efficiency – 6; All Others – 0

narrowing of data is considered a positive aspect to ensure prioritization occurs in areas where multiple factors are identified.

Average of Intrinsic, Subregion, and On-Farm Categories

Highlighting Top 20 Percent

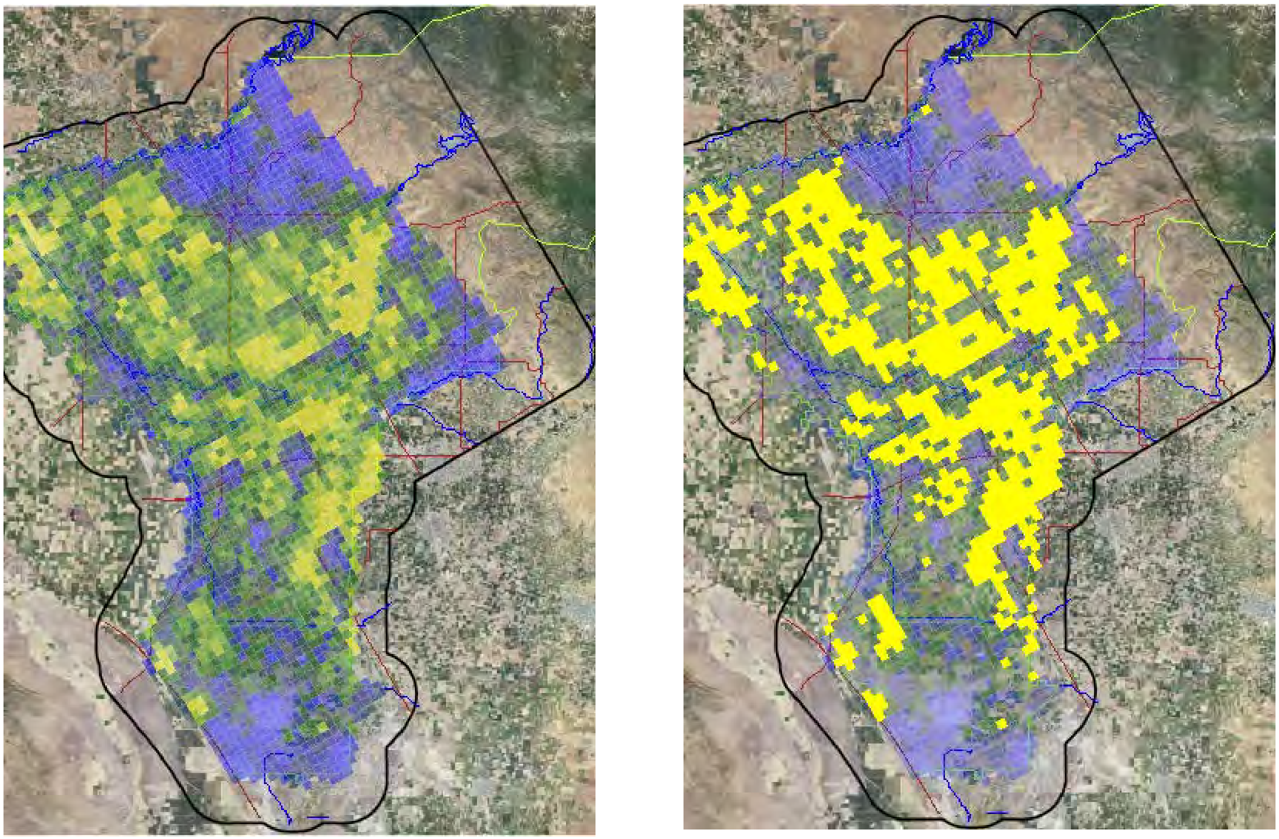


Figure 6-13. Combined Overlay Index Layers Including On-Farm Vulnerability

6.4.3 Understanding the Solution

As a means to better understand the reasons behind a high risk area versus a low risk area, the GAR Analyst includes a graphing utility to show the relative score of each of the index variables that were taken into account leading up to the final score for each cell. Since a weighting schema is applied in this example, the weighted values are shown along with the total average value at the end, re-ranked to values 1 to 10. For example the eight (8) bars represented in the graph in **Figure 6-14** represents the circled cells, by color in the order of the line drawn between points starting in the northwest corner, in **Figure 6-15**. To read, locate the color of the point in the graph and read from left to right with each bar being the score in the identified index variable. The total at the far right is a value of 10 or 9 for all points.

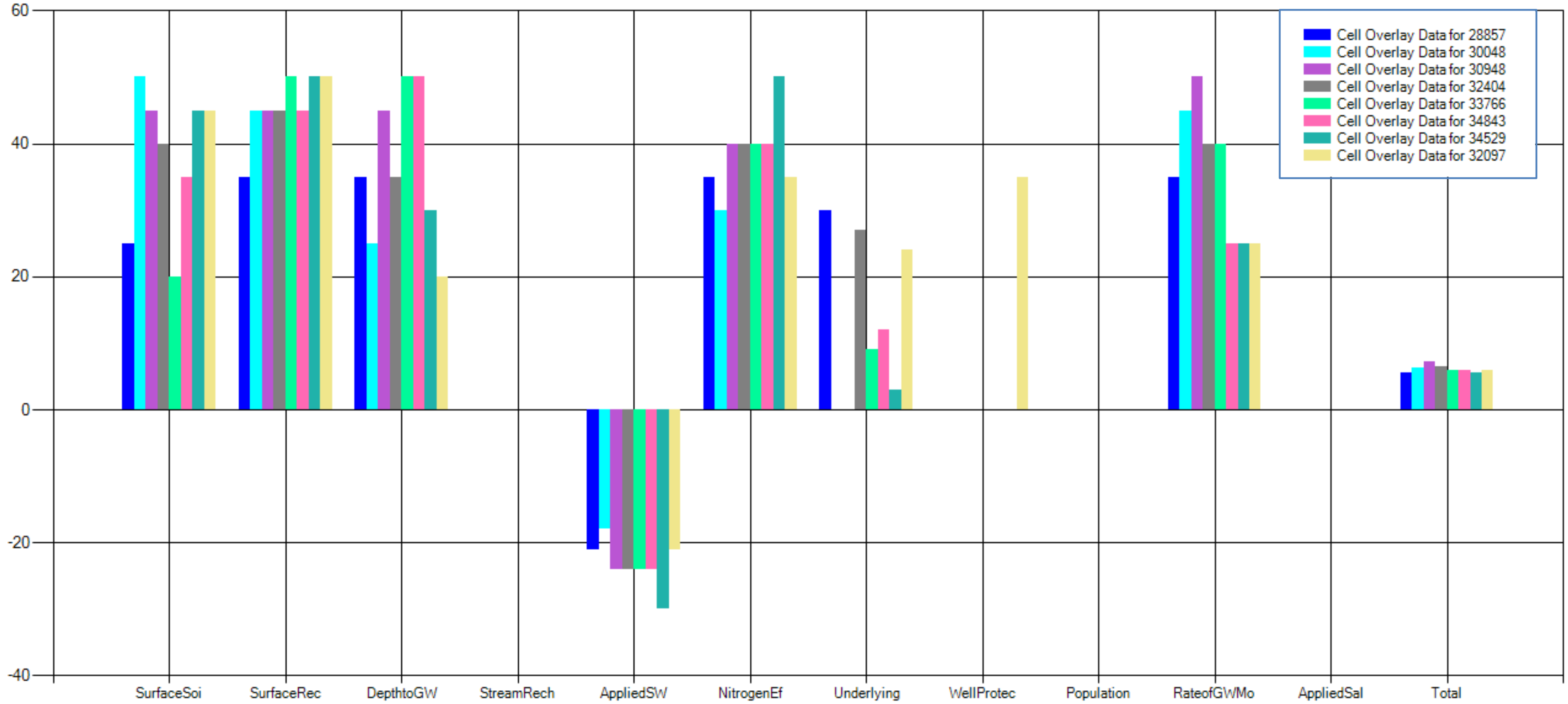


Figure 6-14. Bar Chart of Index Variables for High Risk Areas

High risk areas to the northwest (blue bar) are shown to be influenced by the underlying clay layer and nitrogen efficiency. Northeast (purple bars) areas are influenced significantly by rate of groundwater movement. Middle areas (pink and green color bars) are shown to have higher depth to groundwater and increased rate of surface recharge movement. Southwest areas (dark green) show high surface surface soil permeability, surface recharge, and nitrogen efficiency index variables and lower in the rate of groundwater movement, and underlying clay layer. The last point on the line (yellow) is the only point of the collection where the public well protection overlay moved the cell into a 10 category, even though benefits from stream recharge are in effect.

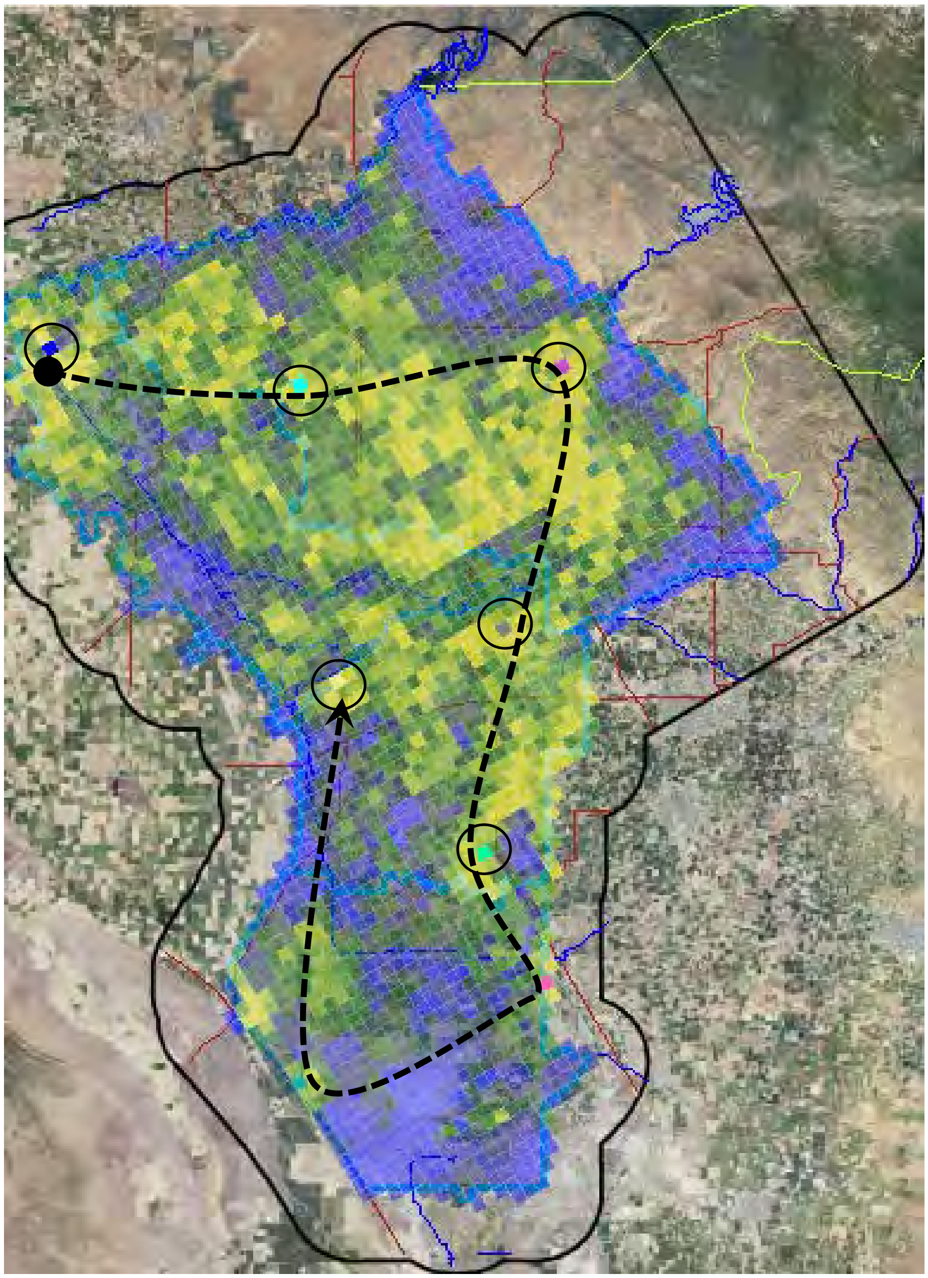


Figure 6-15. Score Comparison Graph of High Risk Areas

By recognizing the patterns of why areas are scoring high relative to each other, begins to suggest additional changes in weighting to ensure the critical index variables are influencing the data appropriately, and, at the same time, being careful to not leave out the other index variables of slightly less significance. The weighting differences cited, reflect the understanding of the data and are in the interest of being conservative when including beneficial influences from intentional stream recharge and applied imported surface water.

6.5 Comparing Overlay Solution to Ambient Nitrate Conditions and Other Sources

6.5.1 General Comparison between the Nitrogen Hazard Index

For purposes of an initial comparison, the Nitrogen Hazard Index (NHI) results are presented in **Figure 6-16**. The comparison between the high risk areas of the NHI and this GAR vary in a significant number of areas with special attention to areas around rivers and streams, and areas overlying the eastern fringes of the Corcoran Clay. When looking at actual monitored concentrations of nitrogen shown in **Figure 6-16**, the NHI areas identify high risk areas where measured nitrate concentrations are shown to be low, and, overall, do not capture the exceedance areas as well as the GAR, which is supported in the following section comparing the Overlay Solution to the exceedance areas dictated by the CV-SALTS wells. Given the differences of the NHI and measured exceedances, and minimal data to develop and support the NHI findings, the GAR methodology is the preferred method for purposes of making a risk assessment.

6.5.2 Comparison between GAR and Measured Nitrogen Concentrations

As a numerical method of comparing the overlay solution to ambient conditions of nitrate as nitrogen, contouring of real data is performed over the 10 year period from 2000 to 2010 in order to capture as many wells as possible over the study area. In the future, monitoring programs should be performed on a regular basis to avoid having to average such a large time span where much can happen with hydrogeologic conditions and concentrations of contaminants.

The two overlays shown in **Figure 6-17** are based on the nitrate contours and the resulting overlay on the CVHM Grid. The left figure represents a contouring (1 mg/l contour levels) of measured nitrogen concentrations using actual monitoring well locations to interpolate between wells as calculated by the Contouring Utility. All well locations and data are based on the CV-SALTS dataset. Areas with no contours or shading indicate insufficient data where the utility is restricting interpolation from taking place where no wells exist within 10 miles of another. The coloration of the OIG is generated by the overlay utility, assigning contour values to each cell and then ranking using the same 1 to 10 scale. The right figure removes the contours and highlights the top 20 percent of measured nitrogen values, after contouring.

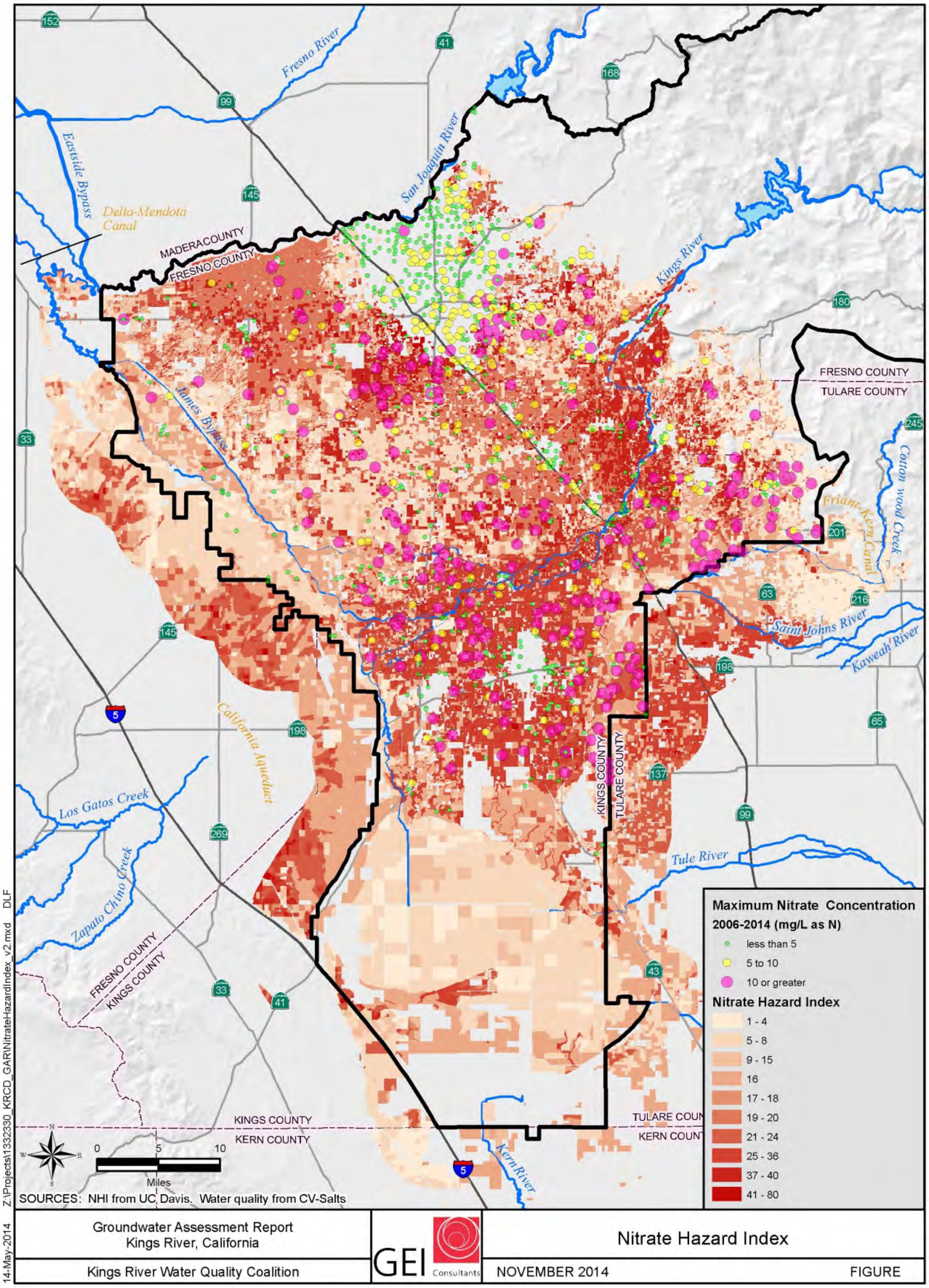


Figure 6-16. Nitrate Hazard Index for the Coalition Area

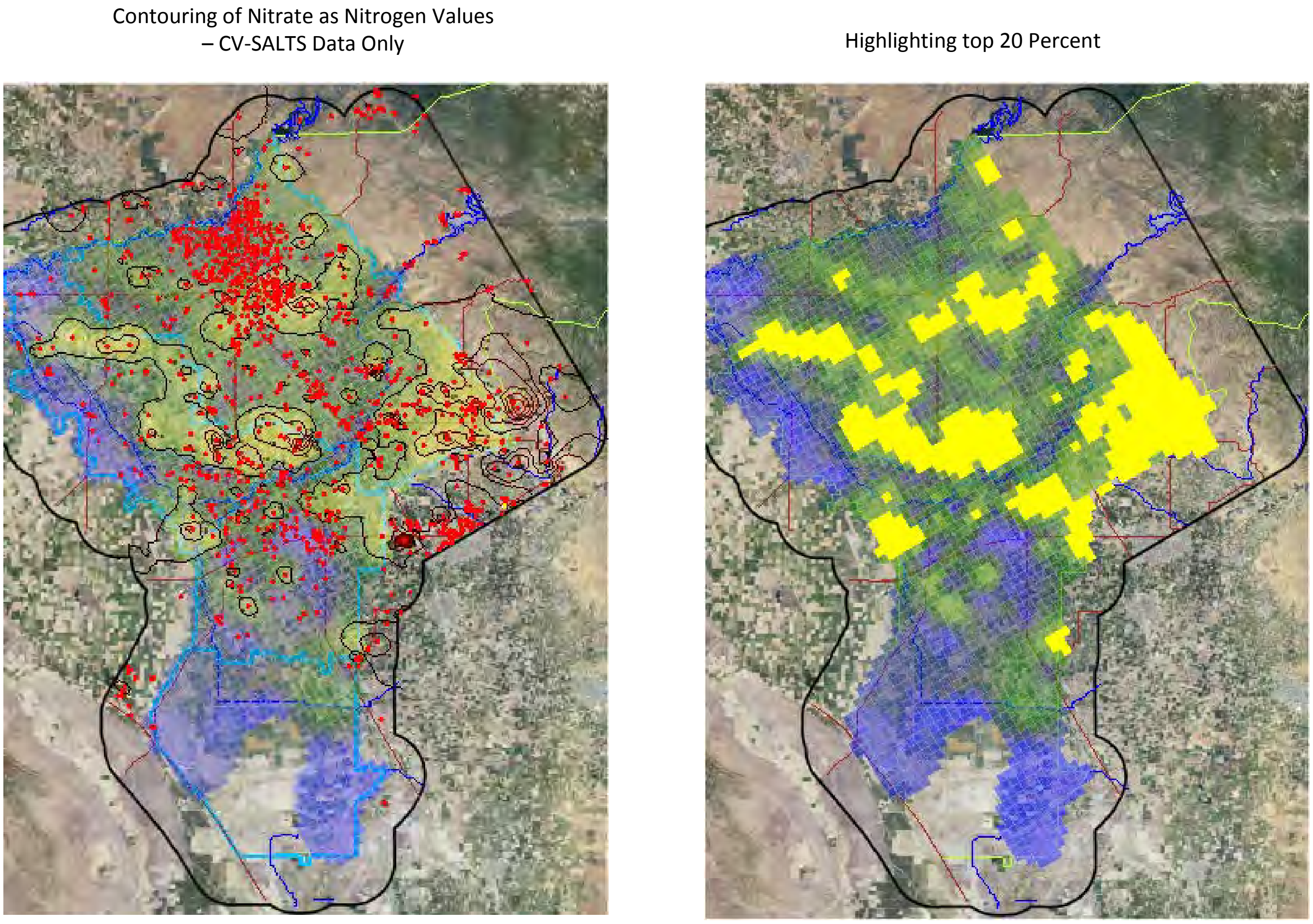


Figure 6-17. Contouring and Representing Nitrate as an Overlay

The difference between the ambient nitrate figure and the solution run (i.e., Nitrate Overlay – Overlay Solution) is shown in **Figure 6-18.** The index overlay produced by this assessment is capturing all but a small percent of the study area (shown in yellow) where difference values are highest (i.e., yellow is showing top 40 percent cells where differences exist). Most of the large differences lie within the eastern foothill regions where the regional aquifer under study is influenced very little or only isolated data points (wells) are available to support the higher nitrate concentration values.

Figure 6-18 highlights, by black circles, differences where two or more exceedance wells have been measured in a location shown as low risk in the GAR solution overlay. Each is numbered to use as a reference in the following section in explaining why these differences exist as they relate to other sources of nitrogen taking place in the basin.

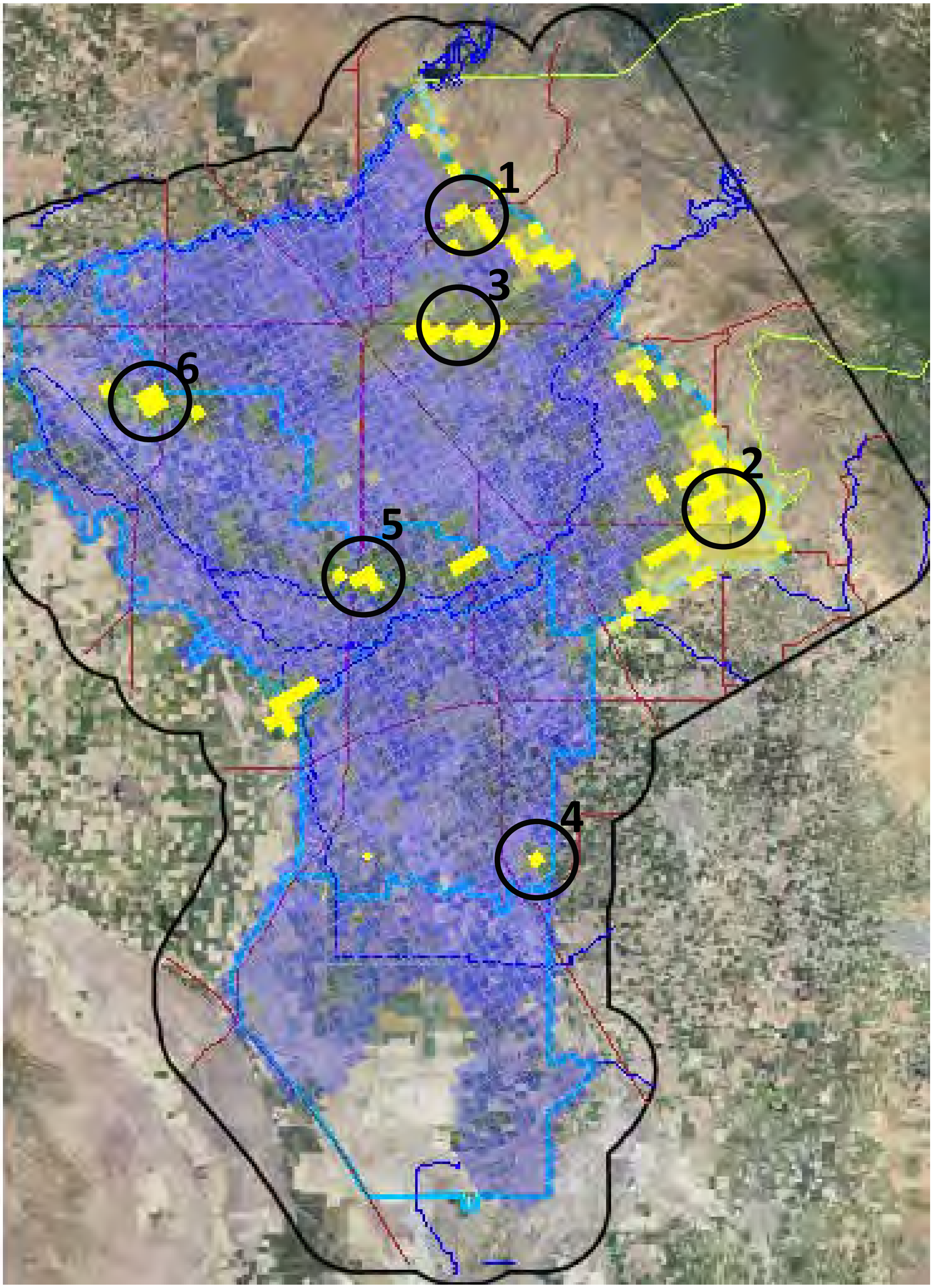


Figure 6-18. Difference Overlay Between Ambient Nitrate and Solution Run

6.5.3 Comparison with Other Sources

Wells with average concentrations above the 10 mg/l MCL within the Coalition area are compared with the Other Sources of Contamination mapping to see if there are other potential reasons for high nitrate concentrations, other than irrigated lands. **Figure 6-19** shows the location of high density septic disposal systems. It is observed that many of the CV-SALTS wells with an exceedance are located near likely high density septic areas, dairies, or other State permitted facilities. The data on types and volumes of discharges, and the nitrate or salt concentrations in the waste streams, was sought from the RWQCB, but was not readily available.

The supporting explanation to those circled areas in **Figure 6-18** is as follows:

1. Septic clusters exist in the area along with some medium risk agriculture. Septic disposal systems are the most likely reason for the exceedance values, given the location and number of potential septic systems in the area. The number and spatial distribution of monitoring wells is also problematic in this region.
2. Septic clusters exist in this area as well, although there does appear to be a wastewater treatment plant (Cutler Orrosi WWTP) for the area as shown in **Figure 6-19.** The exceedance wells in this area are likely due to past septic system use prior to being plumbed for wastewater treatment and discharge.
3. Septic clusters exist in the area along with some medium risk agriculture.
4. Food processing and dairies are the likely reason for the high exceedance wells in this region as shown on **Figure 6-20**. The high densities of both uses are clearly shown and are the likely reason for the difference.
5. The reason for this difference is similar to Area 4 above; however, the location of these exceedance wells near the Kings River is surprising given the amount of natural recharge occurring along the river. Hydrologic year type may make a significant difference in diluting dairy contributions from year to year.
6. This area is known to be influenced by clean-up activities from an abandoned landfill site and from regulated dairies. Data shows an aerial distribution of 29 GAMA clean-up monitoring wells around the landfill site within an approximate 1 square mile area.

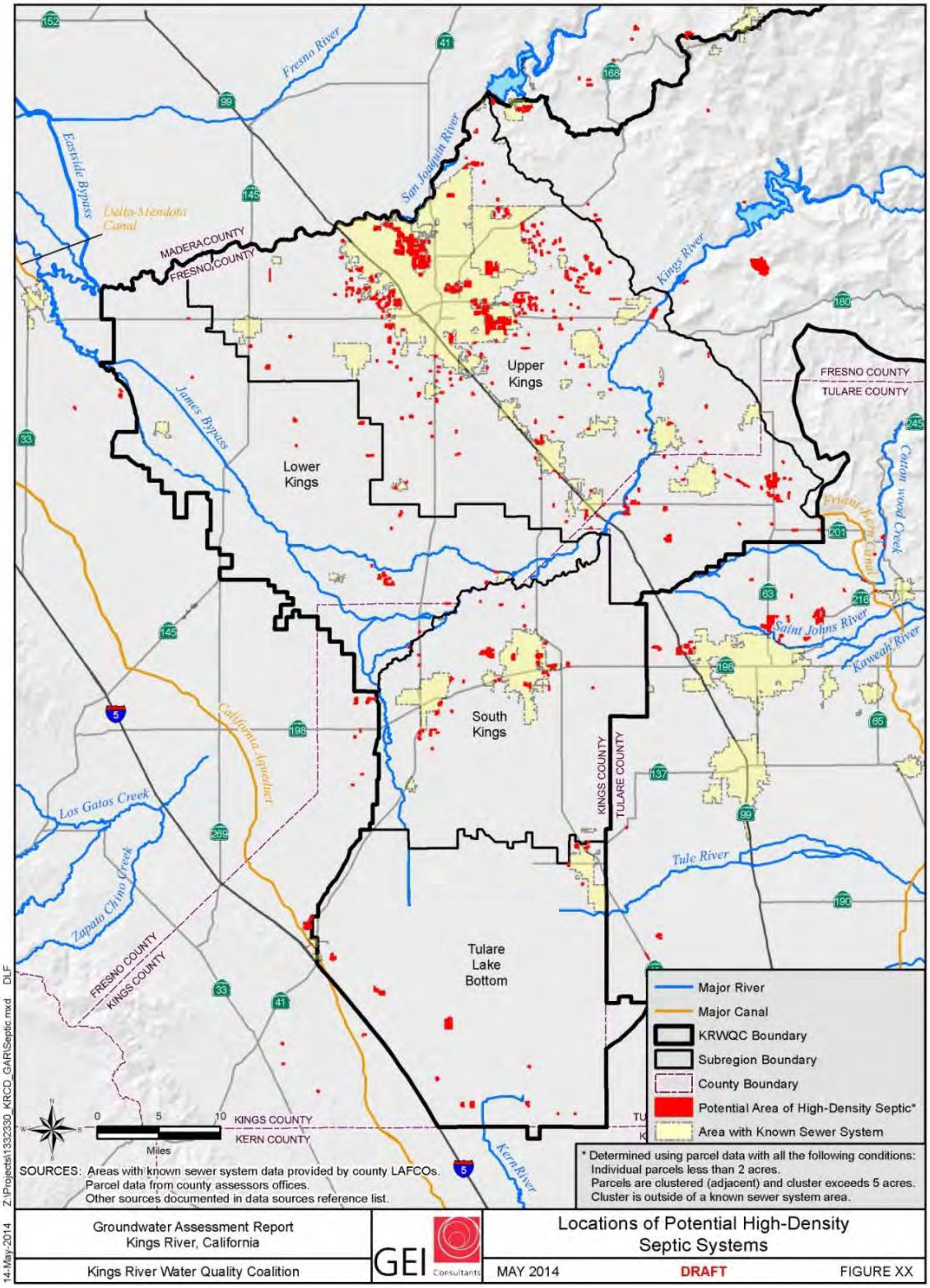


Figure 6-19. Locations of Potential High-Density Septic Systems

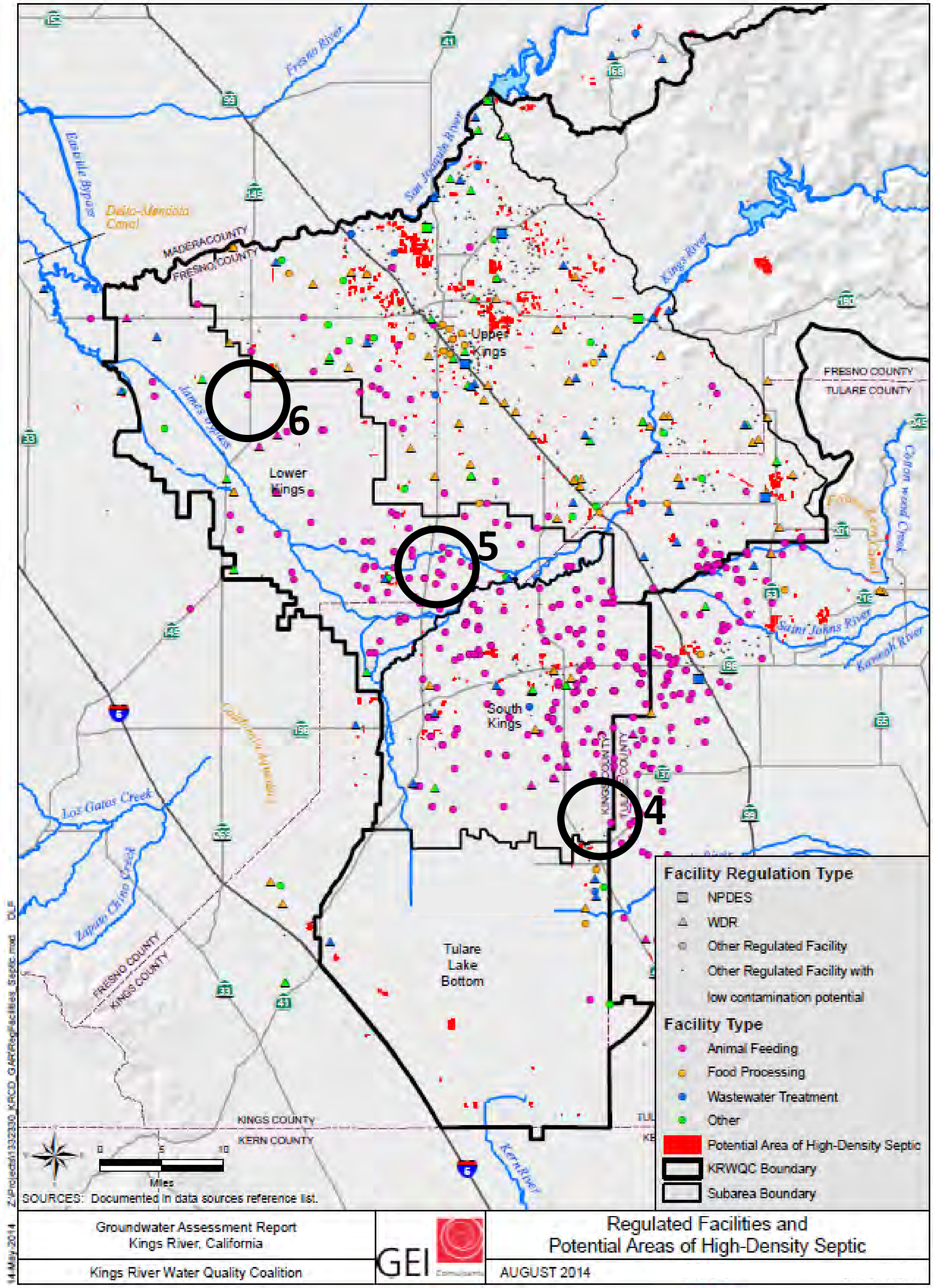


Figure 6-20. Comparison of Regulated Facilities

The conclusion of the difference comparison indicates that other factors lead to relatively higher nitrogen concentrations other than agricultural irrigated lands. Septic systems, dairies, and other regulated clean-up sites need to be included prior to assigning risk to groundwater from agricultural irrigated lands.

6.5.4 Conversion of Groundwater Vulnerability Solution to the Public Land Survey System (PLSS)

The final process for completing Step 1 of the process outline in **Figure 6-2** is the conversion of the CVHM-based dataset to the PLSS grid in order to identify by land section, where vulnerabilities are shown to exist. The process is completed in GIS and uses the weighted average of each CVHM grid cell in overlying each section of each Township and Range within the study area. The PLSS-based weighted average of each section is ranked and calculated similar to the GAR Analyst to develop the relative differences and ranked percentiles.

To further simplify the final delineation mapping, the Coalition defined high vulnerability as the cutoff point. High vulnerability areas are those cells with a ranking greater than the 85^{th} percentile. On the PLSS Grid, the resulting coloration is shown in **Figure 6-21**. This figure is simply stating, with a certain degree of certainty, the areas that on-farm activities may lead to contamination of the groundwater.

6.6 Drinking Water Priority Overlays

The Drinking Water Priority category provides the human health element of concern by taking into account actions which are outside the control of the agricultural community, placing drinking water at risk simply by the location of farms relative to groundwater drinking supply wells and the number of people dependent on groundwater for their potable supply needs. The Population on Groundwater and Well Protection Zone index variables are both used to make this vulnerability assessment.

Since very little information is available publically on private wells and wells which supply small water systems, the (**Figure 6-10**) (a) Population Density dependent on groundwater is used as an index variable to capture the priority of potential risk to human health resulting from nitrate leaching to groundwater drinking supplies. The 2010 Census Tract data is used to calculate the density (or capita) per acre. The low density cutoff point was set at 1 person for every 2 acres (or 0.5 capita/acre) to avoid including farmlands in the dataset. In total much of the area is of sufficiently low density to not be included as a risk.

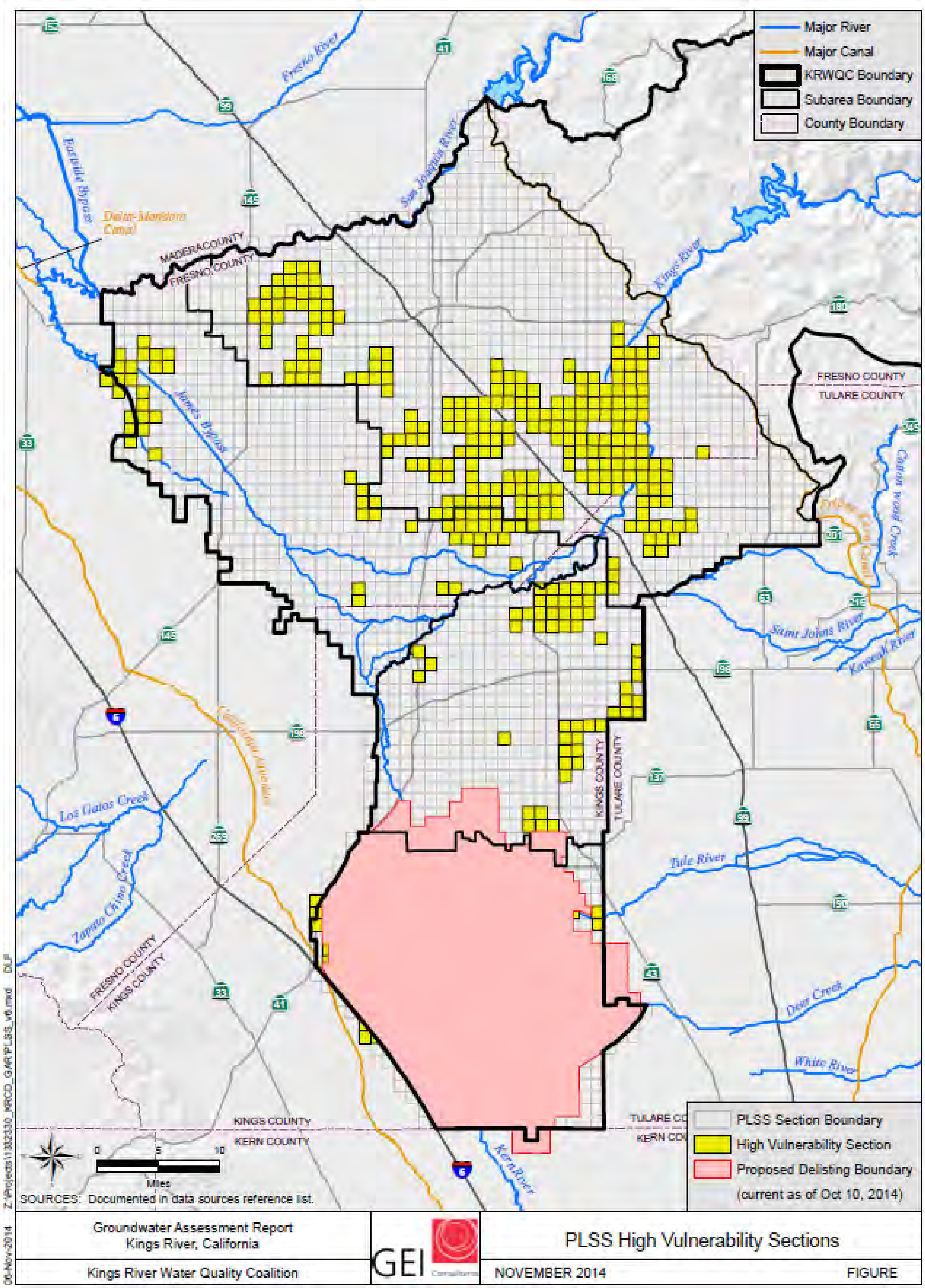


Figure 6-21. PLSS High Ranking of Groundwater Vulnerability Solution

The (b) Well Protection Zones exist around all drinking water supply wells, both public and private. The public supply wells are considered to be a higher risk simply due to the number of people dependent on the supply. In addition, public wells are regulated and information relative to location and construction is known; although, well construction and completion information is not readily available or made public under existing state law.

To work with this dataset, a constant value for each well is assumed to ensure no bias in the data for calculating the protection zones when using the Modified Fixed Radius Method described in **Appendix B**. The result is an overlapping display of circles around and up-gradient of the well in the direction of the groundwater flow. The density of overlapping protection zones is used as the basis for ascertaining relative risk. An illustration of the protection zone concept and its application is provided in **Figure 6-22**. The green dots represent the actual well location and the red dot represents the offset to account for steeper groundwater gradients over a good portion of the region. The shaded circle is the calculated 20-year protection zone.

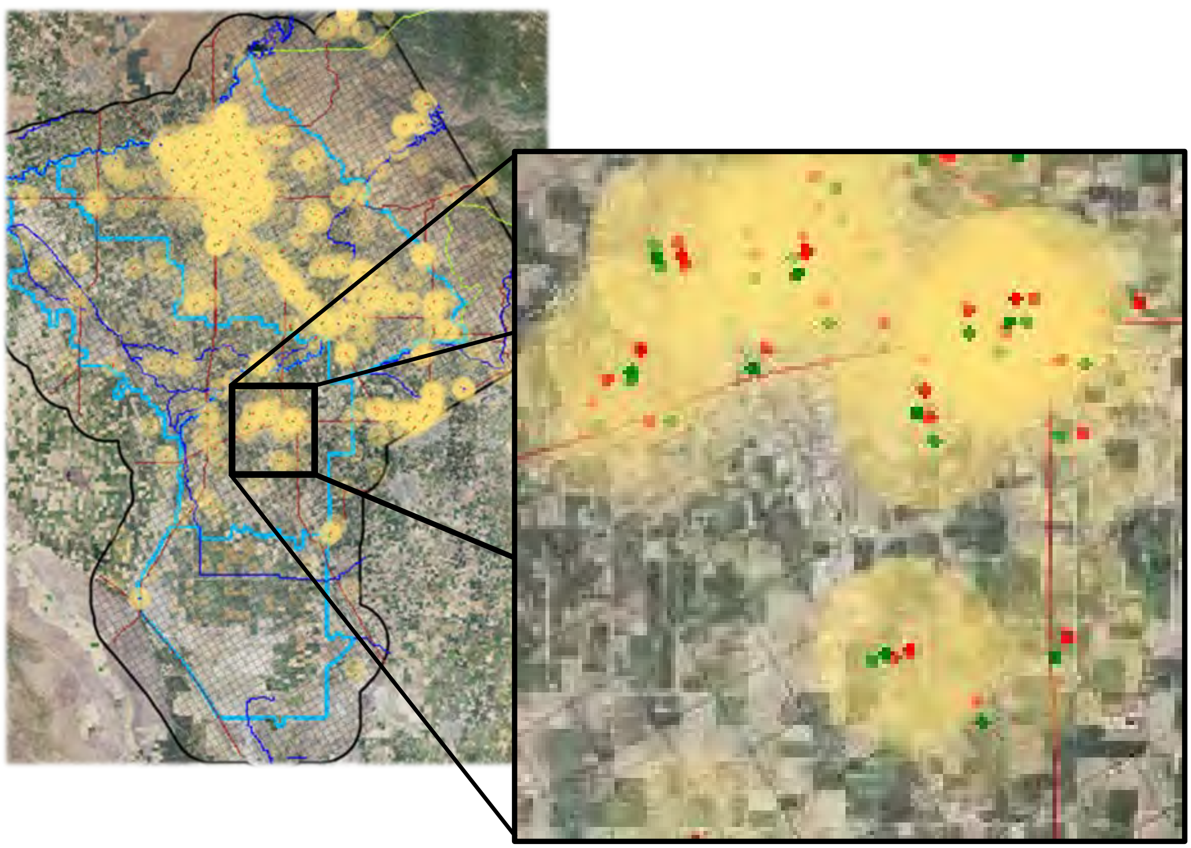


Figure 6-22. Public Well Protection Zones

The density of the protection zones is used as the index variable in this case to differentiate the drinking water system vulnerability. Any agricultural activity taking place within a protection zone is considered to be a candidate for monitoring, it just becomes a matter of priority of monitoring and reporting in the region. The Well Protection Zone overlay shown in **Figure 6-23,** shades areas of high and low densities, and leaves blank areas of low risk where there is no public well vulnerability from agricultural practices.

Both overlays in **Figure 6-24** show the urbanized areas as having the highest potential risk, as can be concluded by the number of wells and the population densities. The solution layer is not surprising with its focus in the urbanized areas. Furthermore, once the same process is applied in converting the CVHM data to the PLSS, additional areas are inherently added because of the cross-section between the two grids; especially, any PLSS grid cell cross section with a CVHM grid of a value other than zero is automatically added to the total number of grid cells to be included in the Drinking Water Priority mapping.

(a)Population Densities Dependent on Groundwater

(b)Well Protection Zones

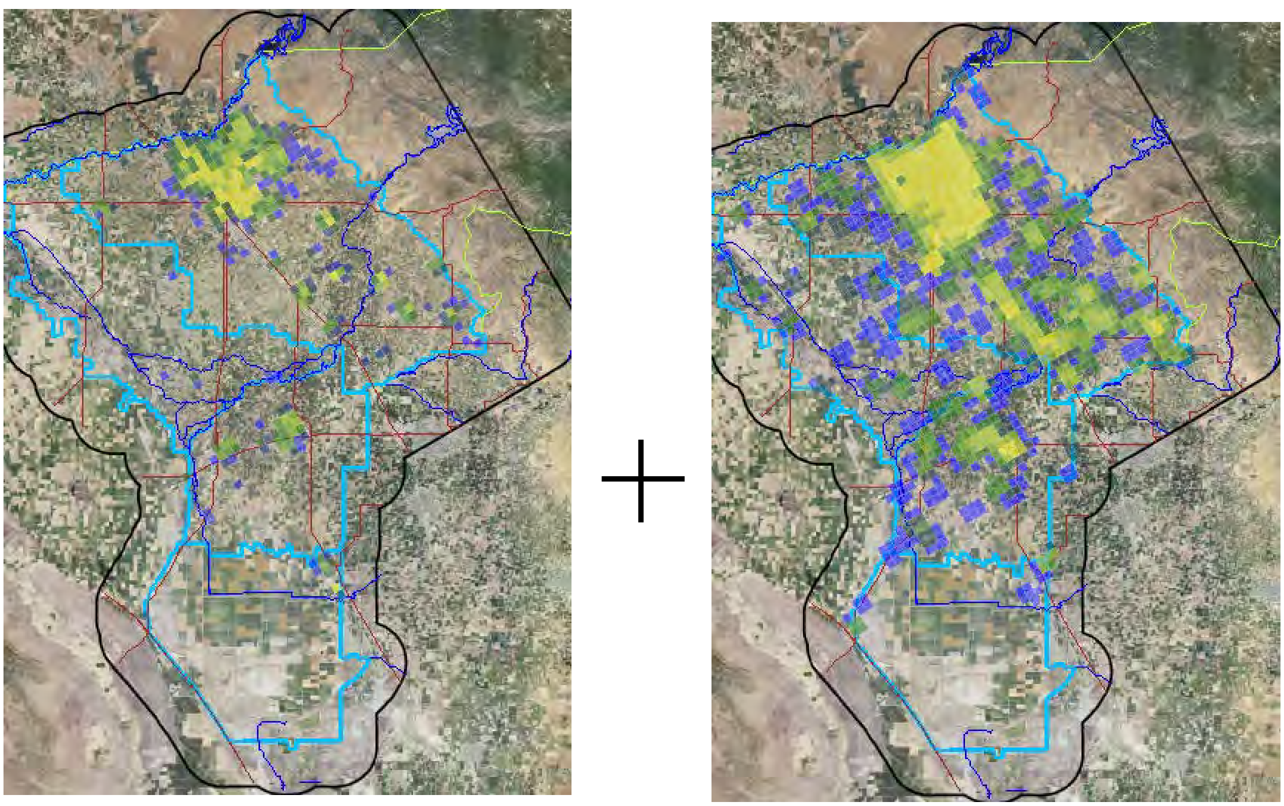


Figure 6-23. Drinking Water Priority Index Layers

Distribution of Drinking Water Vulnerability

Highlighting Top 20 Percent

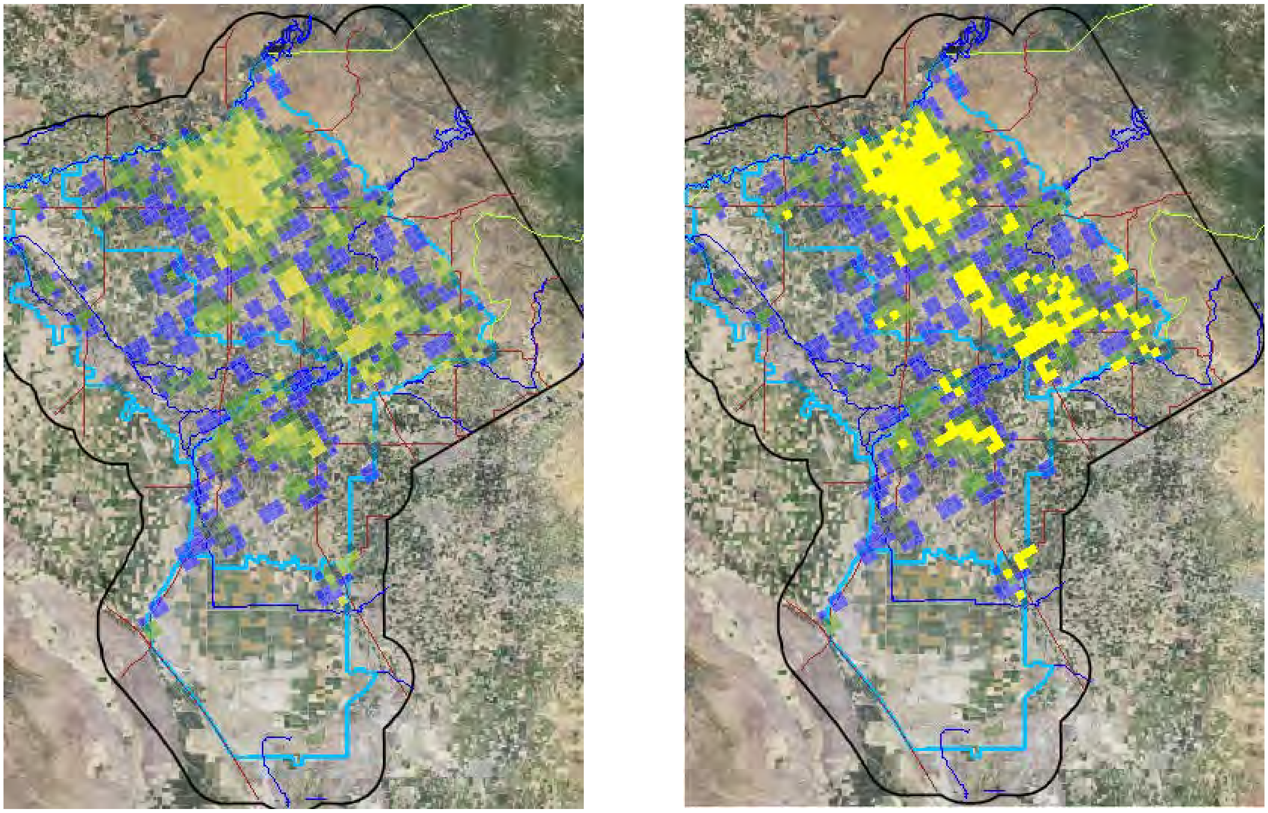


Figure 6-24. Drinking Water Priority Overlay

The conversion to PLSS also converts the data into a similar hi-med-lo split. In the case of Drinking Water Risk, the hi-med-lo values assume a 33-33-34 split, respectively. **Figure 6-25** illustrates this split.

Step 3, shown in **Figure 6-2,** is the final step using the results of Step 1 and Step 2 above, and is completed in **Chapter 8 – Summary of Results and Observations**. Step 3 applies what is known about vulnerability and risk to drinking water, and placing a priority upon high vulnerability areas, in terms of actions by the Coalition moving forward. Chapter 6 leaves off with the two hi-med-lo Vulnerability and Drinking Water Priority maps for use in making these decisions. Other maps including the Well Nitrate Exceedance map, State designated Disadvantaged Community (DAC) Map (see **Figure 6-26**), and Other Activities Producing Nitrogen map also aid in determining the appropriate priority and placement of monitoring and reporting requirements upon certain PLSS sections of the Kings Study area.

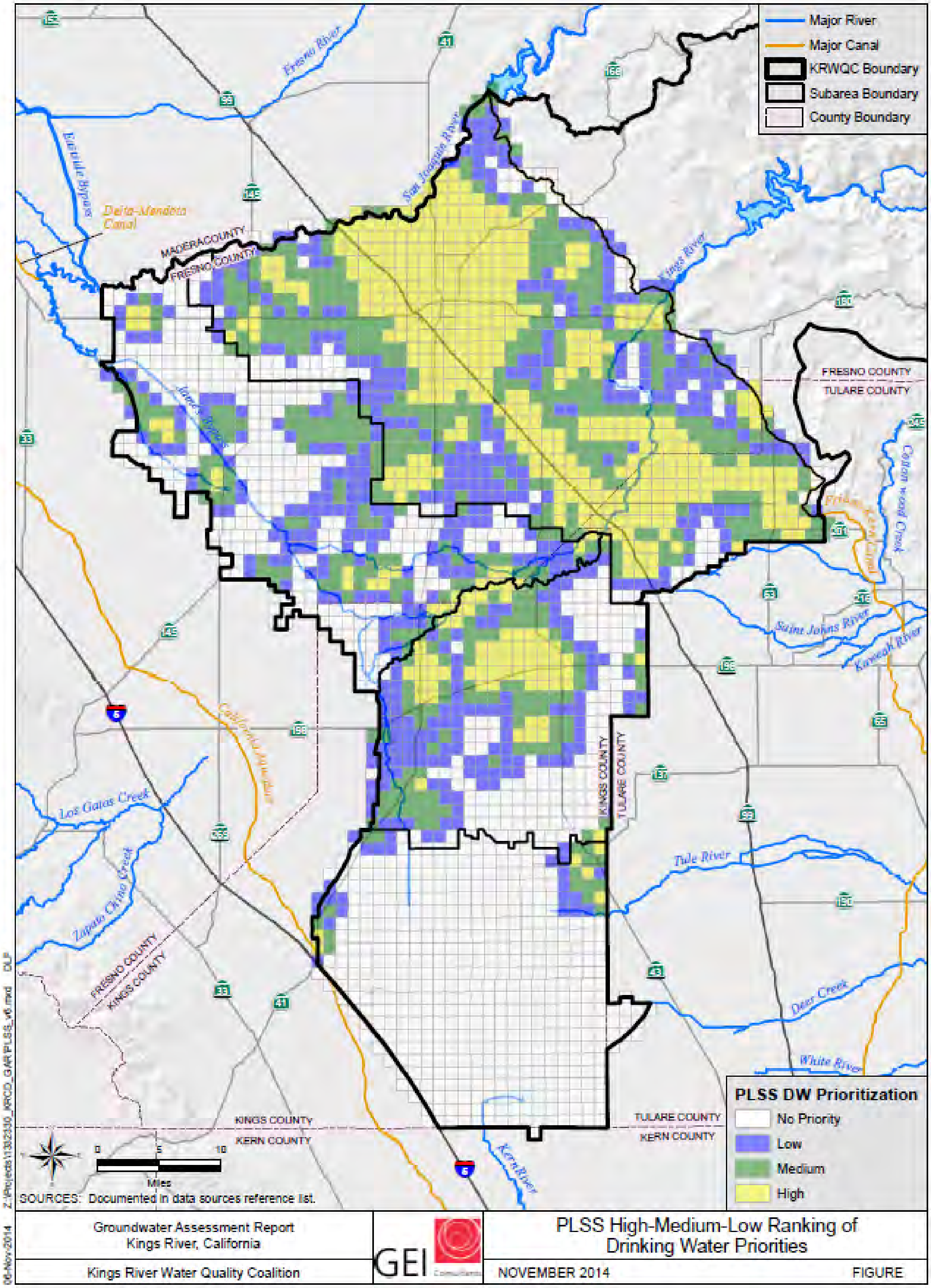


Figure 6-25. PLSS Mapping of High–Medium–Low for Drinking Water Priorities

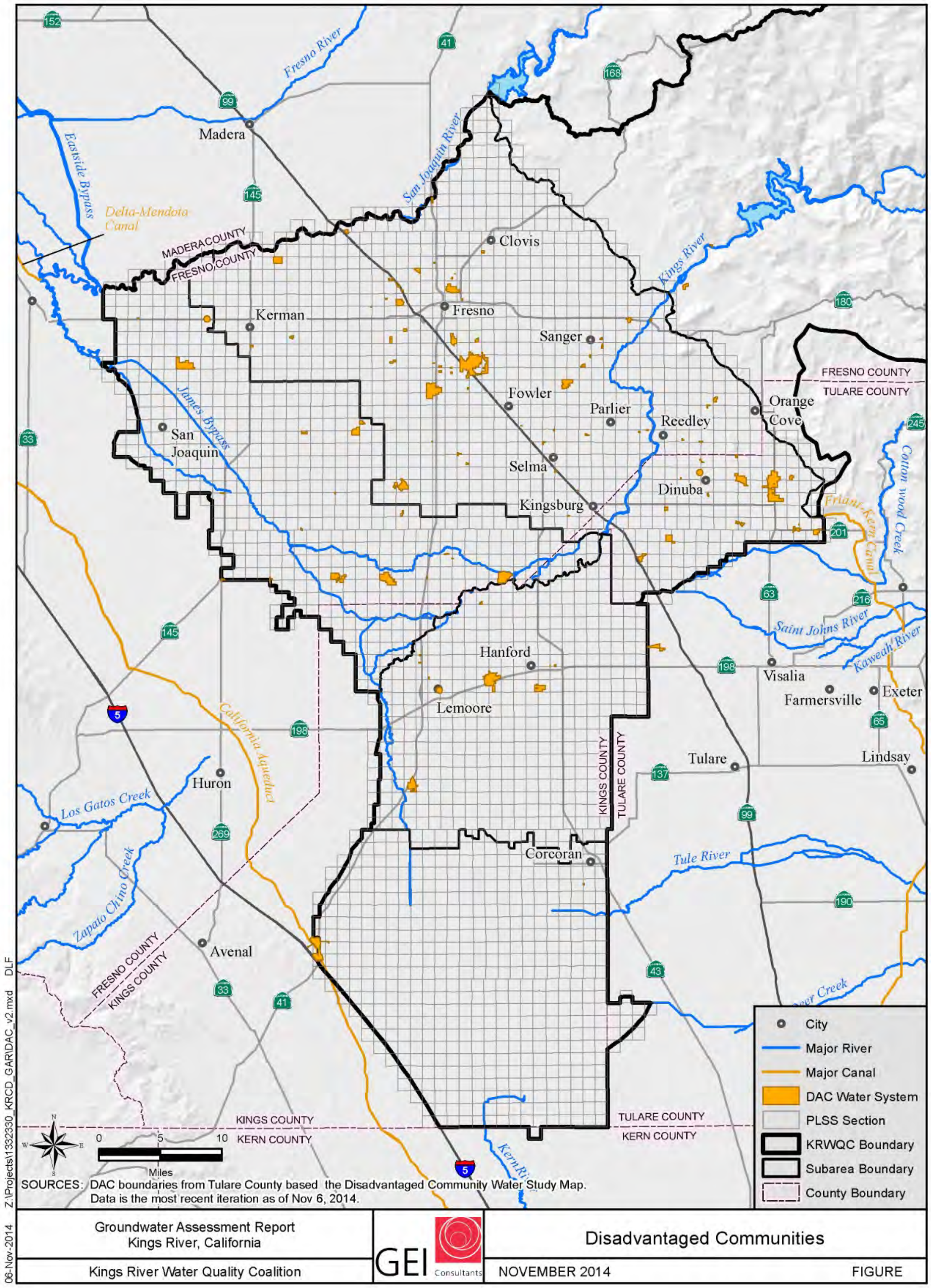


Figure 6-26. Disadvantaged Communities within Study Area

Chapter 7. Groundwater Monitoring

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Chapter 7. Groundwater Monitoring

7.1 INTRODUCTION

The Order requires the GAR to:

- "*establish priorities for implementation of monitoring and studies within high vulnerability areas";*
- "*Provide a basis for establishing work plans to assess groundwater quality trends and to design a groundwater quality trends*" and for "*establishing work plans and priorities to evaluate the effectiveness of agricultural practices to protect groundwater quality*"[1].

As such, the Coalition program would consist of two elements, the Long Term Trend Monitoring and specific Management Practices Evaluation Program (MPEP) Monitoring. The two programs should be closely related and should be co-designed. The MPEP objective is primarily to document the water quality protection benefits of the specific on-farm and commodity activities to be included in the MPEP. The overall objectives of groundwater trend monitoring are defined by the Order and include:

1) To determine current water quality conditions of groundwater relevant to irrigated agriculture, and

2) To develop long-term groundwater quality information that can be used to evaluate the **regional** effects of irrigated agricultural practices[2].

The Kings GAR includes information on existing groundwater data collection and analysis efforts relevant to this Order. The Coalition also needs to assess the possibility of data sharing between the data-collecting entities, other Coalitions and the Regional Board. This includes determining the merit and feasibility of incorporating existing groundwater data collection efforts, and their corresponding monitoring well systems for obtaining appropriate groundwater quality information to achieve the objectives of and support groundwater monitoring activities under the Order.[3]

[1] Section VIII.D.1
[2] Section VII.D.3
[3] Att. B, MRP Section IV.A.2&3.

7.2 GROUNDWATER DATA COLLECTION AND ANALYSIS EFFORTS

There is a number of existing groundwater monitoring programs that have different purposes. They can be broken down into three categories: trend, compliance, and special study monitoring.

Trend monitoring, sometimes referred to as ambient monitoring, is designed to evaluate long term trends from measurements at specific and consistently sampled well locations to identify regional groundwater level and quality conditions.

Compliance monitoring is to ensure that water is meeting related statutory requirements or standards established by agencies like the CDHS for drinking water systems, or the RWQCB for contaminant remediation or other discharge permit activities.

Special study monitoring is typically over a limited time frame for a specific, but more limited set of objectives, and is usually diagnostic or for purposes of testing specific conditions or evaluating specific practices (e.g.; field trials, aquifer test monitor wells, defining the age of groundwater). A single well sampling point could be part of multiple programs. It should be a priority for wells to have a well log and complete construction information if they are to be included in any of the groundwater data collection program.

7.2.1 Ambient Monitoring Programs

7.2.1.1 Groundwater Levels

Since conjunctive use is so important in the Coalition area, annual groundwater data collection and contour mapping have been a priority. Regional groundwater level data is collected and aggregated by several agencies, and much of the information is reported to DWR. Tulare Lake Hydrologic Region has by far the largest number of groundwater level monitoring wells of the ten hydrologic regions (DWR, 2013). Data is collected by individual water districts or pumpers for the different programs. KRCD and Kaweah Delta WCD are the CASGEM designated monitoring entities. KRCD covers the majority of the Coalition area with a smaller area in the Southern Kings subregion. A common protocol for groundwater data level collection has been developed by KRCD. The groundwater level data is provided to KRCD in a variety of formats, including hard copy notes, spreadsheet files, database files, and Geographic Information Systems (GIS) geodatabase files. KRCD staff maintains a geodatabase of groundwater level data and produces contour maps. The Data Management System utilized by KRCD for groundwater data is a geodatabase that enables exporting to common formats such as spreadsheet or database files allowing local agencies, state and federal agencies, and stakeholders to utilize the data.

The local GMPs also document the existing groundwater level monitoring programs, with most GMPs identifying existing and planned groundwater level monitoring activities. Given the different stages of GMP development and adoptions, the implementation status of the planned activities was not investigated for the Kings GAR, and it is highly likely that the programs have and will continue to evolve with time, especially given the development and participation of the DWR required CASGEM program (KBWA, 2012).

7.2.2 Groundwater Quality

There was no long-term, consistent regional ambient groundwater quality monitoring networks identified, though many of the GMPs identified additional groundwater quality monitoring as a planned activity. Some water district plans note that data is collected from existing wells for purposes of planning but that this data typically is considered confidential by the private entities providing the sampling and laboratory results. As part of the Kings GAR, groundwater quality and related data was requested from water districts but no data was obtained.

The reference to water quality monitoring and planned activities described in the overlaying GMPs are listed in **Table 7-1.** To varying degrees, the GMPs recognize the need for water quality monitoring and the activities needed to develop the program, but all take a relatively independent approach based on water district boundaries.

The original Upper Kings IRWM Plan (WRIME, 2007b) also had monitoring, measuring and reporting (MMR) and Data Management Actions (DM) identified including;

- MMR Action 1 - Upper Kings IRWMP Annual Reporting.
- MMR Action 2 - Groundwater Level, Quality, and Flow Monitoring of Recharge Facilities.
- MMR Action 3 - Conduct data network evaluation and design regional monitoring plan.
- MMR Action 4 - Develop regional monitoring wells.
- MMR Action 5 - Fishery monitoring program.
- MMR Action 7 - Supervisory Control and Automated Data Acquisition for Irrigation Systems.
- MMR Action 6 - Water Quality Monitoring.
- DM Action 1 - Develop and Implement Regional Data Management System.
- DM Action 2 - Expand Regional Data Management System and Connect to Statewide System

7.2.3 Compliance Monitoring Programs

The regulatory compliance programs are the primary source of historical groundwater quality data. Spatial and temporal coverage is highly variable.

7.2.3.1 CDPH

CDPH requires monitoring of community public water systems[4] (>15 connections) or regularly serves at least 25 persons at least 60 days a year. Systems with less than 200 connections are defined as small water systems. CDPH has delegated regulatory authority over these systems to local primacy agencies, which in the Coalition area includes Kings and Tulare County. Fresno County does not have local primacy. California Code of Regulations (CCR) Title 22 established the drinking water standards. Water purveyors are required to sample and analyze the water quality. The law defines the frequency of sampling and testing for all drinking water wells, typically triennially but they may require more frequent sampling and testing depending on the circumstances. Much of the CDPH data is available digitally but specific locations are not released to the public in the interest of security. There are about 1200 wells in the CDPH database that are within the Coalition area.

7.2.3.2 County

Kings and Tulare County regulate systems with less than 200 connections. Fresno County regulates only state-small systems, those with 5 to 14 connections, and local small systems, those less than 5 connections. These systems are regulated pursuant to local ordinance which defines constituents and sampling frequency consistent with Title 22. Information to determine the number of wells in the Coalition area that are part of small systems is not readily available.

Domestic wells typically require a sample at the time of construction. The different counties have different information systems and a lot of the data is in hard copy and not readily accessible. Nitrate measurements obtained during the construction of domestic wells was assembled for the UC Davis SB2X study, and 431 of these wells are in the Coalition area. Domestic wells sampled in other programs like GAMA could be added to the groundwater trend monitoring program.

[4] *Section 116275 of the California Safe Drinking Water Act which is contained in Part 12, Chapter 4 of the California Health and Safety Code.*

Table 7-1. Groundwater Management Plan Notes and Planned Activity for Groundwater Quality Monitoring

GMP	GMP Notes	Water Quality Planned Activity
Consolidated Irrigation District GMP	There is no regional, ambient groundwater quality monitoring network. CID does not monitor groundwater quality.	None.
Alta Irrigation District GMP	Water quality is an important aspect of groundwater management. Contamination of the groundwater, resulting in a limitation on its use, is equivalent to a reduction in total water supply with a negative impact on the water balance for the Kings Sub-basin. This loss of supply requires obtaining additional supplies or incurring additional costs for treatment of the contaminated groundwater.	In the future, the District will need to study how and why nitrate and DBCP levels are exceeding relevant water quality standards.
Fresno Area GMP	FID currently collects well water level readings within most of the Plan Area, but the system only includes a few wells in some areas and has very little water quality information. Each agency's water-level measuring-program was established separately and the data are managed separately, but FID compiles all the data into a single database. FID and the City of Clovis monitor wells near their recharge facilities. There are many locations within the Plan Area where little to no water quality monitoring is performed.	• Develop a coordinated monitoring program by methods similar to groundwater level monitoring evaluation; inventory existing efforts, find gaps in data monitoring, then add wells to monitor in gap areas. Critical to this effort will be an understanding of perforation intervals within each well to identify the depth of the various constituents of concern. • Protect wells in monitoring program from being abandoned. • Develop program for sharing data with participants. • Improve access to County individual water quality testing information. • Prepare groundwater quality maps on a periodic basis with the aid of a qualified hydrogeologist. • Collect and compare monitoring protocols from all of the Plan participants. • To ensure the integrity and consistency of the data, protocols for collecting and reporting the data are needed, and must be implemented by each agency.
Kaweah Delta WCD GMP	The Plan will continue to progress toward its goal through ongoing monitoring of the following components: • Groundwater Supply and Quality • Surface Water Supply and Quality • Surface Water Management • Inelastic Land Surface Subsidence	• The District will pursue the collection of groundwater quality data from those agencies that have existing programs that record and report on relevant conditions. The effort's focus is towards monitoring key indicators of groundwater quality for the aquifers lying within the District. The indicators that the Plan will concentrate on will consist of the following: o Temperature o Total Dissolved Solids (TDS) o Electrical Conductivity (EC)

GMP	GMP Notes	Water Quality Planned Activity
		o Acidity (pH) o Chloride o Sodium o Nitrates • The initial effort will be the collection and review of water quality data for adequacy. The Environmental Health Departments of Kings and Tulare Counties will be used as a primary source for acquiring relevant data.
Kings County Water District GMP	The District has only performed limited groundwater quality monitoring in the past, and has relied on private landowners and other agencies for groundwater quality data. As there are very few water quality concerns in the District, this approach has generally provided adequate information to monitor and manage the groundwater quality. Groundwater Quality monitoring efforts serve the following purposes: • Spatially characterize water quality according to soils, geology (above and below the Corcoran Clay), surface water quality, and land use; • Establish a baseline for future monitoring; • Compare constituent levels at a specific well over time (i.e. years and decades); • Determine the extent of groundwater quality problems in specific areas; • Identify groundwater quality protection and enhancement needs; • Determine water treatment needs; • Identify impacts of recharge and banking projects on water quality; • Identify suitable crop types that are compatible with the water characteristics; and • Monitor the migration of contaminant plumes.	Planned Actions • Protect wells in monitoring program from being abandoned • Measure electrical conductivity at all monitoring wells every five years in conjunction with groundwater management plan updates. • Assess the adequacy of the groundwater quality monitoring network annually. • Install ten nested monitoring wells strategically located throughout the District, with the ability to sample groundwater above and below the Corcoran Clay. • Sample the water quality in dedicated monitoring wells for selected constituents annually.
Lower Kings GMP	It may be important to have a network of dedicated monitoring wells to track regional trends and to serve as a warning system for changes in water quality. The efficiency of the process by which KRCD obtains	Planned Actions 1. KRCD will track the Groundwater Ambient Monitoring and Assessment (GAMA) that the state is implementing with support from the USGS.

GMP	GMP Notes	Water Quality Planned Activity
	groundwater level and water resources data can be improved and standardized by developing a data management system for groundwater and water resources data. A Kings Basin Groundwater Data Center (GDC) should be developed by KRCD to support the capture, processing, review, storage, retrieval and reporting of groundwater data.	2. KRCD will evaluate the development of a groundwater quality network of wells as part of the efforts to evaluate the overall monitoring program and network. 3. Collect privately maintained water quality data from willing providers for purposes of project feasibility analysis. Confidentiality of original data must be maintained. 4. Coordinate with member agencies so that uniform monitoring protocols are used. 5. Identify potential wells that USGS could incorporate into the NAWQA well network and determine timing and frequency of monitoring. 6. Promote the creation of groundwater quality monitoring well network. 7. Develop standard procedures for collection of groundwater level and quality data. 8. Provide training regarding standard procedures.
Tulare Lake Bed (TLB) Coordinated GMP	Owners of the CASGEM wells periodically test their well water for electrical conductivity (EC) which relates to the total dissolved solids in the water. EC measurements will be logged by TLB acting as Plan administrator.	None

7.2.3.3 CDPR

CDPR maintains a data base of pesticide sampling results. The data originates with other local, county or state agencies which report the data to CDPR as part of the Pesticide Contamination Prevention Act program. DPR's Well Inventory Database, established in 1983, includes the well number, well type, well location, chemical analyses performed, sample date, sample type (initial or confirmation), analysis date, sample concentration and minimum detection limit (in parts per billion), and laboratory information. Agencies also may send information about well construction or the source of the potential contamination. CDPR also conducts some sampling and testing of wells and has delineated groundwater protection areas defined under the California Vulnerability (CALVUL) program. The specific pesticide management zones were shown previously in **Chapter 5**. DPR cannot disclose the exact location of the wells that have been sampled or personal information about the well owners to the general public. CDPR can release specific well location information to another public agency provided the other public agency agrees, in writing, to protect the confidentiality of the information and documents released

7.2.3.4 RWQCB

The RWQCB has compliance monitoring programs related to specific point sources of contamination (leaking underground storage tanks, landfills, dairies, etc.) to ensure that remedial measures are effective or facilities are meeting their permit standards. The monitor wells are related to the specific requirements of the regulated facility and are not good candidates for the ambient program since they are owned and operated by facility owners, are for very specific requirements for the facility and access could be an issue.

The RWQCB also issues NPDES permits to surface water dischargers and sets Waste Discharge requirements for land disposal of wastewater from municipal and industrial facilities.

The RWQCB regulates confined animal feeding operations and dairies under separate programs with monitoring requirements[5]. The sampling and testing results are utilized to meet multiple program objectives, and some of these wells could be valuable to fill spatial data gaps as part of an ambient, groundwater trend monitoring program. They may also be included in specific

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[5] Reissued Waste Discharge Requirements General Order for Existing Milk Cow Dairies (Reissued Dairy General Order) Order No. R5-2013-0122, Adopted on 3 October 2013

Revised Monitoring and Reporting Program for General Order for Existing Milk Cow Dairies. Issued by the Executive Officer on 23 February 2011. Order No. R5-2007-0035, Revised Monitoring & Reporting Program, 473 KB, PDF (PDF info)

General WDRs and General NPDES Permit for Existing Milk Cow Dairy Concentrated Animal Feeding Operations (CAFOs). Board Order No. R5-2010-0118 was revised by Order R5-2011-0091 special study efforts to better determine the sources of nitrates and salts, and the relative contribution from animal or municipal wastewater disposal practices, dairies or from irrigated agricultural operations.

The data could be beneficially applied for any geographically limited special study program intended to identify sources and loading rates for nitrates and salts.

7.2.4 Special Study Programs

7.2.4.1 GAMA

The GAMA program was established by the SWRCB under the California Groundwater Quality Monitoring Act of 2001 (AB 599 2001) to provide a statewide comprehensive assessment of groundwater quality. The GAMA program is divided into three projects: the domestic well water quality, priority basin water quality, and special studies.

Domestic Wells

Starting in 2002, the GAMA domestic well project sampled domestic wells to develop a baseline for assessing drinking water quality. Tulare County was sampled in 2006. The Tulare County project collected one sample per well and collected samples from 181 wells out of the approximately 26,000 domestic wells in Tulare County (SWRCB, 2006). Highly accurate GPS data exists for these wells; however, for confidentiality reasons, wells are randomized to within ½ mile from the actual well locations. Well depths are available for some wells as reported by the well owners. The accuracy of the well depth information is uncertain (UCDAVIS, 2012). There were 25 wells from this sampling program that are in the Coalition area.

Priority Basin Project

The priority basin project was conducted by the USGS for the SWRCB, and was designed to assess water quality conditions in basins where there is a primary reliance on groundwater. The intent was to establish a baseline groundwater quality monitoring program. The Southern San Joaquin Valley study unit was completed in 2006 and includes the Coalition area (USGS, 2012) (USGS, 2006). Water supply wells, groundwater monitoring wells, and irrigation wells were sampled one time each. There were 54 wells in the Coalition area. A wide variety of natural and anthropogenic chemical were tested including nitrate, bacteriological, and radiological constituents. These wells were geo-located using field GPS and the wells are associated with the DWR well log so perforated intervals, lithology and construction are known.

Special Studies Program

Lawrence Livermore National Laboratory conducted a study of domestic wells by testing nitrate and water isotopes in Tulare County (LLNL, 2013). Sampling and testing was conducted in 2006 on 151 wells. The purpose was to identify the sources of water recharging groundwater produced by the domestic wells and to help to identify sources of nitrate. The analysis indicated that the Kings and Kaweah rivers were the source of recharge water in domestic wells on the valley floor. Nitrate isotopic compositions indicate a dairy manure or septic effluent source for the majority of the most heavily impacted wells, with the exception of one well with high nitrate concentration and an isotopic composition indicative of a synthetic fertilizer source. For less heavily impacted wells, the sparse nitrate isotopic data alone does not definitively constrain the nitrate source. The observed pattern could be produced by a single source (natural soil N) or by mixing between multiple sources (fertilizer, manure, septic). The report concludes that an analysis of land use and the distribution of potential nitrate sources would be extremely useful to more firmly define nitrate sources. The sparse nitrate isotopic data set and the cursory approach to assigning land use limits conclusions, but patterns observed are suggestive of multiple anthropogenic sources, including dairy wastewater, septic effluent and synthetic fertilizer. LLNL also evaluated isotope chemistry to assess nitrate loading from dairies, including three sites in Kings County (LLNL, 2009).

7.2.4.2 Other Special Studies

There have been other special investigations to deal with specific groundwater quality issues. The City of Fresno evaluated sources of nitrate in groundwater due to impacts on drinking water wells (Schmidt, 2004). There are a wide number of site assessments and studies that delineated other contaminant issues such as DBCP plumes in and near Fresno. Many of these studies have more site specific geology from drilling of monitoring wells and exploratory holes and this information may add detail in areas that could be included in the Groundwater Quality Trend monitoring program design. A complete inventory of the available studies was not part of the Kings GAR.

7.3 Order Requirements

The Coalition will need to develop and submit a groundwater quality monitoring workplan to the RWQCB within one year after written approval of the GAR by the Executive Officer. To reach the Order’s stated objectives, the Coalition needs to develop a groundwater monitoring network that will: (1) be implemented over both high and low vulnerability areas; and (2) employ shallow wells, but not necessarily wells completed in the uppermost zone of first encountered groundwater[6].

The network proposed by the Coalition in the Trend Monitoring Workplan needs to consist of a sufficient number of wells to provide coverage in the Coalition area so that current water quality conditions of groundwater and composite regional effects of irrigated agriculture can be assessed according to the trend monitoring objectives. The rationale for the distribution of trend monitoring wells needs to be included in the workplan[7]. The rationale should consider: 1) the variety of agricultural commodities produced within the Coalition's boundaries (particularly those commodities comprising the most irrigated agricultural acreage), 2) the conditions discussed/identified in the GAR related to the vulnerability prioritization within the Coalition area, and 3) the areas identified in the GAR as contributing significant recharge to, or being located nearby, urban and rural communities where groundwater serves as a significant source of supply.[8]

The baseline constituents for the groundwater quality monitoring must be sampled annually or in a five year rotation, including those parameters required under trend monitoring[9].

Table 7-2. Trend Monitoring Constituents

Annual	First year- Then Every 5 Years

• Conductivity (at 25 ºC)* (µmhos/cm)
• pH* (pH units)
• Dissolved oxygen (DO)* (mg/L)
• Temperature* (ºC)
• Nitrate as nitrogen (mg/L)
• *field parameters
	Trend monitoring wells are also to be sampled initially and once every five years thereafter for the following COCs:
	• Total dissolved solids (TDS) (mg/L)
	• General minerals (mg/L):
	  • Anions (carbonate, bicarbonate, chloride, and sulfate)
	  • Cations (boron, calcium, sodium, magnesium, and potassium)

7.4 Feasibility of Incorporating Existing Groundwater Data Collection Efforts and Data Sharing

This section evaluates feasibility by identifying institutional and technical opportunities and constraints to incorporating existing data collection efforts and data sharing. The original Kings IRWM Plan (WRIME, 2007b) noted some of the constraints to developing a water quality monitoring program, stating that:

[6] Att. B, Sect IV.C.2
[7] Att. B, Sect. IV.C.2
[8] Ibid. Sect. IV.D.1
[9] Ibid. Sect. IV.E.3, Table 3

> *"There are limited financial resources to support regional monitoring or to conduct specific studies of current conditions. The general lack of data and the limited accessibility presents a challenge to clearly documenting existing water quality conditions. Available water quality data is in both hard copy and digital formats and widely dispersed with many agencies. Hard copy data are not readily accessible, and electronic data are in multiple formats that complicate capture, comparison, and evaluation. There was limited continuous data to document changes over time or evaluate seasonal cycles that can affect water quality and recharge operations. Groundwater data was also spatially limited and did not represent the entire IRWMP geographic area or all of the possible depths where water is pumped. Significant information was available for the area near cities such as Fresno and Clovis and in depth ranges typically utilized for water supply while limited information was available for more agricultural portions of the Upper Kings IRWMP Region and for aquifers above or below typical water supply aquifers".*

This statement is generally true throughout the Coalition area. Prior to the Order, there had been no mandate to develop ambient, regional groundwater quality monitoring, and little resources available for development of such a program.

The Order recognizes that use of existing wells is less costly than installing wells specifically designed for groundwater monitoring, while still yielding data which can be compared with historical and future data to evaluate long-term groundwater trends; and encourages the Coalition to consider using existing monitoring networks such as those used by agencies with adopted groundwater management plans (GMPs)[10].

7.4.1 Institutional

7.4.1.1 Use of Existing Organizational Structures and Agreements

The experience with the ILRP surface water monitoring program demonstrates that the Coalition has the appropriate institutional structure to develop the groundwater quality monitoring program. The financial capacity and mechanisms will be evaluated once the program is designed and costs are known. KRCD has served as the third party administrator, demonstrating the necessary technical and management capacity for the ILRP surface water monitoring. KRCD is the CASGEM monitoring entity for the groundwater levels program, and demonstrated the technical capacity to collect and manage data from disparate sources and in differing formats, also producing the regular reports and submitting data to DWR. KRCD should build on this background to develop the groundwater quality trend monitoring program and coordinate any MPEP specific special study monitoring. The only constraint is ensuring

[10] Prepared pursuant to AB 3030 and SB 1938. The requirements for groundwater management plans are likely to change under legislation currently being considered.

adequate financial and staffing resources are available. Existing Staff may need training and/or additional staff is likely to be required.

7.4.1.2 Coordinate CASGEM and Groundwater Quality Trend Monitoring Efforts

There are opportunities to integrate the groundwater levels and quality monitoring efforts. From a technical standpoint, there is value in collecting both water levels and quality data from the same wells, having standardized protocols and quality control and assurance processes, and obtaining levels and quality at the same well. This supports improved analysis of hydrogeologic and groundwater conditions. Many of the CASGEM groundwater level wells have well logs which are needed to correctly interpret sampling and testing results. For those that may not, efforts should be made to link the DWR well log with the well. Integration of the collection network is likely to also prove the most cost effective.

Under the existing business model for the regional groundwater level data collection program, the individual water districts collect, manage and report the groundwater level data for their area. Each district has its own data reporting and management approaches. The districts typically do not have, or have a limited groundwater quality collection program. KRCD also has some field collection responsibilities in areas without a district or under arrangement with the districts or private land owners. With CASGEM, KRCD and Kaweah Delta aggregate and manage the groundwater level data for submittal to DWR and for purposes of more regionalized analysis and reporting. The groundwater quality trend monitoring program could follow a similar model, but this is likely to be more complicated because of the volume of groundwater quality data, staffing and training requirements, QA/QC procedures, reporting requirements to the RWQCB, and data management and reporting needs. Within the Coalition area, it will be more cost effective for one agency to take the lead for sampling, laboratory testing, data management, quality control and reporting. Districts should be provided access to the groundwater quality results in order to include them in any future updates of the GMPs.

7.4.1.3 Sampling and Testing of Private Wells

There are spatial data gaps based on review of the available water quality data from municipal and domestic drinking water wells. Drilling monitoring wells to close the data gaps is costly as compared to sampling existing wells. Agreements with well owners may be necessary to gain access and allow turning on the well. Production wells are increasingly in locked enclosures to prevent vandalism or theft so managing access is important. Coordination of sampling with growers when they are irrigating is another option. Growers could sample the wells and provide results. Agreements may require confidentiality of location. The location could be kept confidential in a similar fashion to the municipal supply wells, and results could be reported only by the section or quarter section. Well modifications may be needed to gain physical access to the well (installation of a sampling port).

Domestic wells are candidates for shallow groundwater sampling but may not be available in some areas where there are data gaps. Agricultural wells typically are deeper but may be dually perforated above and below the clay layers, providing a mixed water sample. Growers may be reluctant to participate given the potential for liability with the RWQCB for wells that exceed drinking water standards. This disincentive could also result in growers drilling deeper wells to avoid pumping shallower water that could be contaminated. Drilling and sealing wells beneath the Clay layers would help in obtaining representative samples for the deeper aquifers, but this would reduce the ability to pump water from shallow aquifer zones that may contain nitrates, resulting in application of this water to crops which can then use the nitrogen.

7.4.1.4 Coordinate with Other Coalitions

The groundwater quality trend monitoring program will require management, processing, analysis, storage, retrieval, sharing and reporting of the collected data. The Kings Coalition will have very similar requirements as the other water quality coalitions and there may be opportunities to share the cost for development of a data management system to meet the Orders requirements and reduce the cost of regulatory compliance. Constraints are related to timing and cost of development, establishing cost sharing agreements, defining diverse user requirements and assigning responsibilities for management of such a system. Development of a shared set of tools that could be tailored to any unique needs could reduce the overall development and program management cost to all the coalitions and third party administrators seeking to comply with the order.

7.4.2 Technical

The goal for a trend monitoring program is to achieve representative spatial, depth and temporal sampling at the least cost. A program objective should be to make use of the existing sampling programs and available historical records. A program requirement should be that all wells to be added to the trend monitoring network have a DWR driller's log, and preferably an electric geophysical log to characterize the hydrogeology and define the zones of completion. Design criteria, and program opportunities and constraints are discussed below. The existing records can be used to help finalize and establish a list of candidate wells to be included in the trend monitoring network to provide representative spatial coverage in the vulnerable areas. Where records are incomplete or not readily accessible, opportunities to improve the data set are to be noted in the database.

7.4.2.1 Use of CDHS and Local Water Systems Well Data

The GAR relied primarily on municipal and domestic well results. These wells provide the longest continuous time series. The trend monitoring will continue to rely on aggregating data from the compliance monitoring test results to extend these records and evaluate changes over time. Cost effective and timely capture of results is needed through electronic records exchange and sharing. Accessing future electronic CDPH data is relatively straight forward. There will be additional work to access and make use of the small local county water systems records; and both the historical records and future data that is collected need further analysis for developing the trend monitoring program. Data access and sharing agreements may be needed, including defining electronic access and exchange standards. An issue with public drinking water wells is that the data point could be lost if the well exceeds standards, or is out of compliance and could be shut down. The goal should be to replace the well without having to abandon the monitoring well, to ensure long term monitoring compliance as part of the trend monitoring program.

7.4.2.2 Temporal Data Gap and Continuous Records

A goal of the trend monitoring program is to track conditions over time at the same well. The USGS GAMA wells have good but not continuous data. The USGS developed a spatially representative sampling program and these wells are good candidates for the trend monitoring program since some data is available and the wells provide a place to continue to monitor and track changes.

7.4.2.3 Spatial Data Gaps

There are large spatial data gaps in the agricultural areas which preclude full evaluation of the groundwater quality conditions. Further evaluation of where these gaps are and how they can be filled is needed to develop the trend monitoring program. These gaps could be closed through gaining access to private wells (see above) or drilling monitor wells.

7.4.2.4 Well Logs

The lack of Well Completion Reports linked to existing wells in a useable data base complicates network design. Linking logs with wells takes significant effort and cost, but knowing well construction and completion details is needed to ensure representative sampling. The area has a complex geology with differential flow paths, making evaluation of fate and transport very complex. Many wells are completed both above and below confining clay layers and samples are a composite of the different production zones. There are cases where a large percentage of the measured concentration at the surface could be originating at a very discreet production zone. Wells added to the trend monitoring program should have both a well log and an electric geophysical log. This should be primary selection criteria for a candidate well.

7.4.2.5 Accurate locations

The accuracy of the interpretation will always be affected by the accuracy of the well location, especially when trying to interpret or aggregate data. Ideally, the other third party administrators would be granted access to accurate location data and there would be an agreement and protocol for presenting and aggregating data (e.g.; by section or management area), or presenting results at spatial scales where well locations cannot be effectively identified.

Chapter 8. Summary of Results and Observations

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Chapter 8. Summary of Results and Observations

The Kings GAR analysis provides a defensible groundwater vulnerability assessment by applying accepted scientific methods, and the Kings GAR report provides documentation of data, observations, and methods of investigation to allow for reproducible results. The Kings GAR resulted in collection, qualification and application of the available, applicable and relevant data and information; and used the information in the GAR database and analysis utilities to determine the high and low vulnerability areas where discharges from irrigated lands may result in groundwater quality degradation. **Table 8-1** shows the sections of the report intended to meet the Orders requirements.

In selecting the Hybrid Index Overlay approach, the tradeoffs were carefully considered among the competing influences of the cost of an assessment, the scientific defensibility, and the amount of acceptable uncertainty in meeting the objectives of the water-resource decision maker. The Kings GAR provides an evaluation of the *relative risk* of contamination from irrigated agriculture; and the technical basis to informing the scope and level of effort for development and implementation of the MPEP and groundwater monitoring requirements. The Kings GAR was not intended to evaluate the salt or nutrient budget. It was not intended to assess assimilative capacity or absolute risks; nor did it analyze the effects of potential future changes to water management, land use-crop type or irrigation systems.

One of the values of the Kings GAR tool developed for this analysis is its capacity to bring together data from both the field-level and basin-level frames of reference. In particular, the tool enables presentation of information and analyses performed at the field-level frame of reference within a basin-wide context. This allows users to better understand the implications of field-level parameters, such as irrigation efficiency, on basin-wide groundwater management.

Table 8-1. General Order Requirements and Kings GRA Cross Reference

Order Requirements	GAR Reference
Objectives (Att. B.IV.A.1)	
Provide an assessment of all available, applicable and relevant data and information to determine the high and low vulnerability areas where discharges from irrigated lands may result in groundwater quality degradation.	Throughout
Establish priorities for implementation of monitoring and studies within high vulnerability areas.	Ch. 6

Table 8-1. General Order Requirements and Kings GRA Cross Reference, Continued

Order Requirements	GAR Reference
Objectives (Att. B.IV.A.1), continued	
Provide a basis for establishing workplans to assess groundwater quality trends.	Throughout
Provide a basis for establishing workplans and priorities to evaluate the effectiveness of agricultural management practices to protect groundwater quality.	Throughout
Provide a basis for establishing groundwater quality management plans in high vulnerability areas and priorities for implementation of those plans.	Throughout
Components (Att. B.IV.A.2)	
Detailed land use information with emphasis on land uses associated with irrigated agricultural operations; identify the largest acreage commodity types in the third-party area, including the most prevalent commodities comprising up to at least 80% of the irrigated agricultural acreage in the third-party area	Ch. 4. Sect. 4.1.2 Figures 4-33 to 50
Information regarding depth to groundwater, provided as a contour maps	Ch. 4. Sect. 4.2.1, Figures 4-33, 34, 39
Groundwater recharge information, including identification of areas contributing recharge to urban and rural communities where groundwater serves as a significant source of supply	Ch. 4. Sect. 4.1 Ch. 6. Sect 6.6 App. B, Sect. B.6 to B.9
Soil survey information including significant areas of high salinity, alkalinity, and acidity	Ch. 4.2.1. Figures 4-23, 24, 25
Shallow groundwater constituent concentrations	Ch. 5 Entire Chapter
Information on existing groundwater data collection and analysis efforts relevant to this Order	Ch. 3., Ch. 7
GAR data review and analysis (Att. B.IV.A.3)	
Determine where known groundwater quality impacts exist for which irrigated agricultural operations are a potential contributor or where conditions make groundwater more vulnerable to impacts from irrigated agricultural activities.	Ch. 5, Entire Chapter Ch. 6, Entire Chapter App. B, Sect. B.8 & B.9
Determine the merit and feasibility of incorporating existing groundwater data collection efforts, and their corresponding monitoring well systems for obtaining appropriate groundwater quality information to achieve the objectives of and support groundwater monitoring activities under this Order. This shall include specific findings and conclusions and provide the rationale for conclusions.	Ch. 7
Prepare a ranking of high vulnerability areas to provide a basis for prioritization of workplan activities.	Ch. 6, Entire Chapter
Discuss pertinent geologic and hydrogeologic information for the third-party area(s) and utilize GIS mapping applications, graphics, and tables, as appropriate, in order to clearly convey pertinent data, support data analysis, and show results.	Ch. 4 & 6 App. A & B

Table 8-1. General Order Requirements and Kings GRA Cross Reference, Continued

Order Requirements	GAR Reference
Groundwater Vulnerability Designations	
Designate high/low vulnerability areas for groundwater in consideration of high and low vulnerability definitions	Ch. 6 App. B
The vulnerability designations will be made by the third-party using a combination of physical properties and management practices	Ch. 2. Ch. 4 & Ch. 6 App. A & B
Rationale for proposed vulnerability determinations	Ch. 2 & Ch. 6 App. A & B
Prioritization of high vulnerability groundwater areas (Att. B.IV.A.5)	
Identified exceedances of water quality objectives for which irrigated agriculture waste discharges are the cause, or a contributing source.	Ch. 5, Entire Chapter Ch. 6. Sect. 6.5.2, Fig 6-21 Sect. 6.5.3, Fig. 6-23, 6-24
Proximity of the high vulnerability area to areas contributing recharge to urban and rural communities where groundwater serves as a significant source of supply	Ch. 6, Section 6.6 Att. B, B.10 & B.11
Existing field or operational practices identified to be associated with irrigated agriculture waste discharges that are the cause, or a contributing source	Chapter 4, Sec. 4.33 & 4.34
Largest acreage commodity types comprising up to at least 80% of the irrigated agricultural acreage in the high vulnerability areas and the irrigation and fertilization practices employed by these commodities	Ch. 4, Sect. 4.3.2 Ch. 8.
Legacy or ambient conditions of the groundwater	Ch. 4, Sect 4.2 Ch. 5, Entire Chapter
Groundwater basins currently or proposed to be under review by CV-SALTS	Throughout. Upper and Lower Kings were part of the CVSALTS ICM Phase 1 Archetype study.
Identified constituents of concern	Ch. 1 & Ch. 2

8.2 Results and Observations

This section summarizes the final results and provides observations on both the results and the analysis, also identifying areas of uncertainty that could be addresses in site specific analysis or in subsequent updates of the Kings GAR.

8.2.1 Vulnerability to Nitrates and Priorities

Figure 6-21 showed the groundwater vulnerability areas based on the Public Land Survey System (PLSS) indicating high vulnerability. Property ownership and farm units are based on the PLSS. The Central Valley Hydrologic Model (CVHM) grid analysis was translated to the PLSS using the GIS. The PLSS was used to facilitate subsequent development and implementation of the Management Practice Evaluation Program (MPEP) and groundwater trend monitoring.

High, medium and low drinking water priorities were shown in **Figure 6-25**. The Kings GAR evaluated risk to drinking water systems as a basis for prioritizing subsequent MPEP action and groundwater trend monitoring. The population and well capture areas were used to define the relative risk and proximity of municipal pumping to the high vulnerability areas, and to priority areas contributing recharge to urban and rural community dependent on groundwater for drinking water supplies.

Pursuant to the Order, priorities were established based on the prior vulnerability analysis and discussion with KRCD and the Coalition. Priorities levels were defined using the groundwater vulnerability analysis results, drinking water vulnerability results, and the areas where there was observed drinking water exceedence.

8.2.2 Intrinsic Vulnerability

In areas where there are extensive clays, wells perforated below the clay layers are less vulnerable to nitrates and salts that may originate from irrigated agriculture. Areas above the clays are in direct contact with surficial sources of contamination, have lower volumes of groundwater in storage and are more susceptible to contamination. These areas also tend to be more reliant on groundwater and receive less surface water and this influences the mass balance for salts and nitrates.

The USGS aquifer texture model is the best regional interpretation of the available information regarding subsurface geology. There remains uncertainty in the heterogeneity of the aquifer materials in the complex alluvial fans on the east side of the Coalition areas; preferential flow paths of highly permeable materials may allow for more rapid transport of dissolved contaminants contributing to well production; and the presence or absence of clay layers that could control contaminant flow pathways and provide a degree of protection from surface sources of contamination that could reach a well.

Observed exceedances of the MCL do not necessarily implicate current overlying agricultural activity. The exceedances observed today may be from prior overlying agronomic practices that happened years in the past; or from non-overlying agronomic practices that occurred upgradient. Aquifer heterogeneity and preferential flow paths of highly permeable material can influence time of travel from upgradient areas, and todays observances may be indicative or historic agronomic practices that were applied at distance from the sampled well. These are areas of significant uncertainty not readily explained by a broad regional analysis.

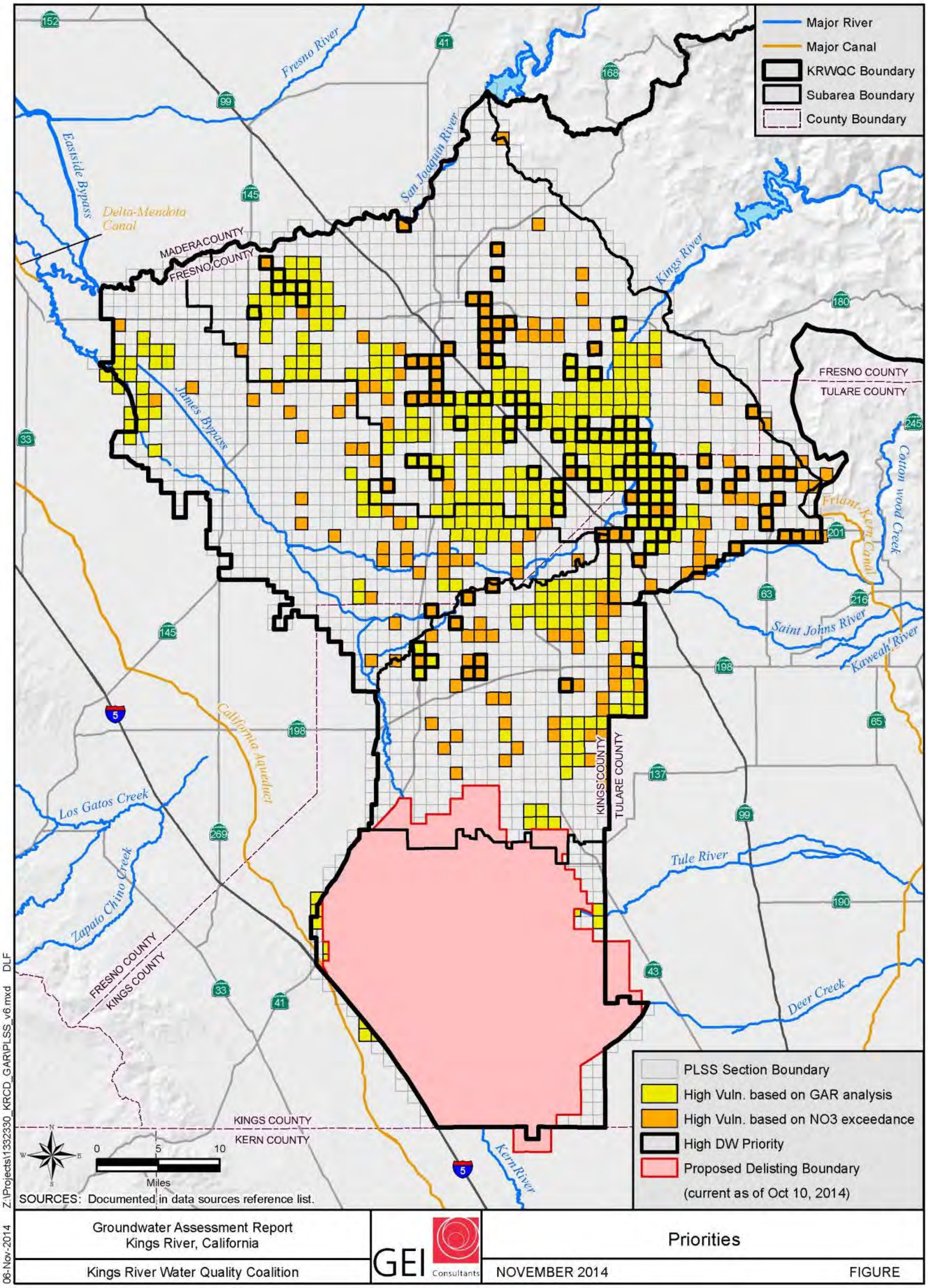

Figure 8-1. Kings GAR Priorities

8.2.3 Regional Water Management and Vulnerability

The regional and on-farm water budgets are closely related in the Coalition area. The regional water management factors (macro scale) have a strong bearing and relationship to the on-farm management factors (micro-scale). Regional water management actions affect the water budget, salt and nutrient mass balance and contaminant concentrations, and hence, vulnerability. This effect will vary in the different subareas. The history of conjunctive use operations, intentional groundwater recharge and management actions of the water districts have an effect on vulnerability and risk. Regional water management is very efficient as measured by the low amount of water leaving the Upper and Lower Kings subareas. The South Kings and Tulare Lake Bed subareas are part of the closed, internally drained Tulare Lake Basin. Water use has a high regional efficiency in this area as well.

8.2.4 On-Farm Vulnerability

Deep percolation generated by on-farm irrigation practices can be a beneficial source of groundwater recharge in areas which receive high quality water for irrigation. However, deep percolation is also the mechanism that conveys nitrates and other agricultural chemicals from the soil surface to groundwater. By reducing deep percolation, one of the outcomes of growers' adoption of advanced irrigation practices is a reduction in leaching of nitrates and other water quality constituents. Therefore, while deep percolation that recharges groundwater can be of value from a basin-wide perspective, deep percolation's transport of contaminants is problematic from both the on-farm and the basin-wide frames of reference. One of the key insights that results from understanding factors influencing nitrate concentrations now observed in groundwater is that the mass of nitrate leached to groundwater is a function of volume of deep percolation that drains from the root zone and the concentrations of nitrate in the soil at the time leaching occurred. Research suggests that irrigation management has been and continues to be at least equal to, and possibly of greater importance than, fertilizer application in affecting and controlling the leaching of nitrate (Letey, et al., 2013).

As evidenced by grower surveys and DWR land use mapping, on-farm agronomic practices have changed over time, and irrigation technologies are being widely adopted by growers to improve irrigation efficiency, reduce deep percolation, and reduce the risk of contamination. Existing field or operational practices were not identified at the field scale, and this can be done in developing the MPEP to test the range of practices historically used (e.g.; flood) and which have been deployed (micro/drip).

In spite of gaps in data and understanding, information provided in the Kings GAR illustrates the dynamic nature of farming practices in the study area and suggests the impact that improvements in irrigation practices and management of fertilizer may have on reducing nitrate leaching. Information presented in the GAR also illustrates the spatial variability of intrinsic conditions that influence susceptibility and vulnerability to nitrate contamination, and shows the impact of crop types and irrigation practices on deep percolation rates. The results suggests the degree to which adoption of advanced irrigation and fertilizer management techniques may be able to counteract intrinsic conditions that render areas with underlying groundwater susceptible to nitrate contamination.

8.2.5 Vulnerability to Salts

Areas where imported SWP or CVP are used for irrigation have a higher groundwater vulnerability to TDS contamination. The internally drained Tulare Lake Basin and the Tulare Lake Bottom area in the center of the valley have naturally occurring high salt concentrations in groundwater above the Corcoran clay. Areas more reliant on water originating in the Sierra Nevada are less vulnerable to groundwater contamination from salts.

8.2.6 Development of a Groundwater Trend Monitoring Program

The delineation of priorities provides a basis for development and implementation of groundwater trend monitoring program. A priority should be for monitoring, and should be in the areas that contribute groundwater to drinking water supplies.

8.2.7 Other Potential Sources of Exceedence

Areas where the GAR results indicated low risk and vulnerability, but where exceedence of standards was observed are identified along with other potential sources of contamination that could be contributing to the exceedence. These areas may merit further study to identify the contribution from other sources and lead to better priority designations and subsequent actions or analysis. Other potential contributors to exceedence may be associated with dairies, which are regulated under a separate order; or with septic, municipal or industrial waste disposal practices.

8.3 AREAS OF UNCERTAINTY

All efforts have been made to identify and reduce areas of uncertainty. This report seeks to provide insights through the synthesis and integration of available information to distinguish that which is known and well established, from that which is unknown and scientifically uncertain. Areas of uncertainty may provide a basis for subsequent data collection, synthesis and analysis that can be used to improve the understanding of the susceptibility and vulnerability to salt and nitrate contamination; or improve future GAR analysis.

In general, uncertainties are related to lack of data, accessibility of data, and quality of the data obtained (spatial or temporal resolution). Observations on areas of uncertainty are discussed below.

8.3.1 Intrinsic Vulnerability

- The area is defined by a complex geology. The Kings GAR applied regional geological texture analysis of the basin. Site specific hydrogeologic and aquifer conditions can vary, influencing the degree of confinement, levels of protection at an individual well from surficial sources of contamination and time of travel and flow to a well or well field.
- On site, on- farm soils can vary and influence water retention, deep percolation of applied water, and leaching and irrigation water requirements.

8.3.2 Regional Water Budgets

- There was good regional surface water/groundwater budget information in the northern part of the Coalition area, mostly due to the high resolution of surface water and groundwater data found in the Kings IGSM. The same model provided detailed water budgets for parts of the Southern Kings and Tulare area. For those areas further south of the Kings River, no single water budget or readily accessible modeling results were identified that allowed for further discretization and understanding of the benefits derived from known canal leakage and intentional groundwater recharge operations.

8.3.3 Drinking Water, Hydrogeology and Well Capture Zones

- Simplifying assumptions were made to define well capture zones and the relative risk to populations served. The analysis did factors in the combined effects of multiple wells pumping, specific aquifer characteristics at each well, or the well pumping and construction information. Specific well fields and individual wells were not analyzed in detail. Local geologic conditions and site specific variations in aquifer conditions (e.g.; paleo channels) can significantly influence the size and shape of the well or well field capture zones.

8.3.4 Water Quality Data

- There is limited historical groundwater quality data. Available data is not spatially or temporally representative; and most data represent only the past one to two decades.
- Loss of drinking water wells as a sampling point once exceedence occurs limits the ability for interpreting the cause and effect relationships. There are large spatial data gaps.

- Shallow monitoring wells are generally not available or are associated with other compliance or remediation programs targeted to other contaminating land use activities or regulatory programs.
- Lack of well logs for sampled wells limits the ability to determine the depth and perforated intervals and complicates interpretation of groundwater quality sample results.
- Nitrogen disposition in time and space in the soil and vadose zone, and the influence of preferential flow paths, especially in the alluvial fan areas.

8.3.5 Agronomic Practices

This study, and the work by UC Davis and CVSALTS, observes that there is a large measure of uncertainty regarding:

- Relative nitrogen loading rates by crop type, both in the past and under current on-farm management.
- Nitrogen efficiency for the range of crops grown.
- Much of what is observed today is likely the result of past practices. Areas of uncertainty are related to the limited historical data, the inability to quantify the contribution to observed concentrations at a well from legacy sources, and the ability to identify prior agricultural practices with any certainty. The decades-long feedback cycle between farming practices that cause leaching of nitrates and measurement of nitrate levels in groundwater keeps monitoring of current groundwater conditions from being a reliable indicator of the effectiveness of present-day fertilizer and irrigation management practices in controlling nitrate loadings to groundwater.

Chapter 9. References

Chapter 9. References

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Appendices

Kings River Watershed Coalition Authority

Groundwater Assessment Report

November 2014

Prepared for the Kings River Watershed Coalition Authority
Prepared by GEI, Inc. under Direction of the Kings River Conservation District

Appendix A. GAR Analyst & Utilities

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Appendix A. GAR Analyst & Utilities

A.1 Introduction to GAR Analyst Data Utilities

What follows is a discussion of the methods used for developing datasets used for comparative purposes and application in the overlay index. This is not intended to be a user manual for the GAR Analyst tool or utilities; rather, it is a summary of the approach and steps taken to use the readily available data. This section also does not make interpretations of the data, and any table or figures showing data are for discussion purposes only.

A.2 Use of Primary and Secondary Datasets in GAR Analyst & Utilities

In several important cases, primary datasets acquired through review of published reports are used as the basis for calculation of more important secondary datasets. For example, crop type and acreage data are a means to calculating applied water (AW) for irrigation of agricultural lands. The calculation of AW also requires several other primary datasets to account for the growth cycle, irrigation practices, soils, and hydrologic conditions. The utility of the GAR Analyst is combining multiple primary and secondary datasets using scientific methods to generate more meaningful and understood datasets.

The purpose of this section is to document the methodology used in each of the utilities. In those cases where calculations are considered to be single instance data manipulations (i.e., soil transmissivity using texture model data, or soil permeability using SSURGO mapping data), GIS and spreadsheet programs are used to derive the data outside of the GAR Analyst and imported as raw data values. In all cases, it is inherently assumed that all data goes through a quality check to review and validate the data.

Three essential utility applications are included within the GAR Analyst to create secondary datasets. These are summarized as follows:

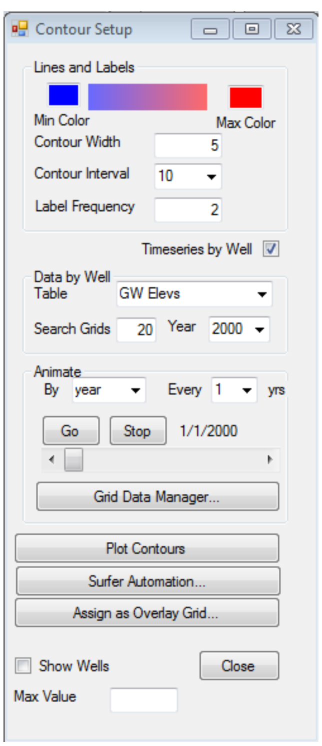
Contouring and Overlay Utility – Creates a gridded dataset from timeseries data at specific well locations. The gridded dataset can be superimposed upon the IOG to create a secondary dataset for overlay analysis.

Well Protection Zone Utility – Creates circular well protection zone delineations for either a 5, 10, or 20 year period to mimic the potential capture zone of each public supply well. The utility results in a count of the number of protection zones within each cell of the IOG.

Applied Water Utility – Creates the full soil moisture accounting summary for three hydrologic year types using crop types identified by the primary CAML dataset for 2010. The utility provides for the calculation of Applied Water, Groundwater Recharge as Deep Percolation, and Nitrogen Loading over the four subregions, and each IOG cell.

A.3 Contouring and Overlay Utility

The figure below provides an example of the contouring utility in terms of its inputs. Similar to many contouring engines, the built-in algorithm requires inputs to guide the contouring engine to the optimum solution given the available data, and the best visual representation. Caution should be used with this utility to ensure the data is sufficiently dense and uniformly distributed in areas where contour intervals are calculated. If Show Wells is checked, each of the wells used in the contouring calculation is shown on the map and can be selected to view the data or hydrograph for quality checks, etc.

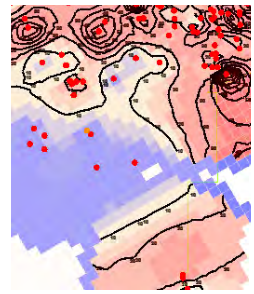


Data is interpolated to the IOG by using each of the four corner nodes of each cell. The method of interpolation used is Inverse Distance Squared, or one over the distance to the data point (or well) squared. Other methods such as Kriging[1] can be viewed through third-party applications such as Surfer. The Inverse Distance Squared method is a simple weighted average interpolator by weighting during interpolation, so that the influence of one point, relative to another, declines with distance from the grid node. Weighting is assigned to data through the use of the weighting power (in this case squared), which controls how the weighting factors drop off as distance from the grid node increases.

To reduce the risk of using contours across large areas with no data, the Search Grids setting forces the search radius to the number of grid cells specified. If no data is found within the number of cells identified, no value is assigned to the node and contouring does not occur as shown by the yellow circle in the figure to the right. In some cases, changing the start year and increasing the time span will pick up data

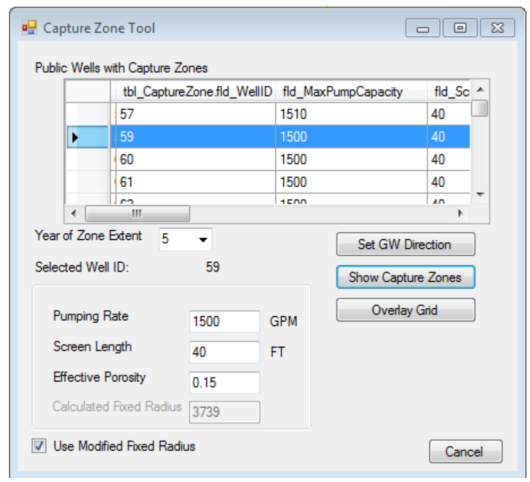
[1] Kriging, a geostatistical gridding method, is often used with groundwater data because of the lack of uniformity in well spacing. The use of tools such as Surfer or GIS Spatial Analyst can import the raw well data from an automatically exported text file to apply these types of statistical methods.

outside of the original dataset. This has an averaging effect on the data and results in less distinct contours (i.e., loss of resolution in viewing the data).



If the weighted values are to be applied as a secondary dataset, the Assign as Overlay button is selected and the user is asked to save the data to one of the overlay dataset layers for further use in the IOG analysis. The colorized figure to the right is an example of transferring partially interpolated contour data to an overlay dataset. In this case, the white colored (or blank) cells are areas where well data does not exist, and are not used in the overlay dataset.

A.4 Well Protection Zone Utility (WPZ)



The calculation of protection zones, an approximation of area around a well which is managed to identify risks to drinking water supply wells, is based on the public well's pumping rate, porosity, screen depth, and groundwater gradient and direction. The WPZ area is meant to conservatively approximate the capture zone of a well.

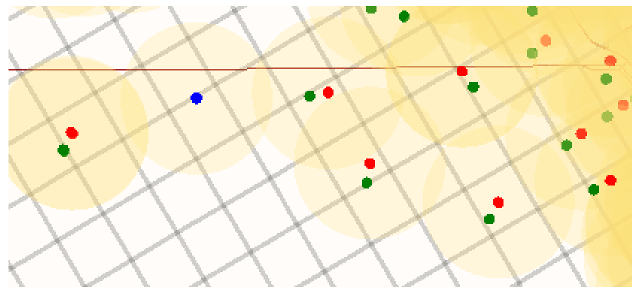
The purpose of this utility is to collect and manage well data, provide porosity data from the USGS texture model, and calculate the slope and direction of the groundwater surface at each well using the contour utility above. The result is an estimated off-set circular area up-gradient of the well which is set at the 2, 5, 10, or 20 year timeframe. The timeframe identifies the aerial extent for a contaminant released at the surface to find its way to the well screens.

The equation applied in this case is taken from the California Department of Public Health Drinking Water Source Assessment Program where the Calculated Fixed Radius Method is used by applying the following equation:

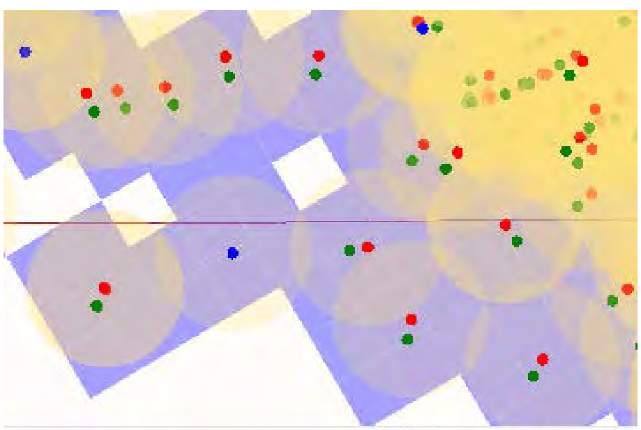
$$r = \sqrt{\frac{Q\,t}{\pi\, n\, H}}$$

Where
Q = Pumping Rate of Well
n = Effective Porosity (0.2)
H = Open Interval or Length of Screen
t = Travel Time to Well (2, 5, 10 years)

In cases where the piezometric surface of a porous aquifer is sloping, a Modified fixed radius is applied to account for the offset in the circular area up-gradient of the well location. The approximate offset is set at 0.5 times the calculated radius.



The utility applies this calculation to each drinking water well and plots the circular areas over the IOG (as shown in the figure to the right) to calculate the relative densities of overlapping protection zones with each cell. The modified offset method is used only in cases where the groundwater gradient is greater than 10 feet of drop over 100 feet of distance. The figure shows the 20 year protection zones as lightly yellow shaded areas with well locations indicated in green (if modified fixed radius is used) or blue (if only fixed radius is used due to reduced slope). The red points are used to indicate the offset direction and extent when compared with its relative location from the green well locations. This is meant as a quality check of the data to ensure the offset correspondence closely with the selected groundwater contours.



The application of this utility is in calculating the density of protection zones for each IOG cell. This density becomes a measurement of the relative level of susceptibility and risk associated with the presence of public drinking water wells in a given area. Note that this overlay of secondary data is a measure of risk only, and does not imply the existing or future presence of nitrogen, salts, or other contaminants.

By selecting the Create Overlay Grid, the utility stores the density information in the tbl_CVHMWell*ProtectionZone* table and indexes the data for visual interpretation through the IOG coloration scale shown to the above. Red shaded cells indicate a high concentration of public wells, and unshaded cells indicate no public well protection zones exist.

A.5 Applied Water Utility

The stepwise approach quantifying the amount of applied water (AW) for agricultural irrigation requires a basic understanding of the methodology and reasons why this utility was developed. The reasoning behind the calculative tool for AW is listed as follows:

1. The amount of AW used for irrigation is influenced by many variables including, but not limited to, the type of crop, farm location, hydrologic conditions, irrigation methods, and soil conditions. Of these variables, the highest quality dataset is the crop type data extracted from the CAML dataset.

2. The confidence of the overlay method is only as good as the lowest confidence dataset. With a considerable number of models and published data, the differences amongst the models and model-year conditions vary greatly in their calculations of AW. Also, agricultural experts may agree or disagree with some of the underlying assumptions applied in these models.

3. The GAR Analyst intentionally avoids modeling as a means of associating a dataset with the susceptibility of contamination; however, the use of CAML crop data as an overlay dataset is considered to be of significantly high importance to warrant development of an analysis utility to simply and uniformly apply basic scientific principles in soil moisture accounting.

4. The resolution of the GAR Analyst is intentionally kept at a high level of study with the use of a square mile grid and a monthly timestep in the handling of timeseries data. Most AW models are daily (or hourly) to capture individual storm events. This level of data resolution is not available and is considered to be not warranted for a study of this scope and magnitude.

5. The AW utility will effectively calculate 1.) the relative recharge from AW as deep percolation, 2.) the relative nitrogen efficiency based on percolated water, and 3.) the amount of salt importation from source water supplies. These three secondary datasets contribute to the final overlay analysis.

6. Given the justification for the AW utility, the algorithms and inputs need to be integrated with the GAR Analyst to easily and quickly test different scenarios or time frames without having to run a full spectrum numerical model such as CVHM (ModFlow) or C2VSim (IWFM).

7. The output of the GAR Analyst only provides the relative ranking of the calculated deep percolation data to avoid potential misuse of actual quantifiable data. This protects the purpose of the tool and gives a much more accurate and higher level of confidence of the identification and ranking of susceptibility.

8. The tool is scientifically based with over-simplifications in cases where insufficient data is available. In the end, there is the recognition of the need to compare results with other model datasets to view and explain differences and reduce uncertainty.

A.5.1 Input Datasets

The AW utility was developed as a separate database to maintain the tool as a preprocessing and analysis tool where calculated data is exported to the primary database of the GAR Analyst. The relational database is designed to be able to calibrate the inputs for each crop type and subregion, and then apply the analysis over the study area, changing soil conditions, rainfall amounts, source water and irrigation practices based on where the crop is located in the study area.

Input datasets related to the AW calculation are listed below:

1. CAML Crop Data provides high resolution crop types over the entire study area for 1990 and 2010. The data carries attributes on irrigation methods for the 2010 dataset. The number of crop categories totals 88 crops.

2. Crop ET data for Typical, Wet, and Dry hydrologic years, 1997, 1998, and 1999, respectively. Data is listed by crop and irrigation method from the Irrigation Training and Research Center (ITRC) website <http://www.itrc.org/etdata/waterbal.htm> . The number of ET crop categories is approximately 35 with the actual total based on the three irrigation methods of flood, sprinkler, and micro/drip.

3. Monthly and daily precipitation data is exported from regional groundwater models and CDEC, listed by station. Combined averages are used in locations where stations and/or data are sparse, for the time periods needed. To ensure consistency in the ET calculation, the years 1997, 1998, and 1999 are used for the three ET year types regardless of the crop inventory year. Stations are assigned to the four subregions of the study area.

4. Irrigation efficiencies for 2010 and 2001 are taken from the USGS 2013 report for 20 crop categories.

5. Soil properties are constant across all crops for purposes of calibration and then adjusted when applied to the model area based on the shallow soil survey data.

6. Nitrogen "harvested-to-applied" ratios are taken from *Nitrogen Source and Loading to Groundwater - Technical Report 2 Assessing Nitrate in California's Drinking Water. Center for Watershed Sciences.* (UC Davis. March 2012) for 9 crop categories.

The mapping of crops within the various datasets is based on the ET crop categories. Meaning, each of the CAML crop types is assigned an ITRC ET crop category using the closest representative crop type if the CAML data contains a crop not specifically listed in the ET crop data. This same approach was taken for the irrigation efficiencies, and nitrogen use ratios.

A.5.2 Soil Moisture Methodology

As a guide, the Food and Agriculture Organizations (FAO) methods are applied according to the "Guidelines for computing crop water requirements – FAO Irrigation and drainage paper 56", (FAO, 1998).[2] All of the theory and underlying equations used in the AW utility can be found in this publication. The purpose of this section is to highlight deviations (often needed to accommodate the longer monthly timestep), assumptions in unavailable data to enable the macro level of analysis applied in this effort.

Given the number of data inputs required in the AW calculation of the Soil Moisture Methodology, the need for a relational database to store input and output information for each timestep becomes the most practical data storage application. In some cases, where data is either not known or not sensitive, a single uniform value is applied to all crop types to reduce the number of variables without impacting the reasonable solution to the soil moisture algorithms. **Figure A-1** is a graphical depiction of the soil column used as the basis for the internal algorithm. The definition of some of the lesser known terms is provided to the right of the figure for reference.

The **Threshold** for triggering the application of water by a farmer is somewhere between when the soil moisture is below the Field Capacity but above the Wilting Point. This **Threshold** is farmer and crop specific and is initially held at 0.5, a commonly used value for many crops, for the AW utility. Deficit irrigation, or the intentional practice of allowing the plant to stress for a period of time, is now often used based on given crop types and is an input to the AW utility.

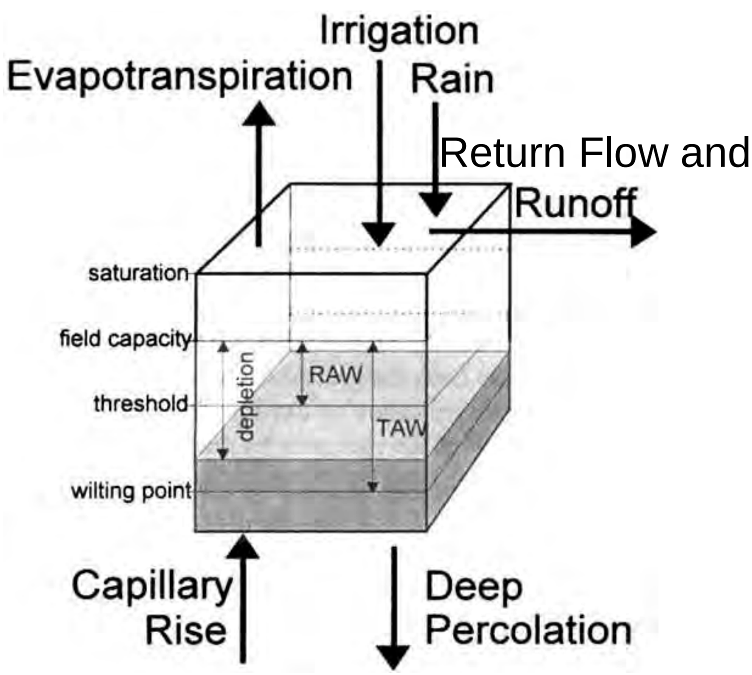
The calculation of AW is the amount of water needed to bring the soil moisture back up to Field Capacity. This amount is based on the following equation (as coded in VB.net):

awcls.IrrigAW(**moncntr**) = (**awcls**.FieldCapacity - **awcls**.Precip(**moncntr**) / **awcls**.Porosity - (**awcls**.CropETInches(**moncntr**) - **awcls**.DeficitIrrig(**moncntr**)) / **awcls**.Porosity) * **awcls**.Porosity / **awcls**.IrrigEff(**moncntr**)

where, **awcls** refers to the crop class or type (e.g., vineyards, pears, etc.) , and **moncntr** refers to the monthly timestep (e.g., Jan, Feb, etc). The Porosity represents the amount of void space available to water as it is adsorbed and flows through pore spaces within the soil column. This equation is determining the amount of water to be applied in a given month should the soil moisture drop below the operational threshold. The calculation starts with the given Field Capacity, subtracts the water from precipitation that does not need to be applied, subtracts the

[2] <http://www.fao.org/docrep/x0490e/x0490e00.htm#Contents>

given months ET requirements minus any intentional deficit operations, and divides the result by the Irrigation Efficiency (IrrigEff). The IrrigEff term is based on the crop type, location, and irrigation method, and ensures the farmer of slightly exceeding the Field Capacity to prevent plant stress from occurring unintentionally.



Definitions
RAW – Readily Available Water
TAW – Total Available Water
Field Capacity – amount of water that a well-drained soil should hold against gravitational forces
Wilting Point – point at which the crop can no longer extract water from the soil, resulting in permanent crop damage
Threshold – water content drops below a value where AW can no longer be transported quickly enough towards the roots to respond to the crop's demands and the crop begins to experience stress

Figure A-1. Soil Column Used in Soil Moisture Algorithm

Source: (FAO, 1998)

The in and out arrows shown **Figure A-1** are either based on a given dataset (i.e., rain or precipitation, and ET), or calculated based on the monthly soil moisture and AW requirements (i.e., Irrigation, Runoff, Deep Percolation, Capillary Rise). A quote from FAO explains their contributions.

> *Rainfall, irrigation and capillary rise of groundwater towards the root zone add water to the root zone and decrease the root zone depletion. Soil evaporation, crop transpiration and percolation losses remove water from the root zone and increase the depletion. (FAO, 1998)*

For the purpose of AW Utility, Capillary Rise is assumed to be zero given that either the water table is well below the root zone, or tile drains are used to keep the water table below the root zone. For each monthly timestep, the following formulas are applied for the Runoff and Deep Percolation values:

```
If netinout > 0 Then
   awcls.RunOffExcess(moncntr) = 0.00 * netinout
End If
```

Where **netinout** refers to the net inflow or outflow over the given month. If this value is positive, a small percentage of the net inflow is typically lost; however, at the resolution of this model, the multiplier is set to zero, assuming no loss of water occurs because of top soil evaporation and interception by leafy plants along with evaporation. Return Flow is water that does not make it into the soil and is assumed to be conveyed back to the headworks of the irrigation system. The Return Flow is assumed to be 10% of the AW if flood irrigation occurs, 5% if sprinkler, 1% if drip/micro, and 4% if other. While this water is not lost to the farmer, it is lost to the model.

```
awcls.ReturnFlow(moncntr) = 0.10 * awcls.IrrigAW(moncntr)
```

If the current soil moisture (or soil moisture at the end of the given month, abbreviated as **CurSM**) is greater than the Field Capacity, gravity is assumed to apply hydrostatic pressure to the water to move the water downward, creating a leachate from the root zone referred to as deep percolation (or deep recharge). For a given month, the rate of Deep Percolation assumes that 71.4% (a calibrated value approximating reported annual average deep percolation amounts) of the water above the Field Capacity is lost in each monthly timestep. If the total soil column is saturated (or the CurSM is as high as the root zone depth), the amount of available water for Deep Percolation is capped and the remaining water is assumed as **excess** runoff and lost to the model.

```
If CurSM > awcls.FieldCapacity Then
   If CurSM > rootdepth Then
      awcls.DeepPerc(moncntr) = 0.714 * (awcls.RootZone - awcls.FieldCapacity) * awcls.Porosity
   Else
      awcls.DeepPerc(moncntr) = 0.714 * (CurSM - awcls.FieldCapacity) * awcls.Porosity
   End If
End If
excess = (CurSM - awcls.RootZone)
```

For each monthly timestep, the calculated values of the above soil moisture calculation are saved for viewing and calibration purposes.

A.5.3 Applied Water Utility Interface

User interaction with the AW utility is organized in a window interface (see **Figure A-2**) from left to right and from top to bottom in terms of its functionality. Once the crop categories are calibrated, the window becomes more of a visual tool to understand the variables needed for the soil moisture accounting and their sensitivity, and to understand the basic operations of the calculation engine before applying the engine to the GAR study area. To summarize its use (i.e., not a comprehensive user guide), the following steps are taken with each ET Crop Category before applying to the GAR study area:

1. Select the subregion where the crop is grown. In most cases, by checking the Apply to All box, any change to the crop is applied to all four subregions.

2. Select the year being modeled based on the CAML land use dataset. In this example, 2010 is currently selected. Other years will be available for comparison by end of project.

3. Select the Crop ET Category in the first list box on the left side, and then check to make sure the associated CAML Crop Types in the adjacent list box apply to the selected category. Select or un-select crop types as needed. The small graph below the list box shows the percentage of the total area made up of the selected ET crop category.

4. Select the type of crop by clicking the appropriate option of Urban, Native/Riparian, or Agriculture. If Urban, identify the percent of area landscaped primarily with turf.

5. For agricultural crop categories, the planting and harvesting dates are approximated to mark the beginning and ending of the irrigation season.

6. Identify Fertilizer Application Events by the number of applications with timing as a percent of the growing season along with pounds of nitrogen fertilizer applied. Total **annual nitrogen volume** and **Nitrogen Harvest to Applied Ratios** applied are taken from published reports. The purpose of this is explained in the next section on nitrogen loading.

7. Soil Moisture Variables are typically not changed unless new source data becomes available. To set the initial variables:

    a. Check Initial Soil Moisture if a percent of soil moisture is to be assumed at the beginning of the growing period.

    b. Select if there is Deficit Irrigation applied throughout the growing season.

    c. Select if there is Pre-Wetting prior to seeding, or the growth period.

8. **Root Zone Depth**, Soil Type, Effective Porosity, and **Irrigation Efficiency** are inputs taken from published reports and studies and should only be changed if growing conditions or practices warrant the change.

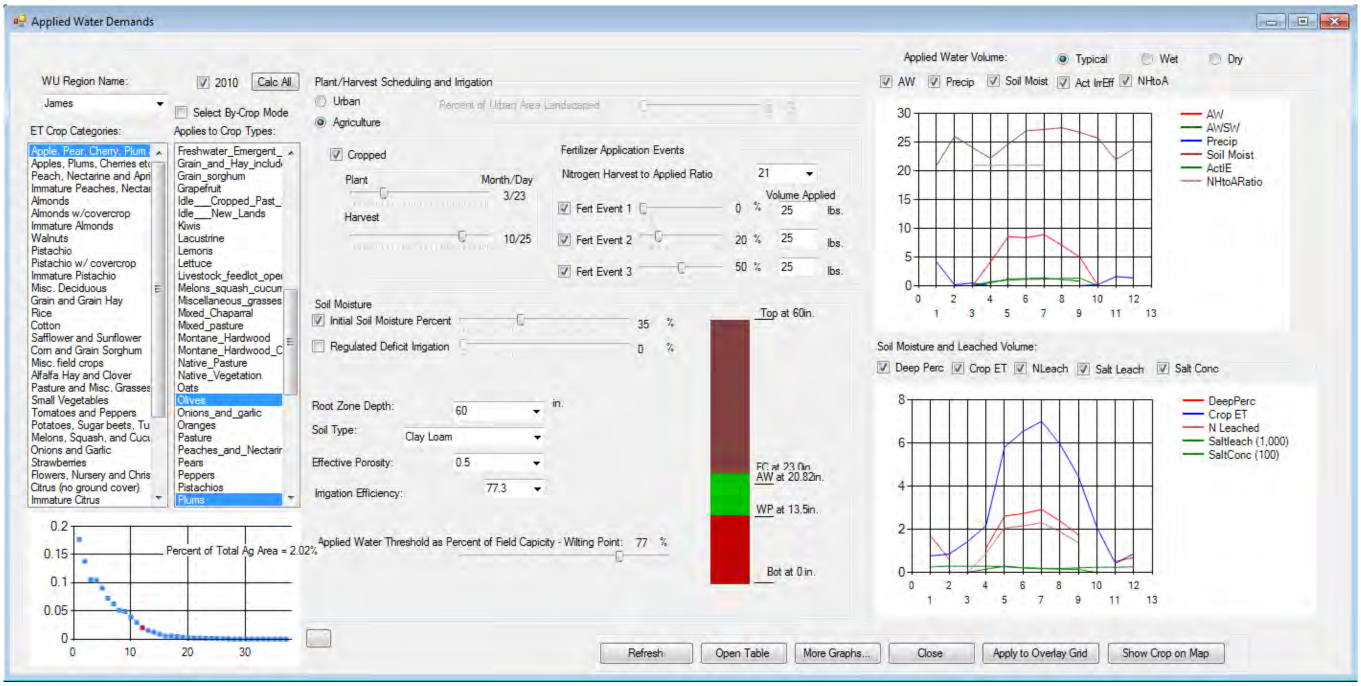


Figure A-2. Applied Water Utility User Interface

9. The AW Threshold is currently set at 50% of the difference between the Field Capacity and Wilting Point as illustrated in the colored soil column figure indicating top of root zone, Field Capacity, AW Threshold, and Wilting Point.

10. Available graphs on the main window provide the amount of AW, soil moisture, and the amount of deep percolation (or Leached Water Volume) over the 1 year model period. There is an option to view the nitrogen loading and source water quality as well.

The steps above are repeated for each of the ET Crop Categories. Upon satisfactory calibration, the values and steps taken are applied to each crop of each IOG cell, as extracted from the CAML dataset. Each cell inherits the site specific soil porosity, source water, and rainfall amounts from stored database tables.

A.5.4 Nitrogen Efficiency Calculation

The research article, *Soil type, crop and irrigation technique affect nitrogen leaching to groundwater (Letey and Vaughan, Oct 2013),* provides the underlying basis for the understanding of potential nitrogen leaching from the soil column. One conclusion of the article is that:

> *Nitrate reaches groundwater only by being transported by water that percolates through the soil…Every crop evapotranspiration (ET) needs, and any irrigation or precipitation that exceeds the soil's water-holding capacity in the root zone will cause soluble chemicals, including nitrate, to leach into deeper groundwater. The amount of N that is leached varies with time and with the amount of water flow and the N concentration in the soil water at the time leaching occurs.*

Meaning, if leaching of water occurs as a result of available soil moisture, as determined in the AW utility above, and given sufficient time, soluble chemicals such as nitrogen, pesticides, and salts will travel in a dissolved state to the groundwater. Furthermore,

> *…the highest correlation coefficient was between the amount of nitrate leached and a combination of drainage volume and fertilizer application, indicating that both factors are important…there was no significant correlation between the nitrate concentration of the drainage water and either the amount of fertilizer applied or the drainage volume.*

This implies that the amount of nitrogen leached is based on two actions occurring. The first, a chemical and physical action, is the build-up of nitrogen concentration in bound in the soil and plant, and the increased volume of dissolved nitrogen in the free water within the root zone. The second is the physical action of applying water to cause the leaching of the dissolved nitrogen-laden water beneath the root zone and into underlying aquifers.

The scientific evidence to draw certainty into the calculation of nitrogen leached to groundwater is not available at the scale and scope of this assessment. As a surrogate, the published ratio of harvested to applied nitrogen (**NHtoA** Ratio, see **Table A-1** for list of ratios used) is used along with a weighting methodology based on the amount and frequency of **DeepPerc** events. Understandably an over-simplification of a complex process, it is believed to provide the understanding and clear interpretation of relative nitrogen contribution of each crop type and area. The VB.net code below shows the simple monthly calculation of relative nitrogen (**NLeached)** with the result being a value for purposes of relative comparison only. This calculation does not result in a total amount of nitrogen reaching the groundwater. The value one minus the ratio is to ensure that the value is what nitrogen is remaining after harvest.[3]

awcls.NLeached(moncntr) = awcls.**DeepPerc**(moncntr) * (1 - awcls.**NHtoA** / 100)

Table A-1. Comparison of N Application Rates to Total N Harvested (lbs/ac)

		1975	1990	2005
Cotton	N application rate	135	214	214
	Total N harvested	71	90	96
	Harvested/Applied	53%	42%	45%
Field crops	N application rate	143	196	248
	Total N harvested	104	164	241
	Harvested/Applied	73%	83%	97%
Grain and Hay	N application rate	113	175	211
	Total N harvested	87	124	152
	Harvested/Applied	77%	71%	72%
Grapes	N application rate	25	41	41
	Total N harvested	16	17	19
	Harvested/Applied	64%	41%	46%
Nuts	N application rate	220	207	207
	Total N harvested	63	78	108
	Harvested/Applied	29%	38%	52%
Rice	N application rate	106	160	160
	Total N harvested	75	98	96
	Harvested/Applied	71%	61%	60%
Subtropical	N application rate	197	117	117
	Total N harvested	40	57	56
	Harvested/Applied	20%	49%	48%
Tree Fruit	N application rate	149	128	129
	Total N harvested	25	28	27
	Harvested/Applied	17%	22%	21%
Vegetables and Berries	N application rate	186	239	237
	Total N harvested	81	99	119
	Harvested/Applied	43%	41%	50%
All crops	N application rate	129	182	191
	Total N harvested	71	89	111
	Harvested/Applied	55%	49%	58%

Source: Nitrogen Source and Loading to Groundwater - Technical Report 2 Assessing Nitrate in California's Drinking Water. Center for Watershed Sciences. UC Davis. March 2012 – Converted from Kg/Ha to lbs/ac

A.5.5 Salinity Loading Calculation

Salinity loading is also an output of the AW calculation, using the source water designation and associated salinity concentration as two data points for introducing salts to the study area. Indigenous groundwater is assumed to be of very low salt concentration and carries a value of

[3] Remaining nitrogen also exists in the plant or tree matter after harvest; especially if significant growth in plant matter occurs during the growth cycle. For this study, this amount is assumed to be relatively low in percent difference amongst the various crops. This is a recommended area of study to quantify the nitrogen left in plant matter after harvest for both tilled crops and permanent crops.

zero, or, if saline groundwater is used for irrigation, the net loading to groundwater remains the constant. The methodology of tracking salts is based on a mass balance accounting method.

The methodology used in this tool is strictly meant for identification and relative ranking of susceptibility.

Determining the source water for every crop in the study area for a given hydrologic year and for differing conjunctive use operations is not feasible. The AW utility in this case makes assumptions on a water district or sub-region scale and assumes a ratio of groundwater to surface water (**SWtoGWRatio**) for each month of the year. GIS is applied to the underlying assumptions in assigning the IOG cells their respective monthly **SWtoGWRatio(s)** based on their overlying water districts and assumed practices in water use taking place in a dry, wet, and typical hydrologic year.

With the timeseries water quality data available for the various surface water supply sources, a concentration of salts is calculated by the amount of AW calculated from above, multiplied by the **SWtoGWRatio,** and then multiplied by the salt concentration for the given month. The cumulative salt total for the year is summed by each month's salt loading.

```
awcls.salinityconc(moncntr) = awcls.IrrigAW(moncntr) *awcls.swToGWRatio(moncntr)* awcls.swsourceconc(monthcntr)
```

A.5.6 Applied Surface Water as Recharge

As water is applied to meet the demand requirements of each crop, the percentage of irrigation water imported from surface water supplies is accounted for and used for calculating the volume of surface water which recharges groundwater. The underlying assumption is that all imported surface water is a positive benefit to the basin, regardless of salinity. Similar to stream recharge effects, in terms of dilution of contaminants in groundwater, application of clean surface water, not laden with nitrogen, has the same dilution benefit to reduce the risk of high concentration nitrogen sinks. The benefit only occurs for the amount of water leaving the root zone of each crop.

Appendix B - Description of Overlay Index Variables

Appendix B. Description of Overlay Index Variables

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Appendix B. Description of Overlay Index Variables

This appendix is a simple compilation of the index variables, and the datasets used in the GAR Analyst Index Overlay calculations. Each begins with a brief description of the data to complement data descriptions in the main body of the report. Following this are the use of the data to derive the index overlay, providing mathematical descriptors for an improved understanding of the both the data variability and its distribution. Lastly, the colorized and ranked overlay layer is presented for purposes of use in the actual index overlay analysis to arrive at the final ranking of the combined overlay indices.

B.1 SURFACE SOIL PERMEABILITY (INTRINSIC SUSCEPTIBILITY)

Surface soils represent the part of the earth's surface in direct contact with daily hydrologic and anthropomorphic activities. Surface soils are described as being different from bedrock due to the influence of climate, vegetation, country, relief, and age, and change over time by the effects of water, air, and living and dead organisms.[1]

B.1.1 Dataset Use

In terms of agricultural uses, surface soils are a critical element in sustaining the natural processes for the growth of food crops, and for providing natural foraging for livestock. The permeability and porosity of surface soils govern the plant growth cycle and the necessary farming practices to produce the highest quality yield in a given area.

SSURGO (Soil Survey Geographic database) refers to digital soils data produced and distributed by the Natural Resources Conservation Service (NRCS) - National Cartography and Geospatial Center (NCGC).[2] The database assigns attribute values based on the soil properties at the 1 to 10 acre level of resolution. Two of the properties calculated from the SSURGO dataset are permeability and porosity, described as:

> ***Permeability*** *is a measure of the ease with which a fluid (water in this case) can move through a porous rock.*
>
> ***Porosity*** *is a measure of how much of a rock is open space. This space can be between grains or within cracks or cavities of the rock.*

[1] Krasilnikov, N.A. (1958) Soil Microorganisms and Higher Plants
[2] <http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_053627>

From the SSURGO properties, the permeability is calculated and mapped to the IOG to represent the relative vulnerability of deep recharge occurring from precipitation, runoff, or applied water at the ground surface. Use of permeability does not consider the current overlying land use, or the exposure to contaminants; however, surface soil permeability does provide one facet of how quickly contaminants, once in contact with the surface soils and mobilized in water, can move through the soil layer to the unsaturated zone where transmissivity of geologic strata govern the time of travel to the groundwater.

B.1.2 Primary and Secondary Datasets

The SSURGO database (Primary Dataset) provides an index value to identify the different types of soils and their unique properties. These index values are the basis for calculating the permeability using a spreadsheet, and applying the following steps and formulas (Secondary Dataset):

B.1.3 Raw Data Statistics

Given the natural heterogeneity of surface soils within each of the IOG cells, an area calculation of each soil classification is performed to assign a weighted average permeability to each cell. The fieldname and statistics of this dataset is provided **Table B-1** below.

Table B-1. Statistics for Surface Soils Permeability Data

Database Field: **fld_SSURGOSoils_AvgWeight**
Number of non-zero data points: 4345
Average: 0.638
Mode (most frequent): 0.010
Number of times: 554.000
Median (odd middle value): 0.953
Maximum: 2.000
Minimum: 0.010
Midrange (average of max and min): 1.005

Distribution

The values of permeability show to be somewhat uniformly distributed with four values occurring significantly more frequent as shown in the distribution graph (**Figure B-2**). The reason for this is the Tulare Lakebed is made up of thick, shallow clay layer as shown by the highlighted cells with a value of 0.01. No edits in the data were made to remove anomalies or outliers believed to be misleading.

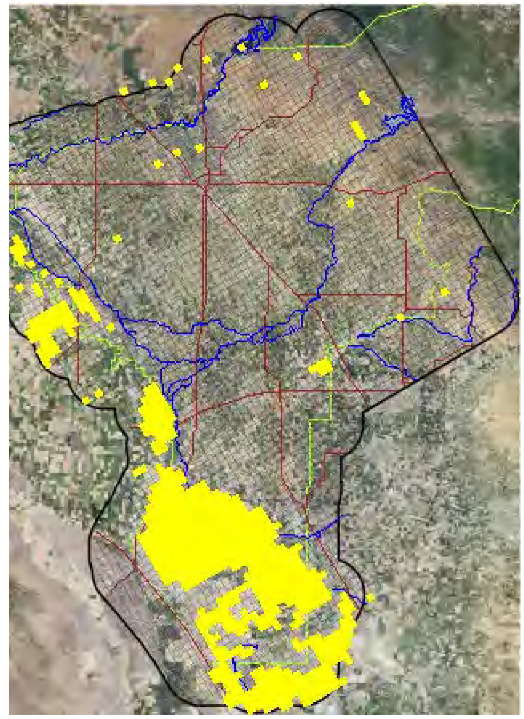


Figure B-1. Low Permeability Values in Tulare Lakebed

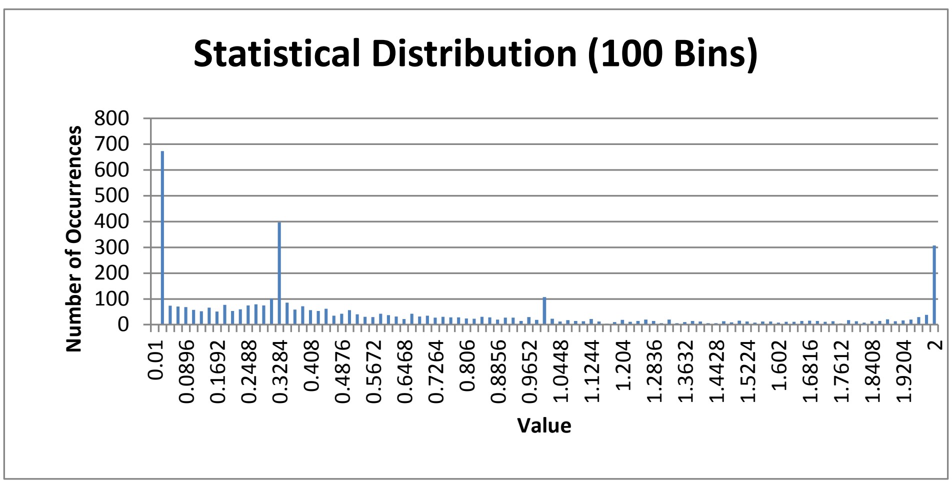


Figure B-2. Surface Soils Permeability Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-3**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative level of permeability between the cells. The higher the number (i.e., maximum of 10), the more susceptible the cell is to transporting contaminants to the groundwater. The data is identified as being **directly** (as opposed to inversely) related to the value of soil permeability.

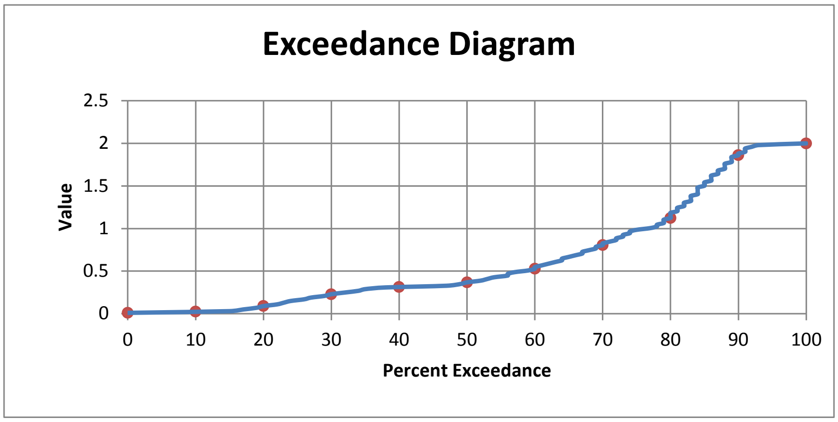


Figure B-3. Surface Soils Permeability Exceedance Diagram

Overlay Index Result

Filtering the soil permeability data through the percentile index ranges in **Table B-2** standardizes the data to the ranked 1 through 10 values. The coloration scale is shown in **Figure B-4**, with red being the areas where higher surface soil permeability creates a higher susceptibility relative to the blue areas which represent the low permeability areas. The yellow highlighted regions represent the top 10 percent of the area where soil conditions are most permeable creating the potential for susceptibility to groundwater contamination.

Table B-2. Surface Soils Permeability Percentile Ranges

Percentile Ranges of Soil Permeability	Weight
0.01 to 0.023	1
0.023 to 0.090	2
0.09 to 0.229	3
0.229 to 0.313	4
0.313 to 0.368	5
0.368 to 0.527	6
0.527 to 0.806	7
0.806 to 1.124	8
1.124 to 1.861	9
1.861 to 2.000	10
End Point	10

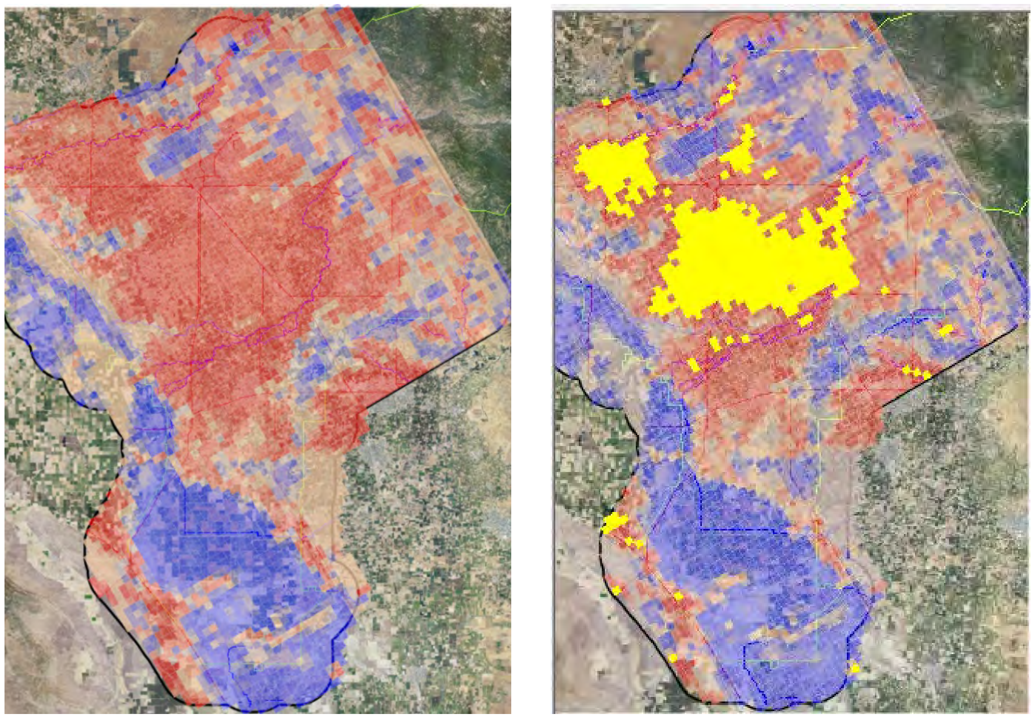


Figure B-4. Surface Soils Permeability Overlay

B.2 Underlying Clay Thickness (Intrinsic Susceptibility)

The presence of clay or other fined grained sediment below ground surface and below the groundwater table effectively creates a barrier for continued vertical movement of groundwater. By hindering waterborne contaminants from further vertical movement, a high concentration mounding effect occurs and pushes contaminants horizontally in the direction of the groundwater gradient as illustrated in **Figure B-9**, also discussed in Depth to Groundwater index variable.

B.2.1 Dataset Use

The presence of the Corcoran Clay Member is a defining intrinsic and geologic indicator for differentiating one zone of the IOG region from the other (i.e., Upper Kings and Lower Kings areas). The USGS description of the Corcoran Clay Member of the Tulare Formation is stated:

> *Numerous lenses of fine-grained sediments are distributed throughout the southern Central Valley (San Joaquin Valley) and generally constitute more than 50 percent of the total thickness of the valley fill. Generally, these lenses are discontinuous and not vertically extensive or laterally continuous. However, the Corcoran Clay is a low-permeability, areally [aerially] extensive, lacustrine deposit (Johnson and others, 1968) as much as 200 feet thick (Davis and others, 1959; Page, 1986). This continuous clay divides the groundwater-flow system of the western San Joaquin Valley into an upper semi-confined zone and a lower confined zone (Williamson and others, 1989; Belitz and Heimes, 1990; Burow and others, 2004).*[3]

Of importance to this dataset layer, is the depth to the Corcoran Clay Member from ground surface, the thickness of the continuous clay layers, the depth of groundwater on top of the clay layer, and the difference in piezometric head between the upper unconfined (or semi-confined) and confined aquifer layers. The combination of these two factors determines the potential risk of contaminating groundwater becoming a risk to drinking water supplies.

B.2.2 Primary and Secondary Datasets

The source of data for each is as follows:

Depth from Ground Surface and Thickness – The CVHM stratigraphy data identifies the Corcoran Clay Member as layers 4 and 5 of the model grid. The primary data source of this data comes from the USGS Central Valley Texture Model. Top of layer elevations are taken from the CVHM data to determine depth from groundwater surface and thickness of clay layer.

Depth of Groundwater Above Corcoran Clay – Given the combined nature of this overlay dataset and resolution of the stratigraphy data, the average depth of groundwater above Corcoran Clay is resolved based on CVHM model data at the same square mile grid of resolution.

The combination of attributes is based on combining the data in a manner which pulls out the intrinsic conditions leading to the highest risk of susceptibility of contamination to drinking water supplies. For instance, a shallow depth to the Corcoran Clay Member from ground surface creates a relatively higher risk because of the reduced time of travel. The percentile ranking risk is **inversely** (left image in **Figure B-5**) related to depth with the shallow depth being the higher ranking.

[3] < http://water.usgs.gov/GIS/metadata/usgswrd/XML/pp1766_corcoran_clay_thickness_feet.xml>

The greater thickness (considered as being relatively more impervious) portions of the Corcoran Clay Member layer, combined with a shallow unconfined groundwater thickness with a flat gradient[4] creates the highest concentration of contaminants occurring above the Corcoran Clay Member. Meaning, thicker shallow clay regions, and shallow groundwater thicknesses, will suffer from waterborne groundwater contamination (salinity and nitrogen), due to less dilution and mobility (vertically and horizontally) and, over time, create nitrogen and salinity “sinks” (destination areas where the contaminants travel to and accumulate over time).

While the generation of high concentration sinks can be problematic, they do offer a greater ability to manage and perhaps remove the contaminants over time. In addition, understanding where sinks may occur can direct drinking water wells to be screened beneath the impervious Corcoran Clay Member. The percentile ranking for clay layer thickness is therefore **inversely** (center image in **Figure B-5**) related to the measured height of the Corcoran Clay Member with the thinner thickness being the higher ranking.

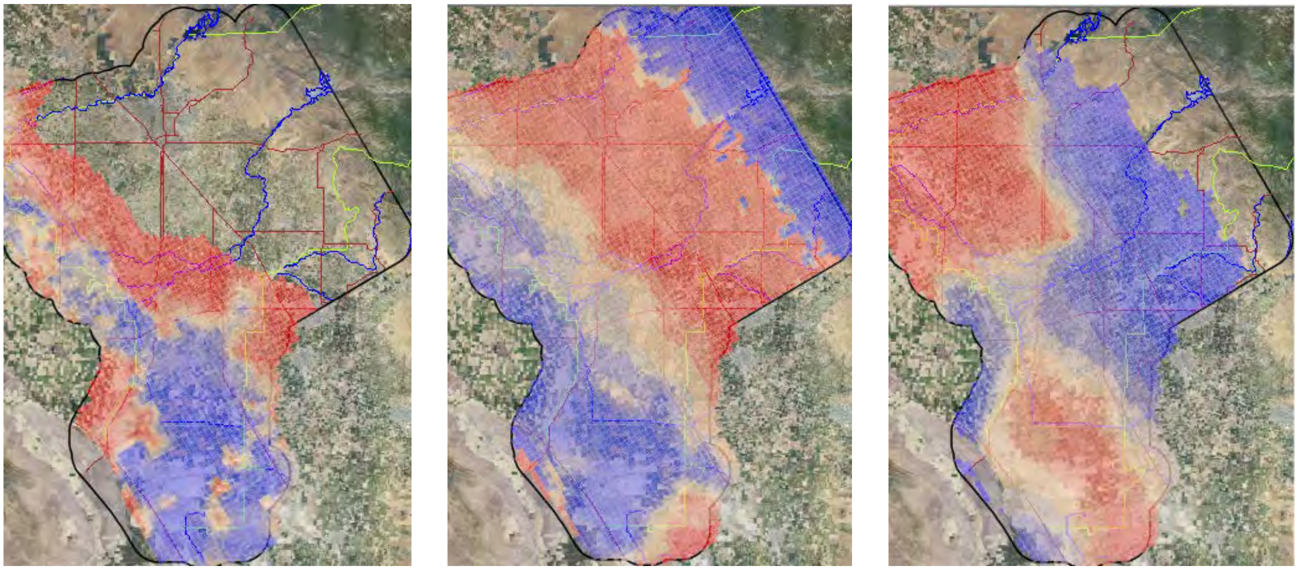
Similarly, if the groundwater thickness is large, the relative risk to drinking water from above the Corcoran Clay Member is reduced because contaminants become diluted and mobile, reducing the possibility of high concentration sinks from occurring. As a result, the percentile ranking for depth of groundwater above the clay layer is also **inversely** (right image in **Figure B-5**) related with a shallow depth if groundwater being the higher ranking.

In the combining these three ranking values, the end result is expected to show that shallow, thin portions of the Corcoran Clay Member, combined with a shallow groundwater depth creates the highest risk conditions; whereas, a deeper thick clay layer with a deep groundwater depth creates the lowest risk conditions.

B.2.3 Raw Data Statistics

The combination of the above intrinsic attributes is done by averaging the three percentile ranking values for each IOG cells overlying the Corcoran Clay Member. The resulting distribution and exceedance rankings are described and illustrated below. In cells where the Corcoran Clay Member is not present, no value is assigned, resulting in the Underlying Clay Thickness overlay not having an influence of greater risk in these areas.

[4] Groundwater gradient represents how fast or slow the water moves through the porous materials. For purposes of



Thickness of Clay Layer — Red = Thin

Depth from Ground to Top of Layer 4 — Red = Shallow

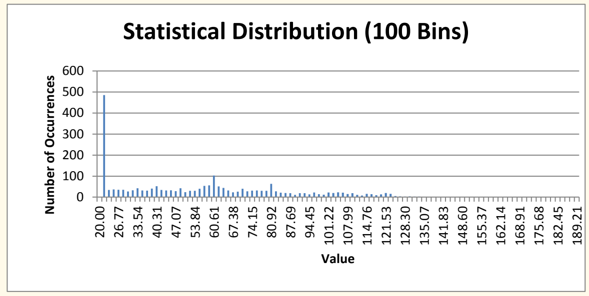
Thickness of Groundwater on Layer 4 — Red = Thin

Figure B-5. Comparison of Three Index Layers for Underlying Clay Thickness

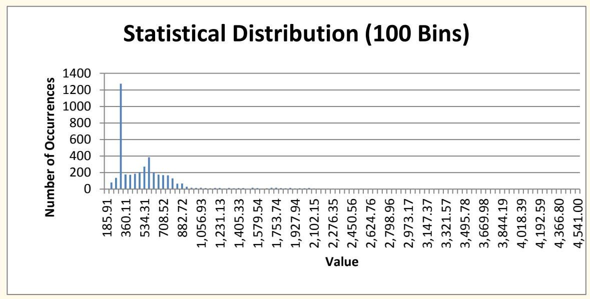
Table B-3. Statistics for Underlying Clay Thickness

****

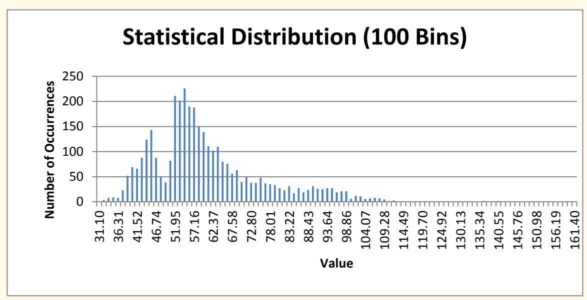
Database Field: fld_Thickness
Number of non-zero data points: 2282
Average: 55.609
Mode (most frequent): 20.000
Number of times: 316.000
Median1 (even middle value): 60.118
Median2 (even middle value): 61.699
Maximum: 189.214
Minimum: 20.000
Midrange (average of max and min): 104.607



Database Field: fld_Depth
Number of non-zero data points: 4345
Average: 591.538
Mode (most frequent): 299.776
Number of times: 31.000
Median (odd middle value): 1,716.000
Maximum: 4,541.000
Minimum: 185.907
Midrange (average of max and min): 2,363.453



Database Field: fld_GWDepthTo
Number of non-zero data points: 3520
Average: 60.110
Mode (most frequent): 53.000
Number of times: 27.000
Median1 (even middle value): 91.200
Median2 (even middle value): 93.300
Maximum: 161.400
Minimum: 31.100
Midrange (average of max and min): 96.250



Database Field: fld_CombinedIndex
Number of non-zero data points: 2282
Average: 5.565
Mode (most frequent): 5.333
Number of times: 178.000
Median1 (even middle value): 5.000
Median2 (even middle value): 5.000
Maximum: 10.000
Minimum: 2.333
Midrange (average of max and min): 6.167

Distribution

The *fld_CombinedIndex* field of the overlay table includes the raw data after the three indices are averaged from above process. Any cell with a zero to 1 m clay layer thickness was automatically set to zero to effectively turn the cell off. The distribution of the combined dataset below (**Figure B-6**) follows a slightly skewed normal distribution over the range of values from 2.0 to 8.4. The values in this case are unitless and only represent a relative scale of risk due to the intrinsic attributes of the Corcoran Clay and its geospatial relationship with the ground surface and the groundwater. No further edits in the data were made to remove anomalies or outliers believed to be misleading.

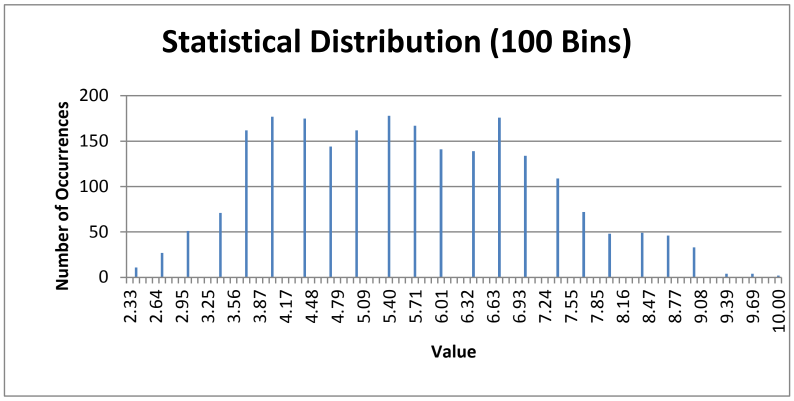


Figure B-6. Underlying Clay Thickness Distribution

Exceedance and Percentile Rankings

The exceedance diagram shown in **Figure B-7** results in the percentile ranges as delineated on the figure by the red points and listed in **Table B-4**. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative difference between the cells. The higher the number (i.e., maximum of 10), the more susceptible the cell is to becoming a high concentration sink placing drinking water at risk.

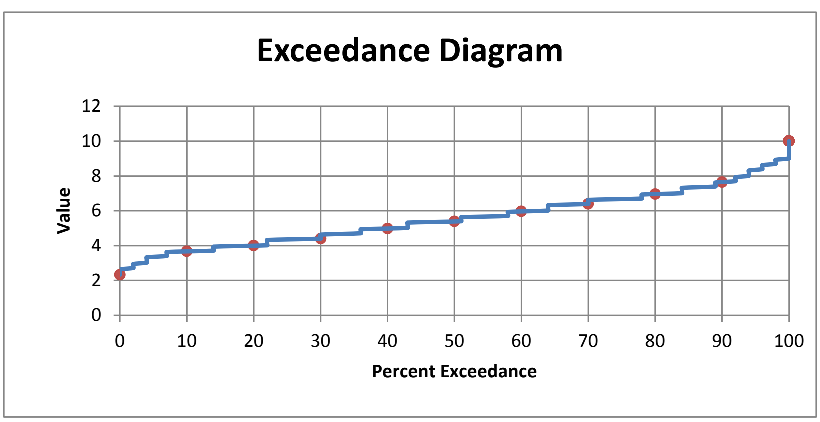


Figure B-7. Underlying Clay Thickness Exceedance Diagram

Overlay Index Result

Filtering the combined index used for the Underlying Clay Thickness data through the percentile index ranges in **Table B-4** standardizes the data to the ranked 1 through 10 percentile values. The coloration scale is shown in **Figure B-8**, with red representing high susceptibility areas and blue low susceptibility areas, both resulting from the presence of the Corcoran Clay Member. The yellow highlighted regions on the same map (right side) represent the top 10 percent of areas where the Corcoran Clay Member increases susceptibility to drinking water supplies.

Table B-4. Underlying Clay Thickness Percentile Ranges

Percentile Ranges of Combined Average Index Values	Assigned Weight Value
2.333 to 3.670	1
3.67 to 4.001	2
4.001 to 4.403	3
4.403 to 4.984	4
4.984 to 5.390	5
5.39 to 5.962	6
5.962 to 6.397	7
6.397 to 6.959	8
6.959 to 7.649	9
7.649 to 10.000	10
End Point	10

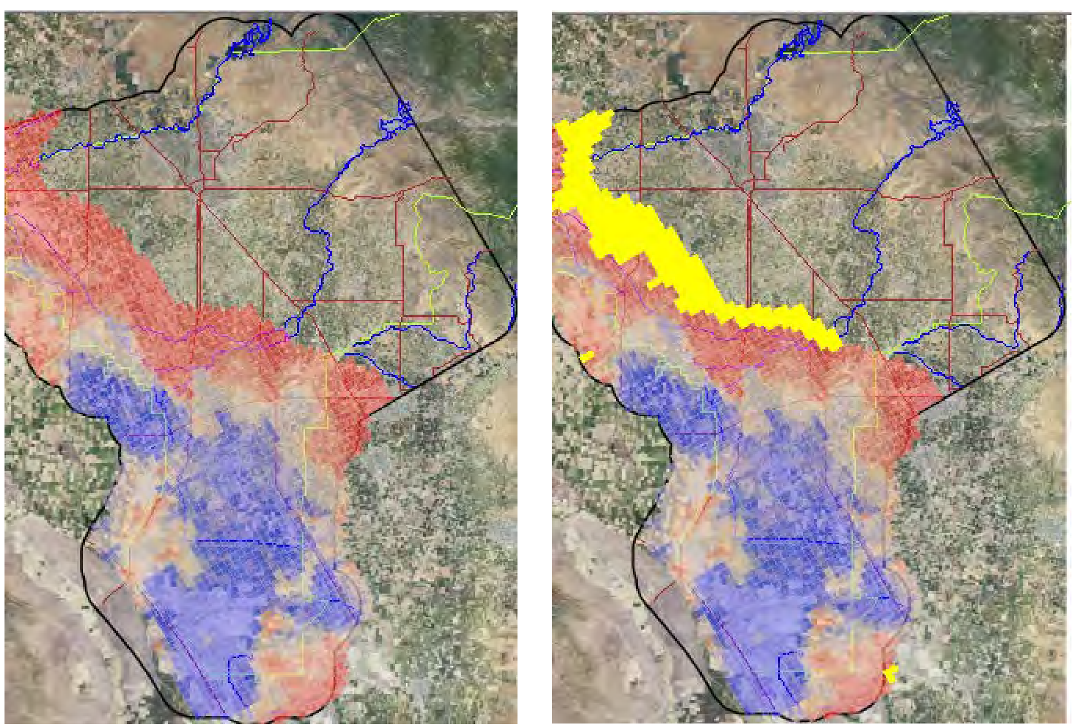


Figure B-8. Underlying Clay Thickness Overlay

B.3 DEPTH TO GROUNDWATER (INTRINSIC SUSCEPTIBILITY)

Depth to Groundwater from ground surface is important to: 1.) length of time (or time of travel) a contaminant takes to leach through the shallow soil layer and into the groundwater, and 2.) unwanted mobilization of contaminants captured in the shallow soil and unsaturated zone, allowing contaminants to travel vertically and down gradient of the confined source (see . An aquifer near the ground surface becomes contaminated much faster (and more often), and, for nitrogen, offers less natural reduction in free nitrogen due to capture through ionic bonding in the soil substructure, chemical breakdown, and plant uptake.

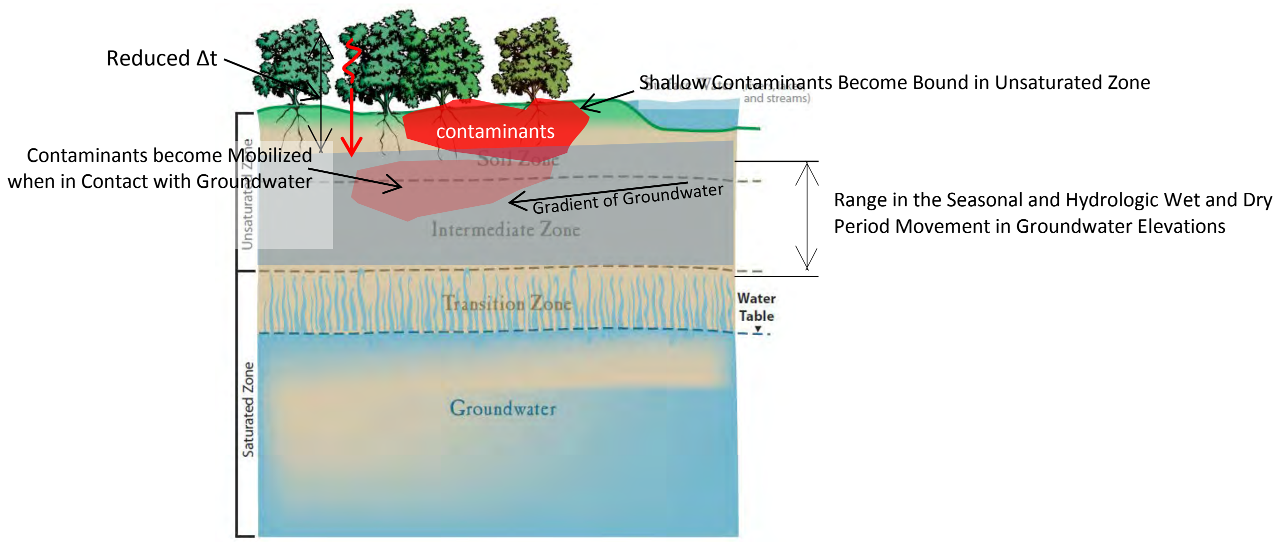


Figure B-9. Depth to Groundwater Illustration of Risks

B.3.1 Dataset Use

A continuous data series over a period of hydrologic years is necessary to characterize the groundwater table at its highest elevation. There are two conditions to consider when selecting the high elevation years. The first is where groundwater elevations are in a quasi-equilibrium state where groundwater elevations are stabilized around an average with full recovery at or above the average in wet years. One example of this condition is seen in the monitoring well hydrograph (**Figure B-10)** in the Upper Kings area. This figure illustrates the cyclic pattern and the operational range of approximately 35 feet from wet to dry periods with full recovery in wet years. Years considered to be of significance to this condition are the high groundwater elevation events (red dots).

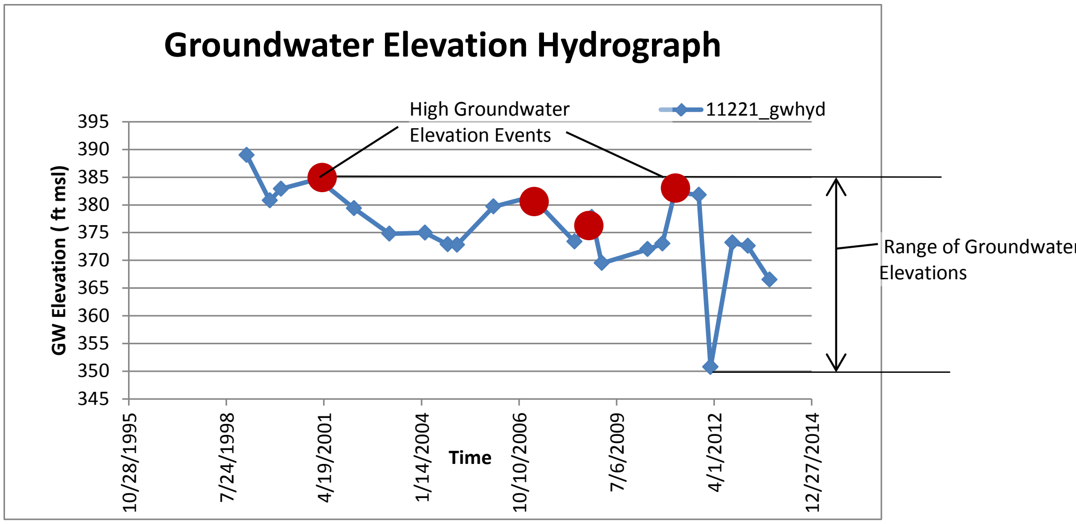


Figure B-10. Groundwater Elevation Hydrograph at Equilibrium (Upper Kings)

The second condition is where the groundwater is not in equilibrium, but is moving either upwards or downwards, likely the result of a persistent reduction or increase in pumping, respectively. In the case of the Lower Kings hydrograph (**Figure B-11**), the groundwater recharge sources are not sufficient to fully recover the basin in the wet years, resulting in a constant downward trend (i.e., overstressed basin). Since the point of equilibrium has not been reached, the most recent spring value of the dataset is used as the depth to groundwater, assuming the elevations may stabilize near this point, as a worst case. The same approach is taken for cases where there is a constant upward trend.

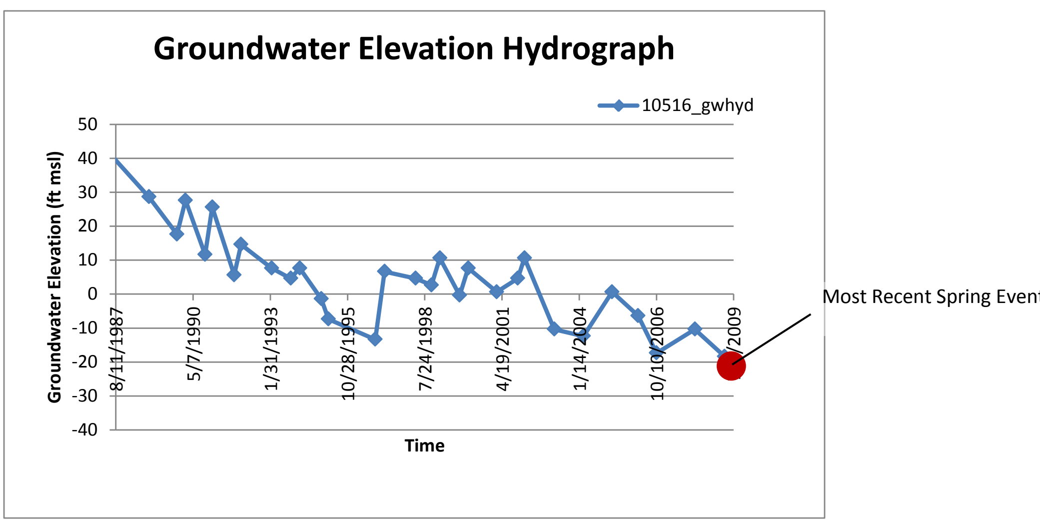


Figure B-11. Groundwater Elevation Hydrograph of Overstressed Aquifer (Lower Kings)

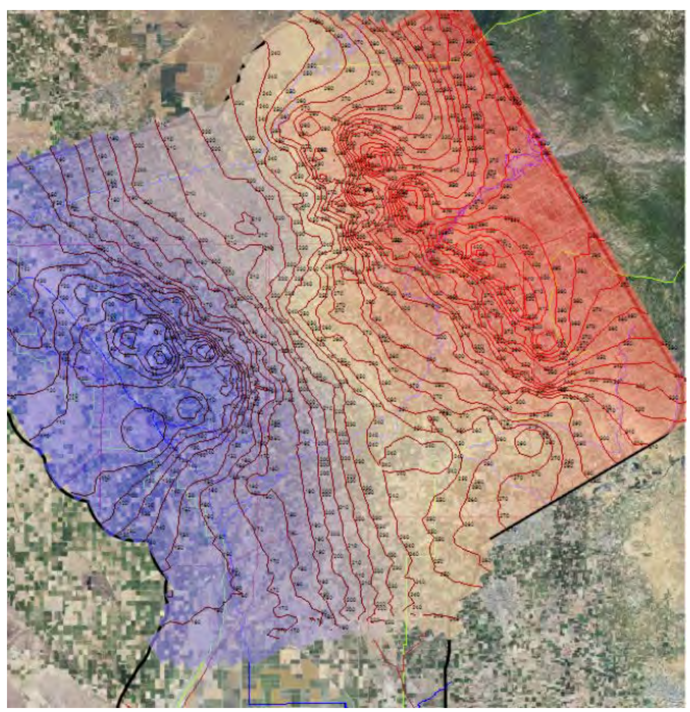
B.3.2 Primary and Secondary Datasets

The source of data for depth to groundwater comes from several primary and secondary datasets, in the form of actual depth to groundwater measurements, and from calibrated groundwater models, respectively.

Depth to Groundwater Data for Kings Area – The selected dataset for the Depth to Groundwater overlay in the Kings IGSM area originates with the calibration wells for the Kings IGSM model. The model data (not the actual data) is used in this case to ensure a complete dataset across the Kings region for hydrologic years. The primary dataset is the actual depth to groundwater level measurements used for at the same wells for calibration purposes.

Depth to Groundwater Data Tulare Lakebed – For portions of the study area outside Kings IGSM region, the CVHM model output data for layer 3 is used as the secondary source of data to achieve a standard of accuracy comparable to the Kings data.

Ground Surface Elevations – Similar for all overlays, the groundwater elevation data is extracted from the CVHM model input files with the source data originating with the primary texture model dataset.



Cell Capture of Contours

To identify which of the two cases exist in the secondary dataset of the Kings IGSM Data, the model hydrograph data for each well is used to contour the basin and produce an overlay of average elevations on top of the IOG (see figure). This was done for the years 2001 through 2004. For cells not populated by the IGSM data, the CVHM head values were extracted for approximately the same hydrologic period. Since the Tulare Basin shows very little change in groundwater elevations as a result of pumping, average elevations are used. As shown in **Figure B-12**, groundwater elevations differ in elevation between wells but show little persistent change over the past 50 years; drawdowns do occur in extended drought periods shown as elevation drops in the hydrograph, and then recover with an above normal hydrologic period.

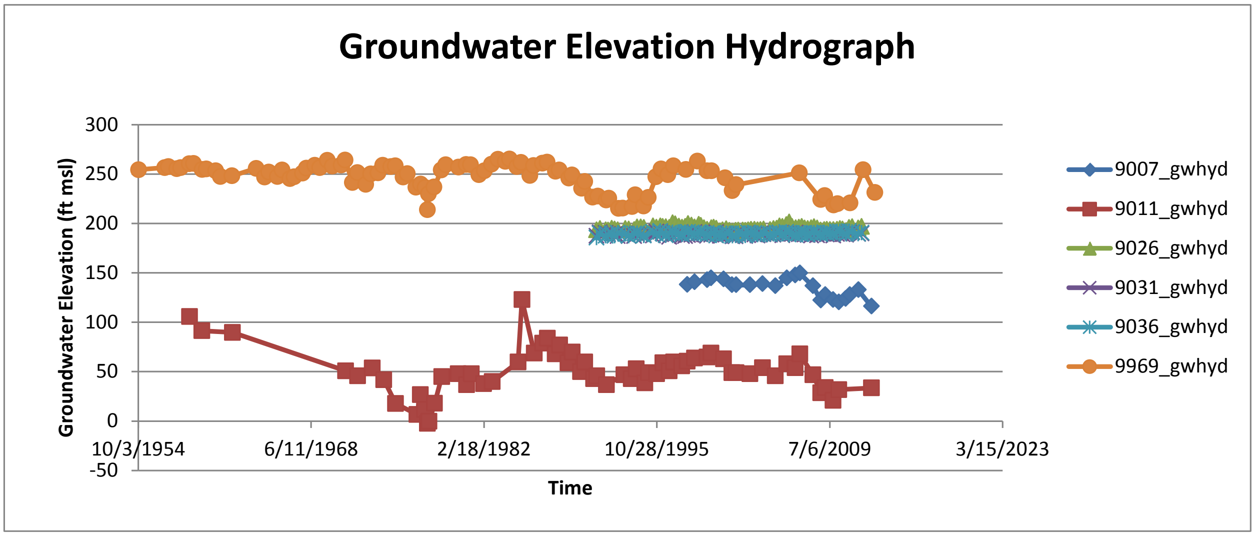


Figure B-12. Groundwater Elevation Hydrograph (Tulare Lakebed)

B.3.3 Raw Data Statistics

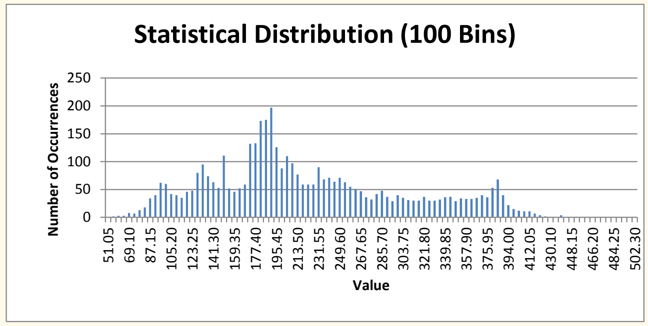
The three datasets in **Table B-5** show a good distribution of the groundwater elevations and ground surface elevation prior to taking the difference. In cases where no data exists in the CVHM model, the IOG cells are turned off. Also, any ground surface elevation above 700 feet was turned off to closely approximate the extent of the regional aquifer. As discussed in the Section __, groundwater exists in the higher elevations, but is considered to be indicative of small perched aquifers, or fractured rock aquifers, not considered as belonging to the larger Central Valley aquifer.

Distribution

Figure B-13 indicates shallow differences as low as 1 foot in depth and an average of 70 feet in depth. Shallow groundwater indicates: 1.) the potential for hydraulically connected (i.e., rivers are in direct contact with the aquifer) or gaining streams and rivers where groundwater is flowing into surface water, and 2.) the potential for high groundwater conditions in the valley floor where piezometric heads are at or above ground surface. In the Tulare Lakebed region, high groundwater conditions are known to exist, requiring tile drains to dewater the aquifer to a managed depth below ground surface.

Table B-5. Statistics for Depth to Groundwater Data

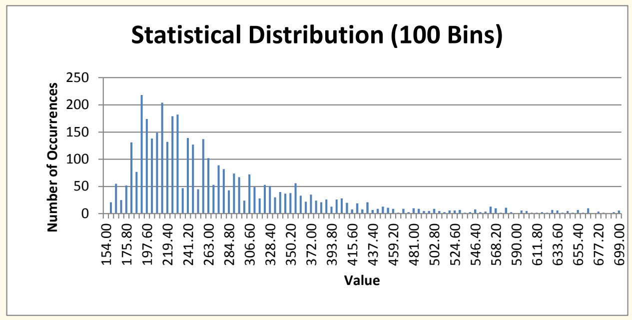
****



Database Field: fld_MaxGWElev
Number of non-zero data points: 4295
Average: 218.383
Mode (most frequent): 187.008
Number of times: 24.000
Median (odd middle value): 225.333
Maximum: 502.297
Minimum: 51.054
Midrange (average of max and min): 276.675

**

****



Database Field: fld_GroundSurface
Number of non-zero data points: 4345
Average: 435.107
Mode (most frequent): 207.000
Number of times: 149.000
Median (odd middle value): 1,716.000
Maximum: 4,541.000
Minimum: 154.000
Midrange (average of max and min): 2,347.500

**

****

Database Field: fld_AvgDepthtoGW
Number of non-zero data points: 3756
Average: 69.505
Mode (most frequent): 19.992
Number of times: 9.000
Median1 (even middle value): 53.019
Median2 (even middle value): 59.070
Maximum: 457.613
Minimum: 1.024
Midrange (average of max and min): 229.318

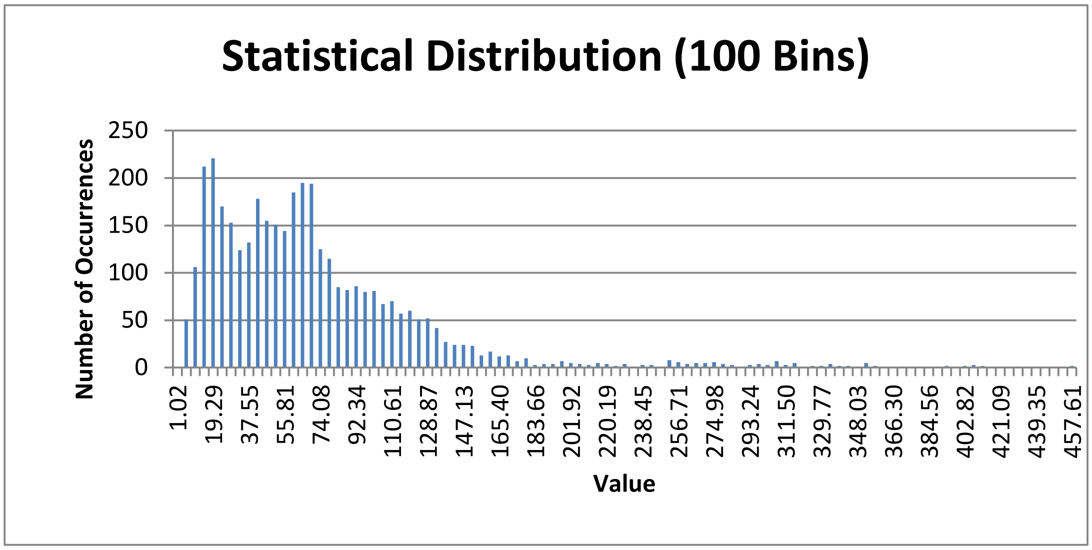


Figure B-13. Depth to Groundwater Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-14**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative depth to groundwater between the cells. The higher the number (i.e., maximum of 10), the more susceptible the cell is to having contaminants come into direct contact with the groundwater basin. The data is identified as being **inversely** related to the Depth to Groundwater value; meaning, areas with a shallow depth to groundwater pose a higher risk.

Table B-6. Depth to Groundwater Percentile Ranges

Percentile Ranges of Surface Soils Permeability	Weight
1.024 to 14.721	10
14.721 to 23.853	9
23.853 to 36.029	8
36.029 to 46.683	7
46.683 to 57.641	6
57.641 to 66.772	5
66.772 to 78.644	4
78.644 to 99.951	3
99.951 to 128.869	2
128.869 to 457.613	1
End Point	1

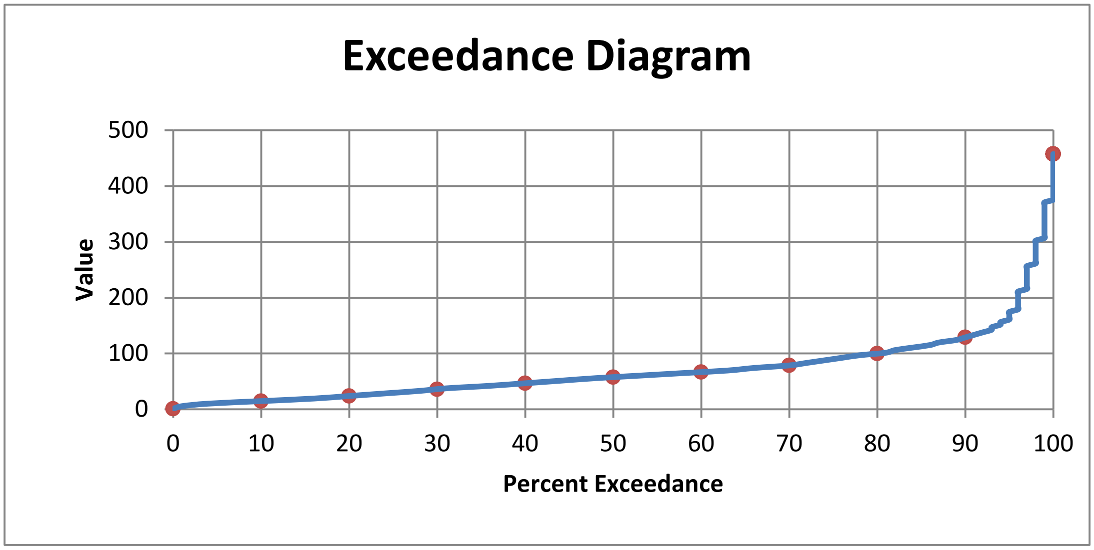


Figure B-14. Depth to Groundwater Exceedance Graph

The coloration scale is shown in **Figure B-15**, with red being the shallowest depth to groundwater areas and blue being deepest depth to groundwater areas. The yellow highlighted regions represent the top 10 percent of the areas where groundwater is 15 feet or less below ground surface.

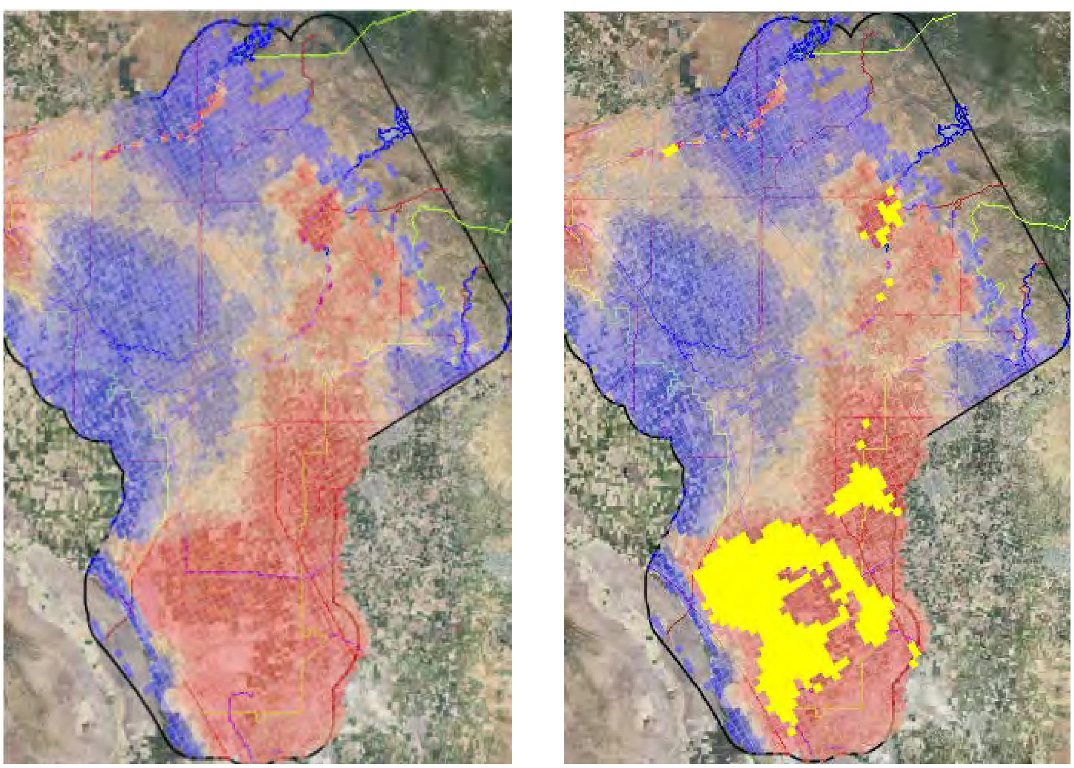


Figure B-15. Depth to Groundwater Overlay

B.4 RATE OF GROUNDWATER MOVEMENT (INTRINSIC SUSCEPTIBILITY)

Risk of groundwater contamination can also be attributed to the transmissivity properties of the aquifers geologic stratigraphy, both horizontally and vertically. Depth to Groundwater (**Section B.3**) is only one part if and how long for a contaminant to reach groundwater. The Rate of Groundwater Movement, both in the saturated and unsaturated zones is important to the understanding of “when” and “if” contaminants will reach the groundwater.

B.4.1 Dataset Use

Since the Depth to Groundwater focuses on when, the emphasis of Rate of Groundwater Movement focuses on soil properties, rather than distance, to understand if contamination will reach the groundwater. If a high density clay lens underlies a source contaminant, creating an effective barrier, the risk of contaminants reaching the groundwater is considered low. If the geologic formations are coarse gravel (i.e., highly transmissive vertically and horizontally), contaminants will move rapidly through the unsaturated zone to the groundwater.

B.4.2 Primary and Secondary Datasets

Aquifer parameters are a large part of the calibration process of groundwater models such as CVHM. The aquifer parameters are, in part, the result of scientific study of drinking water, monitoring, and exploratory well logs, and the driller’s notes on soils encountered at discrete intervals as the soil conditions change during the well drilling process. The USGS Texture Model is the product of a significant effort to capture the lithologic soil profile of the entire California Central Valley through an extensive review of well logs drilled over the past 100 years. While not known, the quality of well logs and soil descriptions was likely a discriminator to maintain quality control over the data.

Percent of Coarse Grained Deposits – The USGS Texture model is considered to be a primary dataset as interpreted by qualified scientists through the review of well logs. The texture model provides the data as a percentage of coarse grained soils at set intervals. This data was superimposed upon the CVHM model nodes, and layers at each node, to develop a secondary dataset for the percent of course grained deposits for each model layer.

Average Soil Transmissivities (K-Values) – the percent of coarse grained deposits is the basis for the calculation of aquifer parameters, such as transmissivity. The process used in the conversion of data to a K-Value soil parameter measuring if contaminants are impeded from movement, is as follows [DF]:

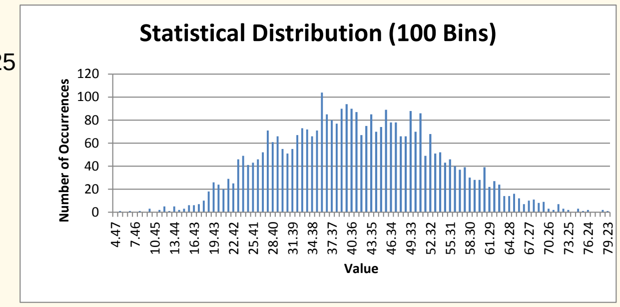
B.4.3 Raw Data Statistics

The two datasets included in **Table B-7** are closely related, although present dissimilar distribution plots. Whereas the primary dataset shows to have a normal distribution, the K-Value skewed normal distribution is over a narrower range and biased to the lower-end of K-Values (i.e., less transmissive).

Table B-7. Statistics for Rate of Groundwater Movement

****

Database Field: fld_AvgPercentCoarsetoD125
Number of non-zero data points: 3629
Average: 40.903
Mode (most frequent): 37.613
Number of times: 3.000
Median (odd middle value): 48.550
Maximum: 79.233
Minimum: 4.473
Midrange (average of max and min): 41.853



____**

****

Database Field: fld_AvgKtoD125
Number of non-zero data points: 3629
Average: 0.495
Mode (most frequent): 0.654
Number of times: 4.000
Median (odd middle value): 0.550
Maximum: 1.708
Minimum: 0.254
Midrange (average of max and min): 0.981

____

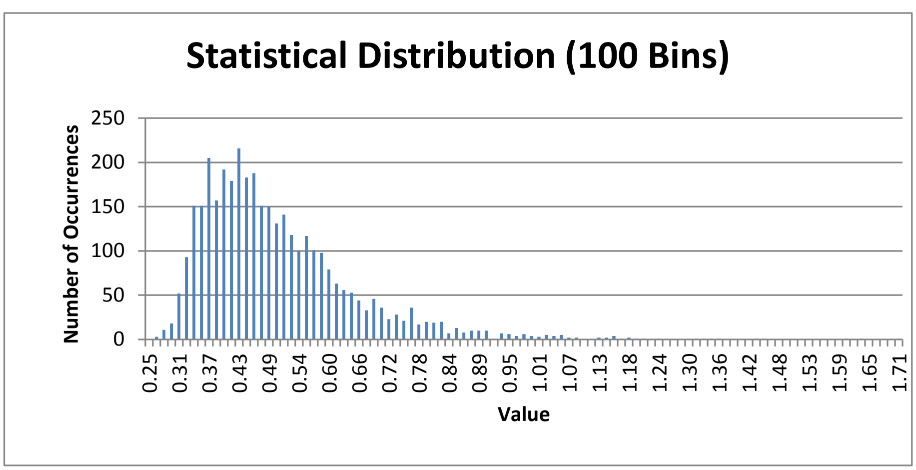


Figure B-16. Rate of Groundwater Movement Transmissivity Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-17**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative level of transmissivity between the cells. The higher the number (i.e., maximum of 10), the more susceptible the cell is to transporting contaminants in the unsaturated zone to the groundwater. The data is identified as being **directly** (as opposed to inversely) related to the value of aquifer K-values.

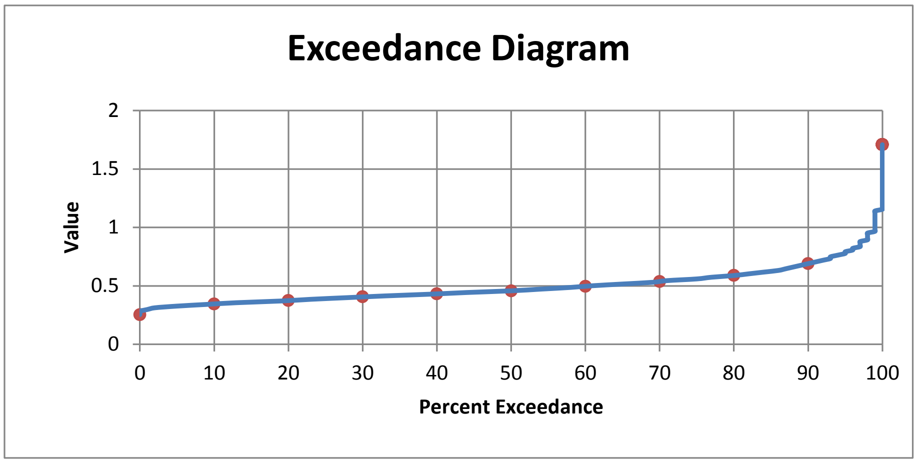


Figure B-17. Rate of Groundwater Movement Exceedance Plot

Filtering the aquifer K-Value data through the percentile index ranges in **Table B-8** standardizes the data to the ranked 1 through 10 values. The coloration scale is shown in **Figure B-18**, with red being most transmissive and blue being least transmissive soil conditions. The yellow highlighted regions represent the areas with the top 10 percent most transmissive soils.

Table B-8. Rate of Groundwater Movement Percentile Ranges

Percentile Ranges of Rate of GW Movement	Weight
0.254 to 0.345	1
0.345 to 0.374	2
0.374 to 0.405	3
0.405 to 0.431	4
0.431 to 0.458	5
0.458 to 0.496	6
0.496 to 0.538	7
0.538 to 0.589	8
0.589 to 0.690	9
0.69 to 1.708	10
End Point	10

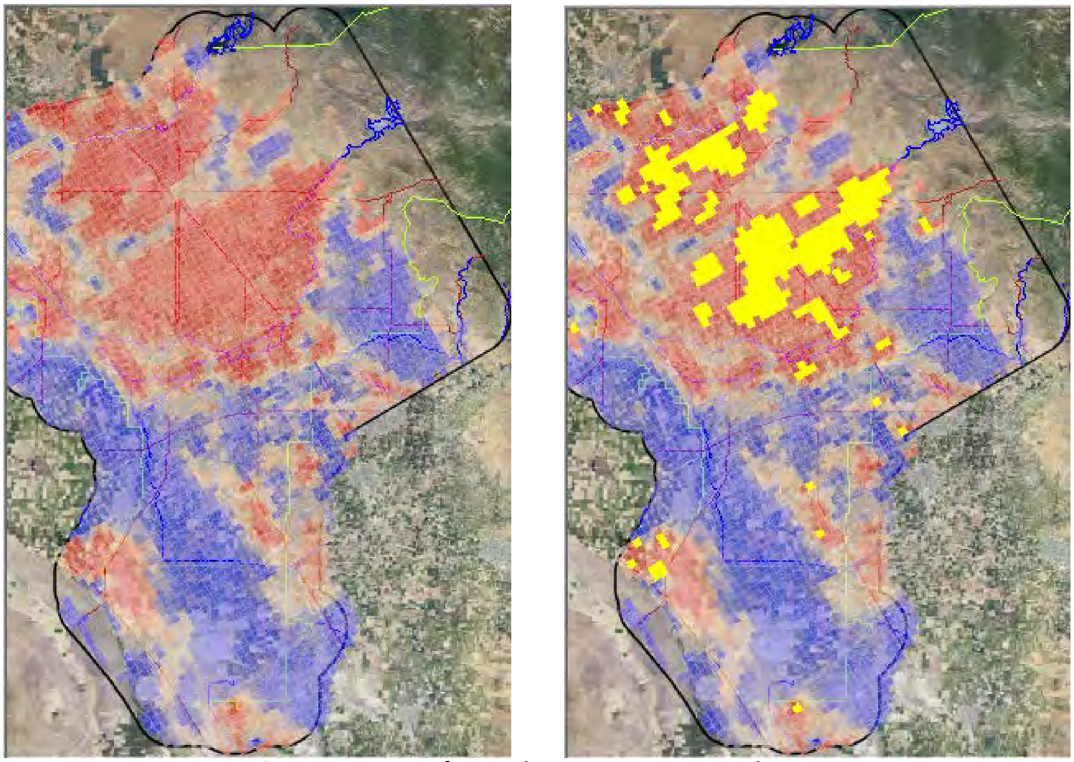


Figure B-18. Rate of Groundwater Movement Overlay

B.5 Applied Salt from Source Water (Regional Vulnerability)

The amount of groundwater and surface water use for drinking water and irrigation changes significantly in any given hydrologic year. This is considered to be another factor differentiating the four sub-regions of the study area. The data for this information is obtained from Kings IGSM and published studies (i.e., for areas outside of Kings IGSM). The factor is intended to capture the effects of surface water quality and conjunctive water use in the region.

A typical hydrologic year, as defined by ITRC, is assumed in this overlay description to provide a neutral dataset not biased in any one hydrologic direction, as explained further below. Due to the change in intentional recharge of clean surface water in the wet years, and availability of same for irrigation, above average and wet year conditions provide the best source of dilution when controlled mountain runoff and snowmelt are used for recharge and irrigation. Applied lesser quality, high TDS, surface water in the lower zones from the State Water Project and water originating from the Mendota Pool, does improve in Wet years relative to Typical or Dry hydrologic year types.

Surface water imported to the lower elevations zones along the western border of the study areas contributes the majority of imported salts. In addition, there is indigenous groundwater laden with salt, nitrogen, and other contaminants being recirculated as irrigation producing no net change in total salt loading. Nitrogen laden groundwater does offer some opportunity for using the nitrogen to meet fertilizer requirements, but insufficient data exists on if this practice is occurring. Nitrogen and salinity concentrations are expected to increase in the Typical and Dry hydrologic year types, increasing the aerial extent of "sink" locations for both contaminants based on groundwater gradients, soil transmissivities, and the presence of the Corcoran Clay Member.

B.5.1 Dataset Use

Matching hydrologic year and actual year amongst the datasets across all overlays produces a challenge since certain datasets are tied to actual years in time, some tied to hydrologic year type, and some associated with present (2010/12) and past (1990/2001). The ITRC definition of year type for Crop ET (1997, 1998, 1999 for Typical, Wet, and Dry, respectively) takes priority and is imposed upon 2012 CAML crop data and 2001 DWR crop data with irrigation methods and efficiencies for same years. Rainfall is based on ITRC years, using local gage data, to match Crop ET climate conditions. Monthly raw surface water quality is assumed as the average over the period of record to fill-in data gaps without biasing data. This single monthly average for all hydrologic years is recognized as being a weakness which, if more data were available, a different monthly water quality pattern would exist for each year type. Using the single year monthly timeseries is considered to be adequate for the purpose of this study effort.

B.5.2 Primary and Secondary Datasets

Outside sources of water originate from various source locations. The four primary sources are the Kings River (at Pine Flat (KNG1) and at Peoples Weir (KNG2)), the State Water Project (SWP), the Delta Mendota Canal (DMC), and the Friant Kern Canal (FKC). The monthly TDS of each source is shown in **Figure B-19** showing the DMC with the highest monthly TDS and then the SWP, mostly due to both sources originating in the California Delta. East supplies from the Kings River and FKC show to be comparatively much lower than the DMC and SWP.

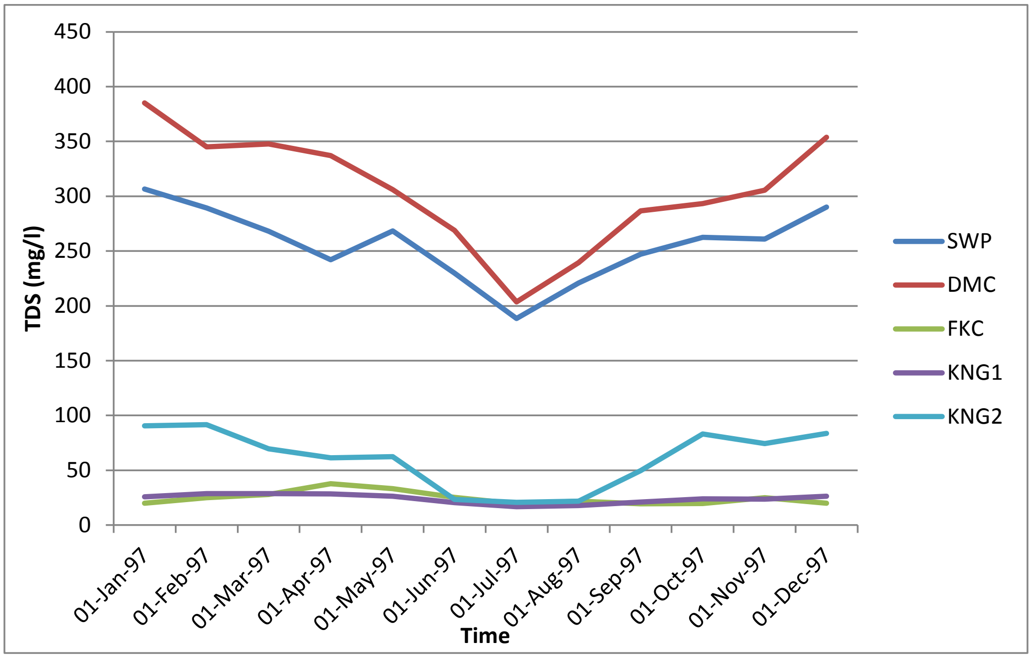


Figure B-19. Monthly TDS Curves for Imported Surface Water Supplies

The amount of surface water is calculated based on the estimated total annual split of surface water and groundwater. The different splits (see **Figure B-20**) were determined through agricultural water management plans and other published documents.

The split is assumed to occur for every month until better data can be used to differentiate the split throughout the year and by hydrologic year type.

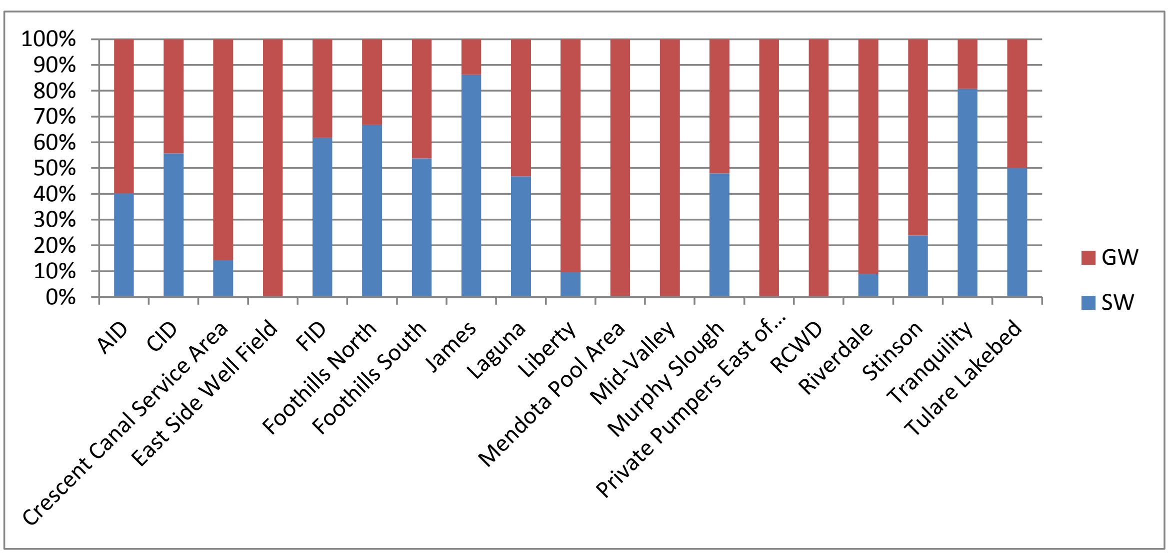


Figure B-20. Diversion Locations of Surface Water Imported to Study Area

B.5.3 Raw Data Statistics

The total salt leached is assumed to be the total pounds of salt in (1,000s) applied at the surface (i.e., not the amount of water leached from root zone). Since salt is persistent, all salt is assumed to leach to groundwater. The salt calculation is based on the total amount of applied water multiplied by the percent of applied which is surface water, and multiplied by the weighted monthly concentration based on the assigned source(s) of surface water to the crop. The crop amount is multiplied by the total area of the crop for each cell to obtain the estimated number of pounds per acre of each crop type.

Table B-9. Statistics for Applied Salt Contribution

```
************************************************************
Database Field: fld_SaltLeached
Number of non-zero data points: 2340
Average: 17,365.976
Mode (most frequent): 385.000
   Number of times: 61.000
Median1 (even middle value): 3,435.000
Median2 (even middle value): 3,236.000
Maximum: 116,922.000
Minimum: 3.000
Midrange (average of max and min): 58,462.500
________________________________________________________________________________
```

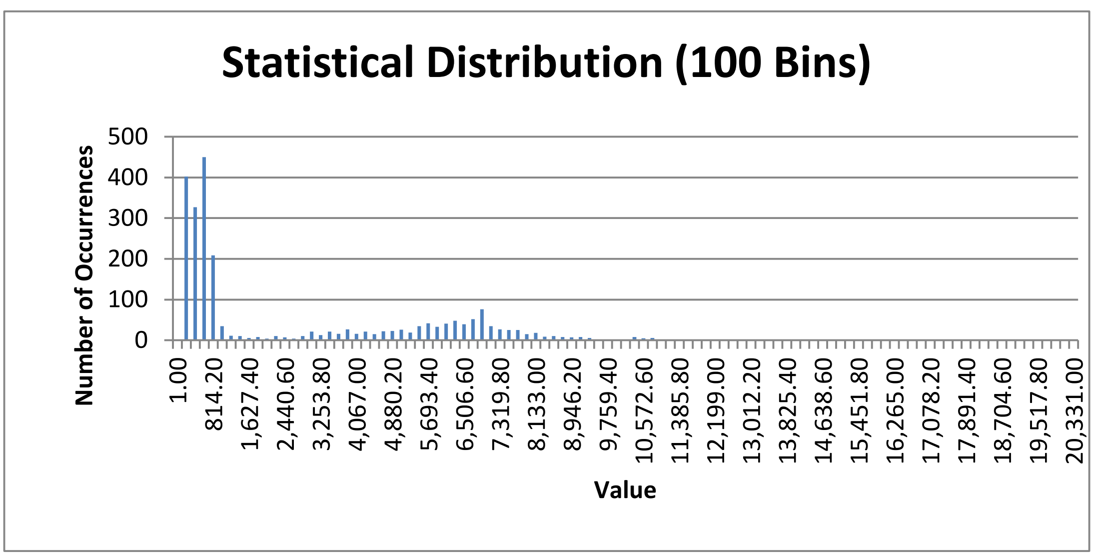


Figure B-21. Applied Salt Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-22**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative level of applied salt between the cells. The higher the number (i.e., maximum of 10), the more vulnerable the cell is to salt being transported to the groundwater from outside sources of surface water. The data is identified as being **directly** (as opposed to inversely) related to the salt loading values.

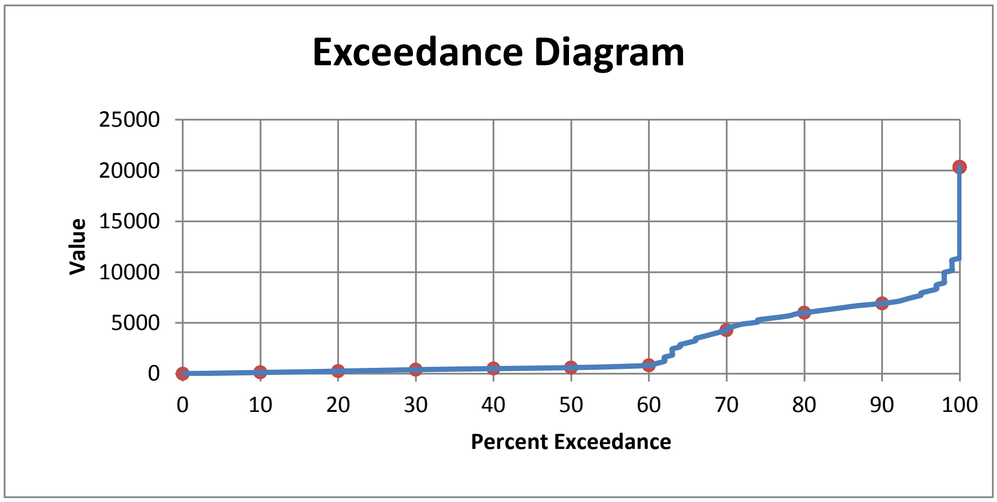


Figure B-22. Applied Salt Exceedance Plot

Table B-10. Applied Salt Percentile Ranges

Percentile Ranges of Stream Recharge	Weight
1 to 127.182	1
127.182 to 265.012	2
265.012 to 430.020	3
430.02 to 537.275	4
537.275 to 644.530	5
644.53 to 966.295	6
966.295 to 4,720.220	7
4720.22 to 6,543.555	8
6543.555 to 7,508.850	9
7508.85 to 21,452.000	10
End Point	10

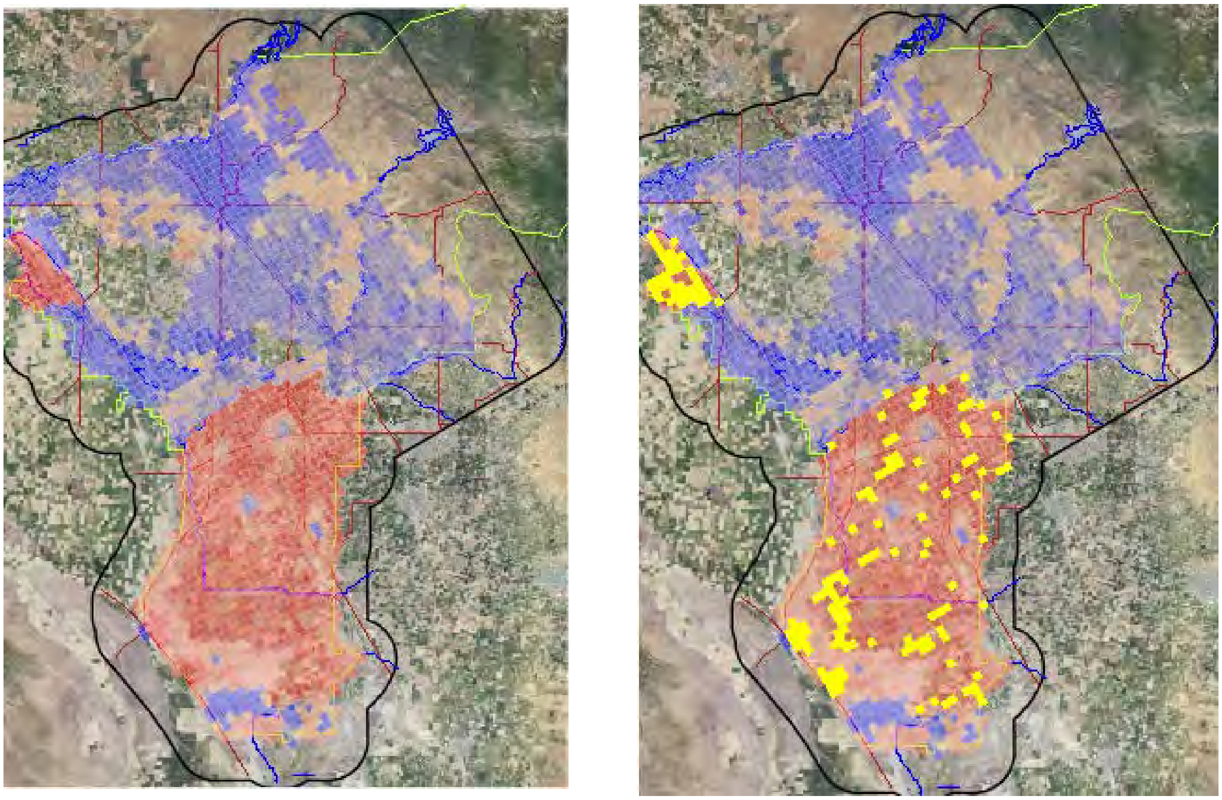


Figure B-23. Applied Salt Overlay

B.6 APPLIED SURFACE WATER AS IRRIGATION (REGIONAL VULNERABILITY)

B.6.1 Dataset Use

Using a similar calculation as Applied Salt, the Applied Water Utility tracks the amount of surface water included in the deep percolation calculation. This is done by the assignment of which areas receive surface water, how much surface water is used compared to groundwater, and where the source of surface water originates. Regardless of the salt content of applied surface water, the importation of water not laden with nitrogen is treated as a benefit to the region and is treated as such by assigning negative values in the ranking of cells receiving surface water and having that surface water result in deep percolation. Benefit is measured by the total volume of surface water included as deep percolation to groundwater.

B.6.2 Primary and Secondary Datasets

See **Section B.5.2** description of the datasets and how the calculations are made in the amount of surface water and groundwater. The only changed secondary dataset is the calculation of the amount of surface water as deep percolation. This is listed in statistics below.

B.6.3 Raw Data Statistics

The total volume of applied irrigation water contains a significant number of inputs dependent on crop type and irrigation method. The calculation in this index overlay results in a volume of applied surface water and a volume of applied groundwater. Applied surface water is calculated on a monthly basis, only when applied water is taking place (i.e., so as not to capture precipitation) and a deep percolation event is taking place. Regardless of salt concentration, applied surface water is calculated as a total percent volume of water leached to groundwater.

Figure B-24 indicates a relatively normal distribution with an average of 1,357 AF/year over the study area. The large number of lower values (i.e., 68 occurrences with 86 AF/year) is due mostly to urban areas where little deep percolation is occurring.

Table B-11. Statistics for Applied Surface Water

```
**********************************************************
 Database Field: fld_AppliedSW
Number of non-zero data points: 2544
Average: 1,357.123
Mode (most frequent): 86.000
   Number of times: 68.000
Median1 (even middle value): 2,453.000
Median2 (even middle value): 2,141.000
Maximum: 2,993.000
Minimum: 67.000
Midrange (average of max and min): 1,530.000
____________________________________________________________________________________
```

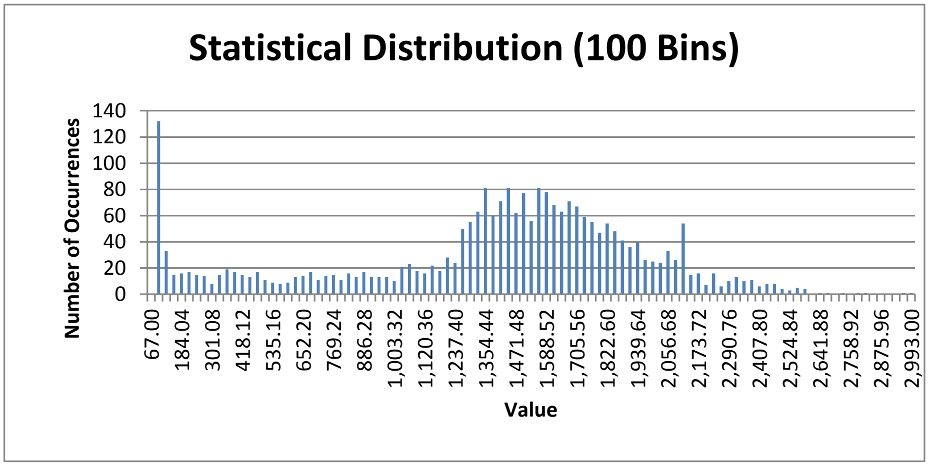


Figure B-24. Applied Surface Water Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-25**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting shown in **Table B-12** is based on the assumption that applied surface water with little to no nitrogen can and should be used to benefit the groundwater basin through dilution. A negative value is applied and is increasing as the amount of surface increases. The higher the negative number (i.e., maximum of -10), the more surface water is said to deep percolate to the groundwater. The blue shaded cells in **Figure B-26** indicate ranked values closer to -10 and those shaded red are closer to -1.

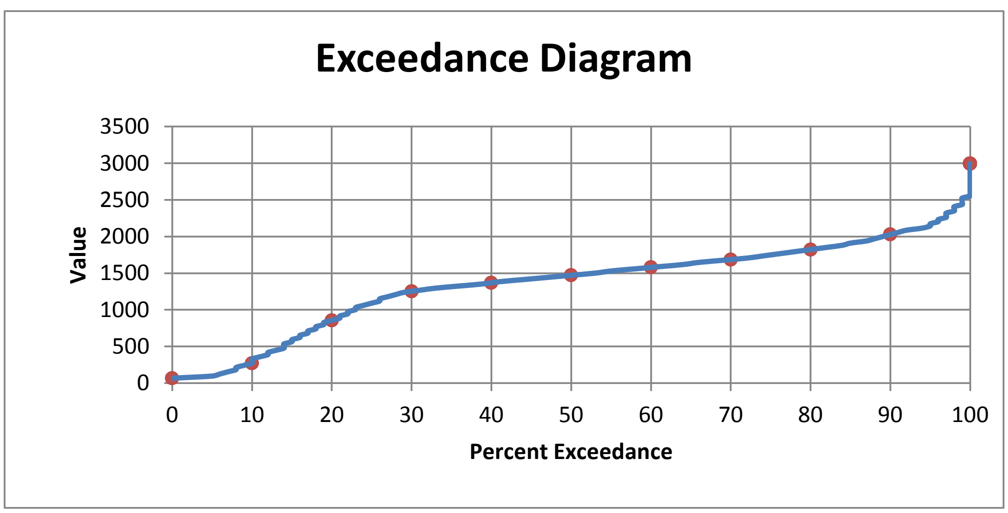


Figure B-25. Applied Surface Water Exceedance Plot

Table B-12. Applied Surface Water Percentile Ranges

Percentile Ranges of Stream Recharge	Weight
67 to 271.820	-1
271.82 to 857.020	-2
857.02 to 1,252.030	-3
1252.03 to 1,369.070	-4
1369.07 to 1,471.480	-5
1471.48 to 1,578.767	-6
1578.767 to 1,686.053	-7
1686.053 to 1,822.600	-8
1822.6 to 2,027.420	-9
2027.42 to 2,993.000	-10
End Point	-10

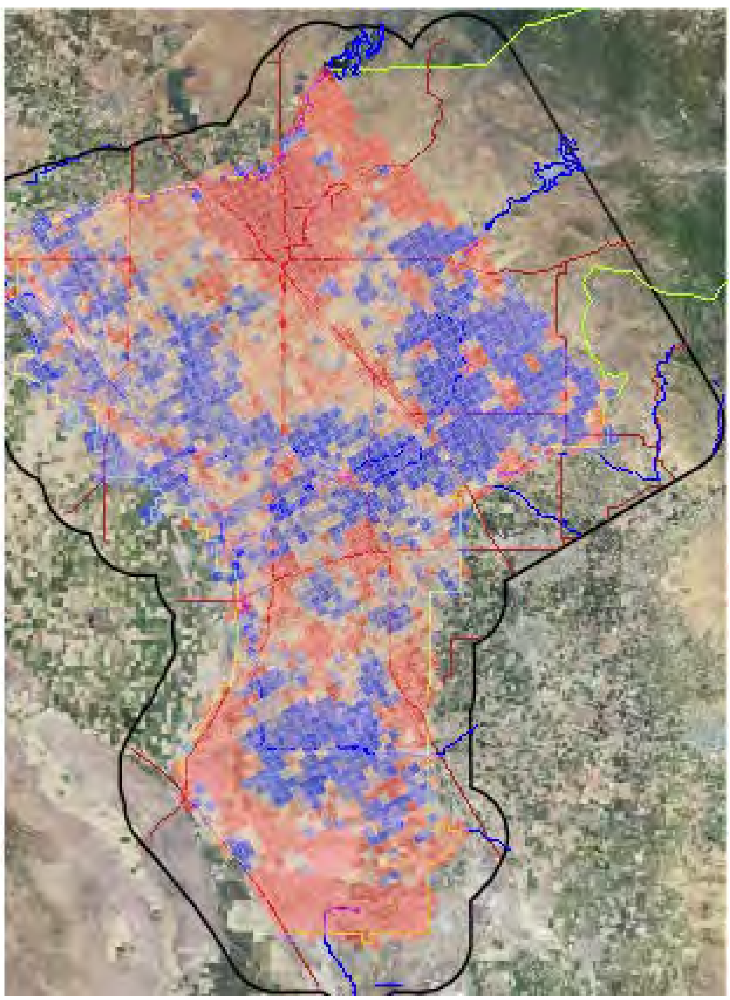


Figure B-26. Applied Surface Water Overlay

B.7 Stream Recharge (Regional Vulnerability)

Natural streams and rivers are a predominant source of recharge for the Kings Basin. Considered to be a management option, recharge of clean water from snow melt and mount runoff effectively reduces contaminant concentrations through dilution. Any amount of natural or artificial recharge using clean water sources is deemed beneficial to reducing nitrogen and salt concentrations.

In nature, the state of hydraulic connectivity between the aquifer and the recharge source (i.e., streams, rivers, unlined canals, recharge basins, flooded fields, etc.) is the limiting constraint on the amount of potential loss or gain volume. The slope of the hydraulic gradient away from the source is directly related to the rate of loss or gain. In the pre-pumping era, the hydraulic slope pointed towards the many rivers and streams, causing a gaining effect as in **Figure B-27** (Condition A). As pumping occurred, groundwater elevations declined reversing the gradient away from the rivers and streams, creating a losing (or recharge) effect (Condition B). Often the groundwater system will reach equilibrium with the amount of induced recharge from streams becoming equivalent to the basin's pumping. If pumping becomes greater than the amount of natural induced recharge, the hydraulic connection is lost (Condition C), creating the maximum recharge effect with no hydraulic impediment. When a stream becomes disconnected, the basin is considered to be in a critical state, requiring additional recharge or reduced pumping to re-establish equilibrium.

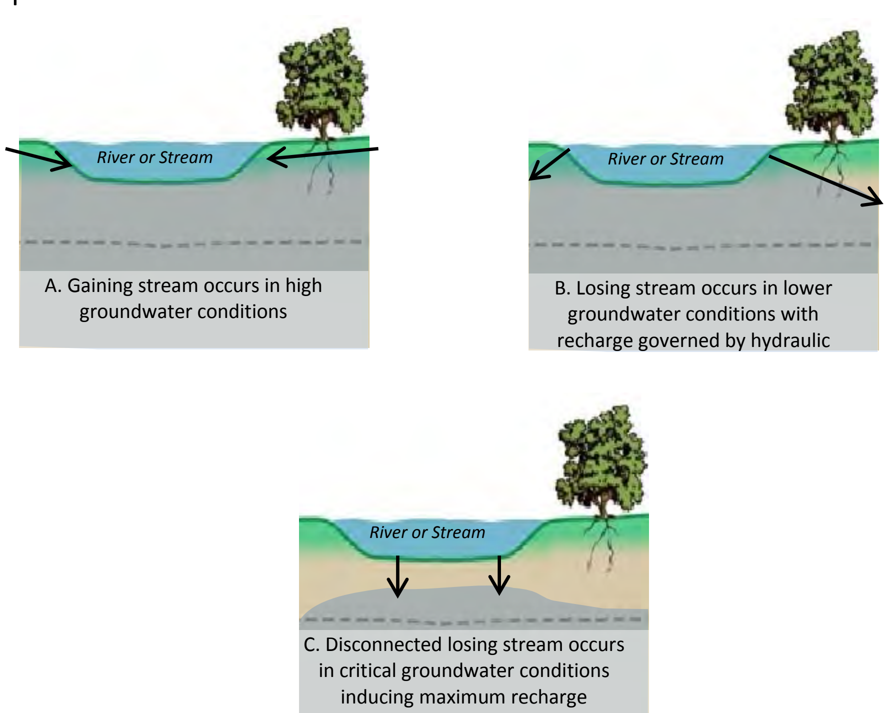


Figure B-27. Differences in Gaining and Losing Streams

B.7.1 Dataset Use

Quantification of natural and artificial recharge rates often requires a groundwater surface water model. Through calibration of the model, using stream-flow and groundwater elevation data as the primary calibration datasets, the model calculates the amount of loss or gain in reaches of the streams, unlined canals, and rivers. The calibrated Kings IGSM is such a model where outputs of recharge (or gain) are provided on a monthly time-step for each reach of the surface water conveyance system, including intentional recharge areas.

The underlying assumption that recharge of clean surface water, whether natural or artificial, is a positive benefit to the groundwater basin and should not be applied to the overlay index in a manner which adds to the groundwater susceptibility of agricultural practices. Rather, a negative value is assigned to essentially reduce susceptibility as a result of the potential recharge capacity of the basin.

B.7.2 Primary and Secondary Datasets

Use of the IGSM data is considered to be a secondary dataset set at the resolution of the stream reach, using the monthly stream (i.e., also includes rivers and canals) reach water budget produced by the model as the overlay dataset. Only losing events are used from this dataset. Stream gain events are considered to have no positive or negative benefit.

Each stream reach is mapped to the IOG with each cell assigned a value according to which stream reach lies within the cell’s bounding area. A routine developed and implemented with GAR Analyst, assigns the cells the recharge rates used in 2004 (i.e., the last year of the model calibration). Given the farther reaching benefits of stream recharge, the routine spreads the recharge effect in reducing amounts to a calculated number of IOG cells surrounding the cell containing the stream reach. The number of colored cells is based on the amount of recharge occurring, not to exceed three cells. The value of recharge is reduced by the percent maximum distance away from the stream (i.e., recharge = recharge_at_cell * (1 – Calculated_Dist / Max_Dist)). The result of this routine is illustrated in **Figure B-28.**

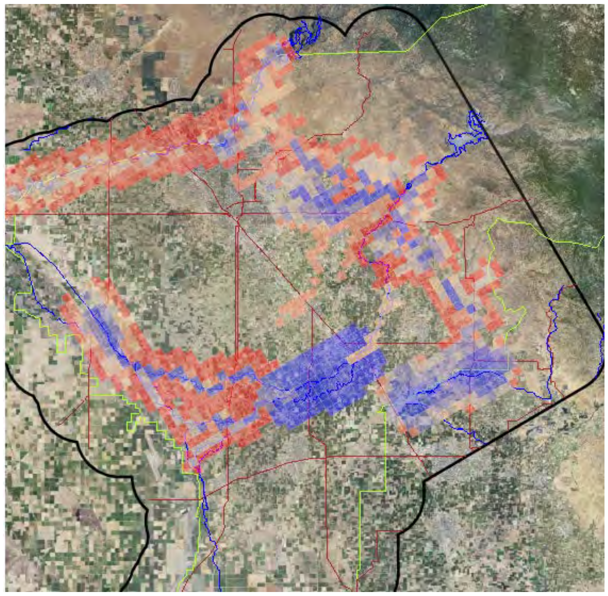


Figure B-28. Stream Recharge Spread Over Cells

The blue shaded cells have the highest recharge with lessening recharge benefit (red) as the water moves away from the recharge source, with the distance and amount depending on the distance away from the recharge source. In all cases, however, shaded cells are considered as benefitting from the recharge occurring.

B.7.3 Raw Data Statistics

The data in this overlay does not capture natural recharge from areas south of the Kings IGSM model area. While sources of surface water sources to the Tulare Lakebed region are known, the quality and quantity as compared to the Kings IGSM area is considered to be much less on an average basis, and deep recharge penetration of the clay lakebed is minimal in comparison to northern sub-region areas. In very wet years, the northern portion of the Tulare sub-region is known to benefit from Kings River water, but only during high controlled flow conditions with intentional recharge sites as the primary location. Any cell in the overlay carrying a zero value is not assigned a benefit from natural recharge.

The distribution of recharge values across the study area are represented in **Figure B-29** where negative values are increasing amounts of water recharging the underlying geology, and eventually the aquifer. Values are skewed to the right as a result of the algorithm above which tapers recharge benefit the further away from the source. The very high value of negative 2,470 AF/year is located in a very pervious soil condition where water is being moved both north and south[MZ to add]; especially in above average and wet years. As mentioned above, the values used are based on 2004 modeling data, indicated as a ___ year.

Table B-13. Statistics for Stream Recharge

****
Database Field: fld_RechargeAFA
Number of non-zero data points: 1033
Average: 187.972
Mode (most frequent): 198.615
Number of times: 94.000
Median (odd middle value): 365.556
Maximum: 2,469.923
Minimum: 1.250
Midrange (average of max and min): 1,235.587

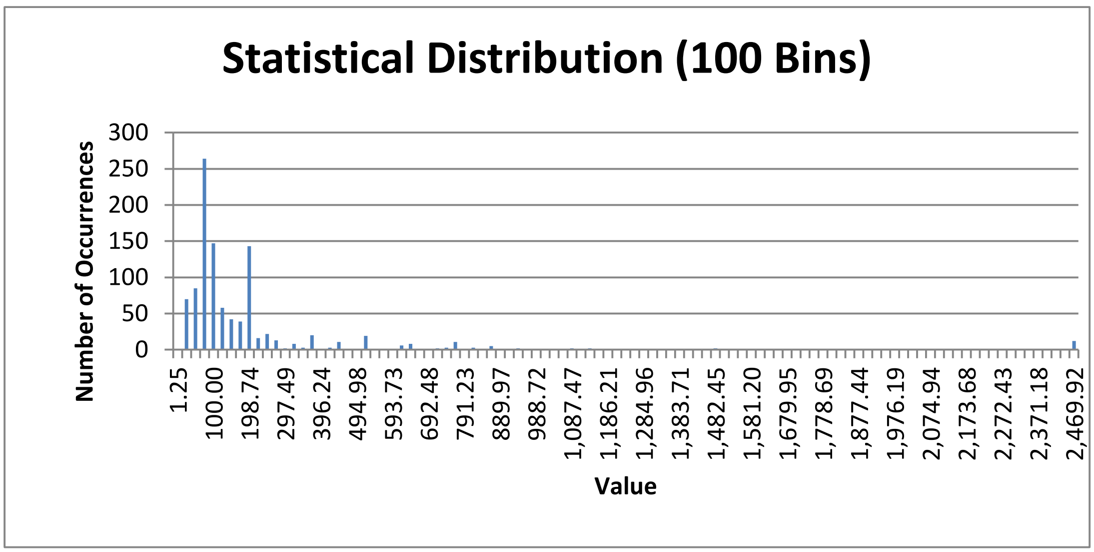


Figure B-29. Stream Recharge Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-30**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative level of transmissivity between the cells. The higher the number (i.e., maximum of 10), the more susceptible the cell is to transporting contaminants in the unsaturated zone to the groundwater. The data is identified as being **directly** (as opposed to inversely) related to the value of aquifer K-values.

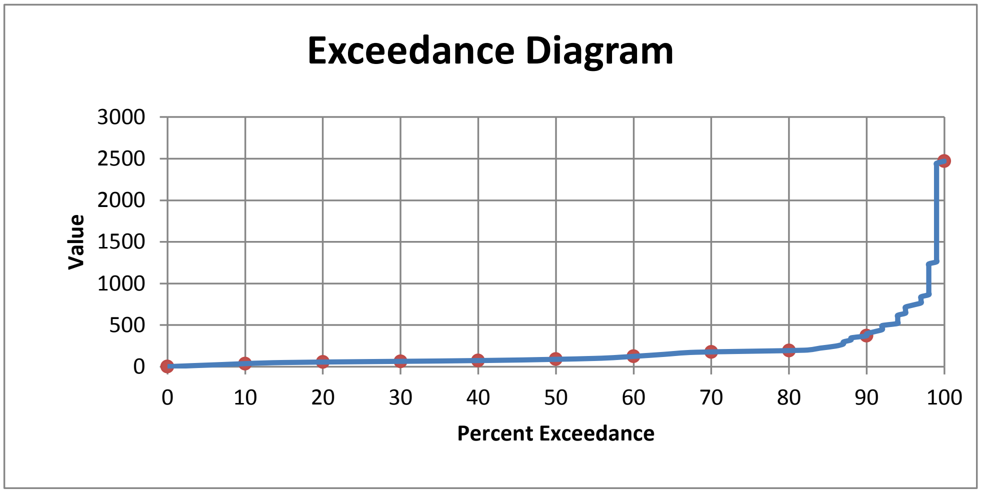


Figure B-30. Stream Recharge Exceedance Plot

Filtering the aquifer K-Value data through the percentile index ranges in **Table B-14** standardizes the data to the ranked -1 through -10 values. The duplicative values of the negative nine (-9) ranking is a product of having the large separation, or departure, in the highest recharge area discussed above. Being a product of the algorithm, no manual change is proposed since both -9 categories are treated as one in the overlay process. The coloration scale is shown in **Figure B-31**, with red being the low recharge areas and blue being the high recharge areas. The yellow highlighted regions represent the areas where the top 30 percent of river or intentional stream recharge is occurring.

Table B-14. Stream Recharge Percentile Ranges

Percentile Ranges of Stream Recharge	Weight
1.25 to 35.194	-1
35.194 to 55.371	-2
55.371 to 64.866	-3
64.866 to 74.361	-4
74.361 to 91.180	-5
91.18 to 124.684	-6
124.684 to 177.584	-7
177.584 to 195.217	-8
195.217 to 371.551	-9
371.551 to 396.238	-9
396.238 to 2,469.923	-10
End Point	-10

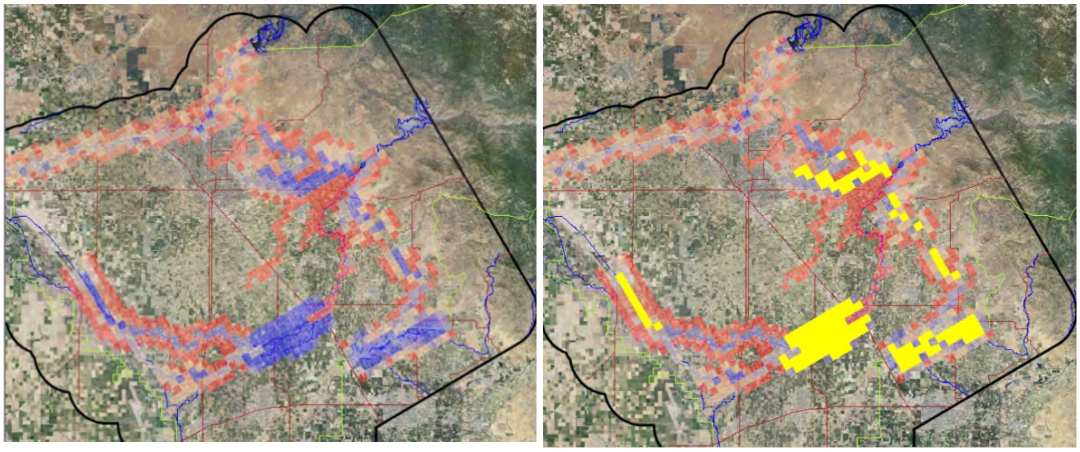


Figure B-31. Stream Recharge Overlay

B.8 Surface Recharge (On-Farm Vulnerability)

The surrogate index variable for surface recharge is deep percolation from applied water over irrigated farmlands and urban landscape areas. To maintain the level of resolution of crop data for 2010 using the CAML dataset provided by UC Davis (see **Chapter 3 – Data Sources and Needs to Support Analysis**), the Applied Water Utility, described in detail in **Appendix A – GAR Analyst Utilities,** is used to calculate deep percolation. Simply stated, deep percolation is water leaving the root zone of an irrigated crop typically induced by rainfall and applied water which exceeds the field capacity of a given soil type. **Figure B-32** illustrates the index variables needed for solving the deep percolation value. The terms and their relationships are described in **Appendix A – GAR Analyst Utilities**.

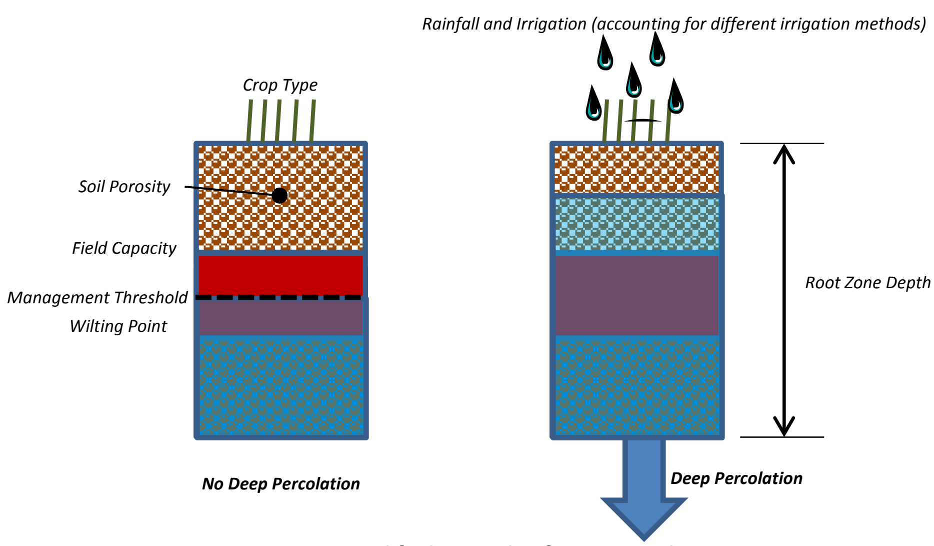


Figure B-32. Simplified Example of Deep Percolation

B.8.1 Dataset Use

Quantification of deep percolation requires several primary and secondary datasets as input to the standard soil moisture accounting method to determine when and how much deep percolation occurs over a year using a monthly time step for three hydrologic year types. Since applied water is the major contributor to deep percolation occurring over farmlands, the datasets leading up to calculation of applied water are presented below in terms of the dataset types and how they are used.

B.8.2 Primary and Secondary Datasets

Crop Type – The selected primary dataset is from the CAML dataset, identified as being the best source and highest resolution of crop and land use data. The number of acres for each crop category (88 total crop categories) in each IOG cell is determined using GIS.

Crop Evapotranspiration (Crop ET) – Crop ET is obtained through the Irrigation Training and Research Center (ITRC) website, where Crop ET data for approximately 32 different crop categories can be downloaded for the study region, and includes irrigation method and hydrologic year type. The years 1997, 1998, and 1999 are used as surrogate years for Typical, Wet, and Dry Hydrologic Years, respectively.

Irrigation Methods – Irrigation methods are obtained through DWR land use surveys for 2010. Survey information identifies the percentage of each irrigation method for various crop categories. These values are site specific and vary across the study area for the same crop category. The aggregated weighted average is used for each crop in each cell for purposes of assigning irrigation efficiency, crop ET, and assumed runoff, resulting in an adjusted amount of applied water and deep percolation.

Root Zone Depth – Root zone depth varies based on the different crop categories. The number of categories for this dataset is limited to eight and is obtained from the Kings IGSM.

Soil Field Capacity and Wilting Point – Both field capacity and wilting point are values obtained through the SSURGO dataset. Absent SSURGO data, a look-up table is produced based on well-published values[5] for six different soil types.

Soil Porosity – given the necessity to conduct actual field measurements to quantify porosity, a constant value of 0.50 (or 50% of the soils is made up of pore space filled with air or water) is used for all soil types based on published accounts.[6] By holding porosity constant, relative

[5] Brady Curves..need reference info
[6] International Soil Moisture Network < http://www.hydrol-earth-syst-sci.net/15/1675/2011/hess-15-1675-2011.pdf>

changes in deep percolation are likely not the result of an assumed value (i.e., minimize the influence of a known data gap) of porosity.

Management Threshold and Regulated Deficit Irrigation – the management threshold is based on many factors including the regulated holding back of applied water to improve crop quality and production. A constant value of 0.50 (or 50% of the measured difference between the field capacity and wilting point) is used.

Irrigation Efficiency – irrigation efficiency is a term used to take into account the irrigation methods and their effectiveness at meeting the crop ET demands. Flood irrigation is associated with lower irrigation efficiencies of 30% versus drip/micro methods which are closer to 90% efficient. The values for irrigation efficiency have also changed over time as farming practices are improved and technology is regulating and timing irrigation events with climate conditions. For this reason, the UC Davis study, "Spatial Analysis of Application Efficiencies in Irrigation for the State of California," prepared for the United States Geological Survey and California Institute for Water Resources [need citation] is used as the basis for irrigation efficiencies for the years 2001 and 2010 based on the Kings and Fresno regions of California.

Rainfall – Monthly rainfall totals are extracted from the Kings IGSM based on rainfall station proximity to sub-regional study areas. Effective rainfall is a term applied to how much of the rainfall actually ends up being available water for the given crop. Since the applied water calculation is taking into consideration runoff and deep percolation, the two largest sources of lost rainfall potential to meet crop ET (i.e., others being evaporation, topography and initial soil moisture content), no further adjustment is made in the rainfall totals due to the resolution of time and available data.

The result of running the Applied Water Utility across the entire study area is a value of deep percolation which is site specific to the IOG cell and sub-region. The algorithm is applied on a cell by cell basis adding up each of the crop categories assigned to each cell. The relative difference in the deep percolation is illustrated in **Figure B-33**. The hydrologic year-type shown is considered to be typical based on the ITRC definitions in crop ET data.

Brady, N. C.: The Nature and Properties of Soils, 8th ed, 12, 1974[need to include in reference]

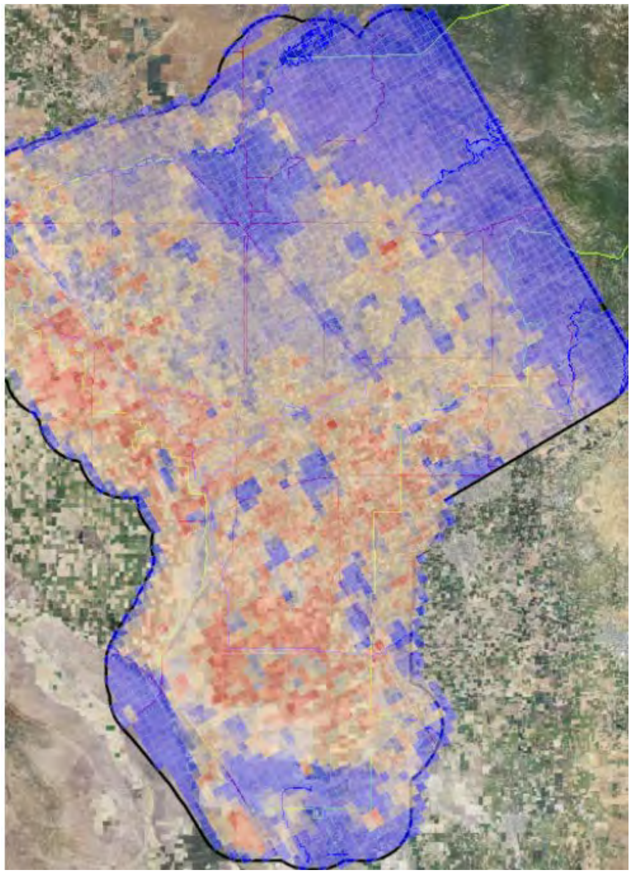


Figure B-33. Deep Percolation Spread Over Cells

The blue shaded cells have the relatively lower deep percolation, termed surface recharge, and the red shaded cells the higher.

B.8.3 Raw Data Statistics

Statistics for each of the meaningful primary and secondary datasets are provided in **Table B-15**. Included are only those datasets meaningful to the understanding of what data was used to make the applied water calculation. Meaning, only values registered to the cell level of resolution are shown. Values held constant or taken from a lookup table are not presented.

Table B-15. Statistics for Surface Recharge

```
************************************************************
Database Field: fld_RechargeAFA
Number of non-zero data points: 4320
Average: 8,929.703
Mode (most frequent): 3,060.248
   Number of times: 1.000
Median1 (even middle value): 15,070.894
Median2 (even middle value): 17,183.099
Maximum: 25,165.582
Minimum: 0.096
Midrange (average of max and min): 12,582.839
```

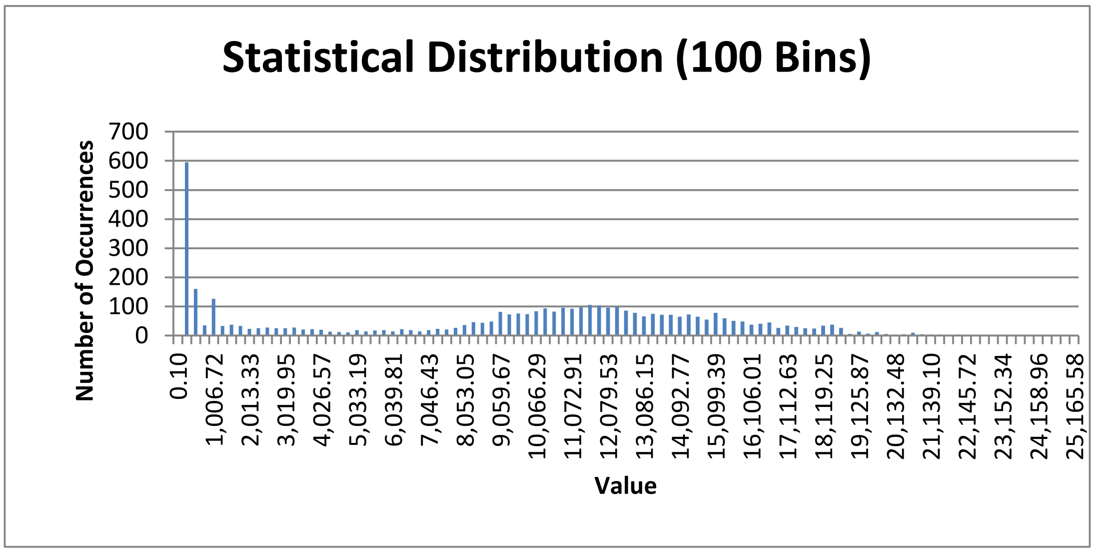


Figure B-34. Surface Recharge Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-35**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative deep percolation between the cells. The higher the number (i.e., maximum of 10), the more deep percolation is occurring in the cell causing the transport of contaminants in the shallow surface soils, root zone, and in the unsaturated zone to the groundwater. The data is identified as being **directly** related to the value of deep percolation values.

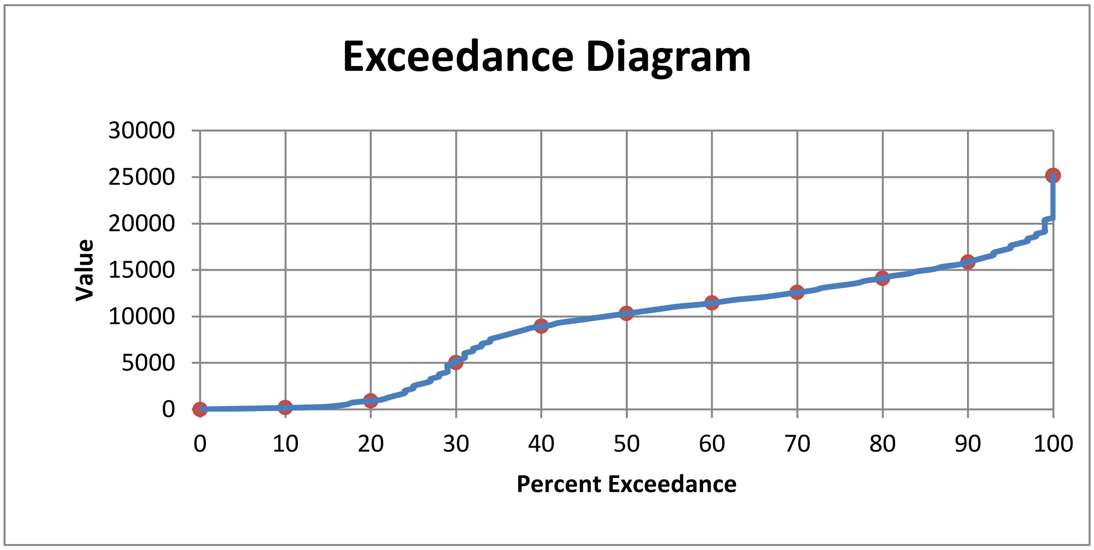


Figure B-35. Surface Recharge Exceedance Plot

Filtering the deep percolation data through the percentile index ranges in **Table B-16** standardizes the data to the ranked 1 through 10 values. The coloration scale is shown in **Figure B-36**, with red being the high surface recharge areas and blue being the low surface recharge areas. The yellow highlighted regions represent the areas where the top 10 percent of surface recharge is occurring.

Table B-16. Surface Recharge Percentile Ranges

Percentile Ranges of Surface Recharge	Weight
0.096 to 179.849	1
179.849 to 922.830	2
922.83 to 5,033.193	3
5033.193 to 8,933.843	4
8933.843 to 10,317.945	5
10317.945 to 11,450.392	6
11450.392 to 12,582.839	7
12582.839 to 14,092.768	8
14092.768 to 15,854.352	9
15854.352 to 25,165.582	10
End Point	10

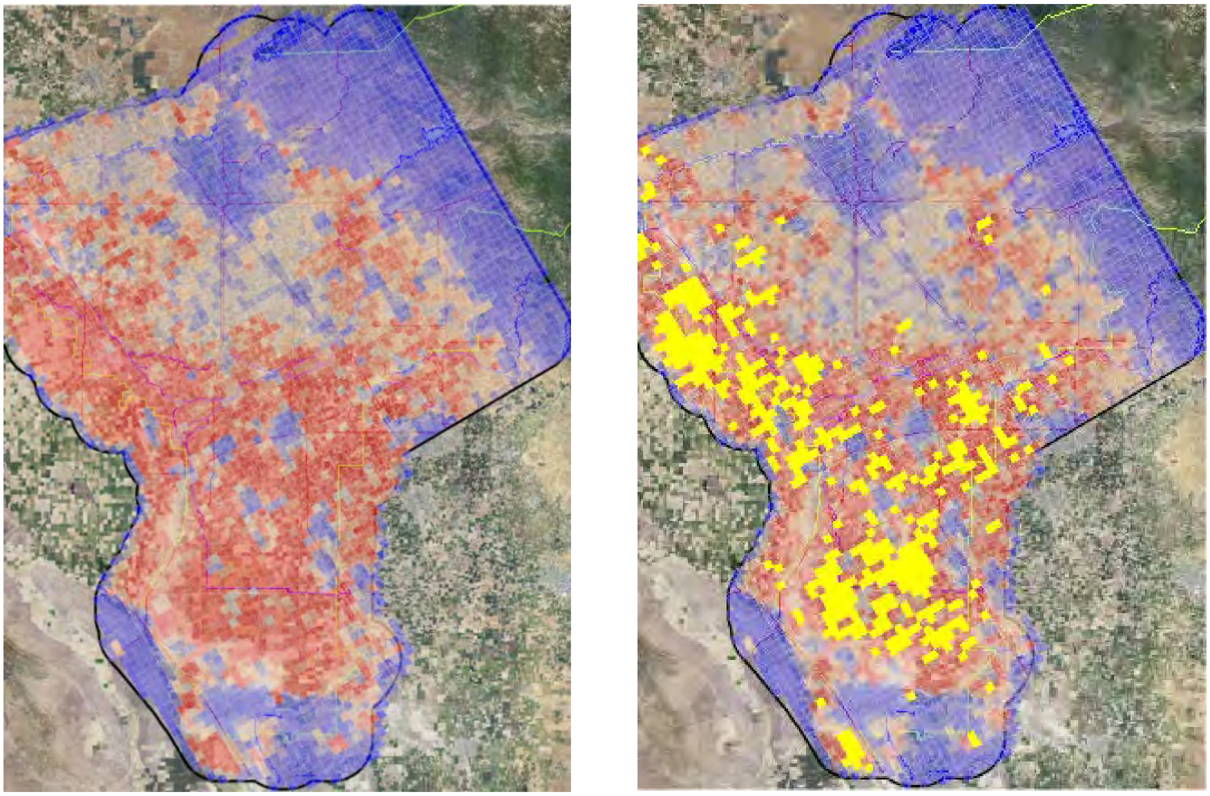


Figure B-36. Surface Recharge Overlay

B.9 NITROGEN EFFICIENCY (ON-FARM VULNERABILITY)

Given the uncertainties with the relative disposition, in time and space, of nitrogen in the soil and biochemical water environment within and below the root zone, a simplified straightforward approach has been taken in developing a nitrogen-to-groundwater efficiency indicator by applying published annual average values of nitrogen-related data for given crop categories.

B.9.1 Dataset Use

The nitrogen efficiency values are a weighted value of both the ratio of harvested to applied nitrogen and the total amount of water deep percolated on annual basis. The product of the two numbers on a single crop category results in a total relative nitrogen weighting the crops which produce more deep percolation multiplied by the acreage of each crop in each cell to account for the amount of agriculture taking place.

Table B-17. Comparison of N Application Rates to Total N Harvested (lbs/ac)

		1975	1990	2005
Cotton	N application rate	135	214	214
	Total N harvested	71	90	96
	Harvested/Applied	53%	42%	45%
Field crops	N application rate	143	196	248
	Total N harvested	104	164	241
	Harvested/Applied	73%	83%	97%
Grain and Hay	N application rate	113	175	211
	Total N harvested	87	124	152
	Harvested/Applied	77%	71%	72%
Grapes	N application rate	25	41	41
	Total N harvested	16	17	19
	Harvested/Applied	64%	41%	46%
Nuts	N application rate	220	207	207
	Total N harvested	63	78	108
	Harvested/Applied	29%	38%	52%
Rice	N application rate	106	160	160
	Total N harvested	75	98	96
	Harvested/Applied	71%	61%	60%
Subtropical	N application rate	197	117	117
	Total N harvested	40	57	56
	Harvested/Applied	20%	49%	48%
Tree Fruit	N application rate	149	128	129
	Total N harvested	25	28	27
	Harvested/Applied	17%	22%	21%
Vegetables and Berries	N application rate	186	239	237
	Total N harvested	81	99	119
	Harvested/Applied	43%	41%	50%
All crops	N application rate	129	182	191
	Total N harvested	71	89	111
	Harvested/Applied	55%	49%	58%

Source: Nitrogen Source and Loading to Groundwater - Technical Report 2 Assessing Nitrate in California's Drinking Water. Center for Watershed Sciences. UC Davis. March 2012 – Converted from Kg/Ha to lbs/ac

B.9.2 Primary and Secondary Datasets

The primary dataset is the by-crop harvested to applied nitrogen values. As a highly averaged primary dataset, the resolution is considered poor. By using applied water, a quantity taking into account many site-specific physical actions, the relative difference in the regional influence of fertilization and irrigation are accounted for in this analysis. Applied water quantities, however, are a secondary dataset calculated based on the Surface Recharge index layer above. The amount of nitrogen assumed as free to travel to groundwater is 1 minus the ratio of harvested to applied nitrogen, so a low ratio generates higher free nitrogen multiplied by the amount of applied water as irrigation, not taking into account rainfall.

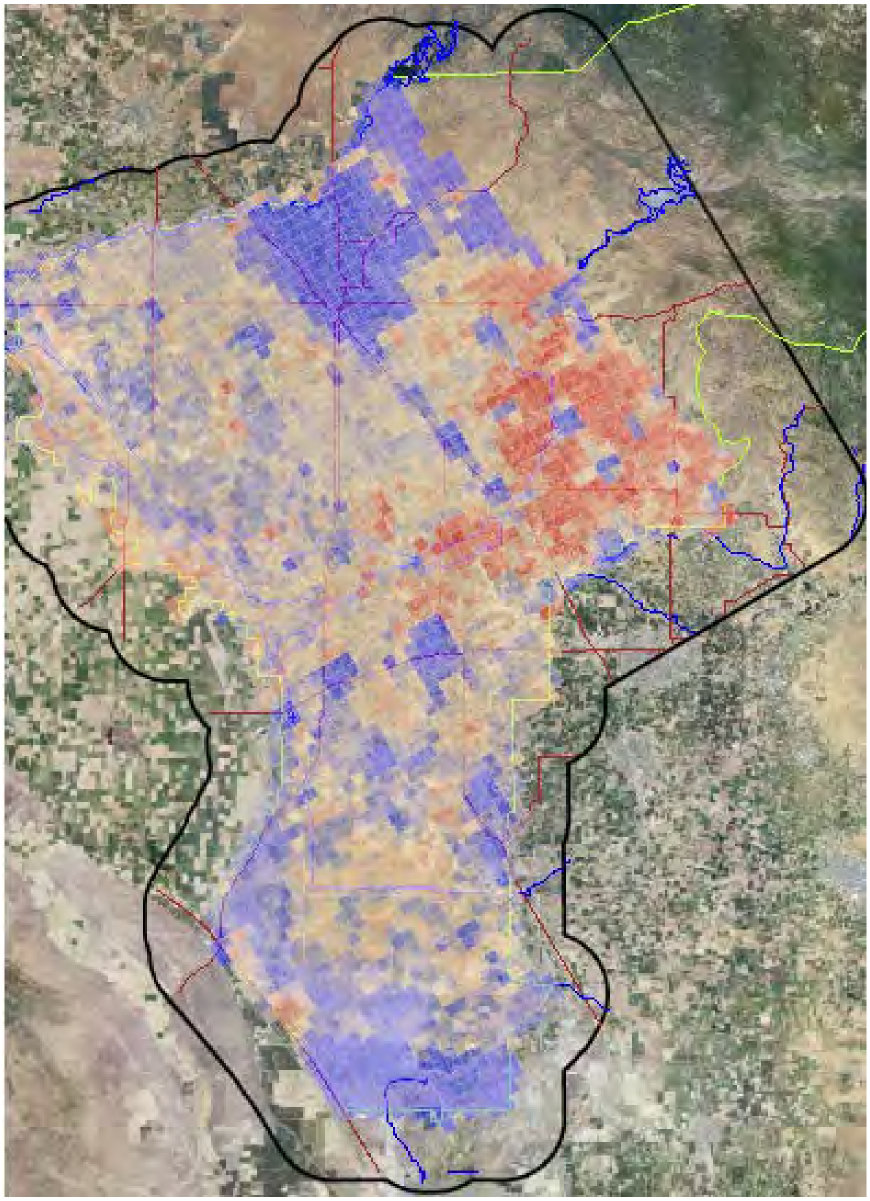


Figure B-37. Nitrogen Efficiency Spread Over Cells

The blue shaded cells have the lowest nitrogen contribution and the red shaded cells the higher contribution. Unshaded cells have no applied nitrogen contribution.

B.9.3 Raw Data Statistics

The raw data of harvest to applied nitrogen ratios is used in this case to be an indicator of how much, on a relative basis, nitrogen is left in the ground as part of farming practices of certain crop types. To account for the movement of nitrogen to groundwater, the ratios are weighted based on the amount of deep percolation to give more weight to the crop ratios with greater deep percolation.

This calculation produces unitless values which are intended to be used for assessing relative differences in nitrogen contributions from the various crop types across the study area.

Table B-18. Statistics for Nitrogen Efficiency

****

Database Field: fld_AmountofN
Number of non-zero data points: 2544
Average: 1,296.012
Mode (most frequent): 86.014
  Number of times: 9.000
Median1 (even middle value): 2,476.046
Median2 (even middle value): 2,187.945
Maximum: 3,063.321
Minimum: 66.559
Midrange (average of max and min): 1,564.940

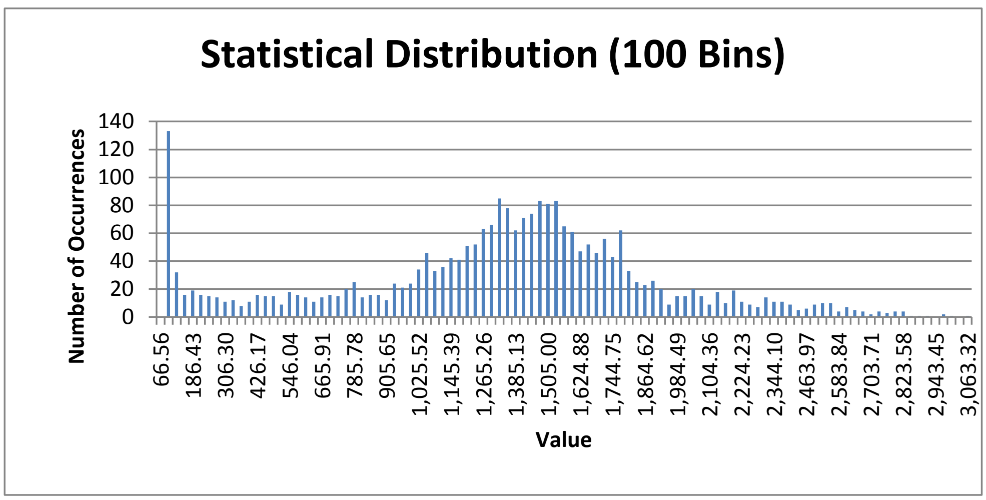


Figure B-38. Nitrogen Efficiency Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-30**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. The weighting is used to illustrate the relative level of nitrogen efficiency between the cells. The higher the number (i.e., maximum of 10), the more susceptible the cell is to transporting nitrogen to the groundwater. The data is identified as being **directly** (as opposed to inversely) related to the nitrogen efficiency values.

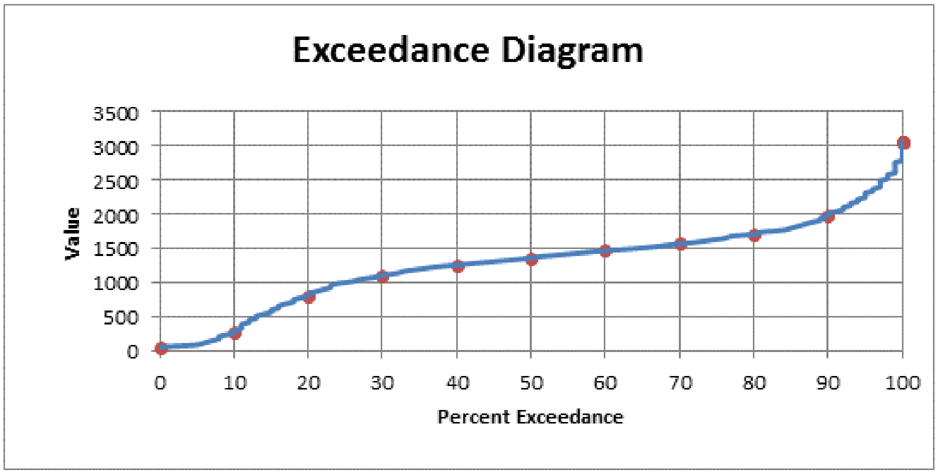


Figure B-39. Nitrogen Efficiency Exceedance Plot

Filtering the aquifer K-Value data through the percentile index ranges in **Table B-14** standardizes the data to the ranked -1 through -10 values. The duplicative values of the negative nine (-9) ranking is a product of having the large separation, or departure, in the highest recharge area discussed above. Being a product of the algorithm, no manual change is proposed since both -9 categories are treated as one in the overlay process. The coloration scale is shown in **Figure B-31**, with red being the low recharge areas and blue being the high recharge areas. The yellow highlighted regions represent the areas where the top 30 percent of river or intentional stream recharge is occurring.

Table B-19. Nitrogen Efficiency Percentile Ranges

Percentile Ranges of Stream Recharge	Weight
66.559 to 276.332	1
276.332 to 815.749	2
815.749 to 1,115.426	3
1115.426 to 1,265.264	4
1265.264 to 1,370.150	5
1370.15 to 1,475.037	6
1475.037 to 1,574.929	7
1574.929 to 1,714.778	8
1714.778 to 1,984.487	9
1984.487 to 3,063.321	10
End Point	10

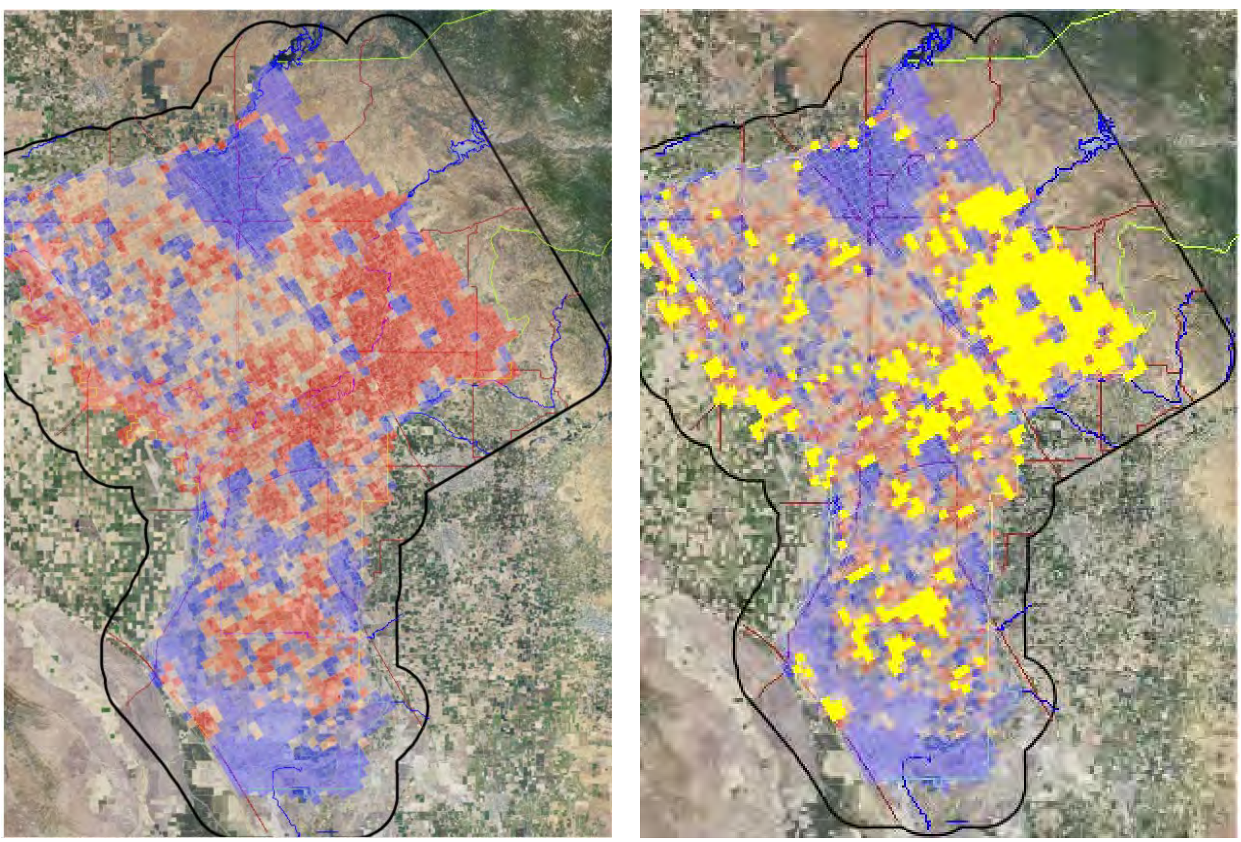


Figure B-40. Nitrogen Efficiency Overlay

B.10 POPULATION DENSITY ON GROUNDWATER (DRINKING WATER VULNERABILITY)

B.10.1 Dataset Use

Vulnerability to drinking water supplies by agricultural practices is measured by the proximity of the farming activities to the drinking water wells and the population who depends on groundwater for their drinking water supply. In the case of population density on groundwater, 2010 census tract information is used to identify high population areas, including rural areas with small water systems or private wells. This index overlay is critical to picking up vulnerable areas where human health and safety are at the highest risk.

B.10.2 Primary and Secondary Datasets

The 2010 census tract data, available on-line using GIS, provides the population count for each 1 square mile grid cell in our study area. The assumption is that all drinking water in the study area is some part groundwater in every month of every year. In this overlay, conjunctive use of groundwater with surface water supplies does not reduce the risk to nitrogen exposure resulting from near proximity farming activities.

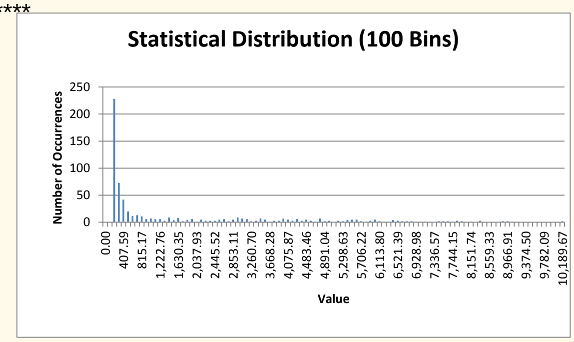
B.10.3 Raw Data Statistics

The population density is the total number of people residing in each cell divided by the total area of the cell (640 acres = 1 square mile). A simple capita count is made of the primary data source and used for purposes of calculating the total population for each cell as shown below. To better visualize the data and to maintain a more appropriate comparison between cells, the calculated density is a preferred method of presenting this index variable. As seen by the distribution in **Figure B-41**, densities considered in this analysis vary from 0.5 capita per acre to 16 capita per acre.

Table B-20. Statistics for Population on Groundwater

****

Database Field: fld_PopulationonGW
Number of non-zero data points: 3398
Average: 340.815
Mode (most frequent): 1.529
   Number of times: 6.000
Median1 (even middle value): 95.266
Median2 (even middle value): 177.594
Maximum: 10,189.674
Minimum: 0.000
Midrange (average of max and min): 5,094.837



****

Database Field: fld_DensityonGW
Number of non-zero data points: 349
Average: 4.661
Mode (most frequent): 0.506
   Number of times: 1.000
Median (odd middle value): 5.403
Maximum: 15.921
Minimum: 0.501
Midrange (average of max and min): 8.211

The 0.5 capita/acre (1 person for every 2 acres) is used as a cutoff to avoid counting small farmlands. Housing densities of 1 residential unit for every 2 acres is typically identified with rural residential development or small ranchette land use zoning. This cutoff suppresses many cells from being considered in this index variable leading to relatively flat distribution in densities in areas of mostly urbanized land uses. [The addition of Disadvantaged Communities (DACs) will be done to ensure we capture all DACs within study area.]

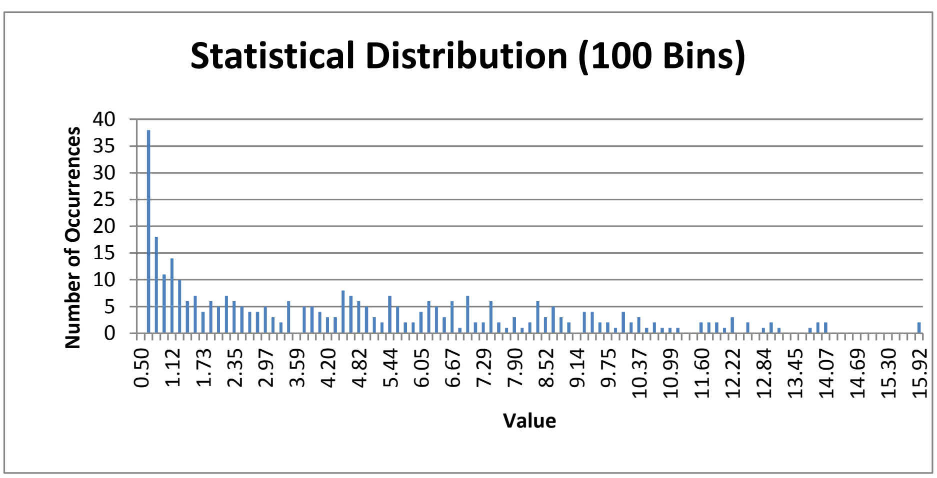


Figure B-41. Population Density Distribution (capita/acre)

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-42**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. A higher density implies a higher level of risk.

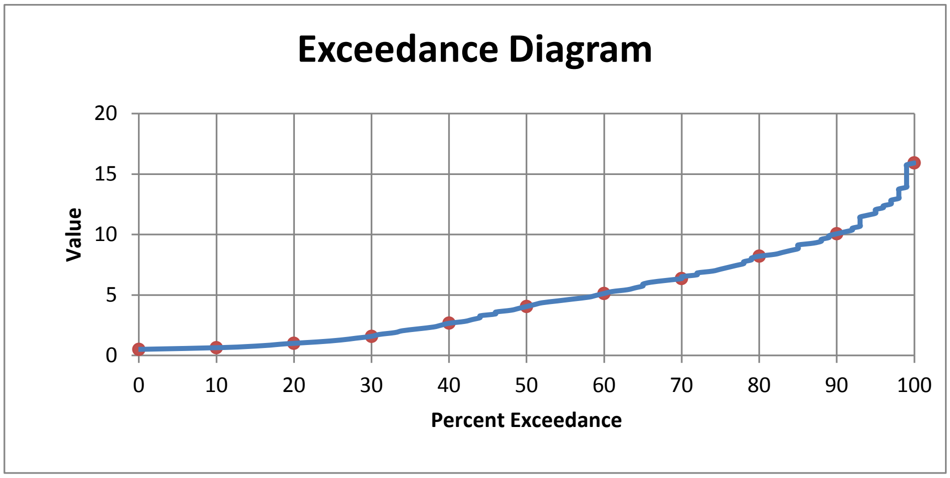


Figure B-42. Population Density Exceedance Plot

Table B-21. Population Density Percentile Ranges

Percentile Ranges of Stream Recharge	Weight
0.501 to 0.641	1
0.641 to 1.002	2
1.002 to 1.580	3
1.58 to 2.660	4
2.66 to 4.048	5
4.048 to 5.127	6
5.127 to 6.361	7
6.361 to 8.211	8
8.211 to 10.062	9
10.062 to 15.921	10
End Point	10

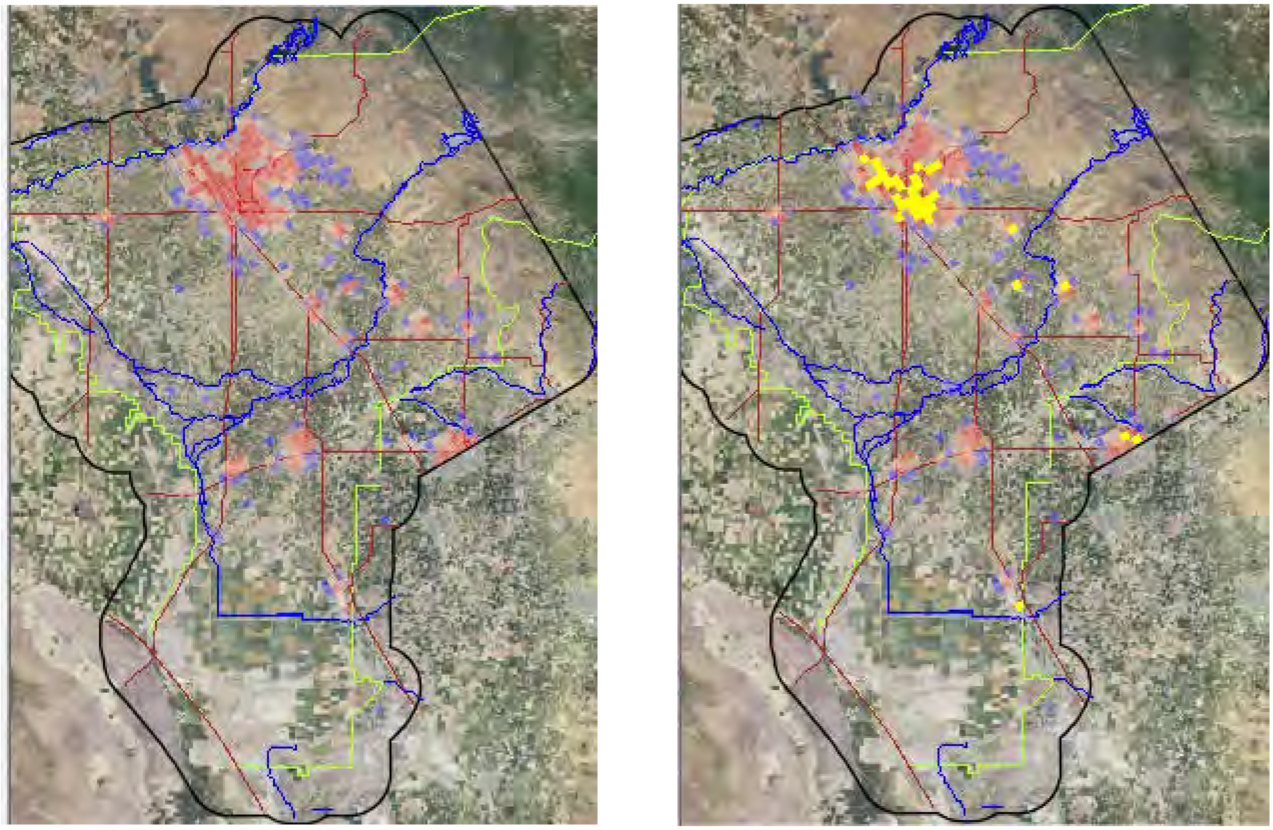


Figure B-43. Population Density Overlay

B.11 PUBLIC WELL PROTECTION ZONES (DRINKING WATER VULNERABILITY)

This index category provides the human health element of concern by taking into account actions which are outside the control of the agricultural community, placing public drinking water at risk simply by the location of farms relative to public drinking water supply wells. The well protection zone is an area around each well delineating an area vulnerable to surface activities which could affect groundwater (e.g., an underground storage tank, industrial uses, and agricultural areas where applied fertilizer is taking place).

Well protection zones exist around all drinking water supply wells, both public and private. The public supply wells are considered to be a higher risk simply due to the number of people dependent on the supply. In addition, public wells are regulated and information relative to location and construction is known; although, well construction and completion information is not readily available or made public under existing state law.

B.11.1 Dataset Use

To work with this dataset, a constant value for each well is assumed to ensure no bias in the data for calculating the protection zones when using the Modified Fixed Radius Method described in **Appendix A – GAR Analyst Utilities**. The result is an overlapping display of circles around and up-gradient of the well in the direction of the groundwater flow. The density of overlapping protection zones is used as the basis for ascertaining relative risk. An illustration of the protection zone concept and it application is provided in **Figure B-44**. The green dots represent the actual well location and the red dot represents the offset to account for steeper groundwater gradients over a good portion of the region. The shaded circle is the calculated 20-year protection zone.

The density of the protection zones is used as the index variable in this case to differentiate the drinking water system vulnerability. Any agricultural activity taking place within a protection zone is considered to be worthy of monitoring, it just becomes a matter of priority of monitoring and reporting in the region. The Well Protection Zone overlay shown in **Figure B-44,** shades areas of high and low densities, and leaves areas blank in cases of low risk where there is no public well vulnerability from agricultural practices.

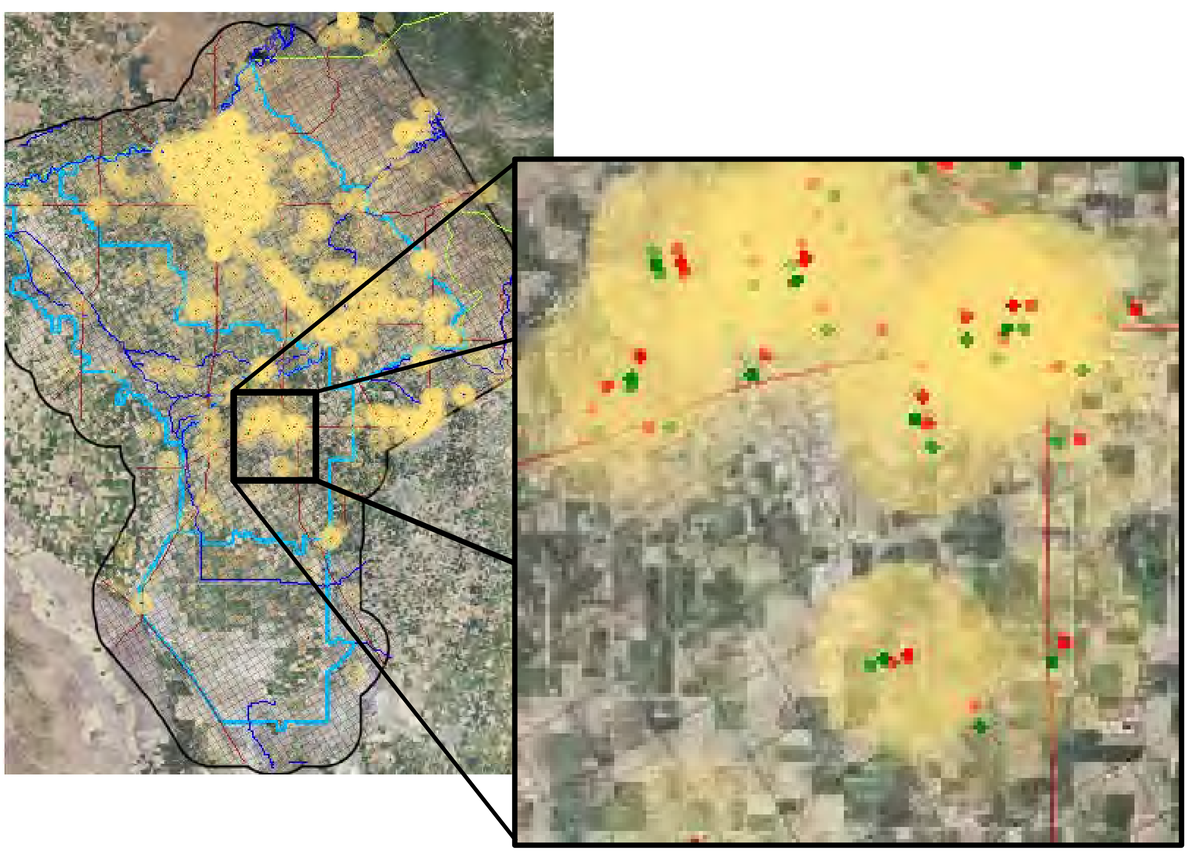


Figure B-44. Well Protection Zone Example

B.11.2 Primary and Secondary Datasets

Primary datasets include the well location and use only. Secondary datasets include the calculation of the groundwater gradient through use of contouring utility, and the diameter and offset of the capture zone circles. The use of the 20-year protection zone is set based on the typical planning criteria for state agricultural and urban water management plans.

B.11.3 Raw Data Statistics

Similar to the Population Density index above, cells not within the protection zone radius are not included in the index overlay as can be seen by then number of blank cells. All areas within a well protection zone are treated based on the density of protection zones.

Table B-22. Statistics for Drinking Water Well Protection Zone

****
Database Field: fld_NumberofWells
Number of non-zero data points: 1388
Average: 4.568
Mode (most frequent): 1.000
Number of times: 476.000
Median1 (even middle value): 9.000
Median2 (even middle value): 1.000
Maximum: 34.000
Minimum: 1.000
Midrange (average of max and min): 17.500

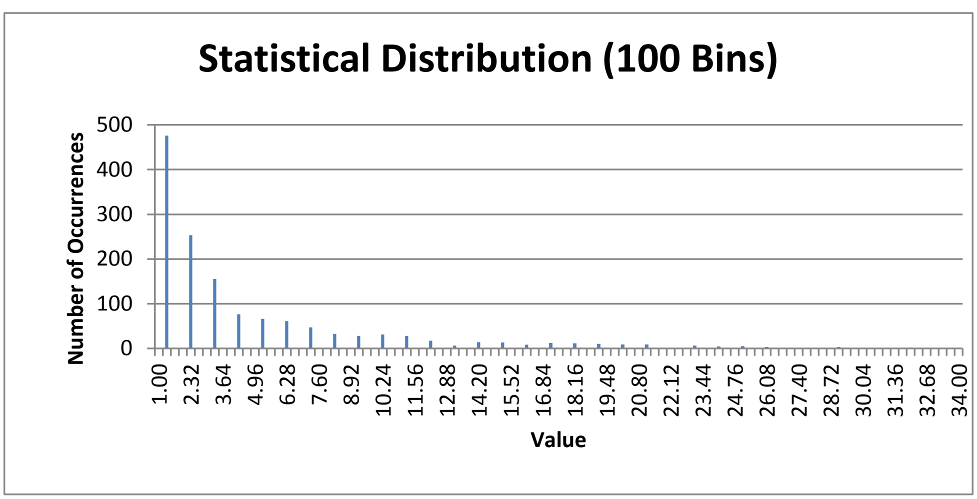


Figure B-45. Drinking Water Well Protection Zone Distribution

Exceedance and Percentile Rankings

The exceedance diagram is shown in **Figure B-46**, and results in the percentile ranges as delineated on the figure by the red points. The weighting value is the auto-assigned weighting based on the range each IOG cell falls within. A higher density implies a higher level of risk.

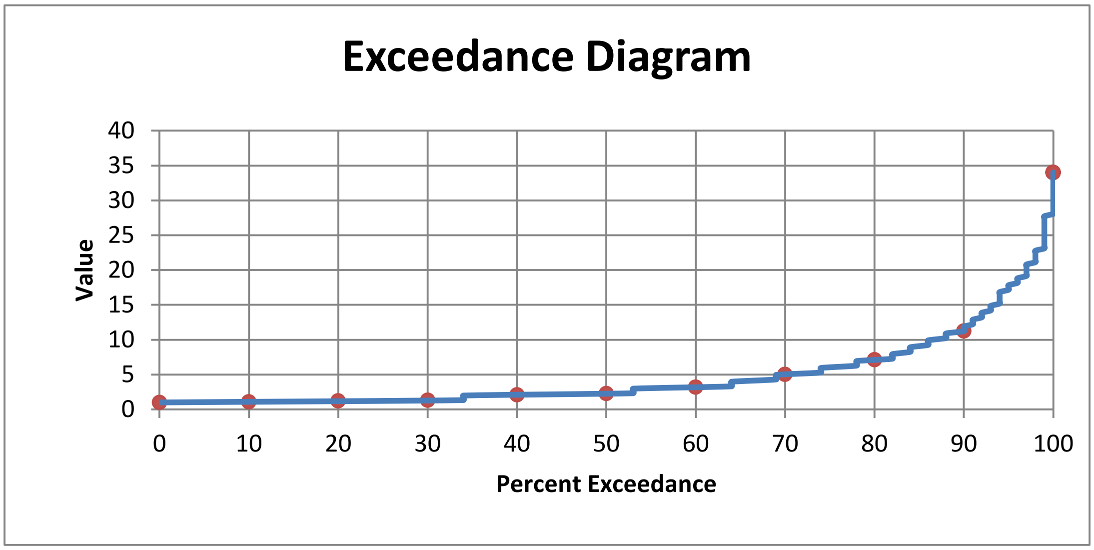


Figure B-46. Drinking Water Well Protection Zone Exceedance Plot

Table B-23. Drinking Water Well Protection Zone Percentile Ranges

Percentile Ranges of Stream Recharge	Weight
1 to 1.097	1
1.097 to 1.194	2
1.194 to 1.291	3
1.291 to 2.094	4
2.094 to 2.268	5
2.268 to 3.190	6
3.19 to 5.026	7
5.026 to 7.105	8
7.105 to 11.230	9
11.23 to 34.000	10
End Point	10

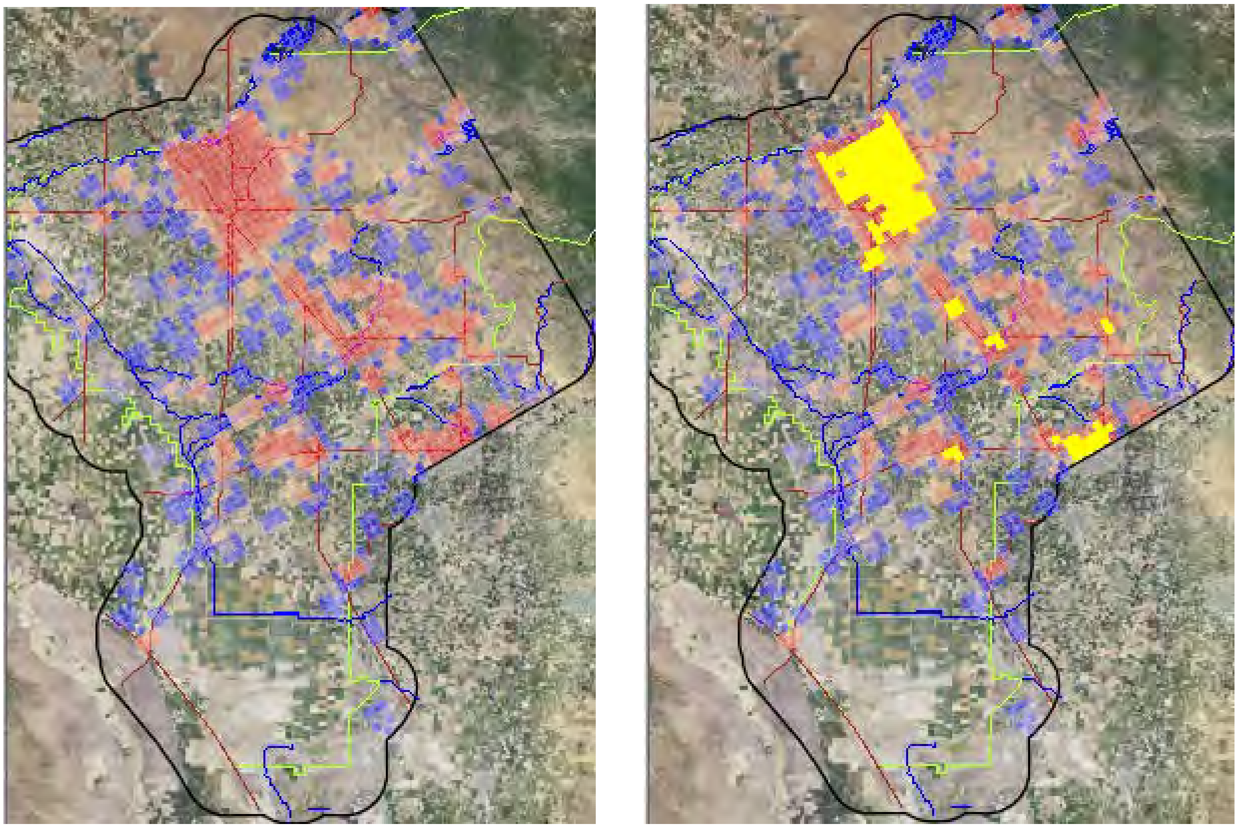


Figure B-47. Drinking Water Well Protection Zone Overlay