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CENTRAL VALLEY SALINITY ALTERNATIVES FOR LONG TERM SUSTAINABILITY (CV-SALTS)

Initial Conceptual Model (ICM) Technical Services

Tasks 7 and 8 – Salt and Nitrate Analysis for the Central Valley Floor and a Focused Analysis of Modesto and Kings Subregions

Final Report

Prepared for

SAN JOAQUIN VALLEY DRAINAGE AUTHORITY

Submitted by

LARRY WALKER ASSOCIATES, INC

In association with

LUHDORFF AND SCALMANINI CONSULTING ENGINEERS

KENNEDY/JENKS CONSULTANTS

PLANTIERRA

SYSTECH WATER RESOURCES

CAROLLO ENGINEERS

LARRY WALKER ASSOCIATES

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Executive Summary

OVERVIEW

Consistent with the Recycled Water Policy[1] for the State of California, the Central Valley Salinity Alternatives for Long Term Sustainability (CV-SALTS) is developing a comprehensive Salt and Nitrate Management Plan (SNMP) for the Central Valley Regional Water Quality Control Board's jurisdictional boundaries. The SNMP will identify the approach and establish the basis for the short and long-term management of salt and nitrate in the Central Valley region.

The Initial Conceptual Model (ICM) is the first of several phases of work that needs to be completed in order to develop the first draft of the Central Valley SNMP by May 2014. The Phase I ICM, which has been developed by the Larry Walker Associates (LWA) Team[2] in a collaborative setting with stakeholders and regulatory and partner agencies, forms the foundation for the subsequent phases of necessary work (Phases II and III). The knowledge base, technical analyses, and associated documentation that are developed as a part of the SNMP will form the basis for corresponding amendments to the Water Quality Control Plans for the Sacramento/San Joaquin Basin and Tulare Lake Basin (Basin Plan Amendments or BPAs) by approximately May 2016. The ICM work effort will also be foundational for the more detailed, sub-regional analyses that may be undertaken in the future by local stakeholder groups if they develop Local SNMPs.

As envisioned by CV-SALTS, the phases of SNMP development in the Central Valley include the following:

- Phase I – Initial Conceptual Model: The goal of the ICM is to produce a 30,000 foot '*concept level'* analysis of water balance and to estimate salt and nitrate load balances for the Central Valley floor in 22 areas of analysis that, for purposes of the ICM, are referred to as Initial Analysis Zones (IAZs).
- Phase II - Development of the Draft SNMP: Phase II will utilize the data collected and/or organized as well as the methods and results developed as a part of the ICM. The Phase II SNMP will provide refined spatial detail in some locations for the water balance, salt, and nitrate modeling of the Central Valley floor. This phase will also be informed by the work that is completed under ICM Task 7, the prototype "proof of concept" analyses of the Stanislaus/Merced area and Kings Subbasin.
- Phase III – Regulatory Approval Process: During Phase III the SNMP will be finalized and the documents that are necessary for the regulatory approval process for the adoption of the SNMP will be developed and submitted as a part of the BPA. This will include the development of the California Environmental Quality Act (CEQA) equivalent

[1] http://www.swrcb.ca.gov/water_issues/programs/water_recycling_policy/docs/recycledwaterpolicy_approved.pdf

[2] The LWA Team consists of the following firms: Larry Walker Associates, Luhdorff and Scalmanini Consulting Engineers, Kennedy/Jenks Consultants, PlanTierra, Systech Water Resources, and Carollo Engineers.

documents, the economic analysis of implementation alternatives, an antidegradation analysis, and the proposed BPA and staff report[3].

- Development of the Local SNMPs: It is anticipated that, upon completion of Phase III and the adoption of the comprehensive SNMP, local-scale SNMPs (Local SNMPs) may be developed and implemented by local and/or regional entities as needed. The Local SNMPs will be informed by prototype and archetype methods as well as the implementation measures recommended in the SNMP.

Below are brief summaries of the key points presented in each of the sections of this Report. The corresponding section number of the report is also provided as a reference.

INTRODUCTION (SECTION 1)

The *Initial Conceptual Model (ICM) Technical Services Workplan* (Workplan) describes the approach, milestones, and deliverables that were completed as a part of the ICM (Phase I) work effort. The completion of the Workplan satisfied the requirements of Task 1, the development of a Project Management Plan, and Task 2, the development of the Workplan.

Project Management Plan

The LWA Team developed and implemented a comprehensive Project Management Plan for implementation of the ICM Workplan to establish and maintain a clear focus on the work effort, communicate progress on necessary technical information, receive early feedback from CV-SALTS stakeholders, and apply that input most effectively.

One key aspect of the project management approach was the establishment of the CV-SALTS ICM Project Committee (PC) and the coordination between the PC and the Technical Advisory Committee (TAC). The CV-SALTS Executive Committee established the PC and delegated the authority necessary so that the PC could provide early review for and approve key work products. Throughout the duration of the project and in conjunction with the various deliverables, the LWA Team coordinated with the PC to discuss and receive early feedback on the interim work products.

ICM Workplan

The key tasks in the ICM Workplan include:

- Task 3 Data Development[4,5] - The primary purpose of Task 3 was to assemble information to be used in the preparation of the ICM.

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[3] For the purposes of this Report, Phase III includes the following items from the CV-SALTS Workplan budget: Phase III (surveillance and implementation 13242, economic analysis, antidegradation analysis) and Documentation Basin Plan Amendment (CEQA equivalent SED and Basin Plan Staff Report, Final SNMP documentation and changes).

[4] *Initial Conceptual Model – Task 3.2:Data Source List Technical Memorandum*, October 3, 2012

- Task 4 Initial Analysis Zones and Phase II Recommendations (December 2012) – This document[6] describes the approach and basis for the hydrologically based IAZs, the approach for IAZs and Management Zones (MZs) for the Phase II Draft SNMP, and options for local and regional entities for delineating MZs for future Local SNMPs.
- Task 5 Recommended Methodologies to Assess Water, Salt, and Nitrate Balances for the Central Valley Floor and Two Prototype Areas (January 2013) – This document describes the methodologies that were used to implement ICM Task 6. The methodologies were used to determine, on a *concept level*, the flow and balance of groundwater, surface water, salt, and nitrate over a 20-year evaluation period for the Central Valley floor[7].
- Task 6 Complete ICM-Concept Level Water Balances and Salt and Nitrate Analyses for Central Valley – Using the methodology defined in Task 5, perform a high-level (coarse analysis on a large scale) analysis of salt and nitrate conditions throughout the Central Valley floor. The methodologies provide the foundation and methods that may be applied to the Phase II Draft SNMP (see Section 10).
- Task 7 Prototype Salt and Nitrate Analyses in Selected Subareas of the Central Valley – Using the methodology defined in Task 5, characterize salt and nitrate at a finer spatial scale than Task 6. The prototypes provide the foundation and methods that may be applied to the Phase II Draft SNMP and/or the Local SNMPs (see Section 10).

IAZ SCALE FOR SURFACE WATER AND GROUNDWATER, SALT, AND NITRATE BALANCE (SECTION 2)

This section describes the basis of the IAZ delineation for the ICM technical analyses.

The CV-SALTS Technical Advisory Committee (TAC) strongly recommended that the ICM work effort use the 2009 Central Valley Hydrologic Model (CVHM) developed by the United States Geological Survey (USGS) as the basis for water balance determinations in the ICM effort. In the CVHM model, USGS defines 21 areas in the Central Valley floor as "water balance subregions". The determination was made to use these 21 areas as the boundaries for ICM IAZs. In response to early discussions with the CV-SALTS TAC Co-Chair, Dr. Nigel Quinn, the CVHM Delta-Mendota Basin was subdivided, so 22 IAZs were ultimately used for the ICM technical analyses.

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[5] *Initial Conceptual Model – Task 3.3 & 3.4: Data Summary and Data Gaps Technical Memorandum*, December 18, 2012

[6] *Initial Conceptual Model Technical Services – Task 4 – Initial Analysis Zones & Phase II Recommendations* Report, December 2012

[7] *Initial Conceptual Model Technical Services – Task 5 – Recommended Methodologies to Assess Water, Salt, and Nitrate Balances for the Central Valley Floor and Two Prototype Areas* Report, December 2012 [Incorporation of addendum January 2013]

The areal dimensions of the 22 IAZs are hydrologically based and directly related to the model structure of the 2009 CVHM model and corresponding water balance regions used by the California Department of Water Resources (DWR). DWR has compiled substantial information on water deliveries and diversions for subregions of the Central Valley floor and has subsequently used these subregions as water supply planning areas. DWR's efforts and contribution toward understanding the hydrology of the Central Valley floor were recognized by the USGS and incorporated in the 2009 CVHM model.

Because the vertical dimensions of the IAZs are significant to the water, salt, and nitrate analyses that have been conducted as part of ICM Task 6, this section describes the approach used to define the depth of the upper part of the aquifer system beneath each IAZ. The water, salt, and nitrate balance calculations are performed for a 20-year time period. To estimate the groundwater affected by activities over a 20-year time period, the vertical travel distance must be calculated. The vertical distance represents the distance that the water, at the water table, would travel downward or upward over a 20-year period. This defines the "shallow" portion of the subsurface where the ICM analysis is performed.

DATA SUMMARY AND DATA GAPS (SECTION 3)

There are three major categories of data that were compiled to complete the salt and nitrate balance calculations.

- Groundwater Quality
- Surface Water Quality
- Inputs for Mass Loading Estimates

These three major categories represent much of the data collection effort needed for calculating salt and nitrate balances. Collection efforts focused on the 20-year time period that would be used during simulation (1983–2003).

Groundwater quality data were collected for the entirety of the Central Valley Region 5 District boundary for chloride, nitrate [as Nitrogen (N)], Electrical Conductivity (EC)[8], and Total Dissolved Solids (TDS). Spatial data gaps for an IAZ were determined visually by identifying areas containing few or no wells or areas with comparatively low densities of wells. Temporal data gaps were identified if there were less than 100 wells in an IAZ for a particular decade between 1980 and 2012.

Surface water quality data within the study area were compiled for TDS (or EC as an analog), chloride, and nitrate (as N). In areas of the Watershed Analysis Risk Management Framework (WARMF)[9] model coverage, surface water quality data for the constituents were available from

[8] EC data were collected and transformed to TDS using the ratio TDS = EC*0.64 for wells without TDS data (Metcalf and Eddy, Inc. 1991).

[9] *User's Guide to WARMF: Documentation of Graphical User Interface*, Electric Power Research Institute (EPRI), Final Report October 2000 [Revised July 2001]. Prepared by Joel Herr, Laura Weintraub, Carl W. Chen, Systech Engineering, Inc.

WARMF databases. Where no WARMF model coverage existed, surface water quality data were compiled from public databases.

Mass loading estimates were made using WARMF model outputs. Mass loading is highly dependent upon land cover. Irrigation water is an important source of salt and nitrate. The amounts applied to the land in irrigation water depend on the water source but are also directly proportional to the amount of water applied, which depends on the needs of the crop. Significant land areas in the Central Valley are natural land covers, fallow land, and impervious areas that do not require irrigation at all. The nitrogen land application rate is also highly dependent on the crop or land use and is a significant source of nitrate.

The ICM Workplan stipulated that existing (and no new) WARMF model runs would be employed. These runs were developed during modeling efforts funded by previous projects, and their use is a technical and budgetary efficiency for the current project. Although most inputs remained unaltered, substantial changes to certain inputs were developed for the purposes of this project, and new runs were executed for every existing WARMF model. Land cover, whether agricultural, urban, commercial/industrial, or “natural” (e.g., grasslands, forests) is categorized into around 30 classes (depending on the area) in the WARMF model runs that were employed.

Amounts of irrigation water, solid salts (amendments and fertilizers), and nitrogen (as inorganic or organic fertilizer) are parameters associated with each land cover class, and were determined as part of WARMF model development as part of previous projects. Revision of these pre-existing WARMF models was generally beyond the scope of this work; however, some work was done on selected parameters:

- Nitrogen fertilization and uptake inputs were reviewed in light of new data sets (Rosenstock, 2013 and Harter, T. 2013 personal communication). WARMF models were re-run with these revised inputs, and outputs from these runs were employed for this project.
- WARMF model outputs were post-processed to examine mixing model sensitivity to salt and nitrate loading rates.

WARMF model loading estimates also included inputs from atmospheric deposition and point source discharges to land and to surface waters.

METHODOLOGY FOR ICM INPUTS TO THE WATER, SALT, AND NITRATE BALANCE CALCULATIONS (SECTION 4)

This section discusses the methodology employed for the ICM IAZ analysis of water, salt, and nitrate for the Central Valley floor. Steps taken to perform the water, salt, and nitrate balance calculations are detailed, along with the description and population of the data decision matrix for determining the suitability of the available data for the purpose of the balance calculations. The methodology has previously been documented in the Task 5 Report, which is summarized in this section. Additional or supplemental descriptions of methodologies employed to estimate ambient groundwater quality, surface water quality, and mass loadings for groundwater recharge are also included in this section.

The methodology for determining the ambient salt and nitrate concentrations attempts to overcome the limitations and biases in the datasets.

- For the groundwater dataset, well construction or well use information is used to separate data into distinct vertical zones.
- Methods to de-cluster groundwater quality data are utilized to ensure that summary statistics over the region will not be skewed by high data densities and better reflect ambient conditions for the region.
- The methodologies for determining ambient surface water quality include a) using information from WARMF models (where coverage exists) and b) using data from representative surface water monitoring sites where WARMF model coverage does not currently exist.
- Volumetric components of water movement within and between IAZs are developed from the hydrology of the USGS-calibrated CVHM model output.

APPORTIONING MECHANISMS (SECTION 5)

This section describes the rationale and methodology for apportionment of mass fluxes[10] of salts and nitrates in WARMF and non-WARMF coverage areas.

Development of the ICM required a determination of the flow and water quality of groundwater recharge and interactions between groundwater and surface water throughout the Central Valley. The model being employed to determine the flows is CVHM model, a groundwater flow model whose domain includes the entire Central Valley floor. Since the CVHM does not simulate water quality, external means are required to determine the concentration and mass fluxes of nitrate and TDS associated with the CVHM model flows.

The WARMF model simulates flow and water quality in surface waters and in the near-surface groundwater zone which interacts with surface water. Its model domain includes much of the Central Valley so it provides a spatially detailed source of water quality information which can be combined with the CVHM model flows in the ICM. The assumptions and hydrologic calibration of the models differ, however, so care must be taken when linking the water quality from WARMF models with the hydrology of the CVHM model.

Since the CVHM model hydrology served as the basis for the IAZ simulations, the hydrology associated with the mass fluxes calculated by the WARMF models had to be considered to ensure that overlap and double counting of mass inputs did not occur. The fluxes calculated by WARMF also needed to be reapportioned among the flow pathways based on CVHM components. CVHM contains significant groundwater recharge as part of the water budget for all IAZs; WARMF has less recharge in some IAZs and does not include recharge in others. This imbalance was found to affect the mass loading apportioned by WARMF for input to the initial simulations; as a result, mass loading for many IAZs was initially underestimated. CVHM is a

[10] The rate of flow of fluid.

calibrated groundwater flow model, whereas WARMF achieves mass balance across a watershed domain based on calibrations using surface water data.

WATER, SALT, AND NITRATE BALANCE CALCULATION METHODOLOGY (SECTION 6)

This section describes the methods used to format data and perform calculations within the databases developed for the ICM.

Due to the large amount of information and interworking nature of a mixing model on the scale of the entire Central Valley floor, a simple spreadsheet model would not adequately perform the necessary water, salt, and nitrate balance calculations. Essentially all of the mass loadings (from WARMF or non-WARMF interpolation), CVHM water budget time series volumes, and time series of ambient surface water and groundwater quality data are housed inside numerous databases[11]. Hundreds of complicated queries are performed on the data to add or subtract volumes and masses of salt and nitrate (sometimes using concentrations with volumes to yield mass values) for each IAZ on a quarterly basis for a 20-year time period between 1983 and 2003. This methodology enables the calculation of water and mass movement simultaneously between each IAZ for the entirety of the Central Valley floor.

WATER, SALT, AND NITRATE BALANCE CALCULATION RESULTS (SECTION 7)

In this section, the results of the water, salt, and nitrate balances for the 22 IAZs (as described in earlier sections) are presented. This includes:

- The results of the groundwater flow budget
- The results of the net mass fluxes into and out of shallow groundwater
- Evaluations of ambient water quality conditions.

The ambient and simulated conditions are combined to rank the IAZs relative to one another in terms of their priority for future study. IAZs with higher ambient and simulated concentrations for shallow groundwater are ranked at a higher priority as compared to IAZs that have lower concentrations. Following the prioritization of IAZs, preliminary assimilative capacities are estimated for each IAZ, based on calculated ambient conditions using the multiple simulations that were performed for nitrate and TDS[12].

Considerable variability exists in shallow groundwater, both in time and space. The analyses presented at the IAZ scale are not adequate to facilitate salt and nitrate management planning at a local or site-specific facility scale. IAZs that appear to have no assimilative capacity when analyzed over the entire region may indeed have areas within the IAZ with higher quality

[11] As described in Section 8.2.1, the LWA Team ran a sensitivity analysis to evaluate sources of uncertainty in the mixing model results. The sensitivity analysis was conducted for six (6) nitrate loading scenarios using various adjustments to the nitrogen application and uptake parameters and three (3) salinity loading scenarios.

[12] See Section 7 for a definition of assimilative capacity and more detailed discussion of computations related to the ICM.

groundwater where there may be some level of assimilative capacity. Similarly, IAZs that appear to have a large assimilative capacity as a whole likely contain areas where shallow groundwater has less assimilative capacity at the local scale (e.g., localized hot spots for TDS or nitrate).

It should also be stressed that any apparent trends indicated at the IAZ scale may be influenced by the limited data that are currently available. In most IAZs, the addition of a few dozen analyses from new wells could change the trend significantly. In order to perform adequate salt and nutrient management at a practical (local) scale, datasets should be supplemented with additional data that may not be readily available from the large statewide databases. For regions where shallow groundwater data are lacking, local entities such as water quality coalitions, irrigation districts, and county health departments may have collected data that have not been included in statewide databases.

UNCERTAINTY (OR SENSITIVITY) ANALYSIS (SECTION 8)

This section describes the evaluation of uncertainty in the ICM analytical effort.

The objective of uncertainty analysis is to determine the effect of errors in ICM inputs and formulation on the results of the ICM. Sources of error include uncertainty of model inputs, errors introduced by the assumptions of the WARMF and CVHM models, and errors in the linkage of the two models. There are thousands of model inputs, but in most cases uncertainty in these inputs has little effect on the ICM results so they do not need to be included in a sensitivity analysis. Sensitivity analysis is an important tool to evaluate the effect of uncertainty in key model inputs. Errors in model representation of actual conditions are minimized by calibration but remain a significant source of error. The linkage between the WARMF and CVHM models creates a novel usage of both models, and the error introduced by this linkage is difficult to quantify but can be described.

As part of the sensitivity analysis that was performed, initial mixing model results were reviewed by the team. In some areas, trends matched observed shallow groundwater quality reasonably well. In other areas, trends appeared quite different. In evaluating sources of uncertainty that could lead to these mismatches, the team identified salt and nitrogen loading rates as predominant.[13] The general approach to the sensitivity analysis was to post-process mixing model inputs for each IAZ, adjusting them in proportion to alterations in fertilizer or salinity loading parameters. The nature of loading parameter alterations, and the manner in which they were translated into alternative sets of mixing model inputs, are described in this section.

In future work phases, priority areas for reducing uncertainty should be identified and addressed. The approach taken here of bracketing uncertain factors by developing varied mass loading scenarios was instructive, and may again prove helpful for factors that remain uncertain (such as variability in actual farming practices).

[13] The WARMF Peer Review Report (Keller 2000) reported that the simulations were generally moderately sensitive to land application rates, but WARMF flux output indicated that land application was generally the largest source of nitrate in Central Valley watersheds.

Factors that could be addressed mainly by providing time and budget to refine tools include the following, noting the timeframes needed to address each:

- Refinement of applied water quality estimates, especially for non-WARMF areas (short);
- Expansion of WARMF modeling throughout the study area (moderate);
- Developing a unified model to handle hydrology and water quality, retaining the best aspects of the CVHM and WARMF models (long); and
- Incorporation of soils (short) and irrigation (moderate) factors into modeling.

Factors that might require non-technical, supporting processes include the following:

- Improvement of data on actual fertilizer and amendment application (long); and
- Development of more current land cover class data, especially for areas thought to be changing rapidly (moderate).

PROTOTYPE AREAS (SECTION 9)

Two prototype areas were selected by CV-SALTS for further refinement. The prototype area analyses served to evaluate the "proof of concept" of the employed tools. The Merced/Stanislaus County area and the Kings Subbasin were identified as areas of interest to develop templates for data analysis methods and modeling tools to characterize water, salt, and nitrate balances, including accumulation and depletion, on a more spatially refined level compared to the IAZ-scale for the ICM. The purpose of these analyses is to provide potential tools to be employed on a level more detailed than the IAZ level, in which management decisions may be based on.

Key findings and results from Task 7 are listed below.

- <u>GIS Mapping Techniques were used to Categorize Zones</u>
    - GIS mapping techniques were used to categorize zones where the groundwater is considered to be of high quality (low concentrations of salt and nitrate), low quality (high concentrations of salt and/or nitrate), and moderate quality. The mapping included depictions of higher to lower quality in the relatively shallower part of the aquifer system and the relatively deeper part of the aquifer system, as available.
- <u>Ambient Groundwater Quality Was Established</u>
    - In the Modesto area, ambient groundwater quality was established using well test data from wells classified as shallow.
    - In the Kings Subbasin, ambient groundwater quality was established for model Layers 1-2, 3, and 6-10 based on well types and, when available, well depths (Layers 4-5 were placeholders for the Corcoran Clay).
- <u>The Two Different Approaches</u> to Evaluating Salt and Nitrate Concentrations and Subsurface Transport
    - <u>Modesto Regional Model</u>: The approach for this model application was to simulate the concentration of water quality within observation wells using

recharge concentrations. This model had an advantage of faster computation time because of its steady state construction. This meant that the movement of particles could be simulated either forward or backward in time for an infinite amount of time. Computation times were relatively shorter for the Modesto Regional Model because there were significantly less particles to be managed during the analysis compared to the Kings Subbasin. MODPATH and then MODPATH-OBS were used to send particles back in time from an observation well to their recharge surface where concentration data was assigned.

  - Kings Subbasin: The CVHM model is a transient model with monthly stress periods for a total of 42.5 years of simulation. The methodology for this prototype area utilizes the last 20-years of the CVHM simulation (1983 to 2003). Observations of groundwater quality were made on an annual basis at each cell of the model cells, using particles in MODPATH and a post-processing alternative to MODPATH-OBS, to simulate the movement of mass loading and subsurface movement of salt and nitrate over time.

- The Simulation Results were Evaluated

  - The Modesto Regional Model simulation results were compared to measured concentrations. The simulated NO_3-N concentrations were low compared to the measured NO_3-N concentrations in the USGS observation wells. The simulated TDS concentrations compared better to the measured TDS concentrations in the USGS observation wells.

  - The Kings Subbasin simulation results illustrated that this “proof of concept” approach can be used to illustrate and quantify the concentration of salt and nitrate in groundwater and identify areas where concentrations are increasing, decreasing, or remaining stable. It was learned that this approach was limited by the transient nature of the CVHM model, which constrains the distance water can move and transport salt and nitrate. Future local area model simulations would benefit from a model that allows for a sufficiently long simulation period.

- Preliminary Assimilative Capacities Were Developed Based on Ambient Shallow Groundwater Quality Data

  - Preliminary assimilative capacity analyses were developed for the Modesto area based on shallow ambient groundwater quality data, which was analyzed on a much finer resolution than for the IAZ scale.

  - Preliminary assimilative capacity analyses were also developed for the Kings Subbasin based on shallow ambient groundwater quality data; similar to the Modesto area, this area was analyzed on a much finer resolution than for the IAZ scale.

The results for the assimilative capacities at the finer resolution were found to be quite different than those estimated for an entire IAZ. Considerable variability exists in the water quality (and therefore the assimilative capacity of that defined area) within an IAZ. The results showed that there can be areas that have no assimilative capacity, while there may also be areas that have greater assimilative capacity compared to the IAZ as a whole.

SUMMARY OF PHASE I FOUNDATIONAL WORK AND RECOMMENDATIONS FOR PHASE II (SECTION 10)

The purpose of this section is to identify what the required elements of the SNMP are, describe how CV-SALTS is phasing the development of the necessary SNMP elements, summarize the key findings from the Phase I - ICM work effort, and provide recommendations for Phase II – the development of the initial draft Central Valley SNMP so that it meets the Recycled Water Policy requirements.

It is important to recognize that the effort undertaken during the development of the ICM is the first time that water quality (salt and nitrate) and quantity (surface water and groundwater, including their interaction) has been simulated for the entirety of the Central Valley floor. It is also important to recognize the benefits and limitations of simulations made at this aggregated or coarser IAZ scale. For example, any apparent trends indicated at the IAZ scale are subject to change based on the limited data that are available. In most IAZs, the addition of a few dozen well tests from new wells has the possibility to change an analysis significantly. In order to perform adequate salt and nutrient management at a practical (local) scale, datasets should be supplemented with additional data that may not be readily available from public databases.

As part of the ICM, two approaches were used to assess salt and nitrate sources, trends, and transport in the Central Valley.

- One approach, the 30,000 foot conceptual approach (Task 6), examined the salt and nitrate loading and transport mechanisms on the scale of the entire Central Valley floor. Twenty-two IAZs were evaluated to assess salt and nitrate accumulation, depletion, or stable trends in surface water and groundwater over a 20-year period for each IAZ as well as transport between IAZs (**Figure ES 1** and **Table ES 1**).
- The other approach (Task 7) examined two prototype areas, the Merced/Stanislaus County area and the Kings Subbasin that were identified as areas of interest by CV-SALTS, to develop templates for data analysis methods and modeling tools to characterize water, salt, and nitrate balances, including accumulation and depletion, on a more spatially refined level compared to the IAZ-scale (**Figure ES 1**).

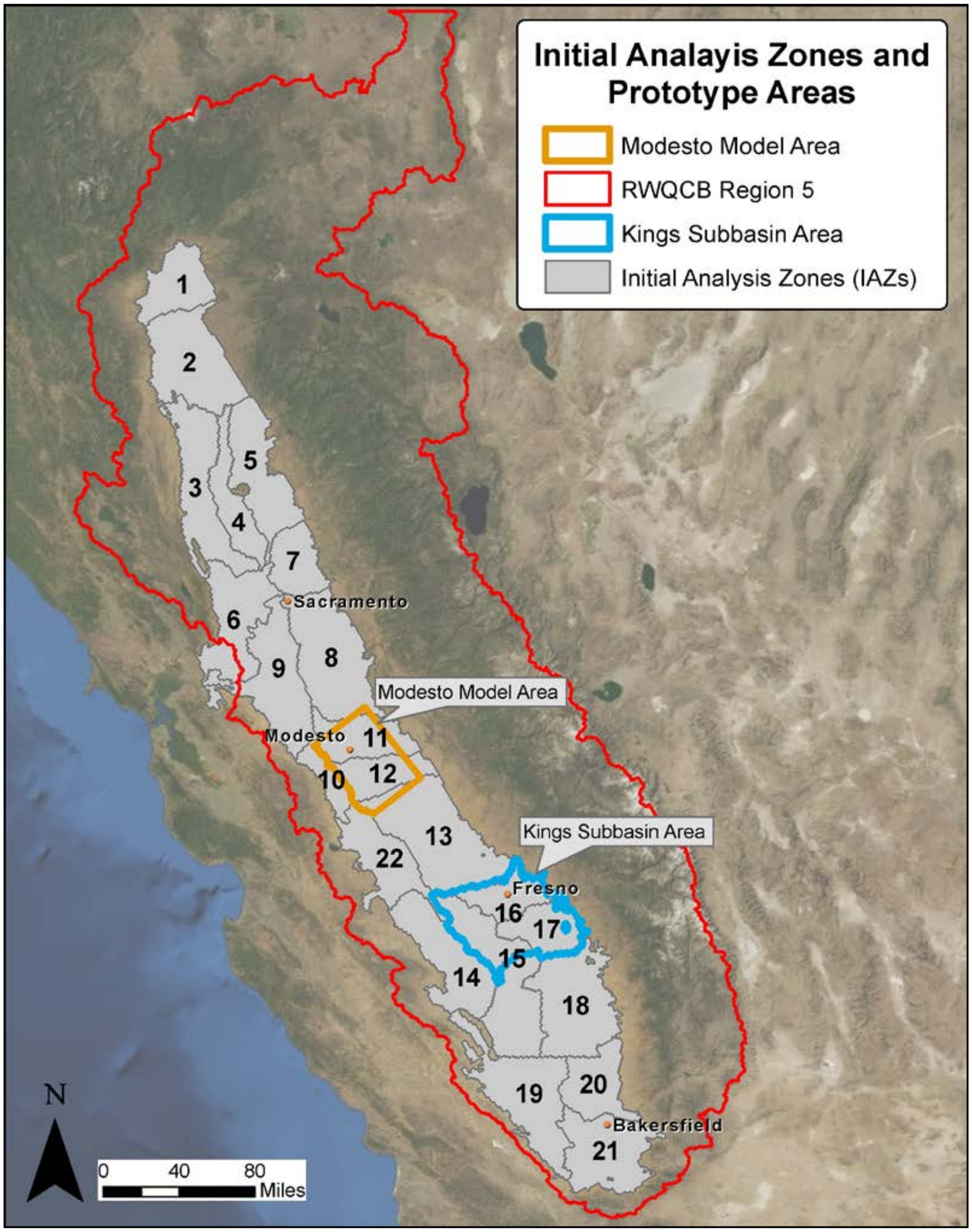

Figure ES 1. Initial Analysis Zones and Prototype Areas

Table ES 1. IAZ Descriptions

	IAZ	Initial Analysis Zone Description
Northern Central Valley	**1**	Sacramento River above Red Bluff
	2	Red Bluff to Chico Landing
	3	Colusa Trough
	4	Chico Landing to Knights Landing proximal to the Sacramento River
	5	Eastern Sacramento Valley foothills near Sutter Buttes
	6	Cache-Putah area
	7	East of Feather and South of Yuba Rivers
Middle Central Valley	**8**	Valley floor east of the Delta
	9	Delta
	10	Delta-Mendota Basin - Northwest Side
	11	Modesto and southern Eastern San Joaquin Basin
	12	Turlock Basin
	13	Merced, Chowchilla, and Madera Basins
	22	Delta-Mendota Basin - Grassland
Southern Central Valley	**14**	Westside and Northern Pleasant Valley Basins
	15	Tulare Lake and Western Kings Basin
	16	Northern Kings Basin
	17	Southern Kings Basin
	18	Kaweah and Tule Basins
	19	Western Kern County and Southern Pleasant Valley Basin
	20	Northeastern Kern County Basin
	21	Southeastern Kern County Basin

Key findings and outcomes derived from the IAZ-scale and spatially-refined prototype scale are summarized below.

- The available groundwater quality data were generally adequate for purposes of the ICM.
- The IAZ-scale analysis shows areas where NO_3-N and TDS/EC are accumulating in the Central Valley.
- TDS shows the most definitive pattern of transport across the Central Valley. Specifically, the salt load to groundwater increases in a southerly direction in the Central Valley.
- On an IAZ-scale, preliminary analyses show relatively less available assimilative capacity with respect to NO_3-N.
  - Nitrate: 4 IAZs exceed the NO_3-N MCL threshold of 10 mg/L, including:
    - IAZ 12 (Turlock Basin)
    - IAZs 16 and 17 (Kings Subbasin)
    - IAZ 18 (Kaweah and Tule Basins)
  - TDS[14]: Most IAZs exceed the assimilative capacity for the 500 mg/L threshold (IAZs 3, 4, 6, 9-20, and 22); 5 IAZs exceeding the 1,000 mg/L TDS threshold, include:
    - IAZ 6 (Cache-Putah area)
    - IAZ 22 (Delta-Mendota Basin/Grassland area)
    - IAZ 14 (Westside and Northern Pleasant Valley Basins)
    - IAZ 15 (Tulare Lake and Western Kings Basin)
    - IAZ 19 (Western Kern County and Southern Pleasant Valley Basin)
- In future work phases, priority areas for reducing uncertainty should be identified and addressed. Factors that could be addressed include the following:
  - Refinement of applied water quality estimates, especially for non-WARMF areas.
  - Incorporation of soils characteristics and irrigation factors into future modeling efforts.
  - Improvement of data on actual fertilizer and amendment application.

The SNMP will be the salt/nitrate management plan adopted for the entire Central Valley Regional Board jurisdiction. The SNMP will utilize information from the Phase I work and

[14] Since groundwater basins do not have water quality objectives by basin, three threshold levels (500 mg/L, 700 mg/L and 1000 mg/L) were used to show the range of impacts if a certain standard were in effect.

supplements that information with additional work performed under Phases II and III. While the Phase I work completed the analyses at the IAZ-scale for the Central Valley floor and tested prototype tools for two subareas with refined spatial analysis, additional work is necessary during Phase II.This work includes developing the background information, refining the analyses in prioritized and/or archetype areas, and/or to developing the approach/methods that are necessary for the various components of the SNMP.

The following technical tasks are recommended to address SNMP requirements:

- Task 1 – Background section of the SNMP
- Task 2 – Goals and Objectives for Water Recycling and Stormwater Recharge/Use
- Task 3 – Salt and Nitrate Characterization - Source Identification and Loading Estimates
- Task 4 – Salt and Nitrate Characterization - Assimilative Capacity
- Task 5 – Implementation Measures
- Task 6 – Monitoring Plan
- Task 7 – Antidegradation Analysis
- Task 8 – Prepare SNMP Guidance with Details Applicable to Higher Spatial Resolution Level of Analysis

It is also recommended that the work effort include the following tasks to support/complement other ongoing CV-SALTS work efforts. These tasks will provide essential information for the development and evaluation of proposed policy changes and policy language to be incorporated in the Central Valley Basin Plans.

- Task 9 – Strategic Salt Accumulation Land and Transport Study (SSALTS)
- Task 10 – Crop Sensitivity Tools (GIS Task 5)
- Task 11 – CV-SALTS Policy Initiatives

These recommended tasks are explained in Section 10.

1. Introduction

Consistent with the Recycled Water Policy[15] for the State of California, the Central Valley Salinity Alternatives for Long Term Sustainability (CV-SALTS) is developing a comprehensive Salt and Nitrate Management Plan (SNMP) for the Central Valley Regional Water Quality Control Board's jurisdictional boundaries. The SNMP will identify the approach and establish the basis for the short and long-term management of salt and nitrate in the Central Valley region.

The Initial Conceptual Model (ICM) is the first of several phases of work that needs to be completed in order to develop the first draft of the Central Valley SNMP by May 2014 (**Figure 1-1**). The Phase I ICM, which was developed by the Larry Walker Associates (LWA) Team[16] in a collaborative setting with stakeholders and regulatory and partner agencies, forms the foundation for the subsequent phases of necessary work (Phases II and III). The knowledge base, technical analyses, and associated documentation that are developed as a part of the SNMP will form the basis for corresponding amendments to the Water Quality Control Plans for the Sacramento/San Joaquin Basin and Tulare Lake Basin (Basin Plan Amendments or BPAs) by approximately May 2016. The ICM work effort will also be foundational for the more detailed, sub-regional analyses that may be undertaken in the future by local stakeholder groups if they develop Local SNMPs.

The development of the Phase I ICM has been on a critical path since Phase II of the SNMP could not be initiated until the ICM work was completed. The relationship of the Phase I ICM work to the future phases of the development of the SNMP is summarized below and further illustrated in **Figure 1-2**:

- Phase I – Initial Conceptual Model: The goal of the ICM is to produce a 30,000 foot level, 'c*oncept level'* analysis of water balance and to estimate salt and nitrate load balances for the Central Valley floor in 22 areas of analysis that, for purposes of the ICM, are referred to as Initial Analysis Zones (IAZs).
- Phase II - Development of Draft SNMP: Phase II will utilize the data collected and/or organized as well as the methods and results developed as a part of the ICM. The Phase II Draft SNMP will provide refined spatial detail in some locations for the water balance, salt, and nitrate modeling of the Central Valley floor, as represented by the mid-size puzzle pieces. This phase will also be informed by the work that is completed under ICM Task 7, the prototype "proof of concept" analyses of the Stanislaus/Merced area and Kings Subbasin.
- Phase III – Regulatory Approval Process: During Phase III the SNMP will be finalized and the documents that are necessary for the regulatory approval process for the adoption

[15] http://www.swrcb.ca.gov/water_issues/programs/water_recycling_policy/docs/recycledwaterpolicy_approved.pdf

[16] The LWA Team consists of the following firms: Larry Walker Associates, Luhdorff and Scalmanini Consulting Engineers, Kennedy/Jenks Consultants, PlanTierra, Systech Water Resources, and Carollo Engineers.

of the SNMP will be developed and submitted as a part of the BPA. This will include the development of the California Environmental Quality Act (CEQA) equivalent documents, the economic analysis of implementation alternatives, an antidegradation analysis, and the proposed BPA and staff report[17].

- Development of the Local SNMPs: It is anticipated that, upon completion of Phase III and the adoption of the comprehensive SNMP, local-scale SNMPs (Local SNMPs) may be developed and implemented by local and/or regional entities as needed. The Local SNMPs will be informed by prototype and archetype methods[18] as well as the implementation measures recommended in the SNMP.

[17] For the purposes of this Report, Phase III includes the following items from the CV-SALTS Workplan budget: Phase III (surveillance and implementation 13242, economic analysis, antidegradation analysis) and Documentation Basin Plan Amendment (CEQA equivalent SED and Basin Plan Staff Report, Final SNMP documentation and changes).

[18] "Prototype" refers to an implementation example (e.g., Task 7 salt and nitrate management subareas). "Archetype" refers to a template for completing a process (e.g., evaluate the attainability of a beneficial use). Both will inform the Central Valley SNMP and be utilized as Local SNMPs are developed.

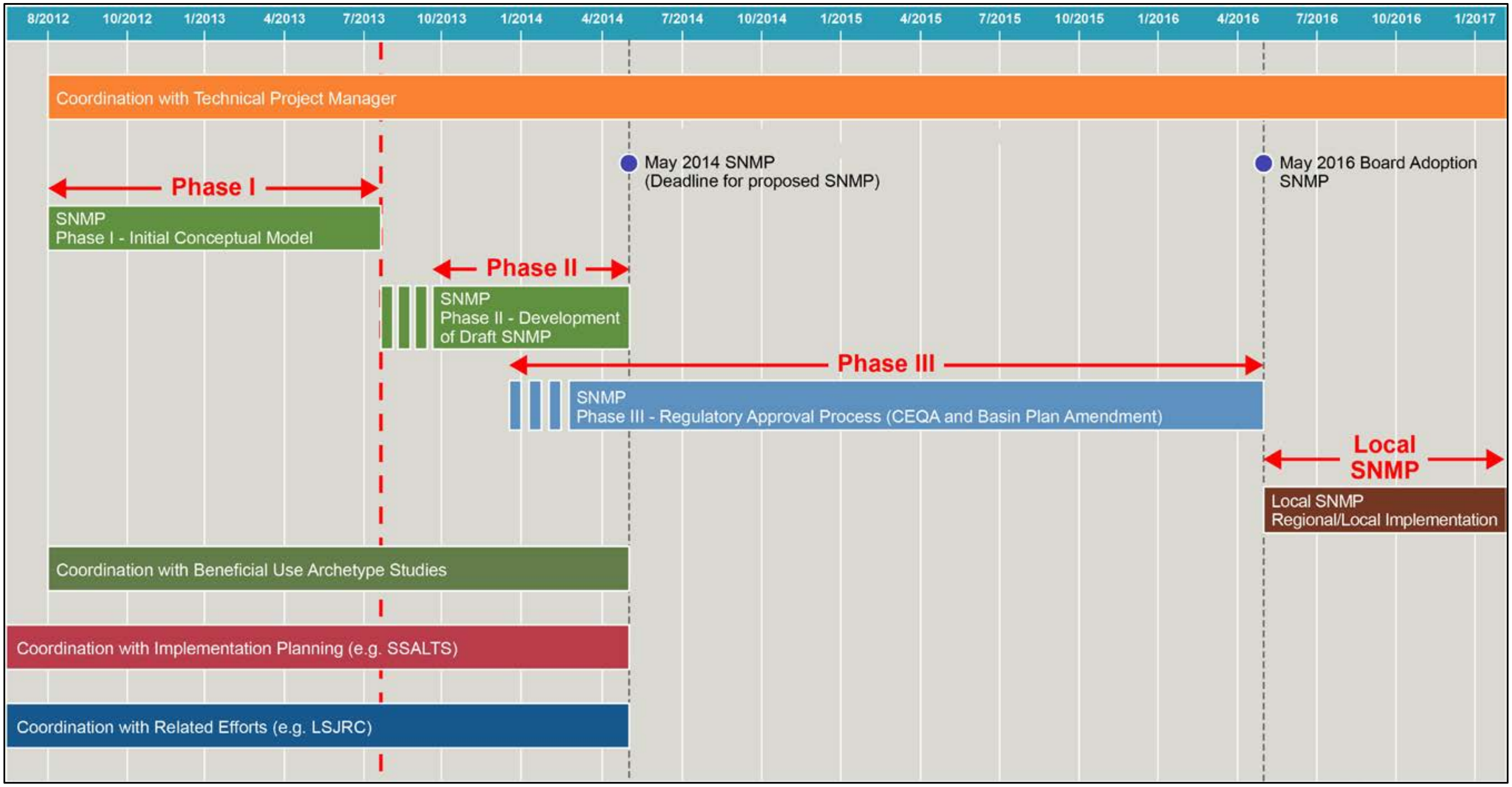

Figure 1-1. CV-SALTS Timeline for the Development of the SNMP

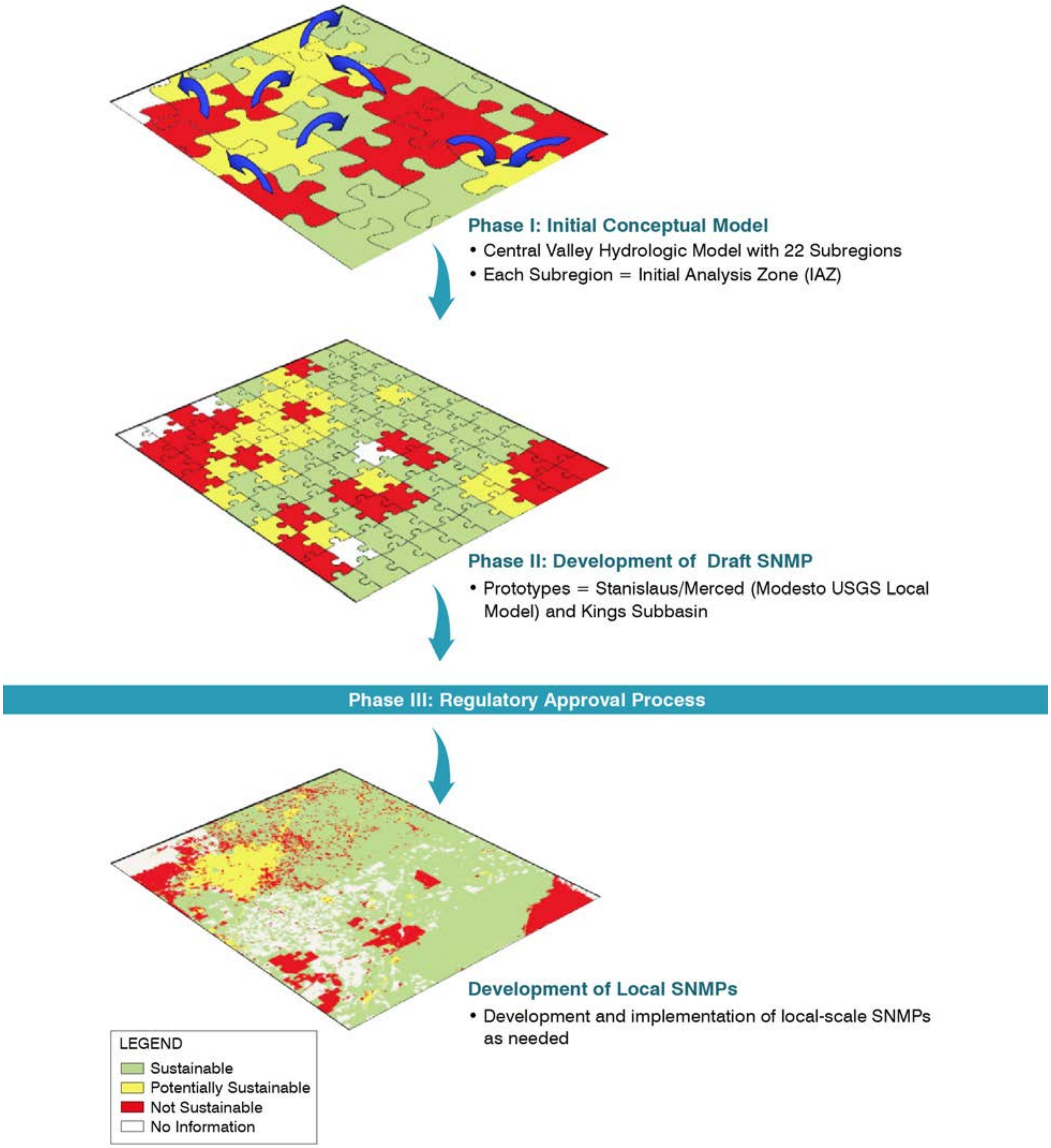

Figure 1-2. CV-SALTS Conceptual Model for the Development of the SNMP

1.1 COORDINATION WITH OTHER CV-SALTS WORK EFFORTS[19]

It is important to note that the development of the SNMP is being coordinated with and informed by other efforts being undertaken by CV-SALTS. The work efforts are identified in **Figure 1-1** and include the following:

Coordination with Beneficial Use Archetype Studies

- Tulare Lakebed Evaluation of Municipal and Domestic Beneficial Uses of Groundwater[20] – This project is developing the technical and regulatory documentation necessary to support a separate BPA for the de-designation of a portion of the Tulare Lakebed MUN beneficial use. This project is essential to evaluate the appropriate designation and level of protection for water bodies currently designated for the MUN beneficial use, taking into account the requirements of the Sources of Drinking Water Policy. Addressing the appropriateness of the MUN designation for one or more of these water bodies provides an opportunity to establish a reference archetype for making subsequent MUN determinations for other water bodies in the future. Although this project is being carried out independently from the SNMP project, the final beneficial use designations will determine what groundwater objectives will apply and, subsequently, the locations and types of management alternatives selected and implemented by the stakeholders as a part of the SNMP.
- Agriculturally Dominated Water Bodies Evaluation – This project is developing the technical and regulatory documentation necessary to support a separate BPA for the potential de-designation of the MUN beneficial use in agricultural drains. This project is essential to evaluate the appropriate designation and level of protection for water bodies currently designated for the MUN beneficial use, taking into account the requirements of the Sources of Drinking Water Policy. CV-SALTS identified receiving waters of four Publically Owned Treatment Works (POTWs - Cities of Willows, Colusa, Biggs and Live Oak) as potential archetypes (case studies) for evaluating the appropriateness of a MUN designation. Addressing the appropriateness of the MUN designation for agricultural drains provides an opportunity to establish an archetype for making subsequent MUN determinations for other water bodies in the future. Although this project is being carried out independently from the SNMP project, the final beneficial use designations will determine what objectives will apply and, subsequently, the locations

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[19] It should be noted that, as the Draft and Local SNMPs are being developed, they will need to be developed within the context of and/or be coordinated with other related efforts within the region (e.g., regulation and siting of Managed Aquifer Recharge facilities/projects, acknowledgement and/or consistency with other goal such as those set for AB-599). This is also recognized within Section 10.

[20] *Tulare Lakebed MUN Evaluation Final Workplan*, June 2012 http://www.waterboards.ca.gov/centralvalley/water_issues/salinity/tulare_lakebed_mun_evaluation/reference_docs/tulare_workplan.pdf

and types of management alternatives selected and implemented by the stakeholders as a part of the SNMP.

Coordination with Implementation Planning

- Strategic Salt Accumulation Land and Transportation Study (SSALTS)[21] – SSALTS will identify areas where salt is accumulating either intentionally or unintentionally and provide the basis for CV-SALTS policymakers to begin consideration of salt disposal solutions to achieve the SNMP requirement to sustainably manage salt in the Central Valley. Specifically, by identifying and characterizing a representative cross-section of salt management concerns, completion of SSALTS will assist CV-SALTS stakeholders to begin to envision the range of potential management alternatives to dispose of salt. Developing an understanding in this area early in the process will support efforts to develop a SNMP that is practicable and implementable.

Coordination with Related Efforts

- Geographic Information Systems (GIS) Technical Services[22] – This project will continue the development of GIS tools to organize and analyze information pertaining to the beneficial uses, water quality objectives, and water quality of surface water and groundwater in the Central Valley. This is important because a comprehensive geodatabase and efficient GIS tools are central to the utilization of these data in analyzing water, land use, and water quality information and for identifying areas of concern and assessing management alternatives for the SNMP. This project is building off of the previous Phase I Beneficial Use Objectives Study (BUOS) GIS data gathering effort and is incorporating new analyses to identify Crop Sensitivity Zones (CSZs) that might form part of the basis for interpretation of narrative water quality objectives protective of AGR (agricultural irrigation) beneficial uses.
- Lower San Joaquin River Study[23] – The goal of this project is to develop the technical and regulatory documentation necessary to support a BPA for the development of water quality objectives for salt and boron on the Lower San Joaquin River (LSJR) from the Merced River to Vernalis. This project is being carried out under the umbrella of the SNMP project, and will develop surface water quality objectives that provide reasonable protection of beneficial uses and implementation measures needed to meet those objectives. The final amendment will provide the foundation for salinity management in the LSJR and a prototype to be considered by the stakeholders as a part of the Central Valley SNMP.

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[21] *Strategic Salt Accumulation Land and Transportation Study (SSALTS) Workplan*, October 2012

[22] *Geographic Information Systems (GIS) Technical Services Workplan*, August 2012

[23] *Workplan for the Development of Water Quality Objectives for Salinity on the Lower San Joaquin River* http://cvsalinity.com/index.php/library/supporting-documents.html

1.2 DEVELOPMENT OF THE INITIAL CONCEPTUAL MODEL

The *Initial Conceptual Model (ICM) Technical Services Workplan* (Workplan) describes the approach, milestones, and deliverables to be completed as a part of the ICM work effort. The completion of the Workplan satisfied the requirements of Task 1, the development of a Project Management Plan, and Task 2, the development of the Workplan. The primary technical tasks are outlined in **Figure 1-3** and include the following:

- Task 3 Data Development - The primary purpose of Task 3 was to assemble information to be used in the preparation of the ICM. In addition, future work and data needs were considered during the development of the ICM, to the extent practicable. This was done, for example, by retaining field- or grid-level land cover data and water/salt/nitrate balances [where available in the Central Valley Hydrologic Model (CVHM) or existing Watershed Analysis Risk Management Framework[24] (WARMF) simulations], and then summing them to coarser-level elements for the IAZ evaluations. This approach sets the stage to allow future, more detailed analyses while performing the necessary aggregation as part of the ICM. The data are housed and available as a part of the *Geographic Information Services (GIS) Technical Services* data framework. The deliverables were:
    - ICM Data Source List (October 3, 2012) – This document identifies the data categories, sub-categories, and sources that were utilized for the ICM simulations. Data gaps were documented along with recommendations identifying how to work around them and/or how they may be addressed in later SNMP phases[25].
    - ICM Data Summary and Data Gaps (December 18, 2012) – This document identifies the data collected for the ICM work effort. There are 22 IAZs located in the Central Valley floor derived from the delineations in the CVHM model. However, the data collection effort was not restricted to the Valley floor. For example, groundwater quality data have been collected for the entirety of the Central Valley Regional Water Quality Control Board Region 5 jurisdiction. The data are summarized according to each IAZ to identify any data gaps[26]. The following data categories were collected as a part of the ICM:
        - Water Supply
        - Climate and Hydrology
        - Land Cover & Hydrography
        - Subsurface Characteristics
        - Applied Materials
        - Uptake and Losses
        - Point Sources
        - Nonpoint Sources

[24] *User's Guide to WARMF: Documentation of Graphical User Interface*, Electric Power Research Institute (EPRI), Final Report October 2000 [Revised July 2001]. Prepared by Joel Herr, Laura Weintraub, Carl W. Chen, Systech Engineering, Inc.

[25] *Initial Conceptual Model – Task 3.2:Data Source List* Technical Memorandum, October 3, 2012

[26] *Initial Conceptual Model – Task 3.3 & 3.4: Data Summary and Data Gaps* Technical Memorandum, December 18, 2012

- Task 4 Initial Analysis Zones and Phase II Recommendations (December 2012) – This document describes[27]:
    - o The approach and basis for the hydrologically based IAZs for purposes of the ICM;
    - o The approach for IAZs and Management Zones (MZs) for the Phase II Draft SNMP;
    - o The approach for the MZs for purposes of Local SNMPs;
    - o The focus of the ICM on the Central Valley floor and considerations relevant to the Phase II Draft SNMP and Local SNMP efforts in the entire Central Valley Regional Water Quality Control Board (Region 5) jurisdictional area;
    - o Options for local and regional entities for delineating MZs for future Local SNMPs; and
    - o Summary of recommendations.
- Task 5 Recommended Methodologies to Assess Water, Salt, and Nitrate Balances for the Central Valley Floor and Two Prototype Areas (January 2013) – This document describes the methodologies that were used to implement ICM Task 6. The methodologies were used to determine, on a *concept level*, the flow and balance of groundwater, surface water, salt, and nitrate over a 20-year evaluation period for the Central Valley floor[28]. The key tasks included the following:
    - o Develop methods to assess the data organized as part of ICM Task 3 and estimate and depict ambient surface water and groundwater quality for each of the 22 IAZs covering the Central Valley floor.
    - o Prepare a matrix that focuses on the surface water and groundwater data compiled and synthesized. The matrix included a temporal component to identify the period of available historical surface water and groundwater quality records for each IAZ. In addition, the matrix was used to assist in identifying hotspots (areas with salt and nitrate accumulation trends) as well as prioritization criteria that were used to identify high-priority areas/IAZs.
    - o Develop analysis methods and tools for calculating water, salt, and nitrate balances for surface water and groundwater.

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[27] *Initial Conceptual Model Technical Services – Task 4 – Initial Analysis Zones & Phase 2 Recommendations* Report, December 2012

[28] *Initial Conceptual Model Technical Services – Task 5 – Recommended Methodologies to Assess Water, Salt, and Nitrate Balances for the Central Valley Floor and Two Prototype Areas* Report, December 2012 [Incorporation of addendum January 2013]

- Task 6 Complete ICM- Concept Level Water Balances and Salt and Nitrate Analyses for Central Valley – Using the methodology defined in Task 5, perform a high-level (coarse analysis on a large scale) analysis of salt and nitrate conditions throughout the Central Valley floor. The methodologies provide the foundation and methods that may be applied to the Phase II Draft SNMP (see Section 10). The results of this analysis are incorporated into this Report.
- Task 7 Prototype Salt and Nitrate Analyses in Selected Subareas of the Central Valley – Using the methodology defined in Task 5, characterize salt and nitrate at a finer spatial scale than Task 6. The prototypes provide the foundation and methods that may be applied to the Phase II Draft SNMP and/or the Local SNMPs (see Section 10). The results of this analysis are incorporated into this Report.

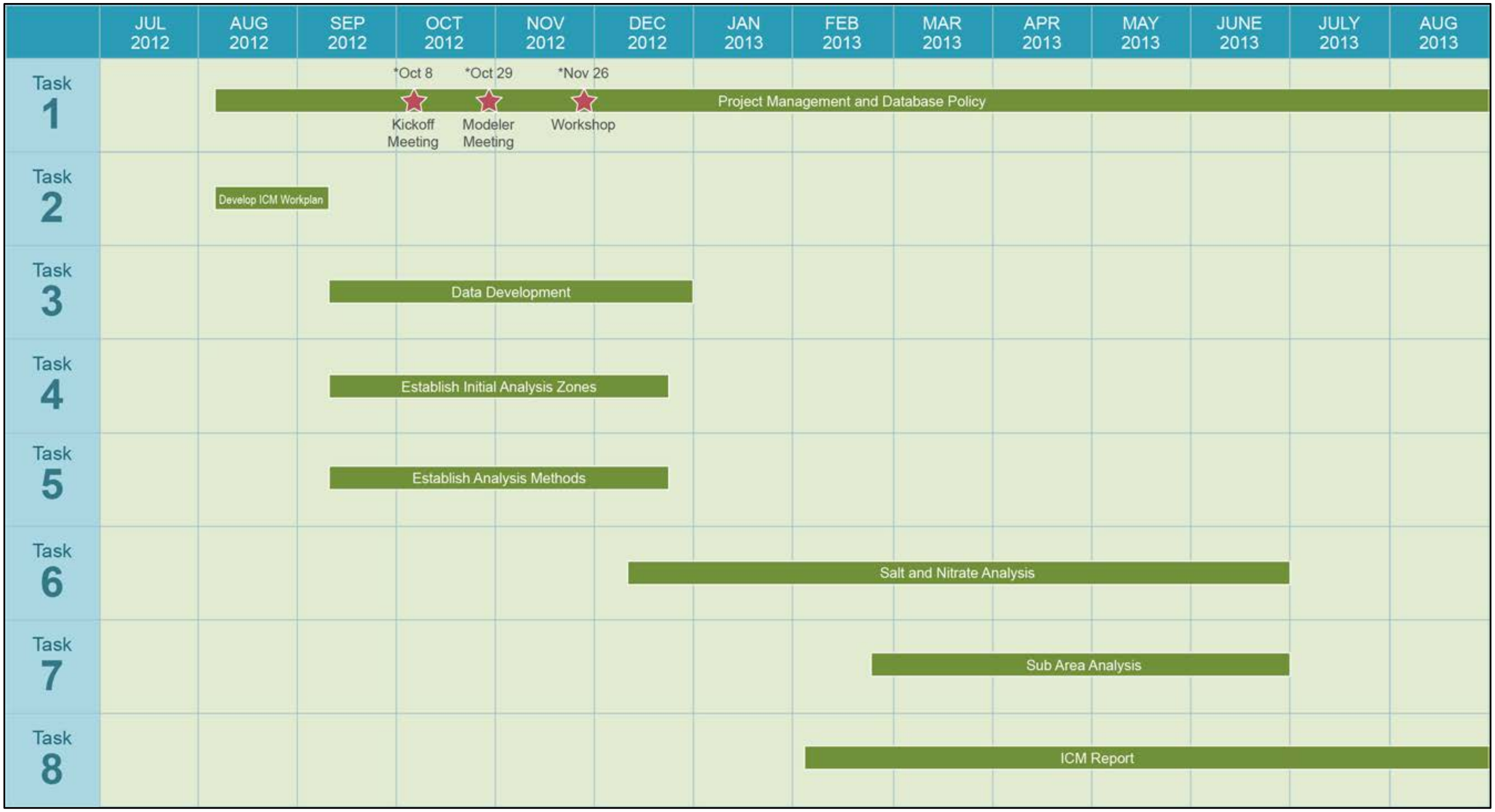


Figure 1-3. ICM Tasks and Schedule

The relationships between ICM tasks 3 through 7 include the following (**Figure 1-4**):

- The data collected from Task 3 were used as inputs to a mixing model database platform that was collectively used to assess the salt and nitrate accumulation and movement in surface and groundwater in the Central Valley floor.
- Task 4 defined the basis for the hydrologically based IAZs that would be analyzed for purposes of the ICM.
- The methodologies described in Task 5 were used to analyze the data in both Tasks 6 and 7. Task 7 involved the development of prototype templates for the data analysis methods and modeling tools to characterize water, salt, and nitrate balances, including accumulation and depletion, in greater spatial detail, in two selected subareas.
- The main goal of Task 6 was to determine which areas are accumulating, depleting, or are in balance in terms of salt and nitrate loadings on an IAZ-scale. As described in Task 4, there are 22 IAZs that were analyzed in Task 6.

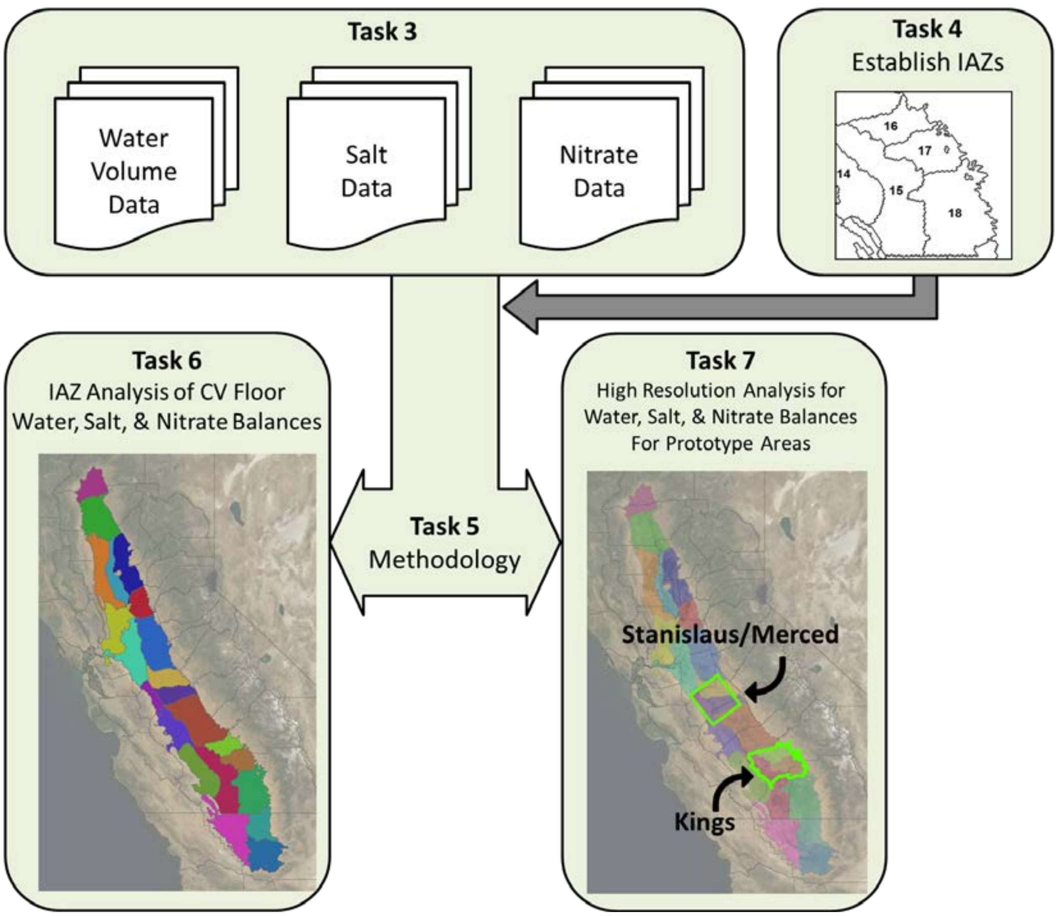


Figure 1-4. Relationships Between ICM Tasks

1.3 COORDINATION AND OUTREACH PROCESS

To establish and maintain a clear focus on the work effort, communicate progress on the necessary technical information, receive early feedback from CV-SALTS stakeholders, and apply that knowledge gained most effectively, the Team developed and implemented a comprehensive Project Management Plan. Given the compressed schedule and budget for this work, it was necessary to streamline the project management approach and deliverable approval process, closely track progress, communicate frequently, and support the sharing of information and feedback needed to complete the project.

The project coordination and outreach from the LWA Team to CV-SALTS, as outlined within the Project Management Plan, is illustrated in **Figure 1-5**.

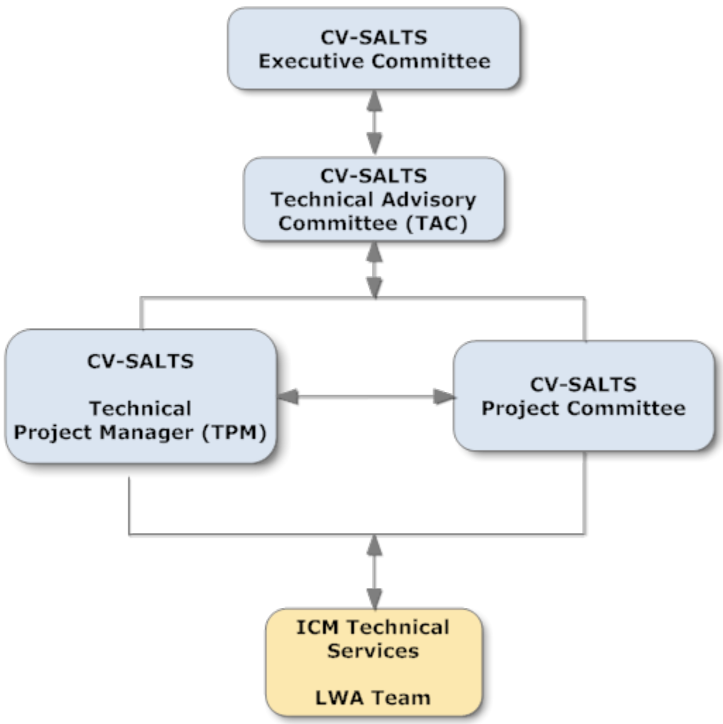


Figure 1-5. LWA Team Project Coordination with CV-SALTS

The key aspects of this coordination and outreach approaches included the following:

- The Technical Project Manager (TPM) was the primary point of contact on behalf of CV-SALTS for the completion of the ICM work;
- The LWA Team coordinated directly with the CV-SALTS TPM; and
- The LWA Team assisted the TPM as needed to provide information to the Executive Committee, the Technical Advisory Committee (TAC), and the CV-SALTS Project Committee (PC).

The specific coordinating activities with the TAC and the PC as well as the outcomes are summarized below.

Technical Advisory Committee and Project Committee

One key aspect of the project management approach was the establishment of the CV-SALTS ICM Project Committee (PC) and the coordination between the PC and the TAC. The CV-SALTS Executive Committee established the PC and delegated the authority necessary so that the PC could provide early review for and approve key work products. The PC members included the following:

- Roger Reynolds, TAC Co-Chair;
- Nigel Quinn, TAC Co-Chair;
- David Cory, Central Valley Salinity Coalition Chair;
- Debbie Webster, Central Valley Clean Water Association (CVCWA);
- Clay Rodgers, Central Valley Regional Water Quality Control Board; and
- Robert Busby, Central Valley Regional Water Quality Control Board.

In addition, two technical advisors were identified to assist the PC with the reviews of the modeling related aspects of the ICM work. The technical advisors to the PC included:

- Randy Hanson, United States Geological Survey (USGS); and
- Thomas Harter, University of California, Davis

The technical advisors, Clay Rodgers, Robert Busby, and Nigel Quinn formed the "modelers" sub-group that provided critical feedback to the LWA Team regarding the modeling aspects of the project. Additional technical and regulatory feedback was also obtained from Jeanne Chilcott, Regional Water Quality Control Board.

Throughout the duration of the project and in conjunction with the various deliverables, the LWA Team coordinated with the PC to discuss and receive early feedback on the interim work products. The close coordination between the LWA Team and the PC allowed the Team to receive the necessary feedback and approval of work products in a timely manner so that the aggressive schedule could be met. Once the PC received and/or approved a final deliverable, the item was also presented to the TAC for their review and comment.

All comments received were catalogued and responses were documented in the comment matrix (**Appendix A**) and/or within the final deliverable.

Other Input

In addition to the coordinating calls with the PC, the LWA Team organized and participated in two workshops and a modeling meeting as described below.

- Kickoff Meeting – October 8, 2012
- Modeling Meeting – October 29, 2012
- Project Workshop – November 26, 2012

The purpose for each of these meetings is described below.

Kickoff Meeting

A project kickoff meeting was held on October 8, 2012 to discuss the approach for the ICM Technical Services (**Appendix A**). The purpose of the meeting was to review the ICM tasks and identify and discuss any technical issues/concerns. During the meeting the LWA Team presented the ICM Workplan and received feedback.

Modeling Meeting

A meeting was held on October 29, 2012 to specifically discuss the modeling approach for the ICM Technical Services (**Appendix A**). The purpose of the meeting was to review the ICM modeling approach and identify and discuss any technical issues/concerns and identify potential solutions. During the meeting the LWA Team presented a brief summary of the approach described in the ICM Workplan and requested feedback.

Project Workshop

A project workshop was held on November 26, 2012 (**Appendix A**). The purpose of the workshop was to:

- Review the key ICM and GIS work efforts completed to date as well as upcoming tasks;
- Discuss the pertinent technical issues; and
- Use the workshop as a forum to collaborate with the CV-SALTS stakeholders.

1.4 REPORT ORGANIZATION

This report is being submitted on behalf of the LWA Team and fulfills the requirements of Tasks 7 and 8 of the ICM Workplan. This report summarizes the relevant findings of the ICM Tasks described above and provides recommendations for the development of the Phase II Draft SNMP. The work completed as well as the results are provided in additional detail below. In addition, each section of the report identifies the specific conceptual model questions[29] that are being answered as a result of the ICM work effort. The key report sections include the following:

- Section 2 – IAZ Scale for Surface Water and Groundwater, Salt, and Nitrate Balances
- Section 3 – Data Summary and Data Gaps
- Section 4 – Methodology for ICM Inputs to the Water, Salt, and Nitrate Balance Calculations
- Section 5 – Apportioning Mechanisms
- Section 6 – Water, Salt, and Nitrate Balance Calculation Methodology
- Section 7 – Water, Salt, and Nitrate Balance Calculation Results
- Section 8 – Uncertainty (or Sensitivity) Analysis
- Section 9 – Prototype Areas
- Section 10 – Summary of Phase I Foundational Work and Recommendations for Phase II

[29] *CV-SALTS Questions Matrix for Conceptual Models with Performance Standards*

2. IAZ Scale for Surface Water and Groundwater, Salt, and Nitrate Balances

Prior to the start of the ICM work, the term “Management Zone” had been introduced. Since the term “Management Zone” has the potential to mean many things to different stakeholders and the basis for their physical delineation may also take many different forms, the LWA Team proposed to use the term “Initial Analysis Zones” or IAZs to better describe the ICM analyses.

2.1 IAZ DELINEATION FOR ICM TECHNICAL ANALYSES

This section describes the basis of the IAZ delineation for the ICM technical analyses. The areal dimensions of the 22 IAZs that were used for the ICM are hydrologically based and directly related to the model structure of the 2009 USGS CVHM model and corresponding water balance regions used by the California Department of Water Resources (DWR). Because the vertical dimensions of the IAZs are significant to the water, salt, and nitrate analyses that have been conducted as part of ICM Task 6, this section describes the approach used to define the depth of the upper part of the aquifer system beneath each IAZ.

DWR has compiled substantial information on water deliveries and diversions for subregions of the Central Valley floor, and has subsequently used these subregions as water supply planning areas. DWR has also based a separate flow model of the Central Valley, called the C2VSim, on these subregions. Further details about DWR’s model are included in the Task 4 report on the ICM Initial Analysis Zones and Phase II Recommendations (December 2012).

DWR’s efforts and contribution toward understanding the hydrology of the Central Valley floor were recognized by the USGS and incorporated in the 2009 CVHM model. The USGS refers to the 21 previously identified areas as “water balance subregions.”

ICM Horizontal Delineation

For the purposes of the ‘concept level analyses for the ICM, the DWR/CVHM subregions in the 2009 CVHM model serve as the IAZs. There are currently 21 CVHM subregions. However, in response to early discussions with the CV-SALTS Technical Advisory Committee Co-Chair, Dr. Nigel Quinn, the CVHM Delta-Mendota Basin was subdivided, thus 22 IAZs were used for ICM Task 6.

Methodology for IAZ Depth (Vertical) Delineation

The water, salt, and nitrate balance calculations are performed on a quarterly basis for a 20-year time period. To estimate the groundwater affected by activities over a 20-year time period, the vertical travel distance must be calculated that represents the distance water, at the water table, would travel over a 20-year period. This defines the “shallow” portion of the subsurface where the ICM analysis is performed. CVHM’s subsurface aquifer properties and layer head elevations were employed to calculate the 20-year vertical travel distance to help identify the shallow subsurface. The vertical distance water will travel over 20 years may be calculated on a CVHM model cell-by-cell basis, using the layer and head properties for Layers 1, 2, and 3, and the heads output in Stress Period 270 (September 1983).

To compute the IAZ vertical dimensions, saturated volumes, volume calculations, and IAZ delineation sections, CVHM parameters of layer thickness, vertical hydraulic conductivity, water level, and specific yield (or porosity) are used in conjunction with Darcy's Law to calculate the vertical velocity of groundwater. The vertical hydraulic gradient is calculated on a CVHM cell-by-cell basis and is multiplied by the equivalent vertical conductivity for layered systems and then divided by the specific yield (or porosity). The resultant vertical velocity is then multiplied by 20 years to achieve the 20-year vertical travel distance for each active CVHM model cell. The calculated 20-year travel distance is shown in **Figure 2-1**, illustrating the variability of calculated vertical 20-year travel distances within each IAZ. It also illustrates the areas where water is moving vertically upwards (shown in gray cells in the Sacramento Valley, and parts of the Delta-Mendota Basin – Grassland)[30]. The majority of the calculated vertical distances that water will travel downward (in the saturated subsurface) over a 20-year period range from 10 to 150 feet.

To maintain the spatial variability described above, each IAZ has an irregular bottom. In other words, this approach allows for more spatial resolution within an IAZ instead of selecting one or more layers to represent the entire IAZ. This allows each IAZ to accommodate areas where water moves faster or slower within an IAZ and also accommodates areas within an IAZ that have variations in the assignment of uppermost active layers. This approach also maintains the assumption that the upper/shallow/20-year travel zone aquifer is above the Corcoran Clay unit even in an IAZ that has a large portion where Layer 6 (below the Corcoran Clay layers) is the uppermost active layer (e.g., IAZ 14).

[30] "During calibration, an additional modification to the layering was added where the water table is deeper than 50 feet (fig. B12 in Faunt et al., 2009). Where the water table is between 50 and 150 feet below land surface, the top layer was thickened to extend to 147 feet below land surface and Layer 2 was configured as a 3-ft-thick dummy layer. Where the water table was between 150 and 300 feet below land surface, Layers 1 and 2 were specified as inactive. Where the water table was deeper than 300 feet, Layers 1-3 were specified as inactive." (Faunt et al., 2009, Chapter 3 pp 126)

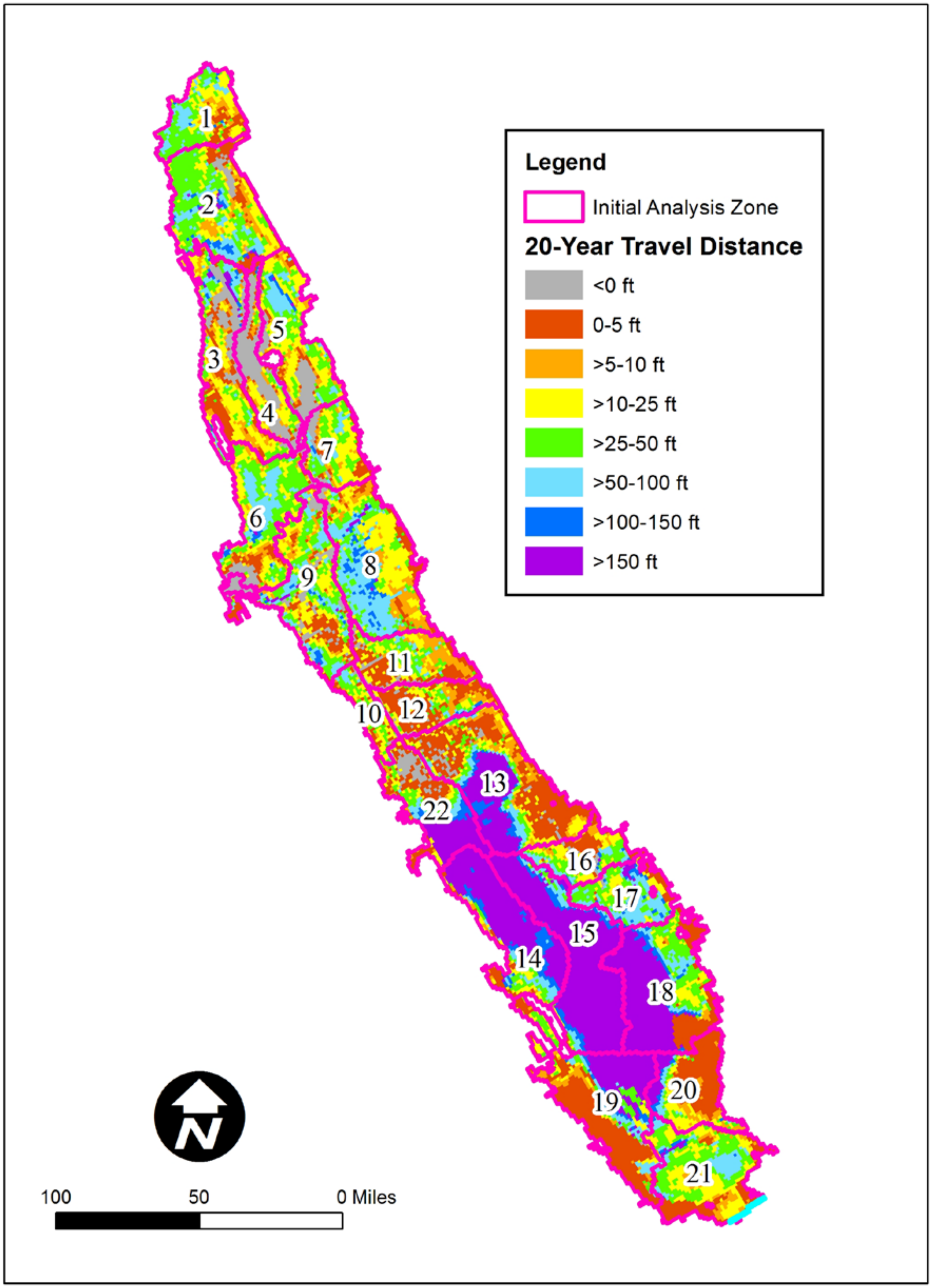


Figure 2-1. 20-Year Travel Distance Calculated on a Cell-by-Cell Basis Based on a Cell-by-Cell Darcian Velocity from CVHM

The methodology to determine what constitutes ‘shallow’ groundwater for the ICM analysis is as follows:

- Determine whether the saturated thickness of the uppermost saturated layer satisfies the 20-year calculated travel distance for each particular cell within the IAZ.
    - If it does, then that layer is the deepest layer selected for the IAZ.
    - If it does not satisfy the 20-year travel distance (calculated 20-year travel distance > saturated thickness of uppermost saturated layer), then the percentage of the next deep layer is determined that would be needed to satisfy the 20-year travel distance.
    - If the difference between the saturated thickness and the 20-year travel zone divided by the thickness of the next deep layer is greater than 50%, then that next deep layer is included. Put another way, if more than half of the thickness of the next deep layer is contained in the calculated 20-year travel zone, then that layer is included in the IAZ thickness.

This test continues to include deeper layers until the 20-year travel distance is satisfied by the available saturated thickness from CVHM. An additional test is conducted to make sure that the deepest layer to be included in the IAZ balance calculation is above the CVHM layers representing the Corcoran Clay (so, if the deepest layer is greater than 3 and the Corcoran Clay is present in that cell, the deepest layer is cut off at Layer 3[31]). This occurred in nine different IAZs:

- IAZ-10 (for two cells out of 282 cells in the IAZ);
- IAZ-13 (for 26 cells out of 1,648 cells in the IAZ);
- IAZ-14 (for 16 cells out of 1071 cells in the IAZ);
- IAZ-15 (for 5 cells out of 1,423 cells in the IAZ);
- IAZ-18 (for 16 cells out of 1,358 cells in the IAZ);
- IAZ-19 (for 4 cells out of 1,365 cells in the IAZ);
- IAZ-20 (for 3 cells out of 705 cells in the IAZ);
- IAZ-21 (for 27 cells out of 1,105 cells in the IAZ); and
- IAZ-22 (for 30 cells out of 801 cells in the IAZ).

Summary of IAZ Area and Depth Information

The table below (**Table 2-1**) summarizes the depth information for each IAZ including the area of each IAZ which corresponds to the number of uppermost active cells, the minimum value of the 20-year travel distance from each cell in the IAZ, the maximum value of the 20-year travel distance from each cell in the IAZ, the average 20-year travel distance for each IAZ, a count of the number of cells within each IAZ that have vertical gradients indicating upward groundwater

[31] CVHM simulates the Corcoran Clay as Layers 4 and 5. Where the Corcoran Clay is present, it is assumed that the mass loading and therefore mixing occurring over 20-years happens above the Corcoran Clay. This means that Layer 3 would be the deepest CVHM layer selected for balance calculations where the Corcoran Clay is present and Layers 1 and 2 do not satisfy the 20-year travel distance sufficiently.

movement over 20-years, the average thickness of each IAZ, the average saturated thickness of each IAZ, and lastly the occurrence of the 20-year travel distance being greater than the saturated thickness of CVHM model Layers 1, 2, and 3 when the Corcoran Clay is present and should not be passed (i.e., the Corcoran Clay "cutoff cells").

Table 2-1. Summary of Depth Information for Each IAZ

IAZ #	Area of IAZ (# of cells or square miles)	Minimum Vertical 20-year Travel Distance (ft)[32]	Maximum Vertical 20-year Travel Distance (ft)	Average 20-year Travel Distance (ft)	# Cells w/ Upward 20-year Travel Distance	Average Thickness (ft)	Average Saturated Thickness (ft)	Number of Corcoran Clay Cutoff Cells
1	611	-4	142	30	1	294	92	0
2	1163	-34	441	34	44	240	93	0
3	1112	-50	331	20	188	187	81	0
4	560	-22	145	2	317	55	71	0
5	957	-16	152	22	172	90	72	0
6	1044	-12	198	31	87	115	63	0
7	534	-9	116	22	59	111	74	0
8	1362	-15	292	40	25	169	92	0
9	1181	-14	204	26	176	67	64	0
10	282	-4	75	22	19	156	65	2
11	664	-13	85	13	60	119	71	0
12	540	-3	373	14	32	99	67	0
13	1648	-8	1044	88	57	132	61	26
14	1071	0	1978	202	0	405	180	16
15	1423	0	4778	599	0	128	93	5
16	478	-8	735	26	17	190	67	0
17	569	-3	523	57	5	142	78	0
18	1358	0	2218	334	0	194	74	16
19	1365	-2	4522	244	4	419	109	4
20	705	0	1030	56	0	481	98	3

[32] These negative vertical distances indicate upward vertical movement as determined from deeper layers having higher hydraulic heads compared to the layer(s) above. Occurrences of negative vertical travel distances resulted in the uppermost active layer being used for the IAZ balance calculations. Additionally, the negative vertical travel distance in some cells may also indicate that groundwater may be utilized by the FARM Process, allowing shallow groundwater to be used for ET. This appears in the form of negative recharge, which is one way the FARM Process deals with groundwater contributions to the farm demands (no mass is associated with this movement of water for the balance calculations).

IAZ #	Area of IAZ (# of cells or square miles)	Minimum Vertical 20-year Travel Distance (ft)[32]	Maximum Vertical 20-year Travel Distance (ft)	Average 20-year Travel Distance (ft)	# Cells w/ Upward 20-year Travel Distance	Average Thickness (ft)	Average Saturated Thickness (ft)	Number of Corcoran Clay Cutoff Cells
21	1105	0	569	32	0	410	120	27
22	801	-2	1381	140	82	141	58	30

The distributions of the 20-year vertical travel distances are shown in the histogram **Figure 2-2** (across the entire Central Valley and range from -50 feet to over 900 feet, with an average of 137 feet, but the downward vertical distance is mainly within the range of 10 to 150 feet.

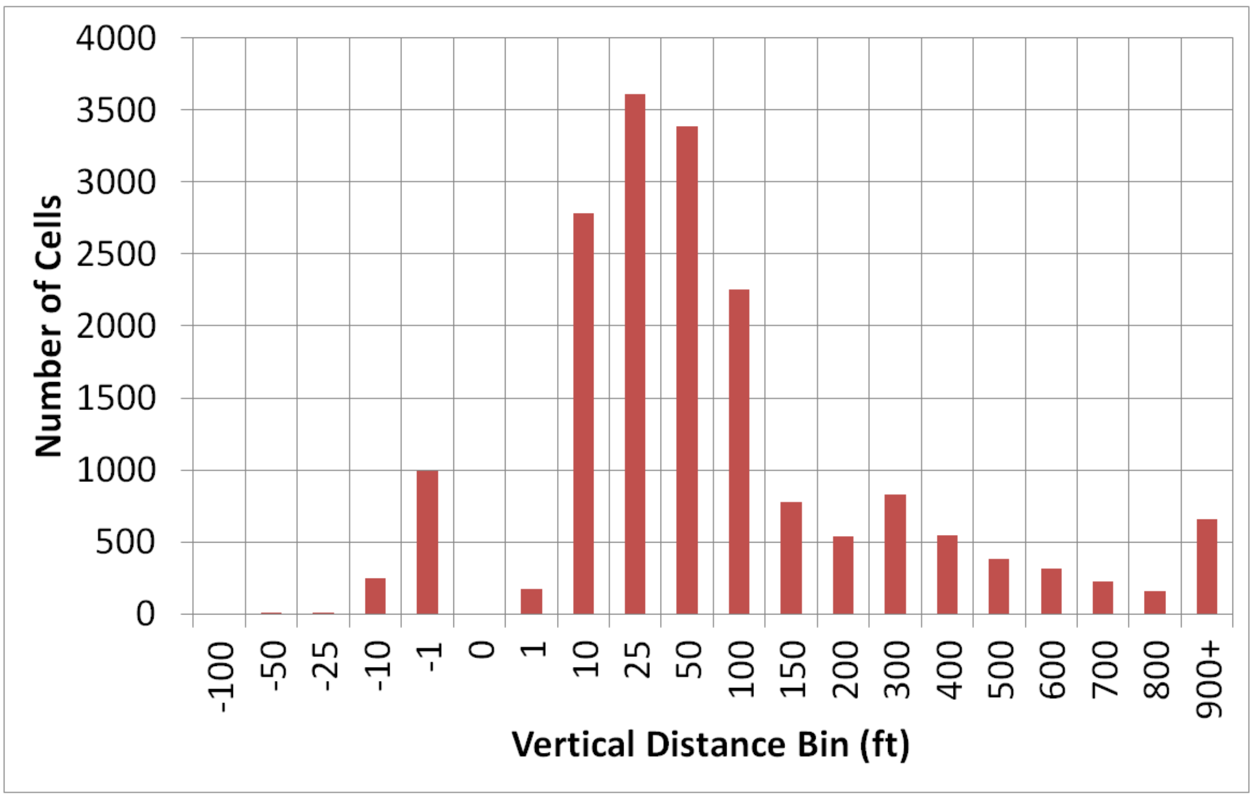


Figure 2-2. Histogram of 20-Year Travel Distance for the Entire Central Valley CVHM Model

IAZ Relationship to CVHM Layers

The depth, in feet, from the ground surface to the bottom of the CVHM layer corresponding to the 20-year travel distance is shown in **Figure 2-3** below. The deepest CVHM layer for each cell to be used in the IAZs is shown in **Figure 2-4**.

The CVHM layering was used to delineate the depth of the 20-year travel zone or ‘shallow’ subsurface[33]. This information was used to post-process the CVHM flow model to extract the flow budget components associated with the 20-year travel zone. Also, now that the depth of each IAZ is defined, the wells with groundwater quality data that have well or hole depth (generally USGS observation wells) can be assigned ‘shallow’ or ‘deep’ on a cell-by-cell basis when plotted against the depth of the IAZ map.

The pie chart below shows the percentages of each depth category seen in the map (**Figure 2-4**), delineating the depth to the bottom of the CVHM layer corresponding to the 20-year travel distance and used for the IAZ analysis representing shallow groundwater (**Figure 2-5)**.

[33] For cells with calculated negative travel distances, the cell in the uppermost active model layer was used to define the base of the IAZ.

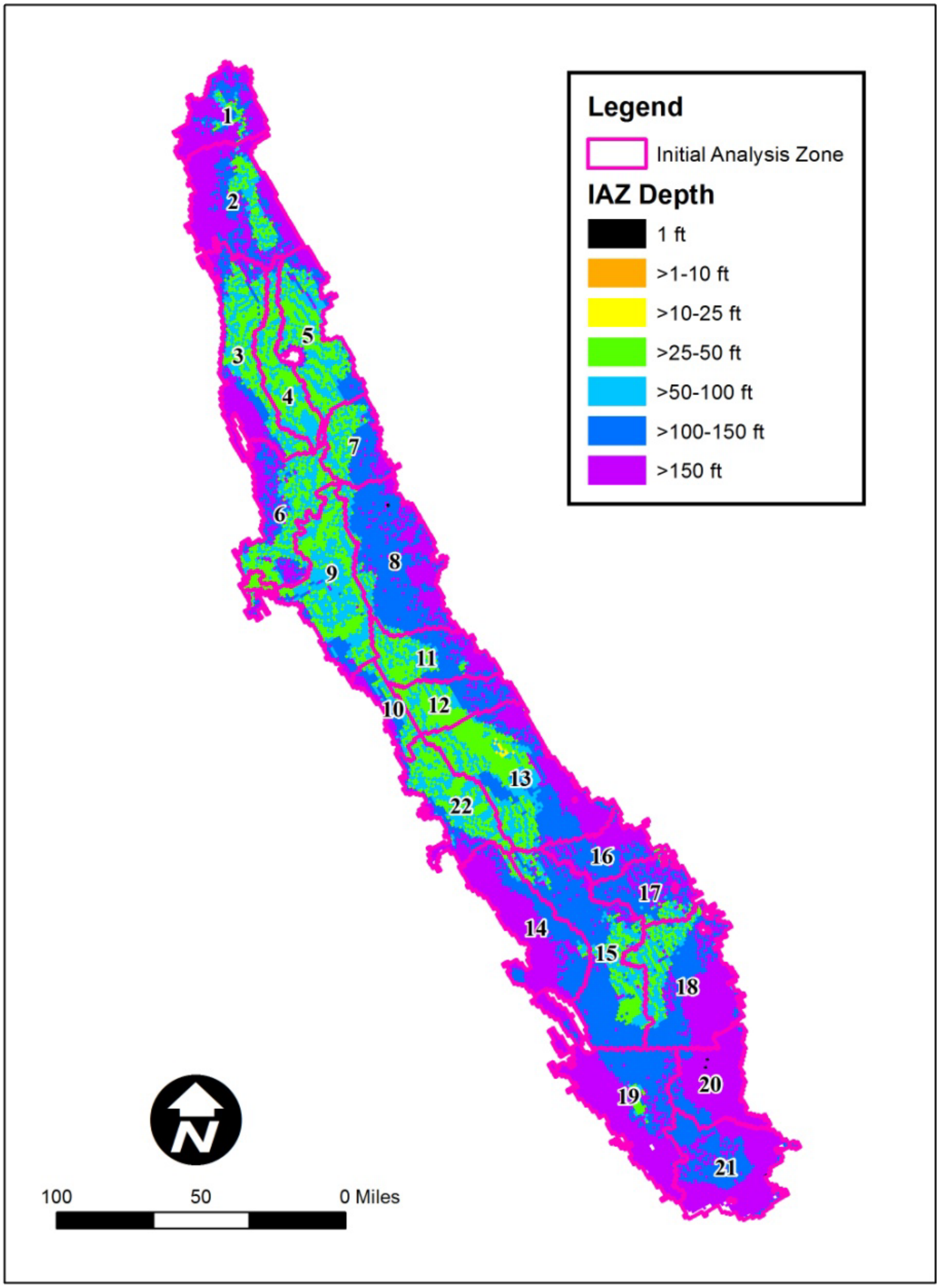


Figure 2-3. Depth to the Bottom of the CVHM Layer Corresponding to the 20-Year Travel Distance

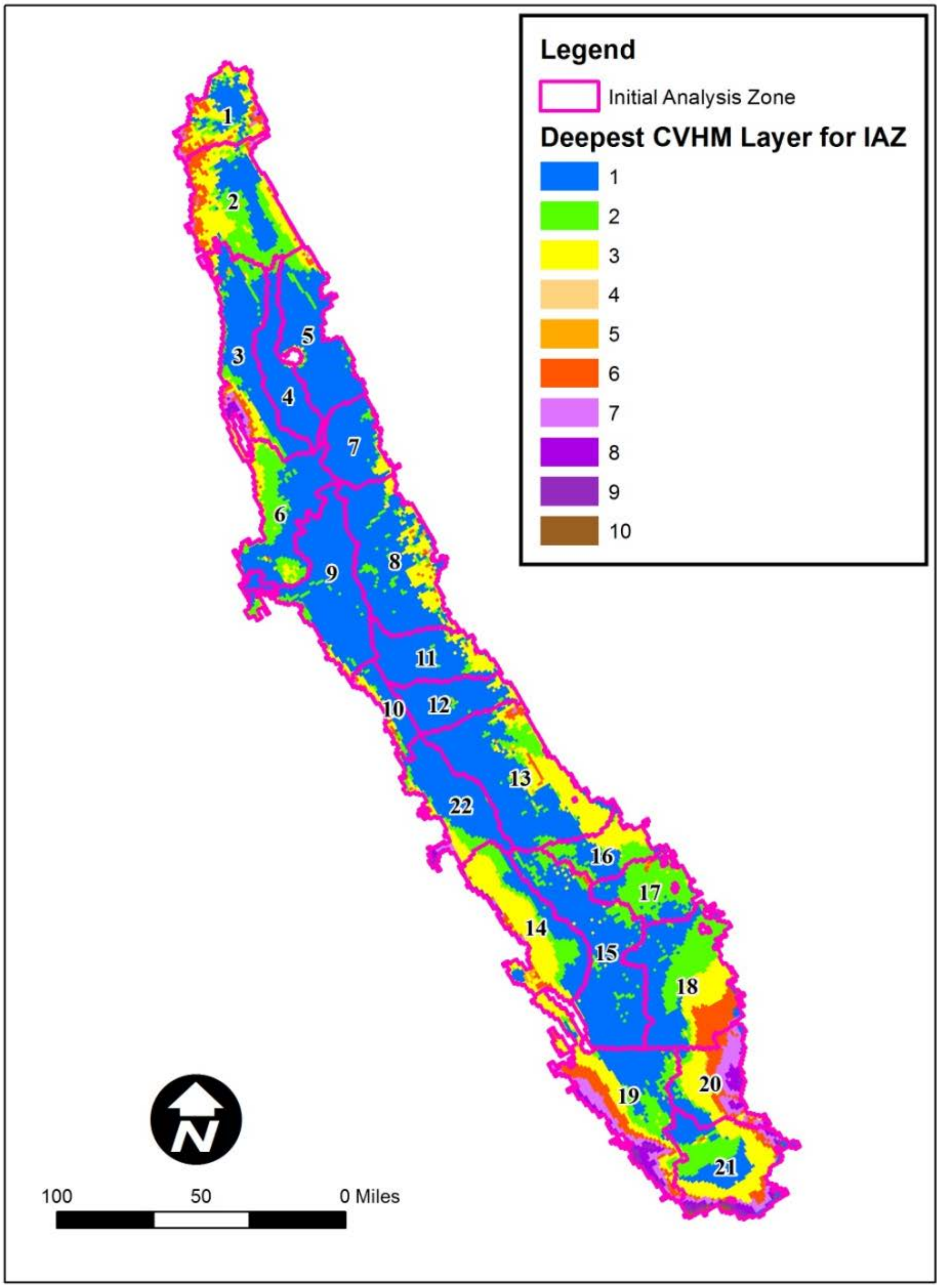


Figure 2-4. The Deepest CVHM Layer for Each Cell to be Used in the IAZs[34]

[34] Layer 6 is only allowed to be the deepest layer included in the IAZ where the Corcoran Clay does not exist.

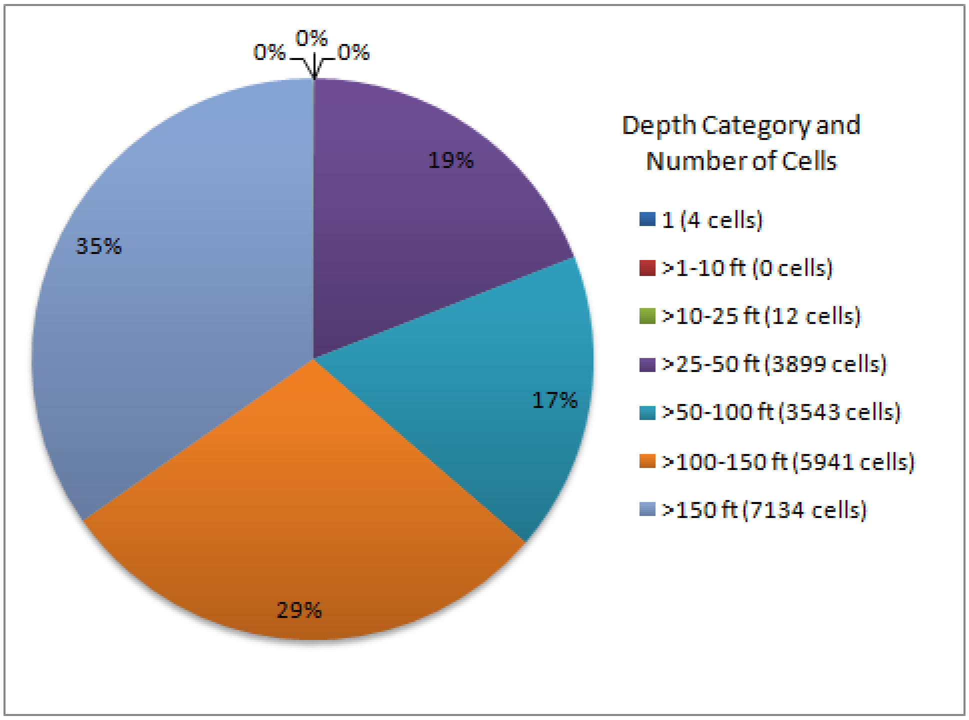


Figure 2-5. Distribution of Depth Categories to the Bottom of the CVHM Layer Corresponding to the 20-Year Travel Distance

2.2 SUMMARY

The vertical dimensions of the IAZs are significant to the water, salt, and nitrate analyses that have been conducted as part of ICM Task 6. This section describes the approach used to define the depth of the upper part of the aquifer system beneath each IAZ. The water, salt, and nitrate balance calculations are performed for a 20-year time period. To estimate the groundwater affected by activities over a 20-year time period, the vertical travel distance must be calculated. The vertical distance represents the distance that the water, at the water table, would travel downward or upward over a 20-year period. This defines the "shallow" portion of the subsurface where the ICM analysis is performed.

3. Data Summary and Data Gaps

The following sections provide summaries of the key datasets and identify data gaps. There are three major categories of data that were compiled to complete the salt and nitrate balance calculations.

- Groundwater Quality
- Surface Water Quality
- Inputs for Mass Loading Estimates

These three major categories represent much of the data collection effort needed for calculating salt and nitrate balances. Collection efforts focused on the 20-year time period that would be used during simulation (1983 – 2003) and are presented below.

3.1 GROUNDWATER QUALITY DATA

The following information about the groundwater quality data utilized for the ICM includes a description of the data collected, how the data were vertically discretized, and a summary of some of the data gaps, in terms of quality assurance and quality control (QA/QC).

Groundwater quality data were collected for the entirety of the Central Valley Region 5 boundary for chloride, nitrate [(as nitrogen (N)], electrical conductivity (EC)[35], and total dissolved solids (TDS). Data sources are described in the Task 3 Data Source List Memorandum[36]. The main data sources for groundwater quality data are:

- Geotracker Groundwater Ambient Monitoring and Assessment (GAMA) program
- U.S. Geological Survey (USGS) National Water Information System (NWIS)
- CA Department of Public Health (DPH)
- Department of Water Resources (DWR)
- Regional Water Quality Control Board (RWQCB) Waste Discharge Requirement (WDR) Dairy Data

Although data were collected for Region 5, only data within the Central Valley floor were processed for use in the ICM. A detailed summary of the groundwater quality data by IAZ is provided in Section B and Attachment B of the Task 3 Data Summary and Data Gaps Memorandum[37].

[35] EC data were collected and transformed to TDS using the ratio TDS = EC*0.64 for wells without TDS data (Metcalf and Eddy, Inc. 1991).

[36] Initial Conceptual Model – Task 3.2: Data Source List Memorandum, October 3, 2010.

[37] Initial Conceptual Model – Task 3.3 & 3.4: Data Summary and Data Gaps, December 18, 2012.

The table below (**Table 3-1**) shows the types and numbers of wells for each dataset:

Table 3-1. Well Types and Number of Wells for each Data Source

		Number of Wells	
Database	Types of Wells	Within IAZs	Full Dataset
RWQCB (WDR Dairy Data)	Monitoring, Domestic, Agricultural	4,157	4,179
DPH	Public Supply	5,540	7,554
DWR	Domestic, Industrial, Public Supply, Agricultural, Monitoring/Observation/Test	13,138	14,407
Geotracker GAMA	Public Supply, Monitoring	6,502	14,847
USGS	Not Reported	3,968	9,491
	Total:	33,305	50,478

Figure 3-1 shows the locations of all of the wells with salt and/or nitrate data by source. This figure also shows the outline of the IAZs in black and the greater Region 5 boundary in red.

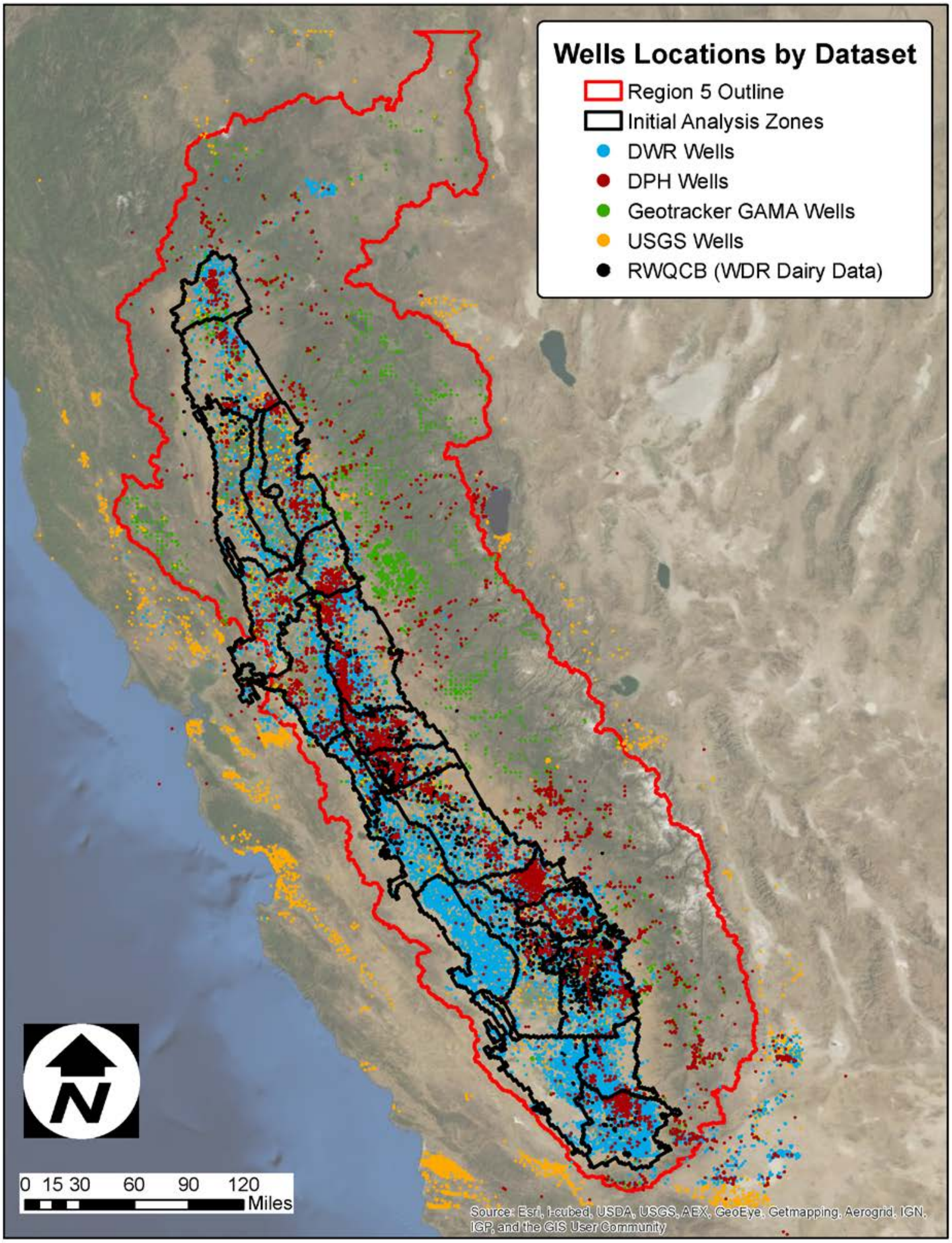


Figure 3-1. Map Showing the Locations of all Wells with Salt and/or Nitrate Data

The data record spans from 1910 to 2012, however, the majority of the well test data is from the 1950s to 2012. The earlier data (1940s to 1970s) are largely from the DWR and USGS datasets, with small amounts of data from the other sources. The later time period (1980s to present) contains data from all five sources; however, the GAMA and DPH datasets make up the majority. Well test data from the RWQCB WDR Dairy dataset is primarily from the 2000s, with a small amount of data in the 1990s. Each decade has roughly similar amounts of well test data for the three constituents of interest (nitrate, chloride, and EC/TDS); however, the 2000s and 2010s decades typically have greater numbers of wells sampled for nitrate as compared to chloride and TDS. Conversely, the earlier decades (1950s to the 1980s) generally contain more wells tested for chloride and TDS as compared to the number of wells tested for nitrate.

The Task 3 Data Summary and Data Gaps Memorandum also discusses data gaps for each IAZ in detail.

- Spatial and temporal data gaps were determined as part of the description of the available data to be used in the Task 6 analysis.
- Spatial data gaps for an IAZ were determined visually by identifying areas containing few or no wells or areas with comparatively low densities of wells.
- Temporal data gaps were identified if there were less than 100 wells in an IAZ for a particular decade between 1980 and 2012.
- Other non-critical data gaps identified in the Task 3 Data Summary and Data Gaps Memorandum include:
    - The lack of adequate well construction information;
    - The lack of spatial coordinate information for some public supply wells in the DPH dataset;
    - The overlapping nature of datasets from Geotracker GAMA, USGS, DWR, and DPH; and
    - The lack of unique well identifiers for the RWQCB WDR Dairy dataset.

Assigning Depth Class to Wells

Wells were classified into three depth classes (Shallow, Deep, and Unknown) based on information provided by the original source, as shown in

Table 3-2. Most wells in the database did not contain quantitative information on well depth or screened interval; however, other information such as well type was used when available to infer the depth from which a well was sampled. Only the USGS database contained quantitative information regarding well depth. For wells lacking a specified value of well depth, the well type was used to infer the depth (see

Table 3-2 for examples). Wells in the DWR, GeotrackerGAMA, and RWQCB WDR Dairy Data databases sometimes contain a description of the well type which enabled categorization of the well into a depth class. All wells from the DPH database were assumed to be drinking water supply wells.

Irrigation/agricultural[38], industrial, and municipal supply wells were classified as “Deep” whereas domestic wells and monitoring wells were classified as “Shallow”. All DPH wells were therefore classified as “Deep” as these were all assumed to be drinking water supply wells. All other well types were classified as “Unknown”.

A large number of USGS wells provided numerical values for well depth; therefore, these were used when provided. USGS wells were assigned a depth class based on the 20-year travel depth for a particular CVHM cell that it was located within. Wells with a depth less than the 20-year travel depth were classified as “Shallow,” and those below the 20-year travel depth were classified as “Deep”. Wells without depth information or a well type were classified as “Unknown”.

[38] Although irrigation and agricultural wells are generally screened for most of their depth, the shallow portion of their screen here is assumed to consist of only a small fraction of the overall length. These types of wells generally penetrate depths much greater than what has been classified here as shallow groundwater; therefore, the water withdrawn from these wells likely reflects deeper conditions rather than shallow conditions.

Table 3-2. Well Classification

Data Source	Well Type Field[39]	Well Type Descriptors	Depth Class
DWR	GWU_DESCRIPTION	Domestic Unused Domestic	Shallow
		Industrial Irrigation Irrigation & Domestic Irrigation & Stock Public Supply Unused Irrigation	Deep
		(Blank) Destroyed Domestic & Stock Observation Recreation Stock Test Undetermined Unused	Unknown
Dairy	Well Type	Monitoring Domestic	Shallow
		Agricultural	Deep
		(Blank)	Unknown
Geotracker GAMA	DATASETCAT	Environmental Monitoring (Wells)	Shallow
		Water Supply (Wells)	Deep
		(Blank)	Unknown
DPH	N/A		Shallow
		All Wells assigned Deep	Deep
			Unknown
USGS	well_depth_va	Based on cell 20-year travel depth	Shallow
		Based on cell 20-year travel depth	Deep
		Wells without Depth information	Unknown

[39] The Well Type Field refers to the actual field heading from the original source data, i.e., DWR's Water Data Library reports a value for their wells called "GWU_DESCRIPTION", which refers to the Ground Water Use description; Geotracker GAMA reports a "DATASETCAT", which refers to a data set category; and the USGS reports a value when available for well depth in their "well_depth_va" field.

The number of Shallow, Deep, and Unknown wells per decade is shown in **Figure 3-2**. **Appendix B** provides graphs and tables of the number of wells and their depth classification for each IAZ.

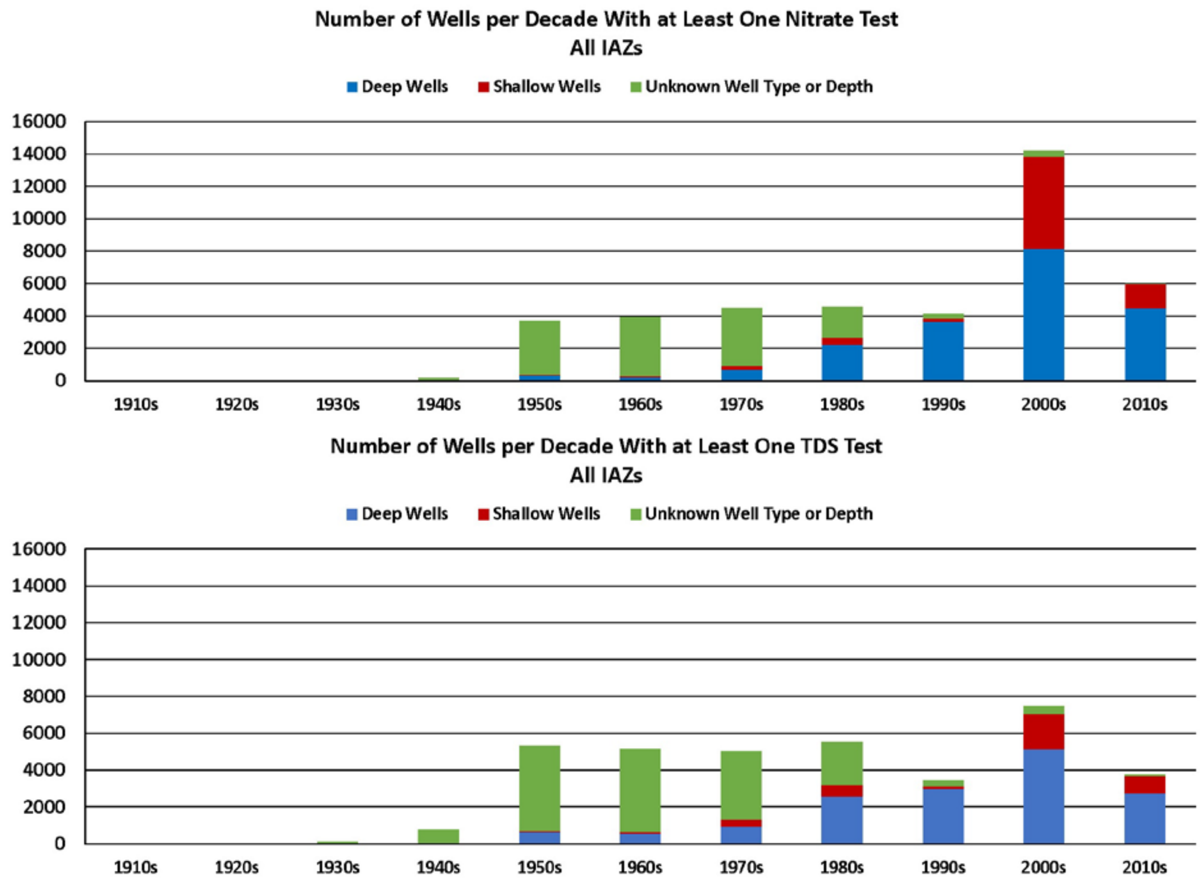


Figure 3-2. Number of Wells and Types

Quality Assurance/Quality Control (QA/QC)

All of the public sources of groundwater quality data have already undergone some level of quality assurance/quality control (QA/QC) from their various reporting agency. It was not in the scope of this project to perform a thorough QA/QC check for all of the groundwater quality data. However, care was taken to address the following data issues.

Accurate location information is sometimes difficult to uncover for many wells in the state of California due to privacy and security issues. As such, many supply wells either did not have a location coordinate entry, or their coordinate was an estimate to the nearest mile, or half mile. For wells with groundwater quality data from DWR, if no coordinate was provided, an estimate based on state well number (provides accuracy down to the section or tract level, which represents 1 mile or ¼ mile accuracy). For wells with groundwater quality data from DPH, coordinate information was extracted from GeotrackerGAMA, historic (pre-9/11) DPH datasets, water system headquarter addresses, other wells in the same water system, or if none of those were possible, the center of the county the water system was associated with.

Supply well water quality sometimes includes blended or treated water. This does not represent raw groundwater and so was discarded for DPH and GeotrackerGAMA data.

Additional Filtering Of Wells

Additional sites were filtered out from the USGS database, the field “site_tp_cd” provided site type codes. Sites with site type codes indicating that the site was a stream, subsurface, lake, atmosphere, and spring were removed, along with their associated tests. For the DPH database, the field “STATION_TY” provided station type descriptors. Sites that indicated they were from a combined source, river, spring, or stream were removed, along with their associated tests.

Removing Duplicate Tests and Wells

Overlap occurs between some of the databases; therefore, before compiling all of the data into a single database, the duplicate well tests were identified and filtered from the database.

The Geotracker GAMA and USGS NWIS databases contain wells and tests that are also included in the DWR and DPH databases (additionally, GAMA contains data from the USGS as well). This is because the GAMA and USGS NWIS databases are intended to be collections of available water quality from various sources. However, these databases are not completely comprehensive. In some cases only a subset of tests are reported to GAMA or USGS, with additional tests still available in the original database. For this reason, wells and tests were identified in both databases and only the data from the original data source were kept.

Wells in different databases were matched based on a well identification field that was provided in both databases. As mentioned, some databases may contain the same wells, but different tests associated with the well; therefore, a method for matching wells *and* tests was needed. To do this, the associated well identification fields were concatenated with the date and analyte (nitrate or TDS). The assumption was that a well was only sampled once for a given date. Duplicate tests were removed via identification with the concatenated field. The reason the result field was not used in the concatenations is due to the potential different number of significant digits provided. For example, a test in one database might have a result of 2.5 where in another database the same result could be 2.5124, where additional digits have been provided.

The hierarchy for establishing which data to keep was based on a preference for the original data source. First, tests from DWR were kept where matches were found within the USGS database. Next, tests from DWR, DPH, and USGS, were kept where matches were found within the GAMA database.

13,837 tests were found to be duplicated between DWR and USGS and were removed from the USGS dataset. 147,209 tests from DWR, DPH, and USGS were found to be duplicated in GAMA and were removed from the GAMA dataset. 4,065 wells which no longer were associated with unique water quality values were removed from GAMA.

Misreported Concentrations

GeotrackerGAMA

During work for Tasks 6 and 7, it was recognized that many records (several 100 to possibly a few thousand) in the GeotrackerGAMA database that suggested that the tests were misreported values. Two issues with the GeotrackerGAMA database surfaced during the analysis. The first was an issue with the monitoring well data [DATASET_CAT = ENVIRONMENTAL MONITORING (WELLS)] and the CHEMICAL field. The issue appears to have come about when the data were transferred from the Geotracker database to the Geotracker GAMA database. Data that were originally reported nitrate as nitrogen (CHEMICAL=NO3N) in the Geotracker database had been changed to be reported nitrate as nitrate (CHEMICAL=NO3) in the GeotrackerGAMA database. The issue appears not to be with the original data (as verified with the electronic data file (EDF) download), but that an error must have occurred when the tests were transferred from the Geotracker database to the GeotrackerGAMA database.

A second issue was also identified, however, it applied to public well data [DATASET_CAT = WATER SUPPLY (WELLS)] from DPH and the USGS. Several records from the DPH dataset appear to have misreported chemicals for nitrate. In these cases, duplicate tests on the same well, on the same day, have reported values that differ by approximately a factor of 4.5, which is roughly the conversion from nitrate reported as nitrate and nitrate reported as nitrogen. Similarly, the USGS tests for TDS on public supply wells appear to have duplicate tests on the same well for the same day that differs by a factor of roughly 1,000,000. The tests with extremely low TDS values from USGS are much more obvious than the misreported nitrate values from DPH. A total of 349 misreported tests for TDS, less than 0.9% of the total number of tests for TDS (39,693), were identified and removed from the database. For both the DPH data and the USGS data, the data downloaded in bulk for Region 5 and the same data downloaded individually by county appear to have the same problem; therefore, this error might originate from when the data were originally provided to Geotracker.

For the analysis, all the data sources were compiled into a master database, though the data from the original source were retained, rather than the secondary source (GeotrackerGAMA). That is, if the same test existed in GeotrackerGAMA's database and in DPH's database, the test data from DPH were retained. Therefore only "unique" tests that remained in the GeotrackerGAMA database were kept. Because the issue was found with GeotrackerGAMA, and not the original source, the ICM analysis was not impacted significantly as GAMA tests represent less than 15% of the tests in the database. Additionally, the misreported TDS values were taken out of the database for our analysis as they were easy to detect. However, the nitrate data were only detectable via spot checking, so it was impossible to review the entire dataset manually under the scope of the ICM. However, the overall effect on the analyses in this report due to the discovery of the above problems with GeotrackerGAMA is likely very small. Due to the temporal and spatial declustering that was used (see Section 4.2 regarding declustering method), the inclusion of data from multiple sources, and the large spatial extent of the IAZs over which the analyses were performed, the results presented here are likely not impacted significantly due to the robust methodologies employed.

Department of Public Health (DPH)

An additional issue was discovered with a small subset of DPH tests that contained an analyte STORET code of 00618. In this case, some of the nitrate values for a well appeared to be misreported. For example, a well that had been sampled frequently had values of 10, 9, 10, 10 and then 45, 48, and then 11, 9, 10. All tests provided units that indicated that the results were reported nitrate as nitrogen. However, only the values that appeared to be concentrations reported nitrate as nitrate (the 45 and 48 tests), rather than nitrate as nitrogen, were associated with the STORET code of 00618. This was seen in several wells, by spot checking. Not all of the tests with a STORET code of 00618 appeared to be misreported; however, it appeared that a significant portion of these data contained errors. Since these tests represented a very small portion of the total number of tests from DPH (1,313 out of 167,347 or about 0.8%) and the fact that the DPH wells generally had many additional tests associated with the wells, the tests with a STORET code of 00618 were removed from the database before the analyses were performed. The results presented here are therefore not affected by this issue.

3.2 SURFACE WATER QUALITY DATA

Surface water quality data within the study area were compiled for TDS or EC as an analog, chloride, and nitrate (as N). The collection efforts can be broadly grouped into two categories: IAZs with WARMF coverage and IAZs without WARMF coverage. Overlay of WARMF over the study domain and IAZs is shown in **Figure 3-3**. In areas of WARMF coverage, surface water quality data for the constituents were available from WARMF databases. The data in the WARMF databases was collected from USGS, DWR, California Data Exchange Center (CDEC), Surface Water Ambient Water Monitoring Program (SWAMP), Irrigated Lands Regulatory Program (ILRP), US EPA STORET, Bay Delta and Tributaries (BDAT), and the Stockton Deep Water Ship Channel DO TMDL upstream studies. The imported data were graphically scanned in WARMF to find outliers and transcription errors. Where no WARMF coverage existed, surface water quality data were compiled from public databases including the USGS, CDEC, SWAMP, and Regional Monitoring Program for Water Quality. Most of these data sources collect grab samples analyzed for a variety of constituents. CDEC collects continuous real-time data for flow and a few water quality parameters including EC.

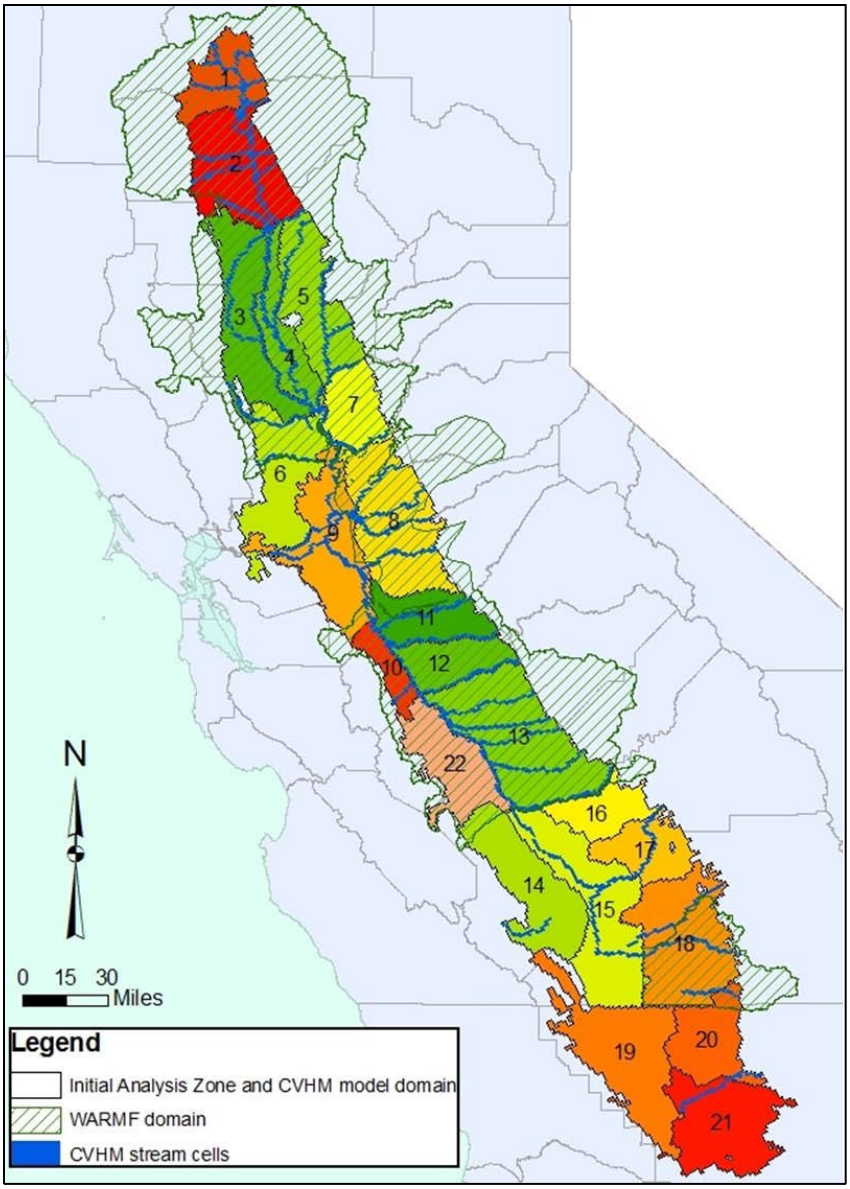


Figure 3-3. CVHM IAZs and Overlapping WARMF Coverage – IAZ without Full WARMF Coverage Include IAZ 6, 9, 14 – 21.

IAZs with WARMF Coverage

WARMF provided a source of surface water quality data within its Central Valley model domains. The WARMF database is a compilation of data from a variety of sources, including USGS, DWR, CDEC, US EPA, SWAMP, ILRP, and specific scientific studies. Data are grouped by location and tagged with the original source. Data were collected back to the 1950's in the Sacramento River watershed and back to 1984 for the San Joaquin River watershed. The data have generally been collected through 2010. Spatial and temporal data density varies greatly in the Central Valley. The San Joaquin River and its tributaries have had a larger amount of data collection than the Sacramento River and its tributaries. The WARMF model simulation results provide a means of filling the gaps in the data. The model is calibrated based on the available surface water data and then provides a daily time series of every simulated constituent in every delineated river segment.

IAZs without WARMF Coverage

Within the study area, IAZs 6, 9, and 14 to 21 were all without complete WARMF coverage. IAZs 6 and 9 border or fully contain the Sacramento-San Joaquin Delta. IAZs 14 to 21 encompass the Southern San Joaquin Valley. The sections below summarize the data collected and data gaps for each area in more detail.

IAZ 6, 9: Sacramento-San Joaquin Delta

Surface water quality data were compiled from multiple publically and privately available databases including WARMF, USGS, and CDEC. The aggregated data were evaluated based on spatial and temporal completeness with representative monitoring sites along modeled CVHM streams selected to represent the most comprehensive water quality gauges. Based on variable WARMF coverage within these IAZ's, which can be seen in **Figure 3-4**, the Delta was broken into three distinct areas: Sacramento River from the City of Sacramento to Rio Vista, Sacramento River downstream of Rio Vista, and Central/Southern Delta. Using available WARMF data (where CVHM stream cells border the IAZs) and representative monitoring sites (for stream cells with no WARMF coverage), a quarterly average water quality was assigned to each of the three areas for the period of 1983 – 2003.

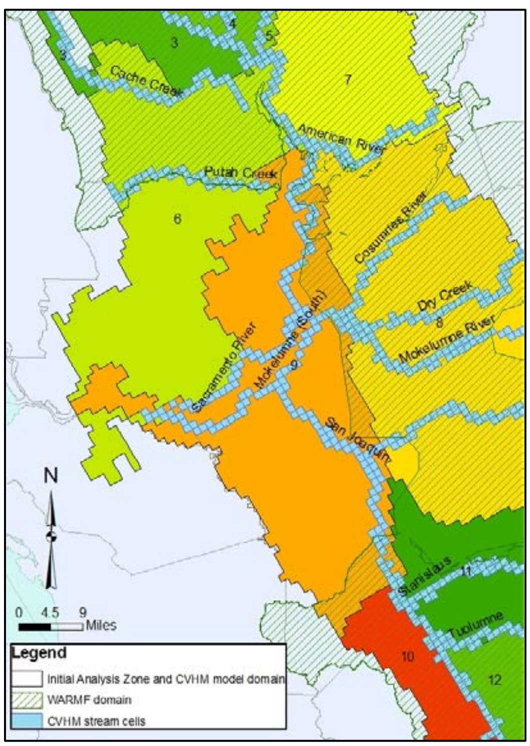


Figure 3-4. Non-WARMF IAZs 6 and 9 (Delta Region)

The Sacramento River from the City of Sacramento to Rio Vista is an area where WARMF cells border the IAZ and were therefore used to compute a full data set from 1983 to 2003 for TDS, chloride, and nitrate (as N). There are no data gaps within this area.

The Sacramento River downstream of Rio Vista lacks WARMF coverage. Representative monitoring sites were selected from the obtained surface water quality data based on the most comprehensive water quality gauges. These include the CDEC gauge Sacramento River at Emmaton (EC), the USGS gauge Sacramento River at Antioch (chloride), and the CEDEN gauge Sacramento River BG20 (nitrate as N). EC data were available daily from 1988 to 2008 and were converted to quarterly average TDS concentrations. Chloride data were not available later than 1969. Nitrate data were available monthly from 1960 to 1969, and 1993 to 2010. Methods used to fill these data gaps are described later within the report.

The Central/Southern Delta lacks WARMF coverage. The Harvey O. Banks Delta Pumping Plant was used as the representative gauge for TDS, chloride, and nitrate (as N). Since TDS is not monitored, EC data were converted to TDS via a site-specific ratio. Daily EC data were available from 1986 to 2006, and there were no significant temporal data gaps. Annual chloride data have only been collected since 2007. Nitrate data were available annually from 2007 to 2012. Methods used to fill these data gaps are described later within the report.

IAZ 14 to 21: Southern San Joaquin Valley

Areas of the Southern San Joaquin Valley without WARMF coverage can be seen in **Figure 3-5**. Surface water quality data within these zones were aggregated from CDEC, USGS, and CEDEN. The relevant data are constrained by modeled CVHM streams, which in the Southern San Joaquin Valley include the Kern River, Kaweah River, Kings River, Fresno Slough, Tule River, and Los Gatos Creek. The data were screened to remove surface water quality points that were not representative of these rivers such as tile drains and irrigation canals. No water quality data were found for Los Gatos Creek in IAZ 14 (Westside and Northern Pleasant Valley). For all other modeled CVHM streams, there are 3 to 5 representative USGS or CEDEN monitoring sites that have TDS, chloride and nitrate (as N) data with periodic grab sample data. Annual water quality data for years missing data were interpolated as described later within the report.

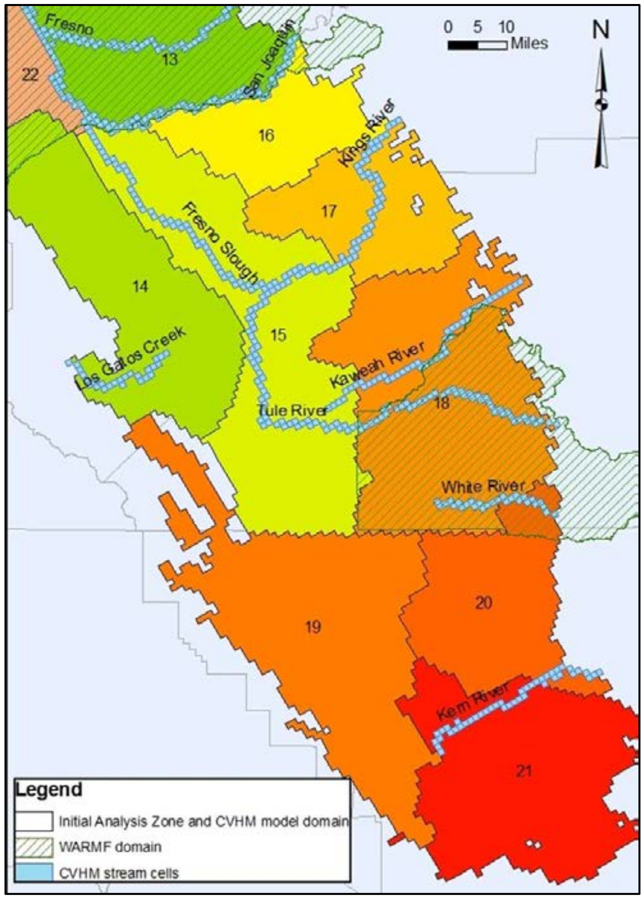


Figure 3-5. Non-WARMF Areas 14 to 21 (Southern San Joaquin Region)

Where WARMF coverage borders IAZ 16 and IAZ 18, San Joaquin River and the upstream portion of the Tule River respectively, water quality was obtained from WARMF. WARMF data in these areas were used to compute a full data set from 1983 to 2003 for TDS, chloride, and nitrate (as N). Since WARMF coverage is used in these areas, there are no data gaps.

3.3 INPUTS FOR MASS LOADING ESTIMATES

This section contains background on mass loading estimates employed in the ICM. Mass loading comes in several forms:

- Dissolved constituents in applied water. This is captured in WARMF because water and solutes are tracked as water flows through the watershed, and WARMF is explicit about the sources and quality of water applied for irrigation.
- Atmospheric deposition. This is also estimated in WARMF.
- Point source discharges. These permits (above a certain threshold size) are reflected in WARMF loadings.
- Permitted land application of dissolved or suspended constituents in municipal or industrial wastewater or solids. These permits (above a certain threshold size) are reflected in WARMF loadings.

- Other materials applied directly to land to grow plants, or added to water during irrigation as a water-borne application method. These fertilizers and amendments are explicit inputs to WARMF, tied to each land cover class as a characteristic.

Facets of mass loadings described in this section include the following:

- Land cover classes
- Land application loadings in the WARMF model (includes permitted and non-permitted loading to land)
- Point sources of loading

Additional, more detailed land cover and loading input data are provided for reference in **Appendix C**. It should be noted that these data are part of the WARMF models whose output was employed in the ICM. The only aspect of the loading that was modified as part of this project was the N mass loading. This modification is discussed in detail, and related data are in **Appendix C**.

Land Cover Classes in the WARMF Models

Mass loading is highly dependent upon land cover. Irrigation water is an important source of salt and nitrate. The amounts applied to the land in irrigation water depend on the water source but are also directly proportional to the amount of water applied, which depends on the needs of the crop. Significant land areas in the Central Valley are natural land covers, fallow land, and impervious areas that do not require irrigation at all. The nitrogen land application rate is also highly dependent on the crop and is a significant source of nitrate. For these reasons, it is important to have an accurate representation of land cover throughout the Central Valley to estimate mass loading.

Collection of land cover data had already been performed for previous applications of the WARMF model (Systech Water Resources 2011(a), Systech Water Resources 2011(b)). Land cover in irrigated areas was derived primarily from the DWR land cover database, which has spatially detailed information about agricultural land uses distinguishing between individual crop types. The DWR land use was replaced with county-level land use data in urbanized areas. The National Land Cover Database was used for natural land cover. Detailed processing was performed to delineate dairy sites and their corresponding land application areas. The GIS processing method is described in the CV-SALTS Salt and Nitrate Sources Pilot Implementation Study report (Larry Walker & Associates et. al. 2010). The resulting GIS coverage was imported into WARMF and overlaid with its catchment boundaries to determine the percentage of each land use in each catchment.

Land cover, whether agricultural, urban, commercial/industrial, or “natural” (e.g., grasslands, forests) is categorized into around 30 classes (depending on the area) in the WARMF model runs that were employed. Classes were originally selected to reflect the breadth of activities and environments in each area, and therefore differ slightly among the Sacramento Valley, San Joaquin River, and Tule River WARMF models. However, in all cases, the classes collect areas with similar conditions from the standpoint of salt and nitrate loading. For example, agricultural crops that are irrigated and fertilized in similar ways are contained in one class, and urban areas with similar intensity of landscaping are also in a single class.

Land Application Mass Loadings in WARMF Model

The ICM Workplan stipulated that existing (and no new) WARMF model runs would be employed. These runs were developed during modeling efforts funded by previous projects, and their use is a technical and budgetary efficiency for the current project. Although most inputs remained unaltered, substantial changes to certain inputs were developed for the purposes of this project, and new runs were executed for every existing WARMF model. Exceptions are clearly noted in the following subsections.

Amounts of irrigation water, solid salt (amendments and fertilizers), and nitrogen (as inorganic or organic fertilizer) are parameters associated with each land cover class, and were determined as part of WARMF model development as part of previous projects. Revision of these pre-existing WARMF models was generally beyond the scope of this work. However, some work was done on selected parameters:

- Nitrogen fertilization and uptake inputs were reviewed in light of new data sets (Rosenstock, 2013 and Harter, T. 2013 personal communication). WARMF models were re-run with these revised inputs, and outputs from these runs were employed for this project.
- WARMF model outputs were post-processed to examine mixing model sensitivity to salt and nitrate loading rates.

Both of these points are described in greater detail in Section 8 and **Appendix D**.

Additional documentation of inputs is provided in reports that were developed for projects under which each WARMF model was originally funded (Systech Water Resources 2011(a), Systech Water Resources 2011(b), Larry Walker Associates et. al. 2010). Explanation here is generic, in that it applies to all WARMF models that were employed for this project.

Solid Salt

Solid salt includes the following:

- Total fertilizer mass
- Soluble, non-volatile portions of other salts (amendments) added, including soluble salts in manure

Inputs from previous models were retained. These were developed from a combination of recommended application rates, checked in some cases against reported fertilizer and amendment sales records. As noted later, data regarding actual applied quantities of fertilizer or amendments are not systematically collected or compiled in the study area, and thus such data were unavailable at the time of this analysis. The data used represent the best currently available estimate of actual fertilizer and amendment application and crop uptake data.

Nitrogen from Fertilizer

Nitrogen (as nitrate-N or ammonium-N, with urea classes as the latter) from combined inorganic and organic fertilizer sources is a key WARMF input parameter. Inputs from previous models were reviewed, along with work by Rosenstock et al. (2013) and data underlying the analysis presented in that study.

The Rosenstock data included estimated N application and uptake for a range of agricultural crop classes in Kings, Kern, and Tulare counties. These were compared with crop classes and rates employed in WARMF models, and used to replace existing N input parameters (which had been less extensively researched and documented) where classes aligned well. However, since these values were developed for the southern portion of the valley, it was appropriate to adjust them somewhat for other areas. To achieve this, several crop classes that span most of the Central Valley were selected, and crop production levels characterized (based on annual crop reports by county Agricultural Commissioners) for counties along a north-south transect. Based on the notions that a) fertilization is generally adjusted in proportion to anticipated crop yield, and that b) uptake is proportional to yield levels, crop fertilization and uptake rates were adjusted to match production data in each of 5 zones.

As mentioned previously, these were the only significant parameter adjustments to previously existing WARMF runs, and their incorporation required re-running of all WARMF models. Outputs from these new runs were used as inputs to the load apportionment process (described later), which in turn served as input to the mixing model.

Permitted Land Application (POTWs)

There are many permitted dischargers in the Central Valley which apply their effluent to the land using a percolation pond or other mechanism. They are generally minor dischargers for which little effluent flow or water quality data are available. Data were collected for previous uses of the WARMF Central Valley model applications (Systech 2011a, Systech 2011b, Larry Walker Associates et. al. 2010). Within WARMF, the flow and associated chemical constituents for each of these dischargers is combined with other flow and mass inputs to the catchment in which they occur and routed to surface water and groundwater recharge dynamically. There is no distinction in the model between the various methods by which the loading may be applied to the land. Permitted dischargers within the WARMF model domains with data are listed in **Table 3-3**.

Table 3-3. Permitted Land Dischargers with Data in WARMF Model Domains

Name	County	Lat	Long	Mean Annual Flow (cfs)	Mean Nitrogen Load (kg/d)	Mean TDS Load (kg/d)
Pacific Coast Producers	Yolo	38.66	-121.69	0.9	7	1,653
Esparto CSD	Yolo	38.71	-122.00	0.6	15	1,525
Madison SD	Yolo	38.71	-121.96	0.2	6	597
Modesto WQCF	Stanislaus	37.52	-121.09	22.8*	453	18,397
CAG45 Inc.	Stanislaus	37.60	-120.98	1.6	42	1,892
City of Ceres	Stanislaus	37.58	-120.98	2.8	75	3,405
Hilmar Cheese	Stanislaus	37.42	-120.85	1.1	90	3,222
City of Hilmar	Stanislaus	37.39	-120.82	1.2	33	1,515
City of Hughson	Stanislaus	37.62	-120.87	1.2	33	1,515
City of Riverbank	San Joaquin	37.74	-120.95	11.6	313	14,196

Name	County	Lat	Long	Mean Annual Flow (cfs)	Mean Nitrogen Load (kg/d)	Mean TDS Load (kg/d)
City of Waterford	Stanislaus	37.63	-120.77	1.6	42	1,892
City of Oakdale	Stanislaus	37.77	-120.85	3.7	100	4,546
Hershey Foods Corp	Stanislaus	37.75	-120.84	7.0	207	9,371
Santa Fe Aggregates, Inc.	Stanislaus	37.65	-120.67	1.6	0	1,136
7 11 Materials, Inc.	Stanislaus	37.64	-120.63	0.7	0	546
Foster Farms	Stanislaus	37.40	-120.73	5.9	151	7,911
Hughson Nut Company	Stanislaus	37.62	-120.88	2.0	60	2,705
City of Lindsay	Tulare	36.22	-119.02	1.9	85	2,137
City of Porterville	Tulare	36.08	-119.05	7.4	327	8,273
City of Exeter	Tulare	36.24	-119.11	1.7	73	1,844
Pixley PUD	Tulare	35.96	-119.31	0.4	27	397
Earlimart WWTF	Tulare	35.89	-119.31	1.2	55	1,379
Strathmore PUD	Tulare	36.14	-119.08	0.5	28	425
Terra Bella	Tulare	35.97	-119.04	0.6	27	689
Woodville WWTF	Tulare	35.97	-119.04	0.2	10	259
Tipton CSD	Tulare	36.06	-119.33	0.6	27	689
Sunkist Growers, Inc.	Tulare	36.05	-119.32	1.2	71	1,652
Sworlco Land Application Site	Tulare	36.20	-119.08	0.7	43	991

*Modesto WQCF discharges to land on a seasonal basis, but flow rate shown is averaged over the whole year.

Irrigation Water

The mass loading of constituents in irrigation water is dependent upon the source and the quantity of applied water. Applied water rates were estimated for each land use type when the WARMF model was set up for each of its three model domains in the Central Valley (Systech 2011a, Systech 2011b, Larry Walker Associates et. al. 2009). The various irrigation sources were then linked with the applied water demand. It was assumed that surface water would be used first to meet the demand. Land within irrigation district boundaries was linked to the surface water diversions of those districts. Riparian diversions were then created to meet the irrigation demand of land outside districts adjacent to major rivers. Any demand unmet by surface water sources was assumed to be met through groundwater pumping in the vicinity of the demand.

The quality of irrigation water depends on the source. Irrigation supplied from surface water retains the quality of the diversion sources. Irrigation applied within the WARMF model domain generally has its sources within the model domain as well. Simulated water quality at the diversion point is used for the irrigation water quality. The water quality of diversions outside the

WARMF model domain is estimated from available data. The quality of groundwater used for irrigation for each catchment is the average of USGS well data from within the catchment.

Atmospheric Deposition

The concentrations of various constituents in air and rain are used as inputs to the WARMF model. For the Central Valley WARMF applications, rain concentration data are from the National Atmospheric Deposition Program (NADP). Air concentrations and deposition velocities are from the Clean Air Status and Trends Network (CASTNET). NADP stations used for the Central Valley WARMF applications are Lassen Volcanic National Park, Sagehen Creek, Hopland, Davis, Yosemite National Park, and Sequoia National Park. CASTNET data were available from Lassen, Yosemite, and Sequoia National Parks. Additional atmospheric dry deposition was calculated by WARMF from the dissolution of carbon dioxide to form aqueous inorganic carbon, in surface waters. Inorganic carbon is a component of measured total dissolved solids. The amount of deposition was calculated by the model as a function of pH, inorganic carbon concentrations, atmospheric carbon dioxide concentration, and re-aeration rate.

Point Sources

Discharges to surface water are permitted under the National Pollutant Discharge Elimination System (NPDES). Available data for point sources had been collected in previous studies and incorporated into the WARMF model (Systech 2011a, Systech 2011b, Larry Walker Associates et al., 2010). **Table 3-4** lists the surface water dischargers with data in the WARMF model domains. Most dischargers have only recent data which has been extrapolated backward to the 1983-2003 analysis period. There are many additional permitted dischargers for which there are no data. Zero flow and loading are assumed for all dischargers with no data.

3.4 SUMMARY

The ICM depends on accounting for surface water quality, groundwater quality, and mass inputs for the entire Central Valley. Available data were collected from many data sources to create a dataset as complete as possible, but locations without the various types of data were identified.

Table 3-4. Permitted Surface Water Dischargers with Data in WARMF Model Domains

Name	County	Lat	Long	Mean Annual Flow (cfs)	Mean Nitrogen Load (kg/d)	Mean TDS Load *kg/d)
Anderson WPCP	Shasta	40.47	-122.28	2.4	34	866
Clear Creek WWTP	Shasta	40.50	-122.37	12.6	474	7,235
Cottonwood WWTP	Shasta	40.40	-122.25	0.2	2	142
City of Redding	Shasta	40.47	-122.29	4.3	418	2,840
Shasta Lake WWTP WQC	Shasta	40.66	-122.39	1.98	39	476
Corning WWTP	Tehama	39.91	-122.12	1.26	52	1,273
Molded Pulp Mill ISW	Tehama	40.17	-122.23	2.4	(1)	(1)*
City of Red Bluff	Tehama	40.16	-122.22	1.8	77	2,032
Willows WWTP	Glenn	39.50	-122.19	1.35	71	1,403
Colusa WWTP	Colusa	39.25	-122.06	0.8	9	646
Maxwell PUD	Colusa	39.28	-122.19	0.02	<1	13
SC-Oroville WWTP	Butte	39.49	-121.56	4.8	149	3,854
Chico WWTP	Butte	39.68	-121.93	11.7	329	11,170
City of Live Oak WWTP	Sutter	39.26	-121.68	0.85	84	1,650
Yuba City WWTP	Sutter	39.11	-121.61	8.9	387	7,191
Beale Air Force Base	Yuba	39.13	-121.39	0	<1	(1)
Linda CO. Water District Water Pollution Control Plant	Yuba	39.10	-121.58	1.86	135	2,690
Olivehurst PUD WWTP	Yuba	38.89	-121.11	3.5	85	2,941
Nevada City WWTP	Nevada	39.26	-121.03	0.8	7	517
Auburn WWTP	Placer	38.89	-121.10	2.2	67	1,164
Lincoln	Placer	38.90	-121.34	5.4	31	3,823
Placer County SMD 1 WWTP	Placer	38.96	-121.11	2.9	37	(1)
Placer CO DFS	Placer	38.80	-121.13	2.6	127	2,356
Pleasant Grove WWTP	Placer	38.79	-121.38	11.8	217	10,063
Roseville WWTP CITY OF	Placer	38.74	-121.29	16.6	1,034	10,741
Sacramento Regional Sanitation Dist.	Sacramento	38.45	-121.46	243	9,363	138,640
Cache Creek Indian Bingo	Yolo	38.73	-122.14	0.3	21	442
City of Woodland WWCF	Yolo	38.66	-121.87	8.8	2,274	22,092
City of Davis STP	Yolo	38.59	-121.67	10.2	168	24,385
University of California Davis	Yolo	38.54	-121.75	2.9	108	8,589
Modesto WQCF	Stanislaus	37.52	-121.09	15.4(2)	374	12,495
City of Turlock WWTP	Stanislaus	37.49	-120.87	17.5	1,086	24,494

1 Discharge has flow data but not nitrogen and/or salinity data

2 Modesto WQCF discharges directly to surface water on a seasonal basis, but flow rate shown is averaged over the whole year.

4. Methodology for ICM Inputs to the Water, Salt, and Nitrate Balance Calculations

This section discusses the methodology employed for the ICM IAZ analysis of water, salt, and nitrate for the Central Valley floor. The methodology has previously been reported in the Task 5 Report, which is summarized below. Additional or supplemental descriptions of methodologies employed to estimate ambient groundwater quality, surface water quality, and mass loadings for groundwater recharge are included in this section. Steps taken to perform the water, salt, and nitrate balance calculations are detailed below, along with the description and population of the data decision matrix for determining the suitability of the available data for the purpose of the balance calculations.

4.1 SUMMARY OF TASK 5 REPORT

The methodologies developed for the ICM to assess water, salt, and nitrate balances for the Central Valley floor are detailed in the Task 5 ICM Report[40] and Task 5 Addendum[41]. They begin with the methodology for assessing the available salt and nitrate groundwater and surface water data. This methodology consists of organizing salt and nitrate concentration data by IAZ using GIS tools. Maps and tables produced in Task 3 were incorporated in this effort to assist in the assessment, including descriptions and statistics on:

- The number of sites (groundwater and surface water);
- The date range of salt and nitrate data;
- The number of salt and nitrate samples;
- Summary statistics including minimum, maximum, average, median, and standard deviation values of salt and nitrate concentrations;
- Maps showing the locations of groundwater and surface water quality sample sites depicted by data source; and
- Maps illustrating the availability of salt and nitrate data using graduated symbol sizes to show the relative number of samples collected in each IAZ.

Biases may occur in the various groundwater and surface water quality datasets. Task 5 methodologies propose several ways of detecting the occurrence of bias in the datasets, including biases in the:

- Frequency of data collection (temporal limitations);

[40] Initial Conceptual Model (ICM) Technical Services, Task 5 – Recommended Methodologies to Assess Water, Salt, and Nitrate Balances for the Central Valley Floor and Two Prototype Areas Report, December 2012.

[41] The Task 5 Addendum was produced based on the review of the Task 5 Final Report by CV-SALTS that an addendum would be added to provide clarification regarding the WARMF-CVHM linkage.

- Date range limitations (temporal limitations);
- Location of data points (spatial limitations);
- Vertical distribution (or lack of knowledge of vertical distribution) among the groundwater dataset (spatial limitations);
- Surface water quality biases; and
- Questionable data, insufficient QA/QC.

The methodology for determining the ambient salt and nitrate concentrations attempts to overcome these limitations and biases in the datasets. For the groundwater dataset, well construction or well use information is used to separate data into distinct vertical zones. Methods to decluster groundwater quality data are utilized to ensure that summary statistics over the region will not be skewed by high data densities and better reflect ambient conditions for the region. More details on the methodology are presented later in this report.

The methodologies recommended in the Task 5 report for determining ambient surface water quality include a) using information from the WARMF models (where coverage exists), and b) using data from representative surface water monitoring sites where WARMF model coverage does not currently exist.

A data/decision matrix is described and outlined in the Task 5 Report to identify the IAZs where salt and nitrate concentrations are elevated (above drinking water standards) and/or increasing trends are indicated in surface water and/or groundwater. These “hotspots” are identified using a matrix that indicates which IAZs have: 1) expansive well-defined datasets or 2) spatially, temporally, or otherwise limited datasets.

The Task 5 report also details the volumetric components of water movement within and between IAZs. These components are developed from the hydrology of the USGS-calibrated CVHM model output. Flow values of water budget components are extracted from CVHM model output using a post-processor (Zonebudget), and converted to volumes by multiplying the flow by the time period the flow value represents. Mass budget components are linked to these volumetric components either by converting concentrations to mass (concentration times volume equals mass), or for the mass loading recharge component, which comes from the WARMF model output.

4.2 ESTABLISH AMBIENT GROUNDWATER QUALITY FOR EACH IAZ

Estimating the ambient groundwater quality for small spatial areas with high spatial resolution of data is often performed using an interpolation method to interpolate values between known data. However, the size of the IAZs in this study, compared to the amount of spatial data available, did not allow for this type of analysis. Shallow well data are often several to 10’s of miles apart, and the uncertainty of the quality between the known data points is too great. Most of the land use in the Central Valley is agricultural land, with agricultural and domestic wells being the most common well types in this setting. Well test data from these types of wells are extremely limited as the results are generally not reported to databases that are available to the public. Of the well test data that are available, the spatial extent for any given time period is sparse. For example, **Figure 4-1a** shows the locations of all nitrate tests for IAZs 1-7 for shallow groundwater, for all time periods. When this is limited to a few years around the starting point of the mixing model, the data become significantly limited as shown in **Figure 4-1b**. Even if the time period is extended to a 15-year time period around the starting date (**Figure 4-1c**), the data remain limited. Large spatial gaps still remain between most well tests.

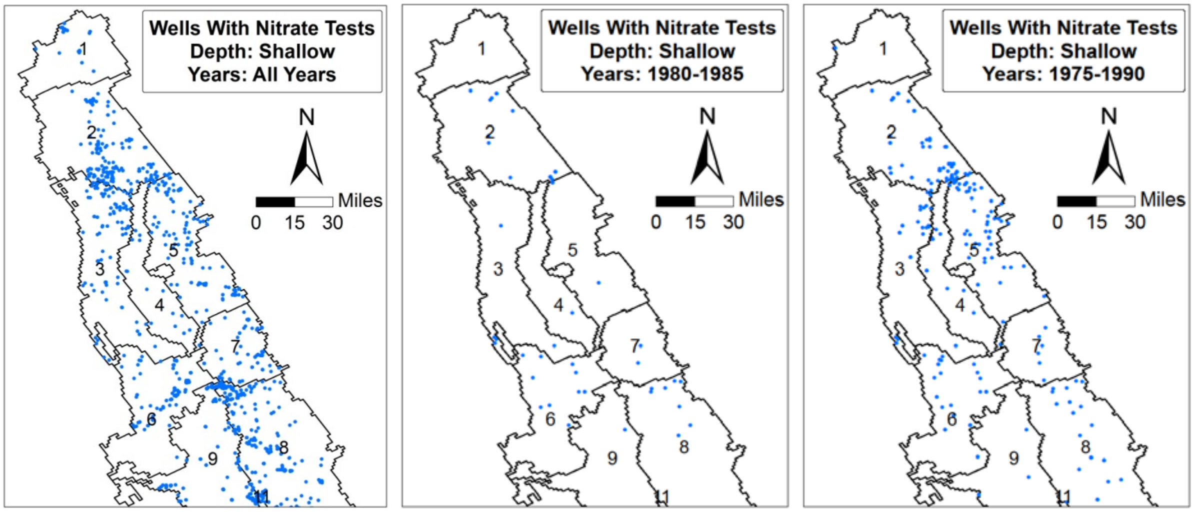


Figure 4-1. Wells with Nitrate Tests: a) All Years, b) 1980 to 1985, c) 1975 to 1990

Declustering the Data Using the CVHM Grid

Rather than using an interpolation method to estimate data at unknown points, the data were treated as a small sample of the groundwater quality. As **Figure 4-1** indicates, the well data tend to be clustered; this means there are some areas with a higher density of well data than other areas. Declustering was used to remove some of the spatial bias in the data by limiting the influence of clusters of data.

The well test data were de-clustered using the CVHM model 1 mi^2 grid. This was to avoid spatial bias from groups of wells located close to each other. Clusters of wells may over-represent the water quality for a particular area if each well is given equal weight in statistics performed over a large area. Additionally, some wells are tested much more frequently than others, resulting in ‘temporal’ clustering. Therefore, grid cells containing well data were assigned annual concentration values, and statistics were then performed on the annual grid cell values, rather than the wells.

To de-cluster the well test data temporally, wells were first assigned an annual concentration, based on the median of available tests for a well within a given calendar year. Next, the median of the annual well medians contained within a grid cell was assigned to the cell. When none were available for a given year for a grid cell, no value was assigned. This was performed for both nitrate and TDS, and for both shallow and deep depths.

Transforming the Data

The annual CVHM cell medians, when plotted in a histogram, show that the values for both nitrate and TDS is not normally distributed. It is highly skewed to the right, which means it has a “tail” of high values. High values can bias statistics toward higher values; therefore, the data were transformed using a log of base 10, i.e., $\log_{10}(c)$ where “c” is the concentration. The distributions of the annual CVHM cell median concentrations are shown below in **Figure 4-2**. The distribution of the log10 transformed values is shown in **Figure 4-3**. The log values of -1, 0, 1, 2, and 3 represent concentrations of 0.1, 1, 10, 100, and 1000. Therefore the log value of 1 is the drinking water limit for nitrate at 10 mg/L NO_3-N, and a log value of about 2.7 corresponds to 500 mg/L, the drinking water standard for TDS.

The fitted normal distribution shown in red indicates that the log10 transformed values approximately follow a normal distribution; however, the TDS is slightly positively skewed and the nitrate is slightly negatively skewed compared to the normal distribution. The large number of tests in the bin at -1.0 for nitrate corresponds to a value of 0.1 mg/L NO_3-N, which was the value assigned to tests that resulted in a non-detection of nitrate and where the detection limit was not provided. Similarly, non-detections for TDS were assigned a value of 10 which corresponds to a log10 value of 1. The log10 transformed values were used in the analyses for establishing ambient concentrations, with the final results being back-transformed to the original units, i.e., $10^{\log10(c)}$.

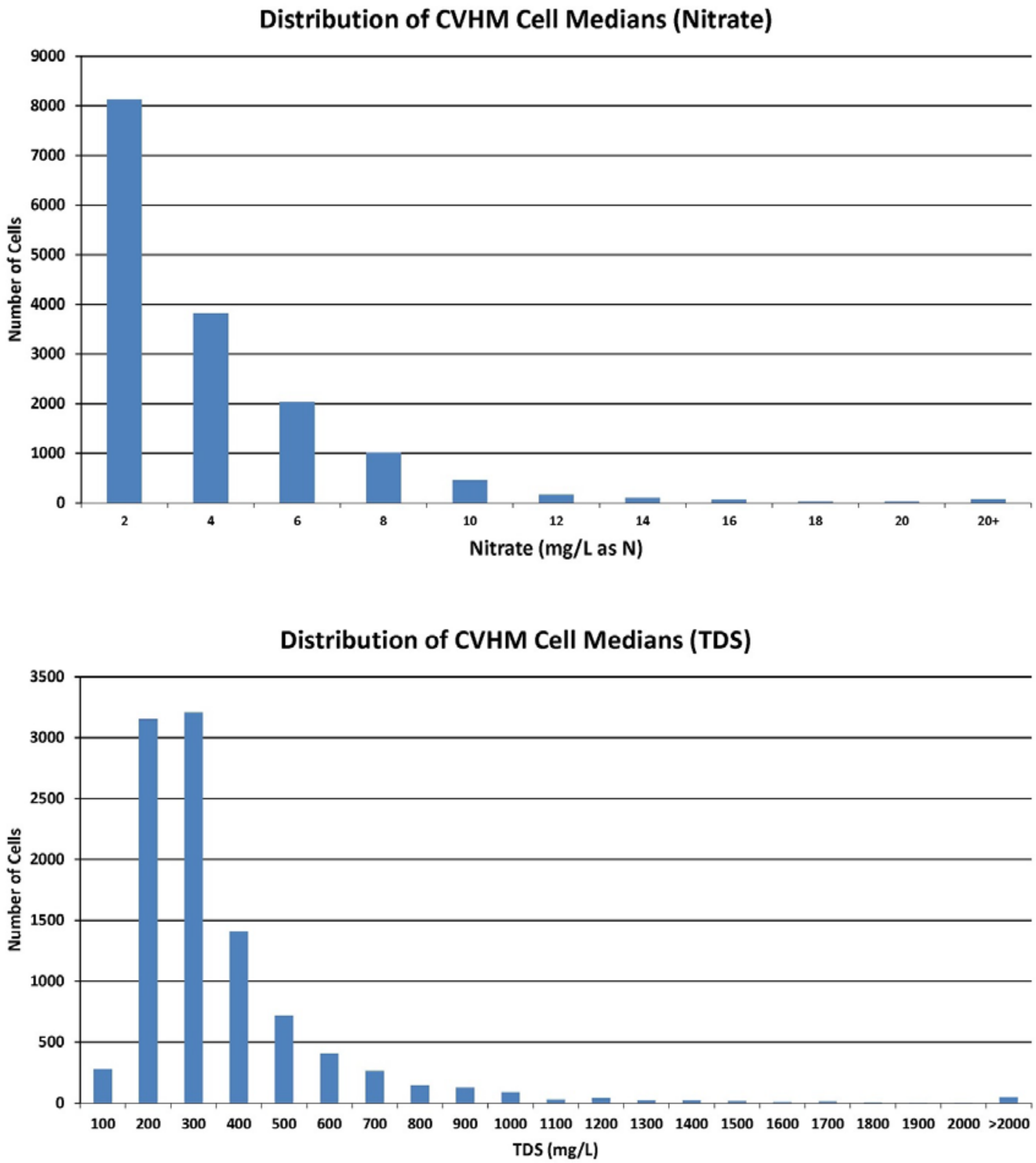


Figure 4-2. Annual CVHM Cell Median Concentration Distribution

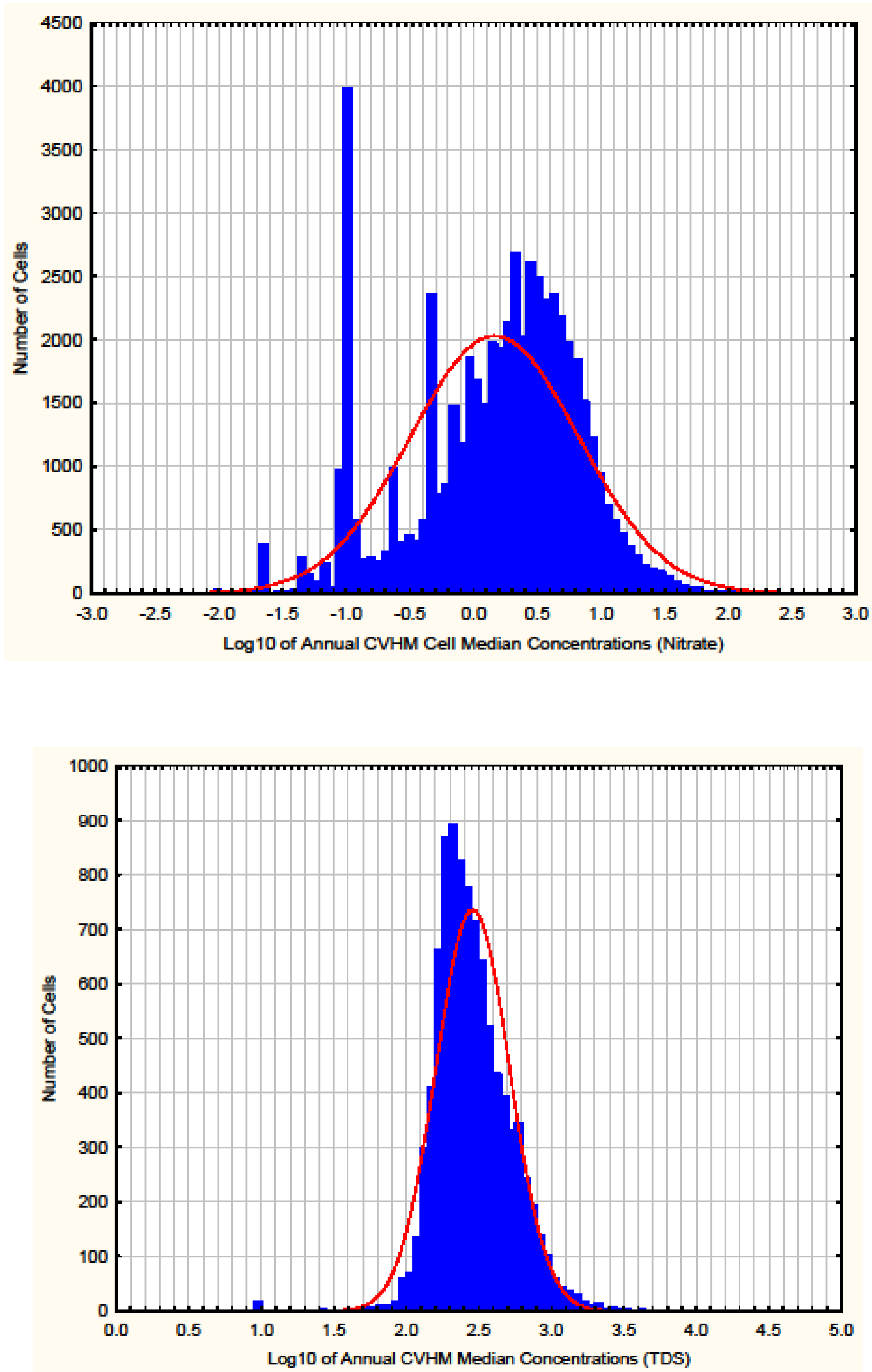


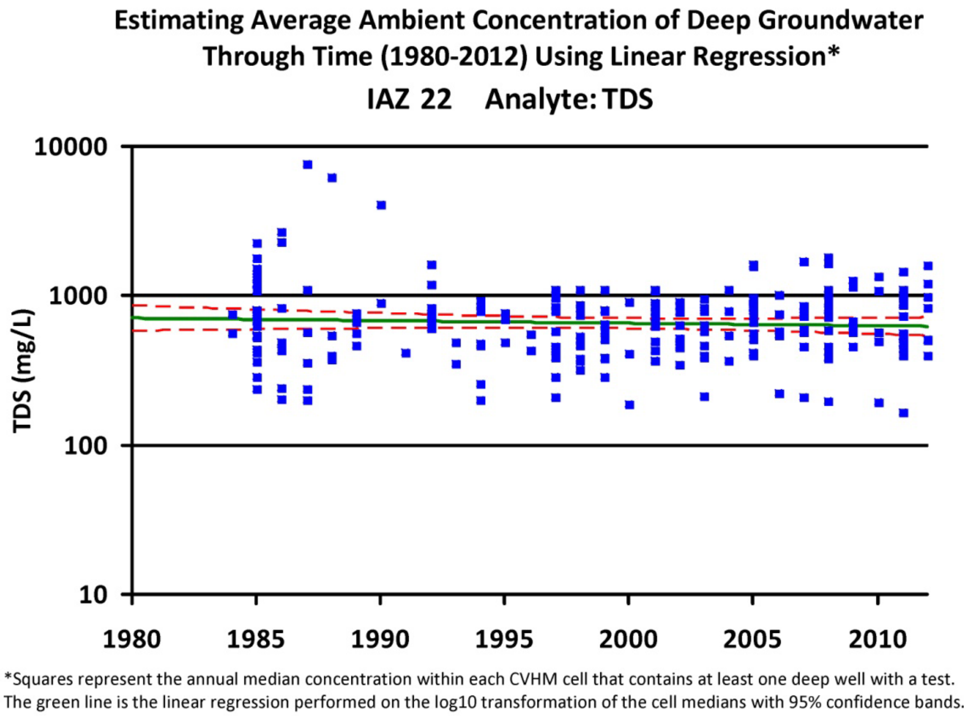
Figure 4-3. Log10 Transformed Values Distribution

Estimating Deep Concentrations Through Time

Portions of the CVHM model contain regions with upward pressure gradients, which indicate that in some locations deep groundwater flows upward into shallow groundwater. To account for the influx of water and solute mass to shallow groundwater, ambient groundwater quality for the deep portion of the aquifer was estimated for the model time period.

Linear regression was used to estimate the average concentration of deep groundwater in each IAZ. Data from 1980 to 2012 were included in this analysis.

Figure 4-4 shows an example of the results for IAZ 22 for nitrate and TDS. Results for all IAZ's are located in **Appendix E**. Linear regression (shown as a green line), and 95% confidence bands (shown as dashed red lines) are shown along with the annual CVHM grid cell median concentrations (blue squares) for the deep well test data. **Table 4-1** provides a qualitative assessment of apparent trends in the deep ambient data for each IAZ. The confidence intervals show the possible range for which the linear regression could lie, and for IAZs where the confidence intervals overlap at the beginning and ending time periods, no trend is distinguishable from the analysis. The concentrations estimated by the linear regression were assigned to the deep groundwater quality for each quarterly time period in the mixing model.



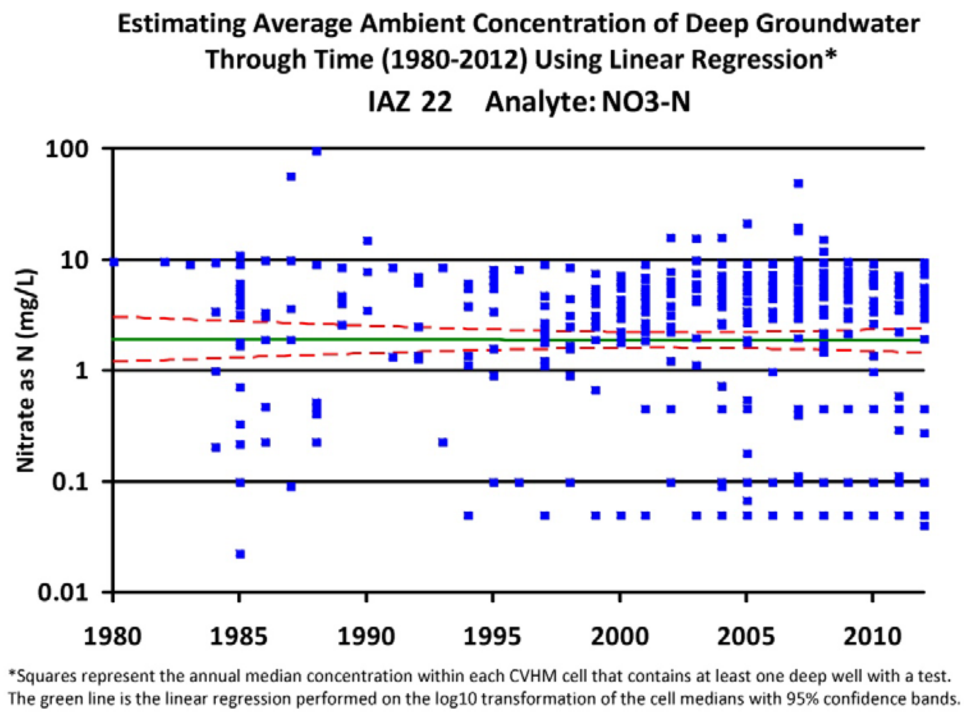


Figure 4-4. Example of IAZ 22 Results for TDS and NO3-N

Table 4-1. Summary of Deep Ambient Groundwater Quality Trends

IAZ	Trend for Nitrate	Trend for TDS
1	Slight increasing trend	No apparent trend
2	No apparent trend*	No apparent trend
3	No apparent trend	No apparent trend
4	Slight decreasing trend	No apparent trend
5	No apparent trend	No apparent trend
6	No apparent trend	No apparent trend
7	Slight increasing trend	No apparent trend
8	Increasing trend	No apparent trend
9	Slight decreasing trend	Slight increasing trend
10	No apparent trend	No apparent trend
11	No apparent trend	No apparent trend
12	No apparent trend	No apparent trend
13	Slight increasing trend	No apparent trend
14	No apparent trend	No apparent trend
15	Increasing trend	No apparent trend
16	No apparent trend	No apparent trend
17	No apparent trend	No apparent trend
18	Slight increasing trend	No apparent trend
19	Slight increasing trend	No apparent trend
20	No apparent trend	No apparent trend
21	Slight increasing trend	No apparent trend
22	No apparent trend	No apparent trend

*No apparent trend here is defined as when the beginning and ending confidence intervals overlap.

Estimating Initial Shallow Groundwater Quality

Shallow ambient groundwater quality data were very limited for the Task 6 analysis (**Figure 4-1**). Shallow groundwater quality is highly variable and the spatial extent of available data did not permit the use of interpolation techniques as well data were very sparse and generally several 10s of miles apart. The annual median concentrations for shallow wells located within a CVHM cell were used to estimate ambient shallow groundwater quality (see Section 4.2 regarding declustering method). Due to the limited shallow groundwater quality data in space and in time, all shallow data within an IAZ were included in estimating a starting concentration for the mixing model. The initial concentration for shallow groundwater was estimated by taking the average of the shallow annual CVHM grid cell median concentrations for each IAZ over all time periods.

Initially, starting masses for each IAZ were calculated using only data from around the 1983 starting period. This resulted in many of the estimated initial masses to be either very large, or very small, as the calculations were based only a very small amount of well test data. When data were included from all time periods, the initial masses better reflected the overall water quality for each IAZ, and thus provided an appropriate initial starting point for the mixing model.

The shallow groundwater volumes used in the mixing model were established using a 20-year vertical travel distance. Therefore, the final concentration and mass calculated with the 20 year mixing model should only be a reflection of the loading inputs to the model during 20 years. Only the final concentration and final mass were used for identifying priority basins in Section 7, where the results and priority ranking of the IAZs are presented.

4.3 ESTABLISH AMBIENT SURFACE WATER QUALITY FOR EACH IAZ

Ambient surface water quality was determined using simulation output from WARMF (where coverage exists) and from representative surface water monitoring sites where WARMF coverage does not currently exist. Constituents evaluated include TDS and nitrate; chloride masses were calculated where enough data are available. When a stream only had water quality data in terms of EC in µmhos/com, then EC was converted to TDS via an appropriate site-specific ratio (if available) or via a standard ratio i.e., TDS = EC * 0.64 (Metcalf and Eddy, Inc. 1991).

For areas with WARMF coverage, salt and nitrate concentrations were extracted from WARMF river reaches that correspond to CVHM stream cells. Using cell-by-cell stream flow volumes obtained from CVHM, a flow-weighted average concentration representing the overall ambient surface water quality was calculated over the entire IAZ.

Areas with WARMF Coverage

For areas with WARMF coverage, salt and nitrate concentrations were extracted from WARMF river reaches that correspond to CVHM stream cells. Using flow volumes obtained from CVHM, a flow-weighted concentration representing the average quality of surface water was calculated over the entire IAZ for each quarterly period between 1983 and 2003.

To characterize ambient surface water quality within the WARMF model domains, WARMF simulation output was used to calculate representative concentrations for each IAZ and each quarterly time step. Each WARMF river segment was assigned to the IAZ in which it falls. WARMF output was processed and aggregate concentrations were calculated by performing flow-weighted averages over all river segments within each IAZ and over all simulation days within each quarterly time step.

Areas without WARMF Coverage

In areas outside the WARMF model domains, average concentrations were determined using water quality data from representative stream monitoring sites on each stream represented in CVHM. For IAZs with stream cells that border WARMF coverages, such as the northern Kings Subbasin bordering the San Joaquin River, concentrations from WARMF were extracted for the cells within the IAZ. Using cell-by-cell stream flow volumes obtained from CVHM, a flow-weighted average concentration representing the overall ambient surface water quality was calculated over the entire IAZ.

South Central Valley Floor

Southern Central Valley floor areas without WARMF coverage include the Westside Subbasin, the Kings Subbasin, Tulare Lake Subbasin, the Kaweah Subbasin, Kern County Subbasin, and the Pleasant Valley Subbasin. In these areas, the major rivers and streams represented in CVHM include the Kings River, Tule River, Kaweah River, Kern River, Fresno Slough, and Los Gatos Creek. Average concentrations were determined using water quality data from representative monitoring sites on each stream represented in CVHM. Where there were enough spatially distributed sites, average concentrations for representative reaches were also calculated. Some rivers, such as the Kern River, do not have any water quality data available in the Central Valley floor, but have monitoring sites at the model boundary (i.e., where the river enters the area overlying the Central Valley groundwater basins). In these cases, the furthest downstream site was assumed to represent concentrations in the entire river. When there were enough data available, water quality data from representative sites were checked for normality, temporal, and seasonal trends to determine appropriate averaging strategies. Gauges with the most complete temporal data set were used; where temporal gaps exist, water quality information was interpolated based on knowledge from available seasonal or temporal trends. For IAZs with stream cells that border WARMF coverages, such as the northern Kings Subbasin, bordering the San Joaquin River, concentrations from WARMF were averaged for the cells bordering the IAZ.

Solano County and Delta Area

Other areas without WARMF coverage include Solano County (south of Putah Creek) and the Delta. As described above, surface water quality can be extracted from WARMF for stream cells that border WARMF coverage areas. For the Delta, representative surface water quality gauges were determined at key points on the Sacramento and San Joaquin Rivers. The Banks and Tracy pumping stations were used to represent average water quality in the Delta IAZ, as the data at these sites represent the resulting quality of the water that flows through the Delta. It is recognized that the Delta is a highly complex flow system which is characterized by high water tables requiring drains to drain soils on Delta islands.

South Central Valley Floor

There are two IAZs, the Kaweah/Tule (IAZ 18) and Cache/Putah (IAZ 6), where just half of the IAZ area has WARMF coverage. For these IAZs, concentrations obtained from WARMF and from representative monitoring sites were used and a flow-weighted average was then computed over the entire IAZ. Ambient surface water quality concentrations for all IAZs were used for the surface water balance calculations for the mass components associated with stream leakage, flow to adjacent IAZs, and surface water diversions/deliveries.

QA/QC Process Used to Validate Data for Use at Emmaton and Banks

Sacramento River at Emmaton

At Sacramento River at Emmaton, EC data were downloaded from CDEC. Daily and hourly EC data were obtained from CDEC for Harvey O. Banks Delta Pumping Plant (Station ID HBP). Daily and hourly EC data were reviewed for EC values that represent missing or non-useful data. EC data values reported as “m” (missing), “0” (zero), or negative values were deleted from the data set. Data from January 1, 1990 through December 31, 1994, were reported in units of mS/cm. These data were converted to µS/cm to be consistent with the rest of the data set. EC data values between 1 and 50 µS/cm were deleted from the data set as they very likely represent erroneous data (EC of drinking water ranges from 40 to 50 µS/cm). Hourly data were averaged by day to generate daily EC data that could be merged with the data reported as daily EC. Outlier results were observed when plotting time series of the data and results were deleted that appeared to be obvious transient spikes or dips in the data. Any data reported as <RL were assumed to be equal to the reporting limit; less than 5% of any of the data-set was reported as ND.

Harvey O. Banks Delta Pumping Plant

EC, Cl, NO_3, and TDS data collected at the Harvey O. Banks Pumping Plant (Station ID KA000331) were downloaded from the Department of Water Resources Water Data Library (DWR WDL). EC, TDS, chloride, and NO_3 data were reviewed and null values and duplicates were removed from the data set. With the exception of one NO_3 result reported as “as N”, all other NO_3 data were reported “as NO_3”. When removing duplicate data from all data sets, the higher data value reported on a particular day was kept and the lower data value was deleted. Any data reported as <RL were assumed to be equal to the reporting limit; less than 5% of any of the data-set was reported as ND.

Data Gap Filling Process

Daily data were the minimum temporal unit considered to preserve variability of data. Trends and correlations were evaluated using all daily data for all time-periods (through Qtr. 3 2012) at all sites. Original quarterly means were always used where available and a least squares model was significantly correlated with water year type and quarter to assist in filling in data gaps. When no quarterly measurements were present over a year, these were estimated using the mean predicted value by water year type. If data were normally distributed, it was deemed appropriate to take the average. If data were log-normally distributed, it was deemed appropriate to take the median.

Sacramento River at Emmaton – Sacramento River downstream of Rio Vista (TDS)

Quarterly EC averages were converted to TDS at the end using ratio EC/TDS =1.75, which is the ratio found from Systech’s evaluation of all data in the Sacramento Watershed. The ratio used in WARMF was closer to 1.5 due to the prevalence of low-salinity streams in the upper watershed. A separate analysis was conducted to evaluate the difference in ratios between the Harvey O. Banks Pumping Plant (1.79) and Freeport (1.54), as shown in **Figure 4-5**. With surface water bodies with higher salinity (such as at Banks), the ratio appears to increase. Thus, considering the higher salinity at Emmaton due to tidal influence, it is thought that the 1.75 ratio is a reasonable estimate of the EC/TDS ratio, especially given that there are no data readily available downstream of Rio Vista to compute a site-specific ratio.

- Ratios do change with time, though the distribution of the data is clustered fairly close to the mean and thus the mean value of the data-sets is considered sufficient for this level of analysis
- Incorporation of varying ratios with time could be considered in future phases
- Ratio is significantly correlated with Water Year Type, but linear least squares model yield poor fit (<0.15 R^2)

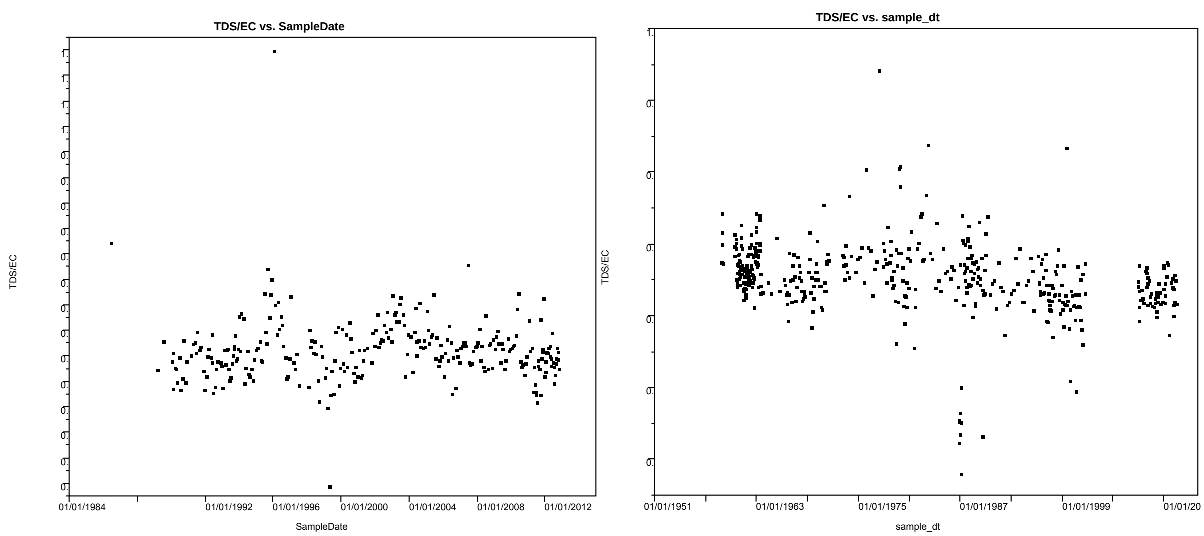


Figure 4-5. TDS/EC Ratio at Harvey O. Banks Pumping Plant and Sacramento River at Freeport

Emmaton - Sacramento River downstream of Rio Vista (chloride)

For the Sacramento River downstream of Rio Vista, no data on chloride were available, therefore a Cl/EC factor was used to convert quarterly EC averages at Emmaton to Cl. Ratios of Cl/EC were evaluated at Banks and Freeport as shown in **Figure 4-6**; Cl/EC ranged from 0.04 at Freeport to 0.14 at Banks. The Freeport ratio of 0.04 was used because the Banks ratio gave unreasonably high Cl values (i.e., higher than any recorded values at Banks), and it was deemed appropriate to use a ratio from the same watershed). The percentage of overall IAZ flow from Sacramento River downstream of Rio Vista is significant, about 30% of total flow for IAZ.

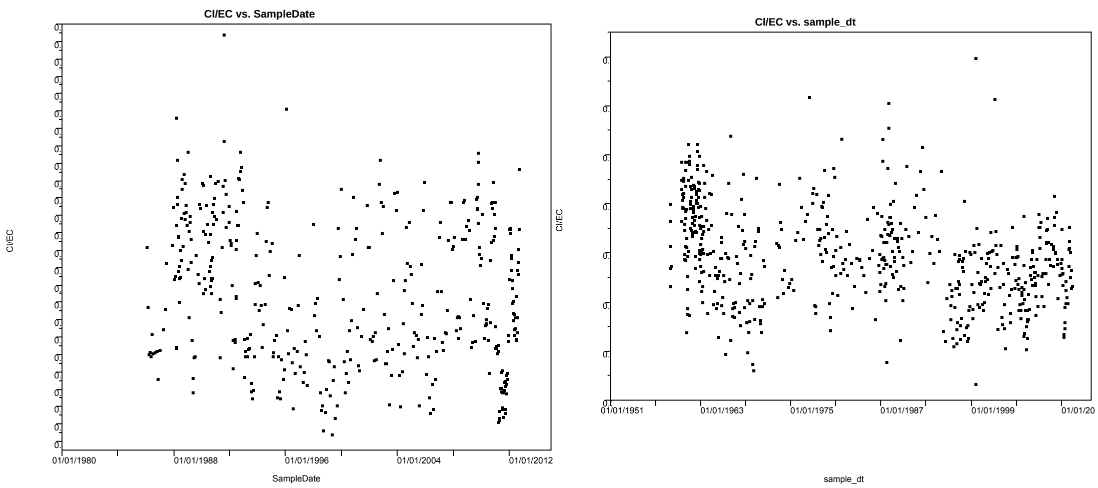


Figure 4-6. Temporal Variation of Cl/EC Ratio at Harvey O. Banks Pumping Plant and Sacramento River at Freeport

Data Gaps and Limitations

Within the study there are areas where the WARMF models do not provide coverage of the Valley floor. In these areas, water quality information from WARMF must be supplemented with data from other sources. The methods utilized to fill in such data gaps vary by location based on proximity to WARMF coverage and prevalence of available water quality information. Flow-weighted concentrations from cells within or bordering non-WARMF IAZs were used to represent concentrations for some streams in non-WARMF areas:

- IAZ 9 – Sacramento River (upstream Rio Vista)
- IAZ 15,16 – San Joaquin River
- IAZ 14 – Los Gatos Creek (no data from Los Gatos; used WARMF values from Panoche Creek)
- IAZ 15 – Lower Tule River
- IAZ 18 – Tule River and White River
- IAZ 20 – White River

Since some streams (particularly Panoche Creek, Tule River, and White River) have intermittent flow, and since concentrations increase as flow decreases, some concentrations for these streams are artificially high, though the effects of the artificially high concentrations will likely be mitigated in the mixing model, as CVHM should (and does) also represent these periods of low-flow.

For example, in IAZ 20, the White River has extremely high modeled concentrations, but this river accounts for less than 1% of the total flow in the IAZ and thus the concentrations in the White River have a very small impact on the overall surface water balance in IAZ 20. Model results were screened where possible for discrepancies between CVHM and WARMF (i.e., if WARMF indicates an unreasonably high concentration (i.e., a low or zero flow), but CVHM indicates significant flows). In these cases, concentrations were adjusted (e.g., average of previous and following realistic quarterly concentrations).

4.4 ESTABLISH MASS LOADING FOR GROUNDWATER RECHARGE COMPONENT

Areas with Pre-existing WARMF Runs

WARMF is a watershed modeling framework which has been set up and calibrated for much of the Central Valley as shown in **Figure 4-7**. WARMF simulates the physical and chemical processes of a watershed on a daily time step to determine concentrations and mass fluxes through near-surface soil layers as shown in **Figure 4-8**.

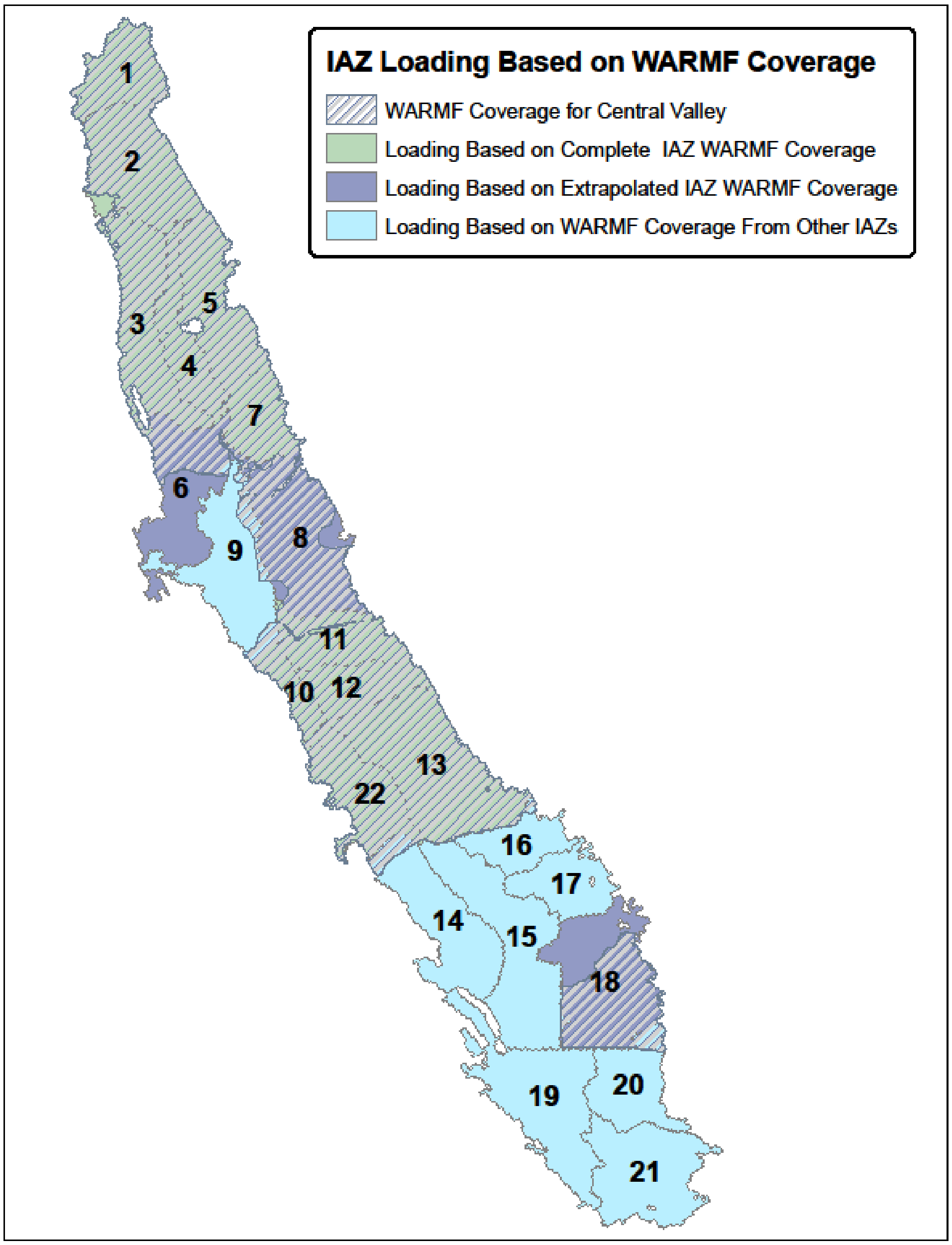


Figure 4-7. IAZ Loading Based on WARMF Coverage

The guiding principles of WARMF simulations are conservation of water volume and conservation of mass. Precipitation and irrigation water percolate into the soil. Within the soil, the water content of each soil layer is tracked dynamically. Above field capacity, water percolates downward and can flow laterally out of the land catchment into a stream (that leaves the land catchment) according to Darcy's Law. Water on the soil or within the soil is subject to evapotranspiration, which is calculated based on temperature, humidity, and sun angle. The amount of water entering and leaving each soil layer is tracked. If more water enters the soil than leaves it, the water content of the soil rises. If the soil becomes saturated, overland flow occurs. The overland flow is calculated by Manning's equation. It is also routed into the stream that leaves the land catchment.

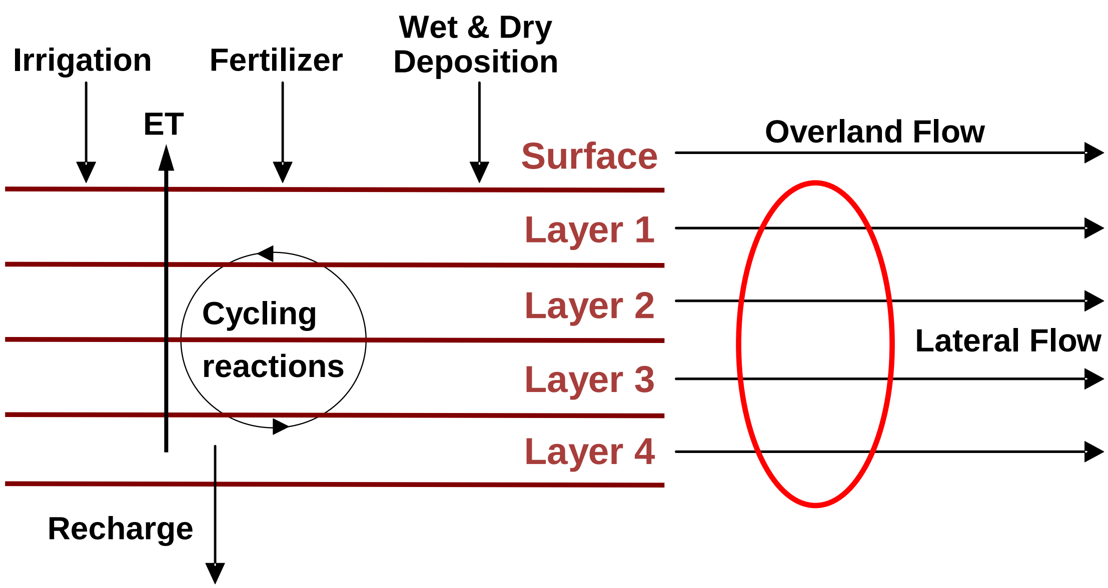


Figure 4-8. Soil Processes Simulated by WARMF

Chemical constituents enter the soil from atmospheric deposition, land application, percolation ponds, and irrigation. Chemical species move with water by percolation between soil layers, lateral flow to rivers, and surface runoff. The land surface and each soil layer within each land use are considered to be a mixed reactor. Within the soil, cations are adsorbed to soil particles through the competitive exchange process. Anions are adsorbed to the soil using an adsorption isotherm. A dynamic equilibrium is maintained between dissolved and adsorbed phases of each ion. Reactions transform the dissolved chemical constituents within the soil. The dissolved oxygen (DO) concentration is tracked, and as DO goes to zero, anoxic reactions take place. When overland flow takes place, sediment is eroded from the catchment surface according to the modified universal soil loss equation. The sediment carries adsorbed ions with it to the river.

WARMF calculates constituent concentrations on the soil surface and in each soil layer. Mass fluxes are the product of those concentrations with the flow rates. For lateral flow, mass flux is the sum of flow times concentration in each soil layer. The mass flux to groundwater recharge is the product of recharge flow and the concentration in the lowest soil layer in WARMF.

Areas without Pre-existing WARMF Runs

While inputs to the mixing model can be derived directly from WARMF analyses in areas where there are existing WARMF models, there are no such, readily available mixing model inputs for areas of the Central Valley that have never been analyzed in WARMF. To address this data gap, as part of this study, water quality parameters (such as those produced by WARMF) were generated for areas where there was no existing WARMF model coverage. This section discusses how this was accomplished. Additional detail is provided in **Appendix C**.

Characterization of Cropping Pattern and Acreage

Input parameters such as salt application, and N application and uptake, are part of the WARMF input data associated with each land cover class, providing the model basic information upon which to base process calculations. Outputs (leaching, runoff, and subsurface recharge to streams) for an area are thus to a large extent dependent on the constituent land cover classes. One of the main differences between two areas, then, will be due to a) differences in the overall area covered (acreage), and b) differences in the land cover blend that make up the acreage in each area. The outputs for one area can thus be estimated from the outputs of the other, if these land cover distinctions are used to establish the estimate. This is the conceptual basis upon which the WARMF-type outputs were estimated for IAZs 6, 9, and 14 to 21 (which are mostly outside the WARMF models' domains), with the help of outputs from nearby WARMF model areas.

Selection of Reference WARMF Catchments

The similarities and differences between non-WARMF and adjacent WARMF areas were evaluated primarily on the basis of crop class blends. The former are reflected in a DWR data set. These parameters are available by detailed analysis unit (DAU, see **Figure 4-9**), which are at a scale somewhat smaller than most IAZ's, but substantially larger than WARMF catchments. DAUs were developed by DWR as the smallest unit of hydrologic analysis in California, and are commonly referenced and employed for this purpose. For this reason, some of their boundaries are similar to those in CVHM, which form the boundaries for IAZs.

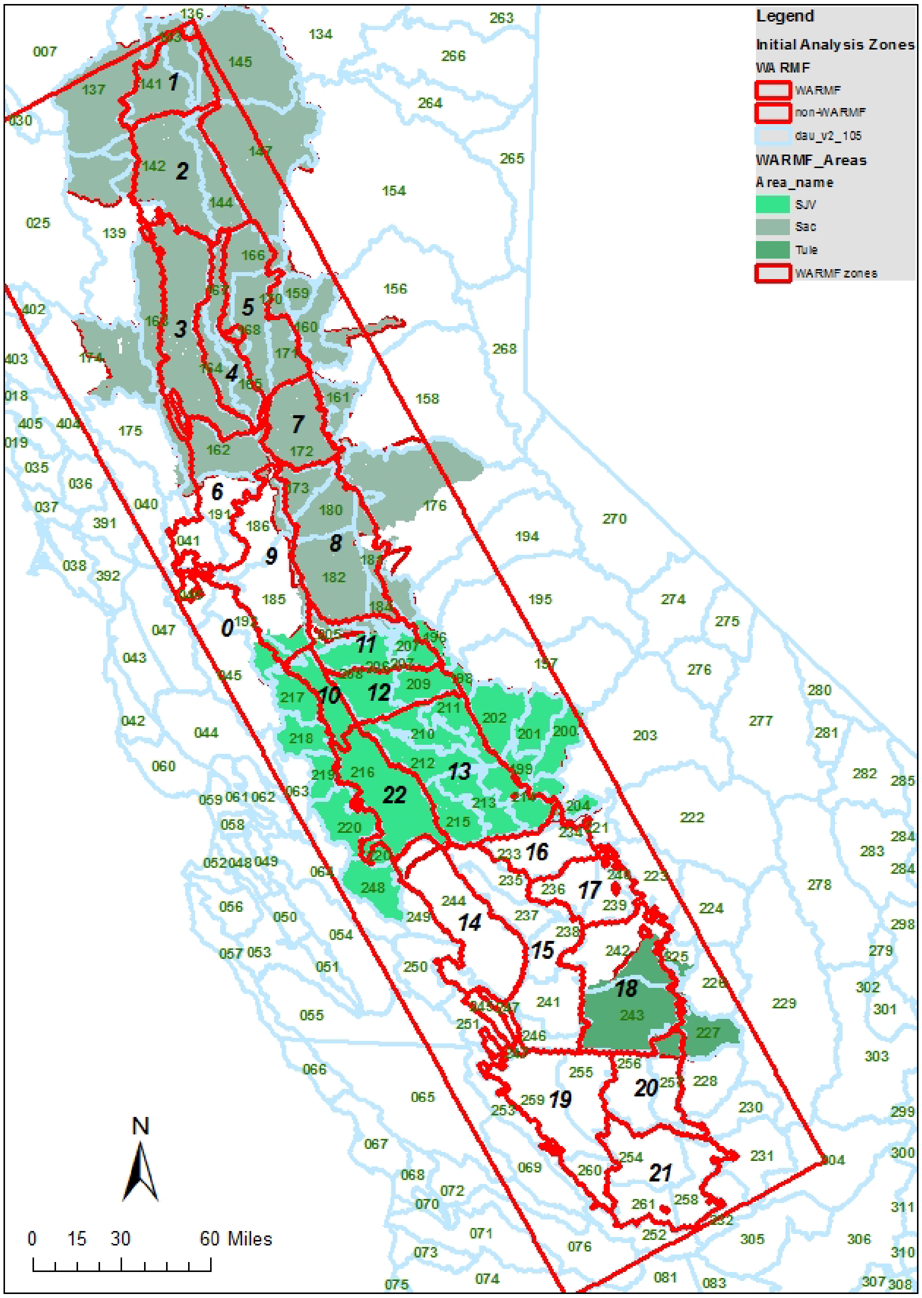


Figure 4-9. California DAU's as Compared to IAZ Coverage

Land application of dairy waste does not appear in these data, but data from the General Waste Discharge Requirements (shown on **Figure 4-10**) delineate these areas. These too were compared between each non-WARMF area and the analogous WARMF area. For each non-WARMF area, one assemblage of WARMF catchments was selected as a "reference WARMF area" based on proximity and land cover assemblage.

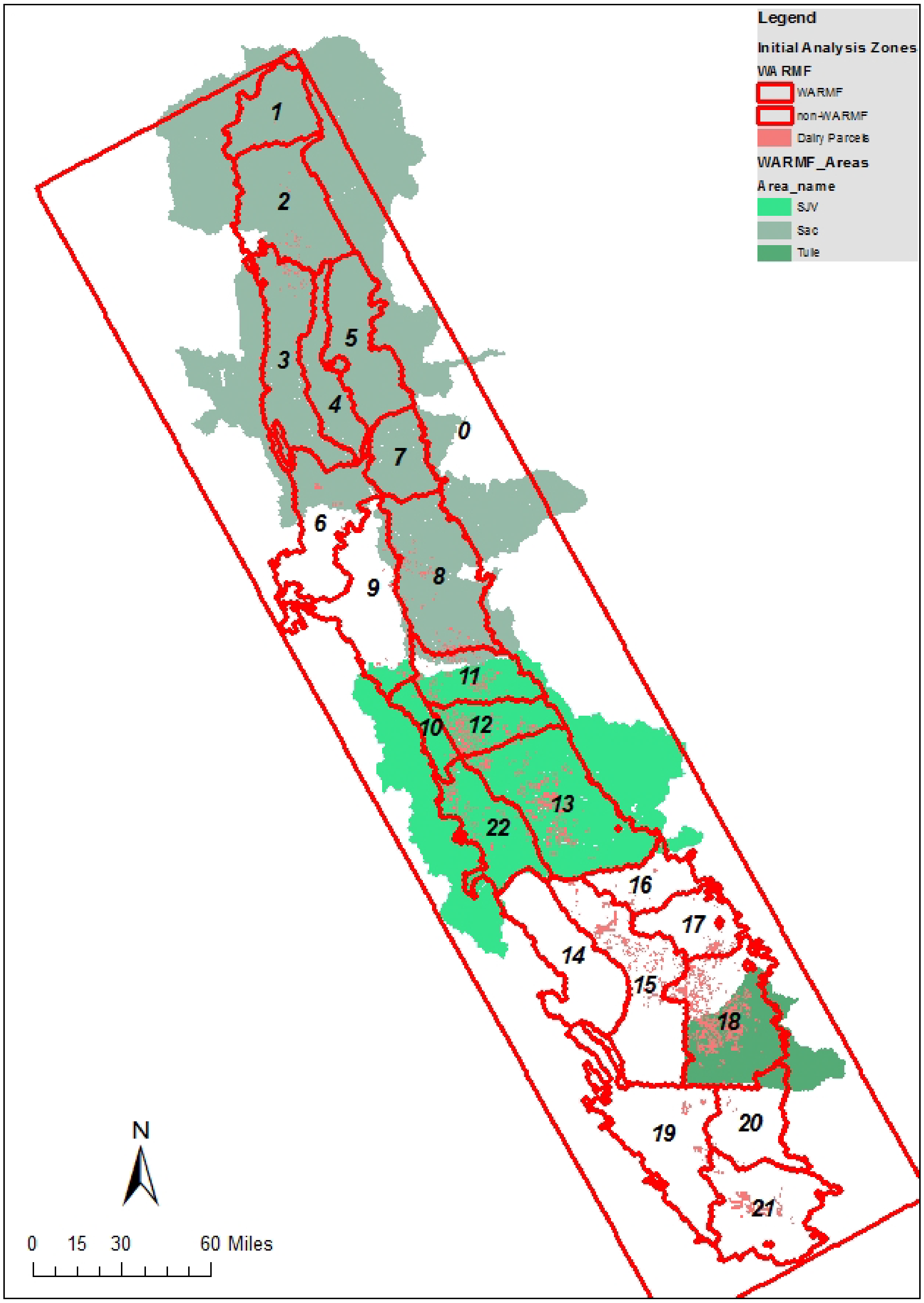


Figure 4-10. Land Application of Dairy Waste from General Waste Discharge Requirements

Re-weighting of Outputs

After reference WARMF areas were identified, output from collections of WARMF catchments that comprise the analogous DAU's was summarized and adjusted for each non-WARMF area. This was possible because WARMF output is available not only by catchment and time step, but also by land cover class. Thus, loads from land cover classes in a set of catchments can be re-weighted to reflect a different crop blend in an otherwise similar area. Of course, the total land area also affects the adjustment, with larger areas of a given land cover class (or a given pattern of classes) producing proportionally greater loads.

In this way, WARMF output from a reference WARMF area was employed to generate load estimates for each area lacking WARMF model coverage.

Characterization of Applied Water Quality

Applied water is the principal source of new salt in irrigated areas. It is therefore an important component of the salt balance for the root system, as calculated by WARMF. Actual salt in applied water depends on three main factors:

1. Salinity of applied surface water
2. Salinity of applied groundwater
3. The proportions of surface water and groundwater in total applied water

No readily available database contains such data on applied water quality for the entire Central Valley, and development of such a database was beyond the scope of this effort. Fortunately, applied water quality for areas with WARMF model coverage is characterized as part of the WARMF data set, and employed in WARMF process calculations. However, applied water quality for non-WARMF areas had to be determined in another manner.

The approach taken in Task 6 was to use readily available data on surface water supply quality, and to use this to adjust salinity loads from output for the reference WARMF area. Where surface water was more dilute than in the reference WARMF area, salt loads were reduced in proportion. Higher surface water salinity concentrations had the opposite effect.

Quantification of Permitted (POTW) Land Application

Permits for POTWs with discharge to land of greater than 5 mgd were reviewed. Constituent (nitrate and salinity) loads were estimated for each non-WARMF IAZ. No reference IAZ's had significant POTW inputs. Thus, where they existed for a non-WARMF IAZ, they were added to the groundwater recharge loads calculated for the various land cover classes in the IAZ. Estimated loads were scaled over the data period based on published demographic (population growth) rates for the municipalities associated with the POTWs.

4.5 CALCULATE IAZ STARTING WATER VOLUME BASED ON 20-YEAR TRAVEL DISTANCE

The volume of water at the start of the 20-year simulation period for the water, salt, and nitrate balance calculations is calculated using the following formula:

$$WaterVolume = SaturatedThickness * SurfaceArea * Porosity$$

The saturated thickness is calculated on a cell-by-cell basis based on the CVHM water table elevation and the bottom elevation of the IAZ in each cell (the elevation of the bottom of the lower-most CVHM layer included in the 20-year travel zone (see also Section 2 of this report)). Each CVHM cell is one mile by one mile, making the surface area for each cell one square mile. The porosity is assumed to be equal to the CVHM-provided specific yield in the unconfined portion of the aquifer (i.e., the 20-year travel zone). The volume of water in the saturated portion of the upper CVHM layers used to define each IAZ is the product of the saturated thickness, surface area, and porosity. Table 4-2 below lists the starting volumes of water associated with each IAZ for the start of the 20-year simulation period (September 1983):

Table 4-2. Starting IAZ Water Volume Based on the 20-Year Travel Distance and CVHM Layering

IAZ Number	Starting Volume of Water		IAZ Number	Starting Volume of Water		IAZ Number	Starting Volume of Water	
	2.7E+11	ft^3		3.3E+11	ft^3		2.7E+11	ft^3
	6,213,275	AF		7,529,659	AF		6,134,752	AF
IAZ 1	7.7E+09	m^3	IAZ 9	9.3E+09	m^3	IAZ 17	7.6E+09	m^3
	4.9E+11	ft^3		9.0E+10	ft^3		4.9E+11	ft^3
	11,250,456	AF		2,059,039	AF		11,253,959	AF
IAZ 2	1.4E+10	m^3	IAZ 10	2.5E+09	m^3	IAZ 18	1.4E+10	m^3
	3.6E+11	ft^3		2.6E+11	ft^3		8.1E+11	ft^3
	8,261,621	AF		5,863,919	AF		18,610,352	AF
IAZ 3	1.0E+10	m^3	IAZ 11	7.2E+09	m^3	IAZ 19	2.3E+10	m^3
	1.6E+11	ft^3		2.1E+11	ft^3		3.7E+11	ft^3
	3,734,853	AF		4,892,742	AF		8,517,704	AF
IAZ 4	4.6E+09	m^3	IAZ 12	6.0E+09	m^3	IAZ 20	1.1E+10	m^3
	3.1E+11	ft^3		5.2E+11	ft^3		9.2E+11	ft^3
	7,018,977	AF		12,030,370	AF		21,098,944	AF
IAZ 5	8.7E+09	m^3	IAZ 13	1.5E+10	m^3	IAZ 21	2.6E+10	m^3
	2.5E+11	ft^3		7.9E+11	ft^3		2.5E+11	ft^3
	5,733,600	AF		18,167,379	AF		5,839,134	AF
IAZ 6	7.1E+09	m^3	IAZ 14	2.2E+10	m^3	IAZ 22	7.2E+09	m^3
	1.5E+11	ft^3		6.8E+11	ft^3			
	3,474,397	AF		15,707,635	AF			
IAZ 7	4.3E+09	m^3	IAZ 15	1.9E+10	m^3			
	5.4E+11	ft^3		1.9E+11	ft^3			
	12,302,372	AF		4,378,786	AF			
IAZ 8	1.5E+10	m^3	IAZ 16	5.4E+09	m^3			

4.6 POST PROCESS CVHM OUTPUT FOR VOLUMETRIC COMPONENTS

To determine the movement of water within and between IAZs, the CVHM model was used. The model output was post-processed to attain volumetric components for each IAZ, using the three main tools: 1) the post processing program Zonebudget, 2) the Farm Process output file, and 3) the stream flow routing package output file.

Zonebudget Input Files

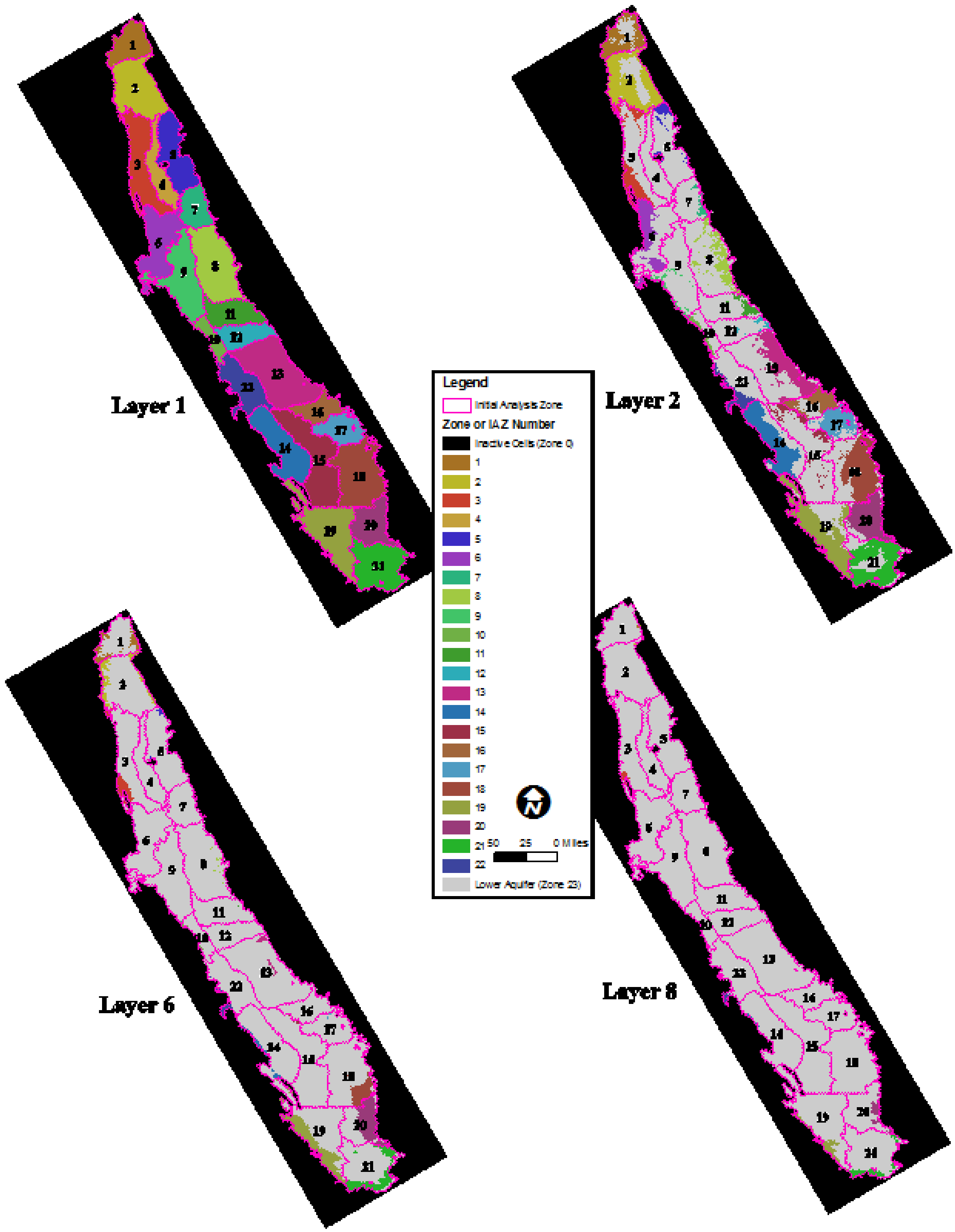
Using the depths from the calculations described in Section 2, the deepest CVHM model layers to be included in the IAZ were identified. Input files for post-processing the cell-by-cell water budget output file using the Zonebudget tool, created for each model layer include a zone number assigned to each cell for each of CVHM's 10 layers (10 different input files, one for each layer). The IAZ number (1 through 22) is used as the zone number assigned to each cell in the layers that correspond with the 20-year travel distance. Cells that are located in layers below each IAZ are assigned to zone number 23 to represent interaction with deeper aquifer units, and the zone number 0 is assigned to inactive cells. Ten input files are created representing each CVHM layer and containing the 'zone number', or IAZ number and the zone number for the aquifer below each IAZ.

Figure 4-11 shows the cells assigned to each zone for a few selected CVHM layers to provide an example that shows the necessary input into the post-processing tool Zonebudget. The edges of the model have different uppermost active model layers as discussed in the text above describing the IAZ depth delineation. The number of cells in each zone for each layer is shown in **Table 4-3**.

Table 4-3. Number of Cells in Each Layer by IAZ

Zone or IAZ	Number of Cells									
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8	Layer 9	Layer 10
1	611	422	363	145	145	145	42	5	0	0
2	1,163	865	533	190	190	188	38	2	0	0
3	1112	422	274	148	148	145	79	32	4	0
4	560	22	3	1	1	1	0	0	0	0
5	957	127	60	19	19	19	8	1	0	0
6	1044	450	118	24	24	24	2	0	0	0
7	534	59	41	0	0	0	0	0	0	0
8	1362	335	255	22	21	18	2	0	0	0
9	1181	95	33	11	11	11	4	0	0	0
10	282	99	72	30	30	30	11	2	0	0
11	664	108	90	3	3	3	0	0	0	0
12	540	44	36	3	3	0	0	0	0	0
13	1648	611	444	39	39	35	3	0	0	0
14	1071	762	576	98	98	87	46	33	12	0
15	1423	212	43	13	13	8	0	0	0	0
16	478	298	135	2	2	2	0	0	0	0
17	569	397	19	11	11	7	0	0	0	0
18	1358	796	433	205	205	203	9	0	0	0
19	1365	1003	776	492	492	491	294	144	47	4
20	705	597	556	368	366	361	227	68	7	0
21	1105	779	592	274	273	272	197	132	81	33
22	801	219	136	68	64	63	49	27	14	0
Lower Aquifer (Zone 23)	0	11811	14945	18367	18375	18420	19522	20087	20368	20496

Figure 4-11. Layers 1, 2, 6, and 8 for Zonebudget Input Files



The maps above illustrate the CVHM model layers that were used to delineate the 'shallow' subsurface for purposes of identifying the 20-year travel zone and performing the water, salt, and nitrate balance calculations. Zonebudget was run using the ten input files described above. This resulted in four output files (compq_bc.in, compq_bc.out, compq_zo.in, and compq_zo.out) which contain various water flow budget components used for the groundwater mixing model. The flow components included in the Zonebudget output files for each IAZ are shown in **Table 4-4**.

Table 4-4. CVHM Post Processing Zonebudget Flow Budget Components

Flow Budget Components
Net Recharge from the Farm Process
Agricultural Pumping from the Farm Process
Municipal Pumping from Multi-Node Wells
Horizontal Inflow from IAZ 1 through 22
Horizontal Outflow to IAZ 1 through 22
Vertical Inflow from the aquifer materials below the 20-year travel zone
Vertical Outflow to the aquifer materials below the 20-year travel zone
Stream Leakage (gaining and losing stream conditions)
Head Dependent Boundary (representing flow through the Sacramento/San Joaquin Delta)
Groundwater Storage

These flow values are reported for each month in the 42.5 year total simulation length (April 1961 to September 2003) in cubic meters per day, but only the most recent 20-year time period (September 1983 to September 2003) flow values will be used for the water, salt, and nitrate balance calculations.

Farm Process Output Files

The Farm Process in CVHM (Schmid and Hanson, 2009) produces information about groundwater recharge volumes, as well as surface water diversion, delivery, and return flow data. The surface water portion of flow data was used for the surface water mixing model analysis.

Stream Flow Routing Output Files

The Stream Flow Routing package in CVHM produces surface water information including flow rates entering and exiting stream reaches and segments. Stream segments and reaches were assigned to each IAZ according to their location, to be used for the surface water mixing model analysis in Task 6.

Conversion of Flow to Volume

CVHM model output is reported in flows, or cubic length (meters) per unit time (days). All of these flows were converted to volumes by multiplying each entry by the amount of time associated with each measurement. The CVHM stress period time length is in months, so each flow rate was multiplied by the number of days in the month that the stress period represents to achieve the volume associated with each month. The Task 6 mixing model analysis is performed on a quarterly basis, so volumes were summed over the months associated with each quarter.

4.7 DATA/DECISION MATRIX

Table 4-5a and **Table 4-5b** provide a description of the availability of ambient groundwater and surface water data. Each IAZ was assessed as to whether the available surface water and groundwater quality data was either adequate (A), somewhat adequate (SA), or not adequate (NA) in terms of its ability to estimate ambient conditions. **Table 4-6a** through **Table 4-6c** summarize the associated ambient groundwater data for each IAZ. Provided in the tables are three descriptions of the ambient data: 1) a count of the number of wells within each IAZ, 2) the number of CVHM model grid cells that contain well data (and the number of cells containing a well over the 10 mg/L NO3-N and 500 mg/L TDS thresholds), and 3) the estimated recent shallow and deep nitrate and TDS concentrations.

4.8 SUMMARY

This section detailed the methodology developed for the ICM analysis on the IAZ scale for water, salt, and nitrate balance calculations. The methodology was initially presented in the Task 5 report, as summarized above, but this section serves to provide additional detail on all of the various steps including:

- Establishing ambient groundwater quality for each IAZ,
- Establishing ambient surface water quality for each IAZ,
- Establishing mass loading for the groundwater recharge component,
- Calculating the IAZ starting water volume based on the 20-year travel distance,
- Post-processing the CVHM output for volumetric budget components, and
- The presentation of the data/decision matrix.

Table 4-5a. Matrix to Summarize Availability of Ambient Groundwater and Surface Water Data

Initial Analysis Zone (IAZ)		Model Coverage: WARMF Coverage Present	Model Coverage: CVHM Coverage Present	Sources of Contribution for Mass Loading	Surface Water – Water Quality – Available: TDS	Surface Water – Water Quality – Available: Nitrate	Surface Water – Water Quality – Spatial: Salt	Surface Water – Water Quality – Spatial: Nitrate	Surface Water – Water Quality – Temporal: Salt	Surface Water – Water Quality – Temporal: Nitrate	Surface Water – Flow: Available	Flow Budget Components: Available
		Yes/No/Partial	Yes/No	WARMF/Other	Yes/No	Yes/No	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	Yes/No	CVHM/Other
IAZ-1	Sacramento River above Red Bluff (Redding Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-2	Red Bluff to Chico Landing (Red Bluff, Corning, Bend, Antelope, Dye Creek, Los Molinos, and Vina Basins)	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-3	Colusa Trough (Most of Colusa Basin and Capay Valley Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-4	Chico Landing to Knights Landing proximal to the Sacramento River	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-5	Eastern Sacramento Valley foothills near Sutter Buttes (North and South Yuba, Est Butte and eastern parts of West Butte and Sutter Basins)	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-6	Cache-Putah area (Western Solano and most of Delta and Yolo Basins)	Partial	Yes	WARMF	Yes	Yes	SA	SA	SA	SA	Yes	CVHM
IAZ-7	East of Feather and South of Yuba Rivers (North American Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-8	Valley floor east of the Delta (Cosumnes and parts of South American and Eastern San Joaquin Basins)	Partial	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-9	Delta (parts of Solano, Eastern San Joaquin, South American, and most of Tracy Basins)	No	Yes	WARMF CDEC CEDEN	Yes	Yes	A	A	SA	SA	Yes	CVHM
IAZ-10	Northwest Side (Northern Delta-Mendota Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-11	Modesto and Southern Eastern San Joaquin Basin	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-12	Turlock Basin	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-13	Merced, Chowchilla, and Madera Basins	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-14	Westside and Northern Pleasant Valley Basins	No	Yes	WARMF	Yes	Yes	NA	NA	NA	NA	Yes	CVHM
IAZ-15	Tulare Lake and Western Kings Basin	No	Yes	WARMF CDEC CEDEN	Yes	Yes	SA	SA	SA	SA	Yes	CVHM
IAZ-16	Northern Kings Basin	No	Yes	WARMF CDEC CEDEN	Yes	Yes	SA	SA	SA	SA	Yes	CVHM
IAZ-17	Southern Kings Basin	No	Yes	CEDEN USGS	Yes	Yes	NA	NA	A	NA	Yes	CVHM
IAZ-18	Kaweah and Tule Basins	Partial	Yes	WARMF CDEC CEDEN	Yes	Yes	SA	SA	A	A	Yes	CVHM
IAZ-19	Western Kern County and Southern Pleasant Valley Basin	No	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM
IAZ-20	Northeastern Kern County Basin	No	Yes	WARMF CDEC CEDEN	Yes	Yes	SA	SA	A	A	Yes	CVHM
IAZ-21	Southeastern Kern County Basin (Arvin-Maricopa area)	No	Yes	CEDEN USGS	Yes	Yes	NA	NA	NA	NA	Yes	CVHM
IAZ-22	Grasslands (Southern Delta-Mendota Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	A	A	Yes	CVHM

Table 4-6b. Matrix to Summarize Availability of Ambient Groundwater and Surface Water Data

		Model Coverage		Sources of Contribution for Mass Loading	Groundwater									
					Water Quality Data								Flow Budget Components	
							Spatial							
		WARMF Coverage Present	CVHM Coverage Present		Available		Areal (All Depths)		Areal (Shallow Data)		Temporal (Shallow)			
					TDS	Nitrate	Salt	Nitrate	Salt	Nitrate	Salt	Nitrate	Available	Additional Data Needs
Initial Analysis Zone (IAZ)		Yes/No/Partial	Yes/No	WARMF/Other	Yes/No	Yes/No	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	Adequate/ Somewhat Adequate/ Not Adequate	CVHM/Other	Phase 2/ Phase 3/ Other Future
IAZ-1	Sacramento River above Red Bluff (Redding Basin)	Yes	Yes	WARMF	Yes	Yes	SA	SA	SA	NA	NA	NA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-2	Red Bluff to Chico Landing (Red Bluff, Corning, Bend, Antelope, Dye Creek, Los Molinos, and Vina Basins)	Yes	Yes	WARMF	Yes	Yes	SA	SA	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-3	Colusa Trough (Most of Colusa Basin and Capay Valley Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-4	Chico Landing to Knights Landing proximal to the Sacramento River	Yes	Yes	WARMF	Yes	Yes	SA	SA	SA	NA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-5	Eastern Sacramento Valley foothills near Sutter Buttes (North and South Yuba, Est Butte and eastern parts of West Butte and Sutter Basins)	Yes	Yes	WARMF	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-6	Cache-Putah area (Western Solano and most of Delta and Yolo Basins)	Partial	Yes	WARMF (extrapolated)	Yes	Yes	A	SA	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-7	East of Feather and South of Yuba Rivers (North American Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-8	Valley floor east of the Delta (Cosumnes and parts of South American and Eastern San Joaquin Basins)	Partial	Yes	WARMF (extrapolated)	Yes	Yes	A	SA	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-9	Delta (parts of Solano, Eastern San Joaquin, South American, and most of Tracy Basins)	No	Yes	WARMF (extrapolated)	Yes	Yes	A	SA	SA	NA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-10	Northwest Side (Northern Delta-Mendota Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	SA	NA	NA	NA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-11	Modesto and Southern Eastern San Joaquin Basin	Yes	Yes	WARMF	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-12	Turlock Basin	Yes	Yes	WARMF	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-13	Merced, Chowchilla, and Madera Basins	Yes	Yes	WARMF	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-14	Westside and Northern Pleasant Valley Basins	No	Yes	WARMF (extrapolated)	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-15	Tulare Lake and Western Kings Basin	No	Yes	WARMF (extrapolated)	Yes	Yes	SA	SA	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-16	Northern Kings Basin	No	Yes	WARMF (extrapolated)	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-17	Southern Kings Basin	No	Yes	WARMF (extrapolated)	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-18	Kaweah and Tule Basins	Partial	Yes	WARMF (extrapolated)	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-19	Western Kern County and Southern Pleasant Valley Basin	No	Yes	WARMF (extrapolated)	Yes	Yes	SA	SA	SA	SA	NA	NA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-20	Northeastern Kern County Basin	No	Yes	WARMF (extrapolated)	Yes	Yes	SA	SA	SA	NA	NA	NA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-21	Southeastern Kern County Basin (Arvin-Maricopa area)	No	Yes	WARMF (extrapolated)	Yes	Yes	A	A	SA	SA	NA	NA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)
IAZ-22	Grasslands (Southern Delta-Mendota Basin)	Yes	Yes	WARMF	Yes	Yes	A	A	SA	SA	SA	SA	CVHM	Shallow Groundwater Data Well Construction (depth/screen)

Table 4-7a. Matrix to Summarize Ambient Groundwater Data

			IAZ NUMBER	1	2	3	4	5	6	7
IAZ Info			Acres	391,040	744,320	711,680	358,400	612,480	668,160	341,760
IAZ Info			Square Miles	611	1163	1112	560	957	1044	534
IAZ Info			Median CVHM (1983) Shallow Groundwater Level ("<0" indicates strong upward gradients and gw discharging to surface water)	167	87	14	<0	<0	22	16
IAZ Info			Avg 20 year travel time vertical distance (feet)	92	93	81	71	72	63	74
IAZ Info			20 year travel time starting volume (Acre-Feet)	6,213,275	11,250,456	8,261,621	3,734,853	7,018,977	5,733,600	3,474,397
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests pre-1980	1	100	38	10	52	19	7
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests 1980-1990	0	5	5	2	4	1	5
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests 2000-2012	135	240	143	9	168	305	174
Well Count	Nitrate	Shallow	**Total Number of Shallow Wells with Nitrate Tests**	**136**	**345**	**186**	**21**	**224**	**325**	**186**
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests pre-1980	1	63	172	90	133	56	59
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests 1980-1990	14	29	16	6	53	50	130
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests 2000-2012	260	541	142	76	347	279	380
Well Count	Nitrate	Deep	**Total Number of Deep Wells with Nitrate Tests**	**275**	**633**	**330**	**172**	**533**	**385**	**569**
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests pre-1980	232	228	153	43	120	102	123
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests 1980-1990	4	114	11	3	30	11	15
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests 2000-2012	8	82	37	40	61	8	14
Well Count	Nitrate	Unknown	**Total Number of Unknown Depth Wells with Nitrate Tests**	**244**	**424**	**201**	**86**	**211**	**121**	**152**
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests pre-1980	42	100	41	10	47	19	7
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests 1980-1990	19	5	14	2	4	29	12
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests 2000-2012	16	88	21	2	82	204	99
Well Count	TDS	Shallow	**Total Number of Shallow Wells with TDS Tests**	**77**	**193**	**76**	**14**	**133**	**252**	**118**
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests pre-1980	37	62	192	84	94	58	46
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests 1980-1990	39	35	31	11	66	144	109
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests 2000-2012	202	396	87	46	275	187	316
Well Count	TDS	Deep	**Total Number of Deep Wells with TDS Tests**	**278**	**493**	**310**	**141**	**435**	**389**	**471**
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests pre-1980	235	226	160	65	206	111	155
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests 1980-1990	6	115	36	5	13	136	73
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests 2000-2012	9	63	49	82	72	9	27
Well Count	TDS	Unknown	Total Number of Unknown Depth Wells with TDS Tests	**250**	**404**	**245**	**152**	**291**	**256**	**255**
			IAZ NUMBER	**1**	**2**	**3**	**4**	**5**	**6**	**7**
			Total Number of (1 square mile) CVHM Cells in an IAZ	611	1163	1112	560	957	1044	534
CVHM Cell Count	Nitrate	Pre-60s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1900-1959)	1	4	1	0	2	2	1
CVHM Cell Count	Nitrate	Pre-60s	Number of CVHM Cells containing a well with nitrate data (1900-1959)	62	83	74	17	28	32	30
CVHM Cell Count	Nitrate	Pre-60s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1900-1959)**	2%	5%	1%	0%	7%	6%	3%
CVHM Cell Count	Nitrate	60s-70s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1960-1979)	0	11	5	2	19	14	0
CVHM Cell Count	Nitrate	60s-70s	Number of CVHM Cells containing a well with nitrate data (1960-1979)	118	215	217	88	208	143	115
CVHM Cell Count	Nitrate	60s-70s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1960-1979)**	0%	5%	2%	2%	9%	10%	0%
CVHM Cell Count	Nitrate	80s-90s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1980-1999)	0	20	7	2	21	20	1
CVHM Cell Count	Nitrate	80s-90s	Number of CVHM Cells containing a well with nitrate data (1980-1999)	64	180	96	51	171	149	144
CVHM Cell Count	Nitrate	80s-90s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1980-1999)**	0%	11%	7%	4%	12%	13%	1%
CVHM Cell Count	Nitrate	2000s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (2000-2012)	1	28	17	3	35	48	7
CVHM Cell Count	Nitrate	2000s	Number of CVHM Cells containing a well with nitrate data (2000-2012)	133	237	131	80	215	168	159
CVHM Cell Count	Nitrate	2000s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (2000-2012)**	1%	12%	13%	4%	16%	29%	4%
CVHM Cell Count	TDS	Pre-60s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1900-1959)	8	4	22	4	2	19	1
CVHM Cell Count	TDS	Pre-60s	Number of CVHM Cells containing a well with TDS data (1900-1959)	64	75	71	17	27	32	27
CVHM Cell Count	TDS	Pre-60s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1900-1959)**	13%	5%	31%	24%	7%	59%	4%
CVHM Cell Count	TDS	60s-70s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1960-1979)	4	9	56	27	34	88	11
CVHM Cell Count	TDS	60s-70s	Number of CVHM Cells containing a well with TDS data (1960-1979)	145	215	228	95	228	149	126
CVHM Cell Count	TDS	60s-70s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1960-1979)**	3%	4%	25%	28%	15%	59%	9%
CVHM Cell Count	TDS	80s-90s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1980-1999)	1	9	44	15	31	165	18
CVHM Cell Count	TDS	80s-90s	Number of CVHM Cells containing a well with TDS data (1980-1999)	101	169	123	51	154	285	188
CVHM Cell Count	TDS	80s-90s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1980-1999)**	1%	5%	36%	29%	20%	58%	10%
CVHM Cell Count	TDS	2000s	Number of CVHM Cells containing a well with TDS over 500 mg/L (2000-2012)	3	12	39	27	51	71	29
CVHM Cell Count	TDS	2000s	Number of CVHM Cells containing a well with TDS data (2000-2012)	114	204	102	75	200	124	138
CVHM Cell Count	TDS	2000s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (2000-2012)**	3%	6%	38%	36%	26%	57%	21%
Ambient Calculations	Nitrate		Last (2012) Upper 95% Confidence Band Value	1.1	1.4	1.9	0.2	1.0	2.3	1.4
Ambient Calculations	Nitrate		Last (2012) value of Linear Regression on Deep Nitrate Data 1980-2012 (regression based on Log10 values)	1.0	1.3	1.6	0.2	0.9	2.1	1.3
Ambient Calculations	Nitrate		Last (2012) Lower 95% Confidence Band Value	0.9	1.2	1.3	0.1	0.8	1.9	1.2
Ambient Calculations	Nitrate		75th Percentile Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.2	1.8	2.0	2.5	0.9	4.8	1.5
Ambient Calculations	Nitrate		Median Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.1	0.7	0.9	0.4	0.4	0.6	0.7
Ambient Calculations	Nitrate		25th Percentile Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.1	0.1	0.5	0.1	0.1	0.1	0.2
Ambient Calculations	TDS		Last (2012) Upper 95% Confidence Band Value	167	228	460	463	321	464	260
Ambient Calculations	TDS		Last (2012) value of Linear Regression on Deep TDS Data 1980-2012 (regression based on Log10 values)	159	220	399	382	299	445	250
Ambient Calculations	TDS		Last (2012) Lower 95% Confidence Band Value	151	212	345	315	278	428	241
Ambient Calculations	TDS		75th Percentile Value of Shallow TDS CVHM Cell Medians (2003-2012)	722	315	1155	774	480	1396	652
Ambient Calculations	TDS		Median Value of Shallow TDS CVHM Cell Medians (2003-2012)	346	200	533	639	323	1063	375
Ambient Calculations	TDS		25th Percentile Value of Shallow TDS CVHM Cell Medians (2003-2012)	203	164	273	543	240	852	284

Table 4-8b. Matrix to Summarize Ambient Groundwater Data

Middle Central Valley										
			IAZ NUMBER	8	9	10	11	12	13	22
IAZ Info			**Acres**	871,680	755,840	180,480	424,960	345,600	1,054,720	512,640
IAZ Info			**Square Miles**	1362	1181	282	664	540	1648	801
IAZ Info			**Median CVHM (1983) Shallow Groundwater Level ("<0" indicates strong upward gradients and gw discharging to surface water)**	39	<0	33	23	7	34	9
IAZ Info			**Avg 20 year travel time vertical distance (feet)**	92	64	65	71	67	61	58
IAZ Info			**20 year travel time starting volume (Acre-Feet)**	12,302,372	7,529,659	2,059,039	5,863,919	4,892,742	12,030,370	5,839,134
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests pre-1980	26	15	3	3	0	3	1
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests 1980-1990	4	2	9	1	5	12	132
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests 2000-2012	742	852	184	685	850	459	272
Well Count	Nitrate	Shallow	**Total Number of Shallow Wells with Nitrate Tests**	**772**	**869**	**196**	**689**	**855**	**474**	**405**
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests pre-1980	46	35	19	48	7	19	28
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests 1980-1990	125	44	26	89	43	91	50
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests 2000-2012	1073	469	93	733	426	661	84
Well Count	Nitrate	Deep	**Total Number of Deep Wells with Nitrate Tests**	**1244**	**548**	**138**	**870**	**476**	**771**	**162**
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests pre-1980	602	563	143	235	121	451	323
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests 1980-1990	17	67	9	1	29	44	120
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests 2000-2012	7	7	0	0	0	0	0
Well Count	Nitrate	Unknown	**Total Number of Unknown Depth Wells with Nitrate Tests**	**626**	**637**	**152**	**236**	**150**	**495**	**443**
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests pre-1980	62	32	7	20	4	14	10
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests 1980-1990	17	3	14	1	8	15	142
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests 2000-2012	310	425	158	173	40	85	56
Well Count	TDS	Shallow	**Total Number of Shallow Wells with TDS Tests**	**389**	**460**	**179**	**194**	**52**	**114**	**208**
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests pre-1980	195	87	53	158	34	115	127
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests 1980-1990	136	93	25	70	54	116	44
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests 2000-2012	553	289	57	402	206	328	50
Well Count	TDS	Deep	**Total Number of Deep Wells with TDS Tests**	**884**	**469**	**135**	**630**	**294**	**559**	**221**
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests pre-1980	785	721	267	371	144	574	486
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests 1980-1990	93	109	8	1	29	44	116
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests 2000-2012	7	7	0	0	0	0	0
Well Count	TDS	Unknown	Total Number of Unknown Depth Wells with TDS Tests	**885**	**837**	**275**	**372**	**173**	**618**	**602**
			IAZ NUMBER	8	9	10	11	12	13	22
			Total Number of (1 square mile) CVHM Cells in an IAZ	1362	1181	282	664	540	1648	801
CVHM Cell Count	Nitrate	Pre-60s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1900-1959)	2	10	4	4	2	2	4
CVHM Cell Count	Nitrate	Pre-60s	Number of CVHM Cells containing a well with nitrate data (1900-1959)	154	119	62	94	38	102	126
CVHM Cell Count	Nitrate	Pre-60s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1900-1959)**	1%	8%	6%	4%	5%	2%	3%
CVHM Cell Count	Nitrate	60s-70s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1960-1979)	10	42	9	15	12	12	13
CVHM Cell Count	Nitrate	60s-70s	Number of CVHM Cells containing a well with nitrate data (1960-1979)	311	231	81	151	94	337	152
CVHM Cell Count	Nitrate	60s-70s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1960-1979)**	3%	18%	11%	10%	13%	4%	9%
CVHM Cell Count	Nitrate	80s-90s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1980-1999)	7	35	13	29	30	13	60
CVHM Cell Count	Nitrate	80s-90s	Number of CVHM Cells containing a well with nitrate data (1980-1999)	205	147	43	139	94	185	138
CVHM Cell Count	Nitrate	80s-90s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1980-1999)**	3%	24%	30%	21%	32%	7%	43%
CVHM Cell Count	Nitrate	2000s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (2000-2012)	88	57	23	136	144	109	33
CVHM Cell Count	Nitrate	2000s	Number of CVHM Cells containing a well with nitrate data (2000-2012)	365	257	58	298	231	326	86
CVHM Cell Count	Nitrate	2000s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (2000-2012)**	24%	22%	40%	46%	62%	33%	38%
CVHM Cell Count	TDS	Pre-60s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1900-1959)	22	110	73	29	18	17	177
CVHM Cell Count	TDS	Pre-60s	Number of CVHM Cells containing a well with TDS data (1900-1959)	216	141	90	172	61	141	203
CVHM Cell Count	TDS	Pre-60s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1900-1959)**	10%	78%	81%	17%	30%	12%	87%
CVHM Cell Count	TDS	60s-70s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1960-1979)	24	233	136	42	33	74	200
CVHM Cell Count	TDS	60s-70s	Number of CVHM Cells containing a well with TDS data (1960-1979)	372	279	150	207	107	406	223
CVHM Cell Count	TDS	60s-70s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1960-1979)**	6%	84%	91%	20%	31%	18%	90%
CVHM Cell Count	TDS	80s-90s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1980-1999)	18	143	40	31	27	25	134
CVHM Cell Count	TDS	80s-90s	Number of CVHM Cells containing a well with TDS data (1980-1999)	281	208	42	134	101	218	145
CVHM Cell Count	TDS	80s-90s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1980-1999)**	6%	69%	95%	23%	27%	11%	92%
CVHM Cell Count	TDS	2000s	Number of CVHM Cells containing a well with TDS over 500 mg/L (2000-2012)	65	146	36	60	32	41	28
CVHM Cell Count	TDS	2000s	Number of CVHM Cells containing a well with TDS data (2000-2012)	258	183	40	183	110	208	32
CVHM Cell Count	TDS	2000s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (2000-2012)**	25%	80%	90%	33%	29%	20%	88%
Ambient Calculations	Nitrate		Last (2012) Upper 95% Confidence Band Value	1.6	0.5	4.7	3.4	3.4	2.7	2.4
Ambient Calculations	Nitrate		Last (2012) value of Linear Regression on Deep Nitrate Data 1980-2012 (regression based on Log10 values)	1.5	0.4	4.0	3.2	3.1	2.5	1.9
Ambient Calculations	Nitrate		Last (2012) Lower 95% Confidence Band Value	1.4	0.4	3.4	3.1	2.7	2.3	1.4
Ambient Calculations	Nitrate		75th Percentile Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	2.5	2.2	3.5	9.3	20.7	10.1	12.7
Ambient Calculations	Nitrate		Median Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.9	0.3	2.5	4.2	8.4	5.9	7.3
Ambient Calculations	Nitrate		25th Percentile Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.3	0.1	0.8	1.7	1.9	2.3	2.0
Ambient Calculations	TDS		Last (2012) Upper 95% Confidence Band Value	246	685	993	287	294	248	719
Ambient Calculations	TDS		Last (2012) value of Linear Regression on Deep TDS Data 1980-2012 (regression based on Log10 values)	238	645	899	274	273	239	624
Ambient Calculations	TDS		Last (2012) Lower 95% Confidence Band Value	230	608	813	261	254	230	542
Ambient Calculations	TDS		75th Percentile Value of Shallow TDS CVHM Cell Medians (2003-2012)	605	1302	1130	920	883	791	1304
Ambient Calculations	TDS		Median Value of Shallow TDS CVHM Cell Medians (2003-2012)	389	935	836	532	827	660	977
Ambient Calculations	TDS		25th Percentile Value of Shallow TDS CVHM Cell Medians (2003-2012)	196	590	484	468	725	392	755

Table 4-9c. Matrix to Summarize Ambient Groundwater Data

Southern Central Valley											
			IAZ NUMBER	14	15	16	17	18	19	20	21
IAZ Info			Acres	685,440	910,720	305,920	364,160	869,120	873,600	451,200	707,200
IAZ Info			Square Miles	1071	1423	478	569	1358	1365	705	1105
IAZ Info			Median CVHM (1983) Shallow Groundwater Level ("<0" indicates strong upward gradients and gw discharging to surface water)	168	26	115	68	54	201	329	109
IAZ Info			Avg 20 year travel time vertical distance (feet)	180	93	67	78	74	109	98	120
IAZ Info			20 year travel time starting volume (Acre-Feet)	18,167,379	15,707,635	4,378,786	6,134,752	11,253,959	18,610,352	8,517,704	21,098,944
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests pre-1980	2	0	1	3	0	1	6	9
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests 1980-1990	113	84	3	16	12	45	1	26
Well Count	Nitrate	Shallow	Number of Shallow Wells with Nitrate Tests 2000-2012	13	260	91	97	475	43	28	62
Well Count	Nitrate	Shallow	**Total Number of Shallow Wells with Nitrate Tests**	**128**	**344**	**95**	**116**	**487**	**89**	**35**	**97**
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests pre-1980	42	15	49	1	11	49	104	64
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests 1980-1990	29	71	151	48	135	21	50	121
Well Count	Nitrate	Deep	Number of Deep Wells with Nitrate Tests 2000-2012	26	317	607	350	916	37	172	462
Well Count	Nitrate	Deep	**Total Number of Deep Wells with Nitrate Tests**	**97**	**403**	**807**	**399**	**1062**	**107**	**326**	**647**
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests pre-1980	523	459	394	224	793	637	585	1766
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests 1980-1990	47	22	47	33	59	55	59	124
Well Count	Nitrate	Unknown	Number of Unknown Depth Wells with Nitrate Tests 2000-2012	46	0	1	0	0	0	0	0
Well Count	Nitrate	Unknown	**Total Number of Unknown Depth Wells with Nitrate Tests**	**616**	**481**	**442**	**257**	**852**	**692**	**644**	**1890**
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests pre-1980	3	15	8	11	4	3	7	12
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests 1980-1990	151	73	5	15	8	44	1	23
Well Count	TDS	Shallow	Number of Shallow Wells with TDS Tests 2000-2012	13	101	24	66	185	37	23	48
Well Count	TDS	Shallow	**Total Number of Shallow Wells with TDS Tests**	**167**	**189**	**37**	**92**	**197**	**84**	**31**	**83**
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests pre-1980	129	59	23	9	72	61	128	81
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests 1980-1990	27	64	101	45	115	22	63	129
Well Count	TDS	Deep	Number of Deep Wells with TDS Tests 2000-2012	13	155	538	247	523	33	127	370
Well Count	TDS	Deep	**Total Number of Deep Wells with TDS Tests**	**169**	**278**	**662**	**301**	**710**	**116**	**318**	**580**
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests pre-1980	1058	622	320	239	901	708	700	1940
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests 1980-1990	57	23	68	33	60	56	58	125
Well Count	TDS	Unknown	Number of Unknown Wells with TDS Tests 2000-2012	53	0	1	0	0	0	0	0
Well Count	TDS	Unknown	Total Number of Unknown Depth Wells with TDS Tests	**1168**	**645**	**389**	**272**	**961**	**764**	**758**	**2065**
			IAZ NUMBER	14	15	16	17	18	19	20	21
			Total Number of (1 square mile) CVHM Cells in an IAZ	**1071**	**1423**	**478**	**569**	**1358**	**1365**	**705**	**1105**
CVHM Cell Count	Nitrate	Pre-60s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1900-1959)	8	1	1	0	25	15	21	29
CVHM Cell Count	Nitrate	Pre-60s	Number of CVHM Cells containing a well with nitrate data (1900-1959)	209	142	96	50	300	199	262	359
CVHM Cell Count	Nitrate	Pre-60s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1900-1959)**	4%	1%	1%	0%	8%	8%	8%	8%
CVHM Cell Count	Nitrate	60s-70s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1960-1979)	11	6	18	29	71	19	56	105
CVHM Cell Count	Nitrate	60s-70s	Number of CVHM Cells containing a well with nitrate data (1960-1979)	311	258	175	125	290	254	208	489
CVHM Cell Count	Nitrate	60s-70s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1960-1979)**	4%	2%	10%	23%	24%	7%	27%	21%
CVHM Cell Count	Nitrate	80s-90s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (1980-1999)	69	36	28	31	65	27	41	54
CVHM Cell Count	Nitrate	80s-90s	Number of CVHM Cells containing a well with nitrate data (1980-1999)	116	174	164	120	231	112	153	297
CVHM Cell Count	Nitrate	80s-90s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (1980-1999)**	59%	21%	17%	26%	28%	24%	27%	18%
CVHM Cell Count	Nitrate	2000s	Number of CVHM Cells containing a well with nitrate over 10 mg/L (2000-2012)	4	78	57	74	283	12	36	47
CVHM Cell Count	Nitrate	2000s	Number of CVHM Cells containing a well with nitrate data (2000-2012)	64	207	228	210	519	40	92	207
CVHM Cell Count	Nitrate	2000s	**Percent of CVHM Cells containing a well with nitrate over 10 mg/L (2000-2012)**	6%	38%	25%	35%	55%	30%	39%	23%
CVHM Cell Count	TDS	Pre-60s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1900-1959)	522	117	4	1	51	135	81	179
CVHM Cell Count	TDS	Pre-60s	Number of CVHM Cells containing a well with TDS data (1900-1959)	523	221	82	51	335	234	295	405
CVHM Cell Count	TDS	Pre-60s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1900-1959)**	100%	53%	5%	2%	15%	58%	27%	44%
CVHM Cell Count	TDS	60s-70s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1960-1979)	351	129	27	22	77	143	96	258
CVHM Cell Count	TDS	60s-70s	Number of CVHM Cells containing a well with TDS data (1960-1979)	354	278	151	136	309	264	222	506
CVHM Cell Count	TDS	60s-70s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1960-1979)**	99%	46%	18%	16%	25%	54%	43%	51%
CVHM Cell Count	TDS	80s-90s	Number of CVHM Cells containing a well with TDS over 500 mg/L (1980-1999)	114	107	15	26	47	80	49	116
CVHM Cell Count	TDS	80s-90s	Number of CVHM Cells containing a well with TDS data (1980-1999)	120	175	158	115	235	112	153	290
CVHM Cell Count	TDS	80s-90s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (1980-1999)**	95%	61%	9%	23%	20%	71%	32%	40%
CVHM Cell Count	TDS	2000s	Number of CVHM Cells containing a well with TDS over 500 mg/L (2000-2012)	62	48	39	41	94	24	34	59
CVHM Cell Count	TDS	2000s	Number of CVHM Cells containing a well with TDS data (2000-2012)	65	99	204	161	300	37	75	173
CVHM Cell Count	TDS	2000s	**Percent of CVHM Cells containing a well with TDS over 500 mg/L (2000-2012)**	95%	48%	19%	25%	31%	65%	45%	34%
Ambient Calculations	Nitrate		Last (2012) Upper 95% Confidence Band Value	1.9	0.9	3.1	3.3	4.0	2.3	2.4	1.9
Ambient Calculations	Nitrate		Last (2012) value of Linear Regression on Deep Nitrate Data 1980-2012 (regression based on Log10 values)	1.1	0.7	3.0	3.0	3.7	1.6	2.0	1.7
Ambient Calculations	Nitrate		Last (2012) Lower 95% Confidence Band Value	0.7	0.6	2.8	2.8	3.5	1.2	1.7	1.6
Ambient Calculations	Nitrate		75th Percentile Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.8	12.3	19.3	20.3	21.2	6.1	9.1	0.5
Ambient Calculations	Nitrate		Median Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.2	3.4	10.6	8.1	11.7	1.7	0.1	0.1
Ambient Calculations	Nitrate		25th Percentile Value of Shallow Nitrate CVHM Cell Medians (2003-2012)	0.2	0.8	1.3	1.6	5.7	0.1	0.1	0.1
Ambient Calculations	TDS		Last (2012) Upper 95% Confidence Band Value	1107	355	231	221	230	472	349	281
Ambient Calculations	TDS		Last (2012) value of Linear Regression on Deep TDS Data 1980-2012 (regression based on Log10 values)	822	317	223	206	220	350	317	266
Ambient Calculations	TDS		Last (2012) Lower 95% Confidence Band Value	610	283	216	191	210	259	289	251
Ambient Calculations	TDS		75th Percentile Value of Shallow TDS CVHM Cell Medians (2003-2012)	5656	1349	694	756	897	13626	910	610
Ambient Calculations	TDS		Median Value of Shallow TDS CVHM Cell Medians (2003-2012)	3364	1004	457	519	600	11242	869	340
Ambient Calculations	TDS		25th Percentile Value of Shallow TDS CVHM Cell Medians (2003-2012)	3149	519	334	304	483	5599	830	238

5. Apportioning Mechanism

Development of the ICM required determination of the flow and water quality of groundwater recharge and interactions between groundwater and surface water throughout the Central Valley. The CVHM model was used to determine the flows of recharge, groundwater and surface water. Since CVHM does not simulate water quality, external means are required to determine the concentration and mass fluxes of nitrate and TDS associated with the CVHM flows.

The WARMF model simulates flow and water quality in surface waters and in near-surface groundwater which interacts with surface water. It simulates approximately 40 water quality parameters including the major ionic components of salinity, ammonia and nitrate, organic matter (including organic nitrogen), and dissolved oxygen. The WARMF models cover much of the Central Valley so they provide a spatially detailed source of surface water quality information which can be combined with the CVHM flows in the ICM.

WARMF simulates surface water hydrology and water quality on a daily time step, which is calculated in land catchments (hydrographic polygons) and river segments throughout the model domains. Precipitation, irrigation, and groundwater recharge are flow inputs to the model. Evapotranspiration is calculated based on temperature, humidity, sun angle, and soil moisture. Leakage from the soil to streams is calculated with Darcy's Law. Surface runoff is calculated with Manning's equation and river flow is routed using the kinematic wave approximation. WARMF model runs have been calibrated to observed in-stream flow and water quality. For the ICM analysis, the calibrated WARMF data are being used to route the mass of salt and nitrate across the surfaces and through the root zones of catchments. Inputs from various sources are tabulated and root zone processes are simulated to determine the net mass leaving the root zone.

CVHM simulates the surface water/groundwater system as well as the landscape components of evaporation and transpiration (six separate terms), runoff, and deep percolation on a monthly time step in each cell of its Central Valley model domain. Water volumes are calculated from inputs to and outputs from each cell. Precipitation, potential evapotranspiration, crop coefficients, root depths, and fractions of cell area for transpiration along with PSI pressures are inputs to the model, which in turn calculates irrigation demand. Potential evapotranspiration is estimated using the Hargreaves-Samani equation and temperature data to achieve monthly values for each 1-mi^2 model cell[42], which were adjusted to match California Irrigation Management Information System (CIMIS) data calculated with Pennman-Monteith (Faunt et al., 2009). Stream flows are calculated by the SFR1 package (Prudic and others, 2004) as a combination of

[42] Gridded regional estimates of temperature were used to estimate a minimum and maximum temperature value and interpolated to the center of each 1-mi2 model cell using bilinear interpolation of the temperature. ETo was calculated at each active cell for each month during the entire period of CVHM model simulation using the Hargreaves-Samani equation. Potential errors in this approach were identified when comparing calculated ETo to California Irrigation Management Information System (CIMIS) weather station measurements and adjustments were made to correct for these potential errors during calibration by use of multipliers on the summer and winter crop coefficient values (Faunt et al., 2009).

non-routed surface water deliveries and semi-routed conveyances from diversions representing natural rivers, manmade canals, and manmade pipelines. The calibration of CVHM involved matching measured water level depths, water level altitude changes, water level and potentiometric surface altitude maps, stream flows and diversions, boundary flows, subsidence, groundwater pumpage, water use, and water delivery observations, all to simulated values (Faunt et al., 2009).

5.1 MASS FLUX APPORTIONING

The mass routing calculations of WARMF are shown in **Figure 5-1**. Mass inputs to the model include fertilizer, wet and dry atmospheric deposition, and chemical constituents in irrigation water. These inputs are dependent on land uses, the areas of which are also model inputs. WARMF performs calculations of nutrient uptake by vegetation and mineralization (transforming organic to mineral forms of nutrients through decay of organic matter). Chemical reactions simulated in the soil include nitrification, denitrification, and sulfate reduction. The model tracks the temperature and dissolved oxygen concentration to determine which reactions are occurring and the rate of those reactions on a daily time step. Where there was coverage, the calibrated WARMF model was run over the study area **Figure 4-7** and mass outputs to surface water and groundwater were aggregated to obtain the total mass output (M_{TOT}) for salt and nitrate for each land catchment.

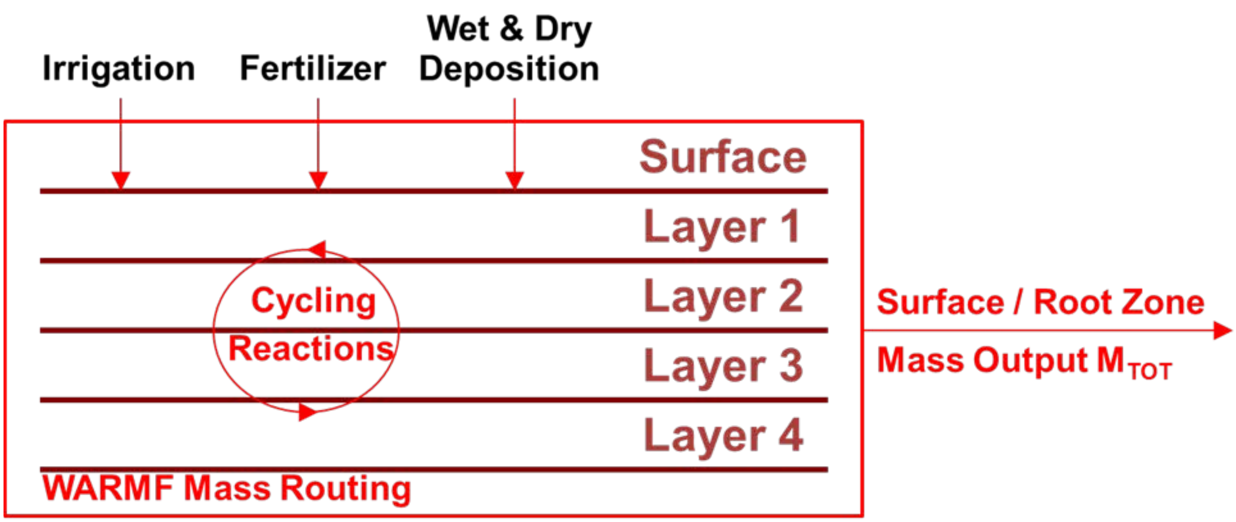


Figure 5-1. WARMF Surface / Root Zone Mass Routing for the ICM

The WARMF total mass output combines component mass fluxes that WARMF would normally route to surface water leaving the catchment and to groundwater recharge. Because hydrologic fluxes between CVHM and WARMF differ, these component mass fluxes are re-partitioned from the total mass output for the mixing model based on CVHM flows. Simulated CVHM hydrology overlaps with WARMF on the land surface and in the root zone as shown in **Figure 5-2**. The WARMF mass routing processes are in red; CVHM hydrology is in blue, and mass fluxes calculated using output from both models is shown in magenta. Runoff from WARMF is flow that travels directly from the root zone to surface water; leakage to stream travels from the root zone to the stream either directly (WARMF) or indirectly via groundwater below the root zone (CVHM). Recharge and leakage from the stream are flows to groundwater from the root zone and streams, respectively.

Mathematically, the WARMF component flows (and masses) tend to differ from those in CVHM, in part because the physical subsurface environment is subdivided differently in the two models, which were conceived for different purposes. For example, WARMF, having a focus on routing of flow and constituents among surface water features, has a prominent root zone. As such, the two models represent the following processes in distinct, but not necessarily conflicting, manners:

1. WARMF satisfies most ET from water in the root zone that has been recharged from the surface. CVHM has both components of vertical recharge down through deep percolation and removes water through evapotranspiration directly in the root zone.
2. WARMF routes significant stream recharge directly through the root zone. Thus, where stream recharge is high relative to groundwater recharge, WARMF shows little or no groundwater recharge. CVHM again takes a greater proportion of root-zone water to groundwater, and then shows a greater proportion of stream recharge to come from groundwater.

In this analysis, WARMF serves primarily to estimate the total loads departing the root zone, carried in CVHM flows through the mixing model. Since flow and dissolved constituents travel together, it is essential to re-apportion the total salt and nitrate loads from WARMF to reflect the flow apportionment in CVHM. In this way, load routing is shifted to reflect CVHM's more groundwater-oriented partitioning of the environment.

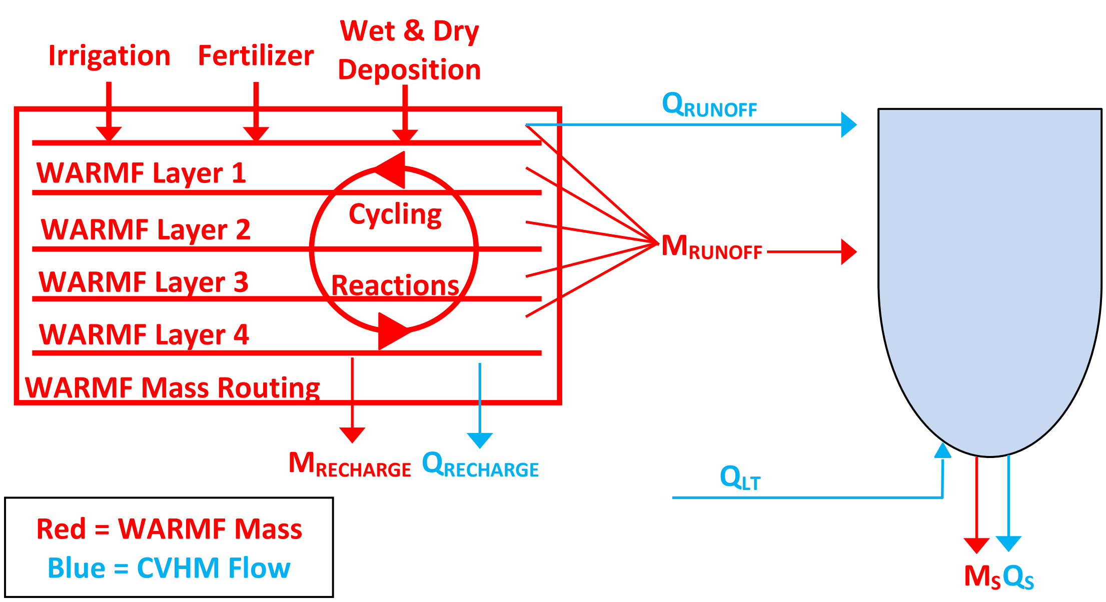


Figure 5-2. WARMF Mass Routing, CVHM Hydrology, and Combined Mass Fluxes

The sum of the four mass fluxes shown in magenta in **Figure 5-2** are equal to the total mass outflux calculated by WARMF and shown in **Figure 5-1**:

$$M_{TOT} = M_{RUNOFF} + M_{LT} + M_{RECHARGE} + M_{S}$$

The apportionment of the total outflux mass among runoff, leakage to stream, recharge, and leakage from stream depends on each CVHM flow output, but the total outflux is assumed to be independent of the flow regime. This is because the mass inputs to the land are fixed and change in storage is small over the 20-year analysis period. Thus, the total mass output is equal to total mass input plus sources minus sinks. Salinity is nearly conservative, with only minor sources and sinks within the soil, so the assumption that total mass outflux is independent of hydrology introduces very little error when the total flows between models are similar. Some additional error is introduced in determining mass fluxes of nitrate with this method because changing modeled flows results in different retention time within the soil and different amounts of nitrification and denitrification. This effect is described in more detail in Section 8.1 of this report.

Care must be taken to account correctly for gaining and losing stream conditions to avoid double-counting mass. There are four combinations or scenarios of gaining and losing stream conditions that are conceptually possible between the two platforms (CVHM and WARMF) where conservation of mass could potentially be an issue. The two models can agree that the stream is either gaining or losing, or they can disagree (one says gaining the other losing). Descriptions of each combination of possibilities and the method developed for the ICM to keep mass conserved are below.

<u>Scenario 1</u>

CVHM – Gaining Stream Conditions

WARMF – Gaining Stream Conditions

> CVHM and WARMF are in agreement that there is a component of groundwater contributing to the mass in the surface water (as shown in **Figure 5-3)**. In this case, to estimate the mass of recharge to groundwater, the two WARMF terms for recharge mass ($Q_{RECHARGE}C_{RECHARGE}$) and lateral mass flux ($Q_{LT}C_4$) will be combined to capture the entire loading to groundwater. This essentially allows the groundwater to incorporate the lateral flow mass component into its shallow ambient groundwater concentration, which then can move to the stream with CVHM's stream leakage volume component that is associated with the gaining conditions.

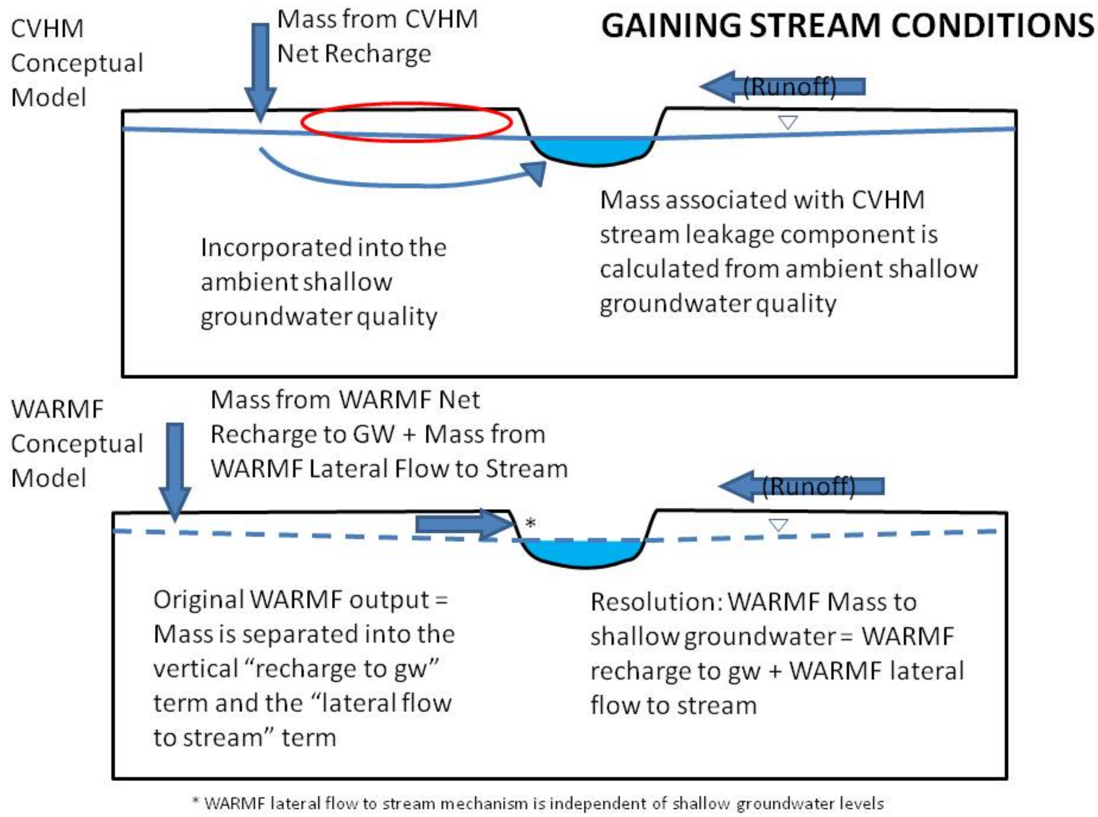


Figure 5-3. CVHM and WARMF Gaining Stream Conditions

There is one exception identified where the approach of combining the recharge and lateral masses is inappropriate. An example of this occurs in the Westside of the San Joaquin Valley (IAZ 22), due to the presence of tile drains. Tile drains prevent lateral flow and mass from moving vertically downward to enter the deeper groundwater body by intercepting and shuttling the flow and mass directly to the stream. Both model platforms still agree that there are gaining conditions, but in this case, only the recharge mass flux ($Q_{RECHARGE}C_4$) is given to the groundwater and the lateral mass flux ($Q_{LT}C_4$) is given to the stream. Mass is conserved and it is assumed that the lateral mass flux component contributes to the stream through the WARMF model and results in appropriate values for ambient stream concentration.

<u>Scenario 2</u>

CVHM – Losing Stream Conditions

WARMF – Losing Stream Conditions

WARMF values for losing stream conditions are actually assigned as "diversions" off of the stream. This occurs in only a handful of stream segments in IAZ 13 and 18 and the flow and mass in WARMF is small. CVHM also has net losing conditions for IAZ 13 and 18, so the two models are in agreement. In this scenario, the WARMF-calculated and calibrated stream concentration is combined with the CVHM stream leakage flow budget component to get the mass flux from surface water to shallow groundwater.

Scenario 3

CVHM – Gaining Stream Conditions

WARMF – Losing Stream Conditions

This scenario does not happen since WARMF only has losing conditions in IAZ 13 and 18, where CVHM also has net losing conditions.

Scenario 4

CVHM – Losing Stream Conditions

WARMF – Gaining Stream Conditions

This combination of conditions requires special attention. If the WARMF lateral flux were to be combined with the WARMF recharge mass flux to represent groundwater recharge, and then CVHM's losing stream flow component were combined with the WARMF stream concentration, there would be an overestimation of mass entering the groundwater body with no way of returning back to the stream. The solution to this dilemma is to assume that the lateral mass flux from WARMF ($Q_{LT}C_4$) gets incorporated by WARMF into the concentration in the stream (C_S), and so should not be included in the mass loading to groundwater recharge, as it shows up in the stream (as part of its concentration). Since it is assumed that CVHM hydrology is correct, and net losing stream conditions exist, WARMF-simulated lateral flow would not travel vertically downward to the water table but would remain with the stream and therefore its mass would be represented by its inherent surface water quality concentration.

Mass fluxes for non-WARMF areas were scaled to CVHM flows, with some modification to account for the more dilute nature of surface runoff. Concerns exist regarding conservation of mass when distributing the WARMF flow and concentration data with the CVHM flow data.

5.2 EXAMPLE CALCULATION

Mass flux apportionment calculations were performed for each quarterly time step for TDS and nitrate in each IAZ. The following example calculation is of TDS for IAZ 10 for the quarterly period from 10/1/1983 through 12/31/1983. During this time period, both WARMF and CVHM are simulating gaining stream conditions for IAZ 10, so no special consideration is needed.

Step 1: Calculate Total Mass Output in WARMF

The total mass exiting each WARMF catchment is calculated from the calibrated model's output with the equation[43] described in the previous section and shown below.

$$M_{TOT} = M_{RECHARGE} + M_{LT} + M_{RUNOFF} + M_{S}$$

To aggregate the daily WARMF time series output into quarterly fluxes, average flows and flow-weighted average concentrations are calculated. For this example, the values are shown in **Table 5-1:**

Table 5-1. WARMF Outputs for Mass Reapportionment Calculations

Description	Abbreviation	WARMF Value	Units
Recharge Flow	$Q_{RECHARGE}$	20.7801	cfs
Runoff (incl. Leakage to Stream for gaining stream conditions)	Q_{RUNOFF}	230.735	cfs
Recharge Concentration	$C_{RECHARGE}$	2444.36	mg/l
Runoff Concentration	C_{RUNOFF}	1952.67	mg/l

WARMF output combines flows between surface runoff and lateral "leakage to stream" through the soil zone, and considers all flow going to surface water as runoff. For the purpose of this example, the leakage to stream flow is embedded in the runoff term. Therefore, the WARMF terms of Q_{LT} and Q_{RUNOFF} are actually just one term and are represented herein as Q_{RUNOFF}. As mentioned above, in this example, WARMF has gaining stream conditions and according to WARMF hydrology, there is no flow from streams entering the groundwater. Multiplying flow

[43] The following example calculation is slightly simplified from the actual calculations performed for the ICM. By necessity, many decisions were made about the many calculations associated with this unprecedented methodology. One of these decisions involved separating the stream leakage terms from CVHM while calculating mass fluxes. Although during gaining conditions WARMF does not specify a "leakage from stream" component, CVHM does have a minor amount of flow in this category (CVHM has some portion of gaining and losing condition volumes associated with its streams that are combined to achieve a "net stream leakage" term used in the mixing model). The addition of this term that uses CVHM "leakage from stream" flows along with WARMF stream water quality concentrations provides a small amount of mass that is in error. Fortunately, this error is very small relative to the overall total mass (varies around less than 5% of the total mass), and has little to no effect on the end results of the ICM analysis.

by concentration to get mass flux, the following calculations are for recharge flux and runoff flux:

Recharge flux:

$$\mathrm{M}_{\mathrm{RECHARGE}} = \mathrm{Q}_{\mathrm{RECHARGE}} \bullet C_{RECHARGE}$$

$$\mathrm{M}_{\mathrm{RECHARGE}} = \frac{20.7801\mathrm{ft}^3}{\mathrm{s}} \bullet \frac{2444.36\mathrm{mg}}{l} \bullet \frac{2.4467\mathrm{kg\text{-}s\text{-}l}}{ft^3 - mg - d} = \frac{1.2428\mathrm{x}10^5\,\mathrm{kg}}{\mathrm{d}}$$

Runoff (and Leakage from Stream) flux:

$$\mathrm{M}_{\mathrm{RUNOFF}} = \mathrm{Q}_{\mathrm{RUNOFF}} \bullet C_{RUNOFF}$$

$$\mathrm{M}_{\mathrm{RUNOFF}} = \frac{230.735\mathrm{ft}^3}{\mathrm{s}} \bullet \frac{1952.67\mathrm{mg}}{l} \bullet \frac{2.4467\mathrm{kg\text{-}s\text{-}l}}{ft^3 - mg - d} = \frac{1.1024\mathrm{x}10^6\,\mathrm{kg}}{\mathrm{d}}$$

Now the total mass flux is calculated by substituting in the original equation where M_{LT} and M_{RUNOFF} are combined and WARMF does not have any flow associated with the "leakage from stream" term, or M_S.

$$M_{TOT} = M_{RECHARGE} + M_{LT} + M_{RUNOFF} + M_S$$

$$1.2428\mathrm{x}10^5\,\mathrm{kg/d} + 1.1024\mathrm{x}10^6\,\mathrm{kg/d} = 1.2267\mathrm{x}10^6\,\mathrm{kg/d}$$

Step 2: Calculate Ratio of $C_{RUNOFF}/C_{RECHARGE}$

WARMF simulates various processes that occur within the soil zone that can change the concentration of salt or nitrate before water leaves the bottom of the soil zone and is allowed to enter groundwater as recharge. Where this occurs, WARMF simulates higher concentrations for recharge compared to its lateral flow component of runoff[44]. The concentrations in each WARMF soil layer are a function of hydrology. It is assumed that with different hydrology, however, the ratio of lateral runoff flow to groundwater recharge ($C_{Runoff}/C_{Recharge}$) is constant. This assumption is necessary to solve for the proportions of mass fluxes under CVHM hydrology.

To solve for the mass fluxes with CVHM flows, an equation is needed to relate the concentrations of runoff and recharge flows. The flow-weighted average concentrations from the WARMF simulation are used.

$$\frac{C_{RUNOFF}}{C_{RECHARGE}} = \frac{1952.67 mg/l}{2444.36 mg/l} = 0.79885$$

[44] Many WARMF IAZs do not simulate groundwater recharge, and for those IAZs the ratio of $C_{RUNOFF}/C_{RECHARGE}$ is set equal to 1.

Step 3: Calculate C_{RUNOFF} with CVHM Flows

The total outflux mass from WARMF needs to be reapportioned between recharge, leakage to stream, leakage from stream, and runoff with CVHM flows shown in **Table 5-2**.

Table 5-2. CVHM Outputs for Mass Reapportionment Calculations

Description	Abbreviation	CVHM Value	Units
Recharge Flow	$Q_{RECHARGE}$	472.848	cfs
Net Leakage to Stream (gaining stream conditions)[45]	Q_{LT}	40.5418	cfs
Runoff	Q_{RUNOFF}	145.411	cfs

By substituting the CVHM flows and C_{RUNOFF}=0.79885$C_{RECHARGE}$ in the original total mass flux equation, one can solve for $C_{RECHARGE}$ and then C_{RUNOFF}.

$$M_{TOT} = Q_{RECHARGE} \bullet C_{RECHARGE} + Q_{LT} \bullet C_{RECHARGE} + Q_{RUNOFF} \bullet 0.79885 C_{RECHARGE} = 1.2267x10^6\, kg/d$$

$$(472.848cfs \bullet C_{RECHARGE(new)} + 40.5418cfs \bullet C_{RECHARGE(new)} + 145.411cfs \bullet 0.79885 C_{RECHARGE(new)}) \bullet \frac{2.4467kg-s-l}{ft^3-mg-d} = 1.2267x10^6\, kg/d$$

With one unknown variable, the equation can be solved and $C_{RECHARGE(new)}$=796.38 mg/l. From the relationship between $C_{RECHARGE}$ and C_{RUNOFF}, $C_{RUNOFF(new)}$ can be solved as 636.19 mg/L.

Step 4: Calculate Re-Apportioned Masses Using CVHM Hydrology for Mixing Model Input

The unknown re-apportioned mass fluxes can be calculated from the CVHM flows and new concentrations.

Recharge flux:

$$M_{RECHARGE} = Q_{RECHARGE} \bullet C_{RECHARGE(new)}$$

[45] As mentioned in a previous footnote, the methodology is simplified slightly for purposes of this example. The term here for "Net Leakage to Stream" is simplified rather than break out the "leakage to" and "leakage from" components that CVHM reports. The *net* leakage to stream term is used to simplify this example and maintain the overall gaining stream condition in this IAZ.

$$M_{RECHARGE} = 472.848\frac{ft^3}{s} \bullet 796.38\frac{mg}{l} \bullet 2.4467\frac{kg\text{-}s\text{-}l}{ft^3 - mg - d} = 9.2135x10^5\,\frac{kg}{d}$$

Leakage to Stream flux:

$$M_{LT} = Q_{LT} \bullet C_{RECHARGE(new)}$$

$$M_{LT} = 40.5418\frac{ft^3}{s} \bullet 796.38\frac{mg}{l} \bullet 2.4467\frac{kg\text{-}s\text{-}l}{ft^3 - mg - d} = 7.8996x10^4\,\frac{kg}{d}$$

Runoff flux:

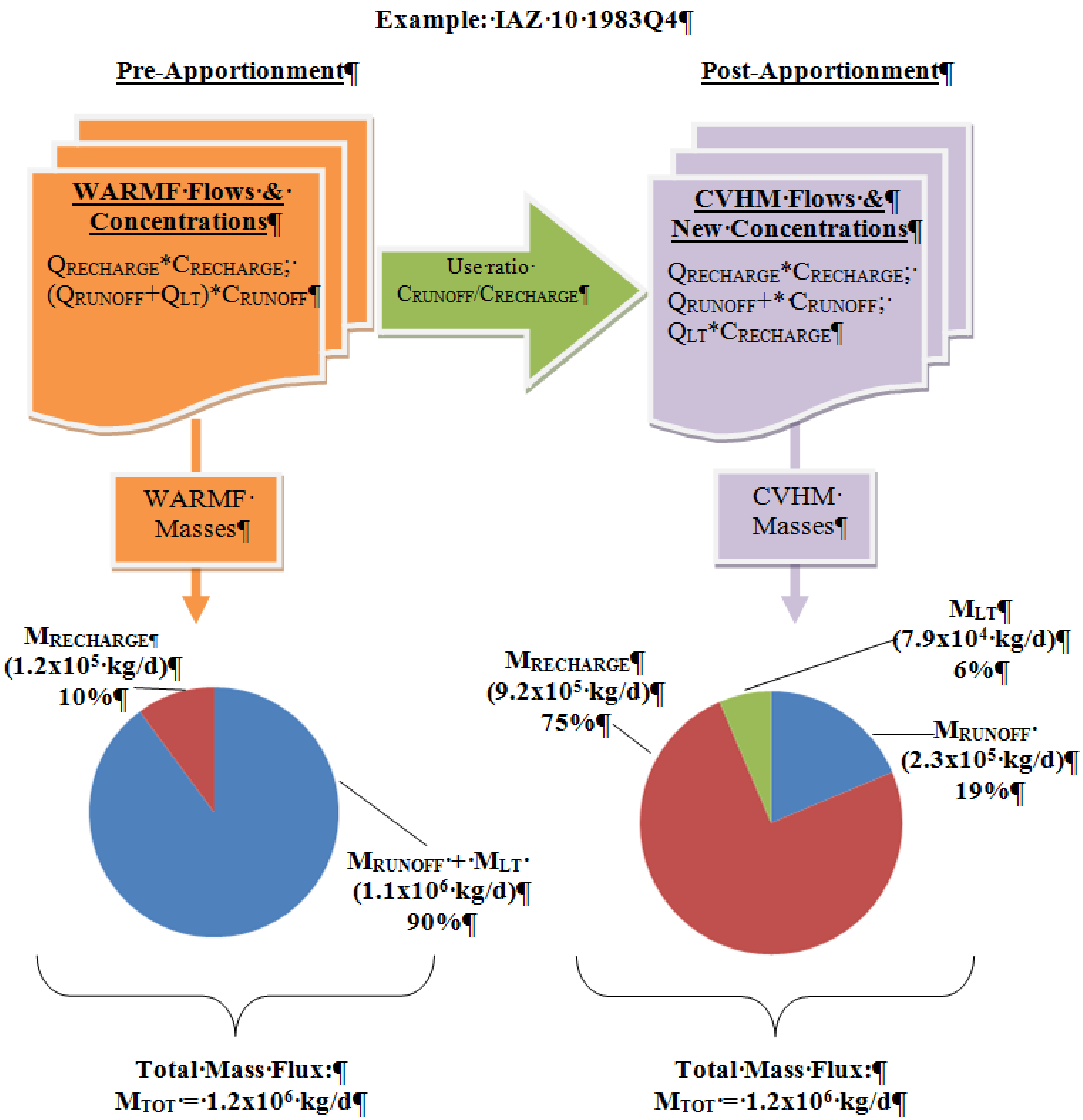
$$M_{RUNOFF} = Q_{RUNOFF} \bullet C_{RUNOFF(new)}$$

$$M_{RUNOFF} = 145.411\frac{ft^3}{s} \bullet 636.19\frac{mg}{l} \bullet 2.4467\frac{kg\text{-}s\text{-}l}{ft^3 - mg - d} = 2.2634x10^5\,\frac{kg}{d}$$

When added up, the total mass, M_{TOT} ($M_{RECHARGE}$ + M_{LT} + M_{RUNOFF} = $1.22668x10^6$ kg/d), is equal after reapportioning to WARMF's original total mass flux calculated in Step 1 for this quarter (1983Q4) for this IAZ (IAZ 10). Therefore mass has been conserved. In this example, the concentration of recharge went from 2,444 mg/L in WARMF to an adjusted value of 796 mg/L after re-apportionment. In terms of mass, WARMF originally estimated 1.24x105 kg/d as recharge mass flux. After re-apportionment, the recharge mass flux became 9.21x105 kg/d. Even though the concentration of recharge was reduced, the overall recharge mass flux term increased. This is due in part to the very different recharge flow values[46] between WARMF (21 cfs) and CVHM (473 cfs). The figure below illustrates the apportionment example described in the above steps, showing the pre-apportioned mass proportions and the post-apportioned mass proportions (**Figure 5-4**).

[46] See Section 8 for a description of recharge values actually used.

Figure 5-4. Illustration of the Apportioning Mechanism as Calculated in the Example



5.3 WARMF/CVHM COMPARISONS

The above example calculation shows how mass flux is conserved between WARMF and CVHM regardless of differences in flows used by each model. WARMF is used as a mass routing mechanism to tabulate incoming loading sources, determine root zone sources and sinks, and then to distribute the net mass among groundwater recharge, runoff, leakage to stream, and leakage from stream, all proportioned with CVHM hydrologic output. Differences in characterization of land cover and hydrology between the models, and the effect of those differences on the ICM model linkage, are described in this section.

Land Use

Each catchment in WARMF is divided among multiple land cover classes (as percentages of the total catchment area). The WARMF land cover database was combined from several data sources. The primary source for irrigated lands is the DWR land use database, which has spatially detailed coverage of individual crop types in agricultural areas. County-level databases have been used to represent land use in urban areas. The National Land Cover Database is used for the remaining natural land cover. Land cover classification schemes from each of these areas is translated into WARMF classifications, which were developed to group lands that are similar in terms of water and constituent balances, and to segregate those that are distinct. WARMF schemes differ somewhat among the three model domains employed, but are generally consistent in this approach, with numerous recurring classifications.

CVHM utilizes the FMP (Farm Process) to estimate components of consumptive use for a wide variety of land uses, including vegetation in irrigated or non-irrigated agriculture, fallow fields, riparian or natural vegetation, and urban landscape settings. The FMP was used to simulate an assortment of irrigation methods and periods of transition between applied methods. The methods range from flood irrigation (for rice and cotton), to drip irrigation of truck crops and orchards. Land use attributes are defined in the model on a cell-by-cell basis and include urban and agricultural areas, water bodies, and natural vegetation. The land use that covered the largest fraction of each 1-square-mile model cell was taken as the representative land use specified for that cell. Five different time frames were used during CVHM's 42.5 year simulation period, with land cover changing between these time frames to reflect each period. Agricultural land use classifications were based on 12 DWR class-1 categories, and a total of 22 different crop types were defined from land-use maps for 1960, 1973, 1992, 1998, and 2000. CVHM specifies time-varying crop coefficients and differentiates between the six components of evaporation and transpiration, fractions of transpiration for precipitation and irrigation water, fractions of runoff as inefficient losses, irrigation efficiencies, and other properties, some of which are varied through time on a monthly time basis. Sources of irrigation water (surface and groundwater) are also apportioned on a monthly basis (Faunt et al., 2009).

The detailed WARMF land cover database provides a strong foundation for tabulating inputs to each land catchment. WARMF catchments have higher spatial resolution than IAZs. When performing analyses on an IAZ basis, the catchment-level inputs and outputs are aggregated over many catchments to calculate totals for each IAZ. CVHM grid cells have higher spatial resolution than WARMF catchments. If analysis is done by CVHM model grid cell, the linkage between the models provides mass fluxes that are uniform on a per-area basis across all the CVHM grid cells that fall within each WARMF catchment. This was the case for the Modesto

Analysis (Task 7). Where no WARMF model data exist, output from land cover classes in an analogous area are applied to DWR land data at the field level. Modifications were made to translate the DWR classification scheme to the applicable WARMF scheme, and to correctly locate POTW infiltration facilities and dairy land application fields. In this case, spatial resolution is generally much finer than the CVHM grid, since fields and facilities are generally less than 1-square-mile in size. This approach was employed for the Kings Subbasin (Task 7).

Hydrology

Figure 5-5 shows the CVHM simulated flows for each IAZ averaged over time and **Figure 5-6** shows the equivalent flows for WARMF in the IAZs within the WARMF model domains. In both models, approximately 76% of combined precipitation and irrigation is lost to evapotranspiration. Among IAZs with WARMF coverage, WARMF has an average of 8% more combined runoff and leakage to stream entering rivers than CVHM. There is wide variation in that difference among IAZs, as well as temporally within the simulation period. Although WARMF simulates small amounts of leakage from streams in IAZs 13 and 18, this leakage is ignored in this analysis (i.e., the mass is re-allocated, as described later). CVHM simulates more net leakage from streams than inflows to streams in much of the Central Valley from the Delta southward. The major difference between the models is in the amount of groundwater recharge. CVHM has large groundwater recharge flows in all IAZs; WARMF has less recharge in some IAZs and does not show recharge in much of the Central Valley. Some of the CVHM recharge is later lost to evapotranspiration from groundwater, whereas WARMF simulates all evapotranspiration coming directly from the root zone. In spite of not showing recharge in some IAZs, the calibrated WARMF model still simulates river flow and water quality similar to measured in-stream values. Because the model linkage procedure maintains mass balance, the flow partitioning differences between the models is not expected to be an important source of error for salinity. A modest amount of error is possible in the nitrate analysis as described in Section 8-1. There is, however, the potential for error associated with different amounts of irrigation water applied and therefore able to percolate into the ground as groundwater recharge. If overall the WARMF flows are consistently lower than CVHM flows (runoff plus leakage to stream plus recharge), for example, and WARMF's recharge concentration values are assumed to be correct, there will not be enough mass produced by WARMF to accommodate the volume of recharge that would percolate according to CVHM. This most likely would be addressed by running WARMF with higher flow volumes associated with groundwater recharge.

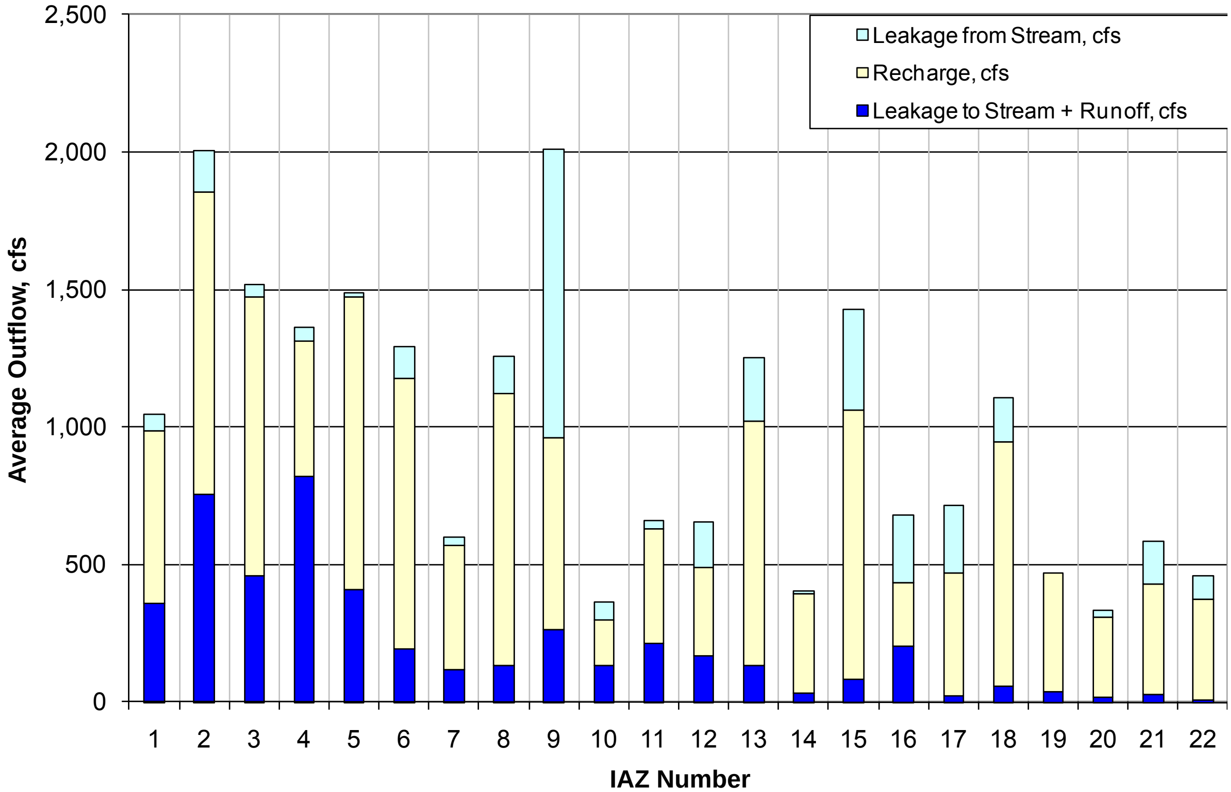


Figure 5-5. Average CVHM Flows by IAZ

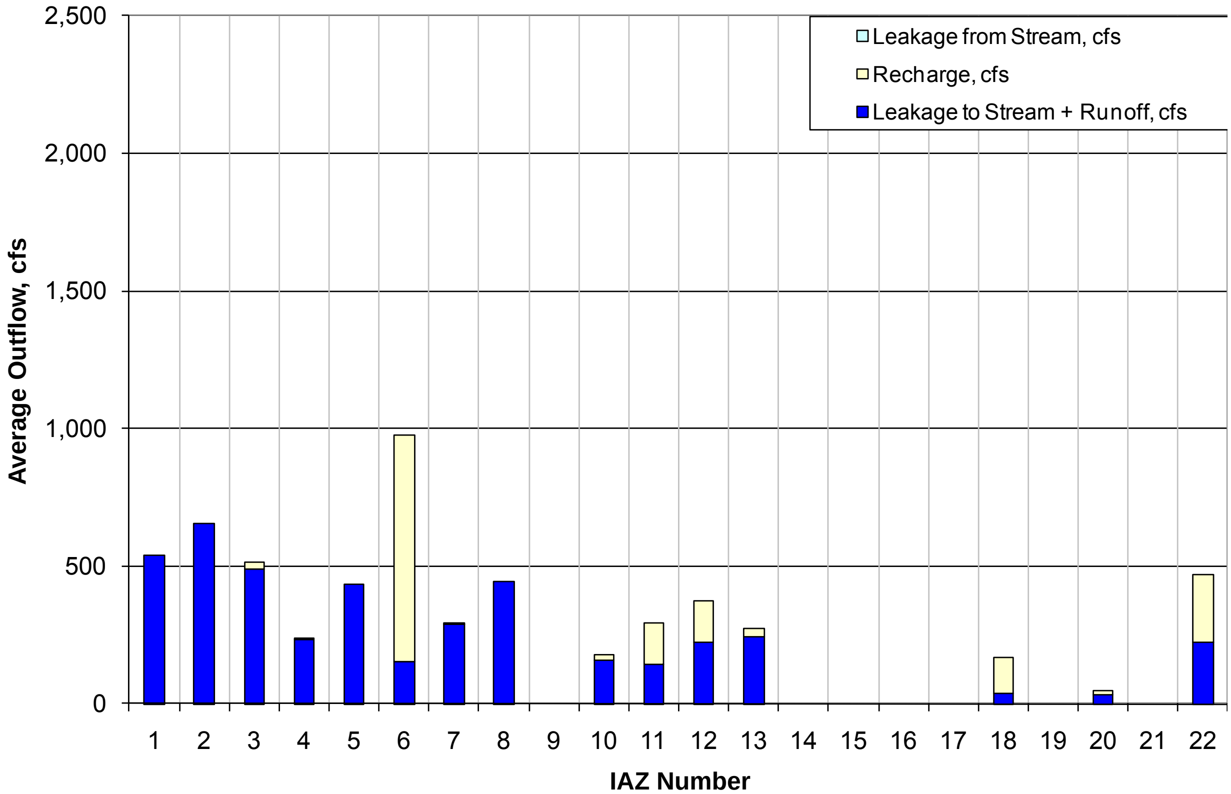


Figure 5-6. Average WARMF Flows in IAZs with WARMF Coverage

The groundwater recharge flows used in the WARMF-CVHM linkage were higher than the correct flows shown in **Figure 5-5**, but this error was discovered too late to make the correction. This resulted in too much salt and nitrate mass being apportioned to groundwater recharge rather than runoff and leakage to stream. The error was least in IAZs dominated by groundwater recharge and greatest in those IAZs with the highest surface water discharge. More information on this source of error is provided in Section 8.

6. Water, Salt, and Nitrate Balance Calculation Methodology

6.1 DEVELOPING INPUTS TO CAPTURE UNCERTAINTIES

Although the general issue of uncertainty is discussed later, specific analyses were added to the originally planned work to bracket uncertainty regarding loading inputs into the mixing model. These were developed for nitrogen and salt and are discussed in additional detail below.

6.2 MIXING MODEL DATABASE SETUP FOR GROUNDWATER AND SURFACE WATER

Due to the large amount of information and interworking nature of a mixing model on the scale of the entire Central Valley floor, a simple spreadsheet model would not adequately perform the necessary water, salt and nitrate balance calculations. Accordingly, a database was developed that contains a series of tables and queries to perform all of the groundwater water, salt, and nitrate calculations on a quarterly basis for a 20-year period for 22 IAZs. A separate database was developed to do the same for surface water. Multiple databases were developed for each nitrate and TDS scenario as well[47]. **Figure 6-1** represents the pieces of the mixing model database, showing how all of the mass and concentrations are linked to the volume components from CVHM.

Formatting Input Data

Due to the various data sources, it became evident that all of the input data needed to be formatted into the same units or format. All of the quarterly dates, flow, volume, mass, and concentration units were standardized for ease of calculating water and mass balances (for example flow in cubic meters per day; volume converted to liters; mass converted to milligrams; concentrations all in mg/L). WARMF and non-WARMF mass loading information were organized in the same format for entry into the mixing model database. These data were processed before entry into the database by combining deep percolation and lateral flow masses for IAZs where CVHM simulated streams show dominantly gaining stream conditions (deep percolation mass alone is used for IAZs where streams are not present or are consistently losing) for the recharge component.

Tables and Queries

The groundwater mixing model database includes seven input tables, and ten tables created from a series of queries and Visual Basic scripts. The first four data input tables for the groundwater mixing model include:

[47] As described in Section 8.2.1, the LWA Team ran a sensitivity analysis to evaluate sources of uncertainty in the mixing model results. The sensitivity analysis was conducted for six (6) nitrate loading scenarios using various adjustments to the nitrogen application and uptake parameters and three (3) salinity loading scenarios.

1. Initial Volume Table
    a. Initial volume values for each IAZ representing the volume of water present in the IAZ for the first quarter of analysis that will be used for the water balance calculations.
        i. This volume was calculated from the sum of the CVHM saturated thickness estimates on a cell-by-cell basis for each layer included in the IAZ for the initial simulation time in September 1983 (CVHM stress period 270), multiplied by the grid cell area (1 square mile), and multiplied by the porosity from CVHM to achieve a volume of water present at the beginning of the simulation.
2. Input Concentration Data Table
    a. Input concentration data are entered into one table to contain quarterly concentration values of nitrate (as N) and TDS for each IAZ for:
        i. Ambient surface water quality (time series values from flow-weighted WARMF or measured concentration data for each IAZ),
        ii. Ambient deep groundwater quality (time series values from measured concentration data from wells categorized as deep for each IAZ),
        iii. Ambient general head boundary (representing the Sacramento/San Joaquin Delta) shallow groundwater quality (from measured concentrations of shallow groundwater quality present in the general head boundary area as delineated by CVHM), and
        iv. Starting shallow groundwater quality for the first quarter of analysis (from measured groundwater quality data for each IAZ).
3. Groundwater Recharge Mass Table
    a. Groundwater recharge mass is contained in a separate input table, with units converted to milligrams, and values for each IAZ for each quarter for nitrate (as N) and TDS (from WARMF and non-WARMF interpolated mass fluxes).
4. Zonebudget Output Flow Table
    a. This table includes all of the flow values for all of the CVHM water budget components on a monthly basis post-processed using Zonebudget for all of the IAZs for the entirety of the CVHM simulation period (1961-2003).
    b. Flow components include:
        i. Recharge,
        ii. Agricultural and Municipal Groundwater Pumping,
        iii. Flow through the Delta (simulated model general head boundary),
        iv. Flow to or from aquifer storage,
        v. Stream leakage,
        vi. Horizontal flow to and from adjacent IAZs, and

vii. Vertical flow to and from deeper aquifer units.

Three additional input tables are for linking and reference purposes:

5. Time Table
    a. The Time Table provides the CVHM model stress period, the corresponding decimal year date value, the number of days in the stress period (month), the quarter designation (e.g., 1983Q3), and the start date of the stress period.
    b. This table is used to convert flows to volume and to coordinate the quarter designation used for the ICM analysis.
6. Zonebudget Parameters Table
    a. The Zonebudget Parameters Table assigns major categories for each of the raw Zonebudget output parameters (e.g., "FROM_ZONE_1" represents "Horizontal Flow" from IAZ -1) as a reference tool.
7. Linkage for Quarterly Concentrations Table
    a. This table is the most important table for the water and mass balance calculations. This table provides the link between IAZs, the quarter date associated with the volume component, the direction of volume movement (in or out), the volume parameter (e.g., "STREAM_LEAKAGE"), the date (quarter and year) of the concentration value that needs to be associated with its the volume parameter, and lastly the IAZ number associated with that concentration.
    b. This table acts like a map that directs the mixing model database to look for a particular IAZ's ambient quality concentration (of salt and nitrate) and link it to its appropriate volume for each quarter of analysis. For example, the volume of water "FROM_ZONE_1" that is assigned to IAZ 2 must have the salt and nitrate concentration associated with IAZ 1.

Several queries are setup to calculate intermediate steps before the volume and mass balance calculations can be performed in more queries that produce and populate additional tables. These are described in more detail in the preceding sections.

Establish Relationships Between Concentrations, Volumes, and Masses for Each Budget Component

The "Linkage for Quarterly Concentrations Table" described above is a table in the mixing model database that establishes the relationships between concentrations, volumes, and mass for each budget component. This takes into consideration the direction of water and mass movement for each budget component and associates the correct concentration value (e.g., nitrate (as N) and TDS concentrations for ambient surface water, ambient deep groundwater, ambient IAZ (shallow) groundwater, etc.) to that volume of water for each quarter of the 20-year ICM simulation period. The concentration is multiplied by the volume to get the value of mass that moves in or out of each IAZ. The table below summarizes the different sources for volume and mass components used for the balance calculations (**Table 6-1**).

Figure 6-1. Schematic Illustrating the Mixing Model Database Inputs and Outputs

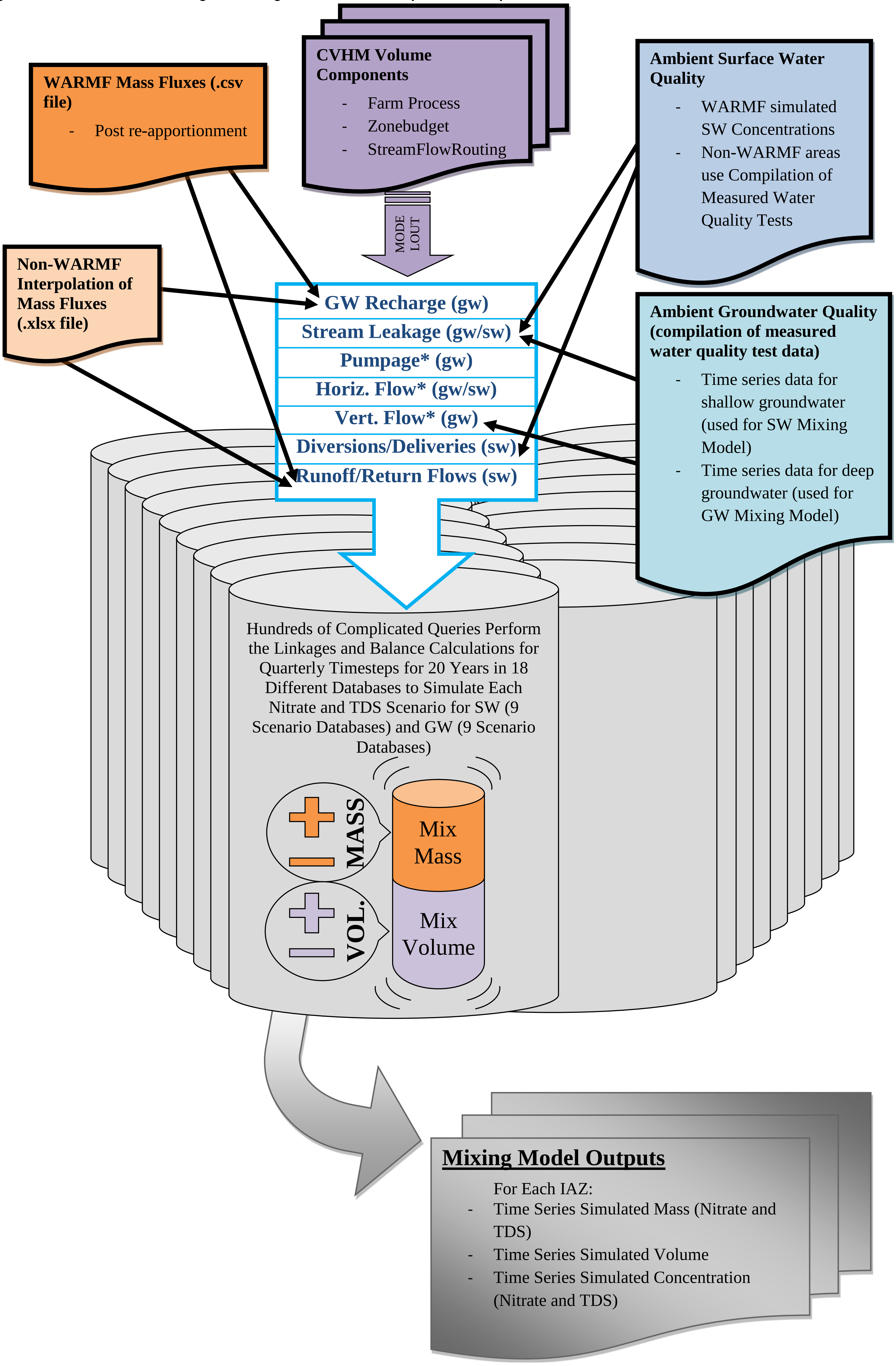


Table 6-1. Sources for Volume and Mass Components Used for the IAZ Water, Salt, and Nitrate Balance Calculations

Component	In/Out	Volume Source	Mass Source[48]
Starting Volume			
Groundwater	-	CVHM – saturated 20-year travel zone within IAZ in 1983	Calculated from ambient shallow groundwater quality
Surface Water	-	CVHM – surface water volume present in CVHM stream cells within IAZ in 1983	Calculated from ambient surface water quality
Inflows/Outflows			
Groundwater Recharge	In	CVHM – zonebudget net Farm Process recharge	WARMF/non-WARMF analysis mass loads
Groundwater Horizontal Movement between IAZs	In/Out[49]	CVHM – zonebudget flows to/from each IAZ 20-year travel zone	1) Calculated from ambient shallow groundwater quality 2) Calculated from previous timestep's ending quality concentration for 20-year travel zone
Stream Leakage			
To stream from groundwater	In/Out[50]	CVHM – zonebudget stream leakage (positive component indicating losing stream conditions)	1) Calculated from ambient shallow groundwater quality 2) Calculated from previous timestep's ending quality concentration for 20-year travel zone
To groundwater from stream	In/Out[51]	CVHM – zonebudget stream leakage (negative component indicating gaining stream conditions)	1) Calculated from ambient surface water quality 2) Calculated from previous timestep's ending quality concentration for surface water
Groundwater Vertical Movement			
Upward into 20-year travel zone	In	CVHM – zonebudget flow from lower layers into IAZ 20-year travel zone	Calculated from ambient deep groundwater quality
Downward into lower aquifer	Out	CVHM – zonebudget flow from IAZ 20-year travel zone into lower layers	1) Calculated from ambient shallow groundwater quality 2) Calculated from previous timestep's ending quality concentration for 20-year travel zone
Groundwater Pumpage	In/Out[52]	CVHM – zonebudget farm and municipal groundwater pumpage from 20-year travel zone	1) Calculated from ambient shallow groundwater quality 2) Calculated from previous timestep's ending quality concentration for 20-year travel zone
Surface Water Horizontal Movement Between IAZs	In/Out[53]	CVHM – streamflow values for each stream segment and reach in each IAZ	1) Calculated from ambient surface water quality 2) Calculated from previous timestep's ending surface water quality concentration
Surface Water Diversions/Deliveries	Out	CVHM – Farm Process surface water deliveries in each IAZ	1) Calculated from ambient surface water quality 2) Calculated from previous timestep's ending surface water quality concentration

[48] When mass is being calculated from concentrations, this approach uses the general formula and isolates the mass term: $Concentration = \frac{Mass}{Volume}$

[49] Groundwater can flow horizontally from one IAZ into another. For example, the water entering IAZ-1 from IAZ-2 is considered to be an inflow component, while IAZ-2 will consider the same value to be an outflow component leaving IAZ-2.

[50] Represents either an inflow component for surface water balance calculations and an outflow component when used in the groundwater balance calculations

[51] Represents either an outflow component for surface water balance calculations and an inflow component when used in the groundwater balance calculations

[52] Though typically pumpage would be considered as an outflow component, CVHM simulates potential wellbore flow between model layers for wells with screens that span multiple model layers (this is done using the multi-node well (MNW) modeling package), which can result in lower model layers actually providing inflow to shallower layers or vice versa.

[53] Similar to the horizontal groundwater flow component, the surface water entering one IAZ is considered to be an inflow component, while the IAZ providing that surface water considers the amount to be an outflow.

6.3 METHOD FOR GROUNDWATER BALANCE CALCULATIONS FOR 20-YEAR SIMILATUION PERIOD

The monthly flow values are converted to quarterly volumes by multiplying the flow values by the number of days in each month and summing the monthly volumes into quarterly volumes. A database query is used to perform these initial calculations. The database is also used to summarize the net volumes (ins and outs) over each quarter, and then determine the net change for each IAZ for each quarter. The starting and ending volumes for each IAZ for each quarter are then calculated outside the database in a spreadsheet using the database-calculated net volumetric changes for each IAZ for each quarter, and subsequently brought back into the database as a new table.

Salt (TDS) & Nitrate (NO3-N)

Mass values are calculated for the volumetric components that are independent of the mixing model, including:

1. Contributions of mass from deep groundwater (Zonebudget zone 23),
2. Contributions of mass from surface water leakage,
3. Contributions of mass from the Sacramento/San Joaquin Delta (general head boundary), and
4. Contributions of mass from groundwater recharge.

A make-table query creates a table that lists the concentration values and associated volume values used to calculate the mass (mass = concentration x volume) for contributions of mass from deep groundwater (3520 records). Append queries are then performed to add values to the newly created mass table for the remaining independent components (surface water (3520 records for 22 IAZs x 80 quarters in a 20-year time period x 2 analytes of TDS and NO3-N), flow through general head boundaries simulating the Delta (160 records for IAZ-9 alone x 80 quarters x 2 analytes)). The methodology for the ICM that links the contribution of mass from the WARMF domain does not use concentrations and volumes, but solely mass. Therefore, the mass calculated following the improved methodology from the Task 5 Addendum is appended to the independent component mass table. Lastly, the initial starting mass is calculated and appended to the independent component mass table based on the starting shallow groundwater quality concentration (44 records).

6.4 METHOD FOR SURFACE WATER BALANCE CALCULATIONS FOR 20-YEAR SIMILATUION PERIOD

The CVHM output file “fort.70”[54] contains the streamflow routing package’s output file. This file contains surface water data for each monthly stress period including but not limited to:

- Layer,
- Row,
- Column,
- Stream segment number,
- Reach number,
- Flow into the stream reach,
- Flow to the aquifer,
- Flow out of the stream reach, and
- Overland runoff[55].

The flow components listed above represent the entirety of movement related to surface water in CVHM, including horizontal flow in and out of each IAZ, vertical flow through streambed leakage, diversions, deliveries, and return flows or runoff contributions back to streams.

Similar to the starting volume calculations for the groundwater balance calculations, the starting volume of surface water present in each IAZ is taken as the initial flow into each stream reach multiplied by the number of days in the time period the flow is attributed to, and summed across the IAZ for the first quarter.

Salt (TDS) & Nitrate (NO3-N)

Surface water quality concentration data are used to link with the various volumetric components to calculate the mass of salt (TDS) and nitrate (NO3-N).

The goal was to examine salt, nitrate, and water balances going forward, if contemporary management approaches were maintained. To do this, an actual climatic regime was employed, not because it represents the future, but because it encompasses a time period containing realistic spatial and temporal climatic variability, and can therefore be reasonably employed to model future conditions for which climate is as yet unknown. Land cover was the relatively recent (approx. 2003+/-, depending on the county), which was what had been developed as part of the WARMF runs that were used. Fertilizer and irrigation management were developed to reflect contemporary practices.

[54] From the CVHM archive output: http://pubs.usgs.gov/pp/1766/PP1766-CVHM_output.zip file named fort.70

[55] This component contains the runoff return flows when the value is a negative number.

6.5 SUMMARY

This section describes the methodology developed for the IAZ water, salt, and nitrate balance calculations for groundwater and surface water. Essentially all of the mass loadings (from WARMF or non-WARMF interpolation), CVHM water budget time series volumes, and time series of ambient surface water and groundwater quality data are housed inside numerous databases. Hundreds of complicated queries are performed on the data to add or subtract volumes and masses of salt and nitrate (sometimes using concentrations with volumes to yield mass values) for each IAZ on a quarterly basis for a 20-year time period between 1983 and 2003. This methodology enables the calculation of water and mass movement simultaneously between each IAZ for the entirety of the Central Valley floor.

7. Water, Salt, and Nitrate Balance Calculation Results

There are many sources of water that contribute to the hydrologic budget for shallow groundwater. Sources of inflow include recharge from the land surface, seepage from surface water, injection wells, upward flow from deep groundwater, upward well borehole flow, and horizontal flow from adjacent aquifers. Sources of outflow include crop transpiration, flow to surface water, pumping wells, downward flow to deep groundwater, downward well borehole flow, and horizontal flow to adjacent aquifers. Associated with the inflows and outflows are dissolved masses of nitrate and TDS. The ICM mixing model tracks the associated masses entering and leaving shallow groundwater via the hydrologic flow components over the 20-year model period.

First, the results of the groundwater flow budget are presented, followed by the results of the net mass fluxes of mass into and out of shallow groundwater. Next, ambient water quality conditions are evaluated. The ambient and simulated conditions are combined to rank the IAZs relative to one another in terms of their priority for future study. The IAZs with higher ambient and simulated concentrations for shallow groundwater are given higher priority compared to other IAZs that have lower concentrations. Following the prioritization of IAZs, preliminary assimilative capacities are estimated for each IAZ, based on the calculated ambient conditions as well as the multiple simulations performed for nitrate and TDS.

7.1 FLOW BUDGET FOR SHALLOW GROUNDWATER

Groundwater flow budgets in the shallow groundwater (namely the 20-year travel zone layers of CVHM), taken from CVHM output, include groundwater pumpage, recharge, stream leakage, and horizontal and vertical flow (**Figure 7-1**) and **Table 7-1** show the net sum of the various flow components into and out of shallow groundwater for each IAZ over the 20-year simulation period.

While some flow components have both inflows and outflows, only the net amount over the simulation period is shown. Positive values indicate a net inflow to shallow groundwater, and negative values indicate a net outflow from shallow groundwater. For most IAZs, recharge from the Farm Process[56] (farm net recharge), which simulates recharge from the land surface, provides the majority of flow into shallow groundwater. IAZs 4 and 9 are unique in this respect as the majority of flow to shallow groundwater in these areas comes from upward vertical flow from deep groundwater (IAZ 4) and recharge from surface water (IAZ 9). Outflow from shallow groundwater for all IAZs is largely composed of downward vertical flow to deep groundwater and well pumpage. For most IAZs, downward vertical flow outpaces groundwater pumpage with the exception of IAZs 15 and 18 which show significant amounts of groundwater pumpage from shallow groundwater. Results for IAZs 1-5 in the northern portion of the Central Valley indicate that a large fraction of outflow from shallow groundwater is to surface water under gaining stream conditions.

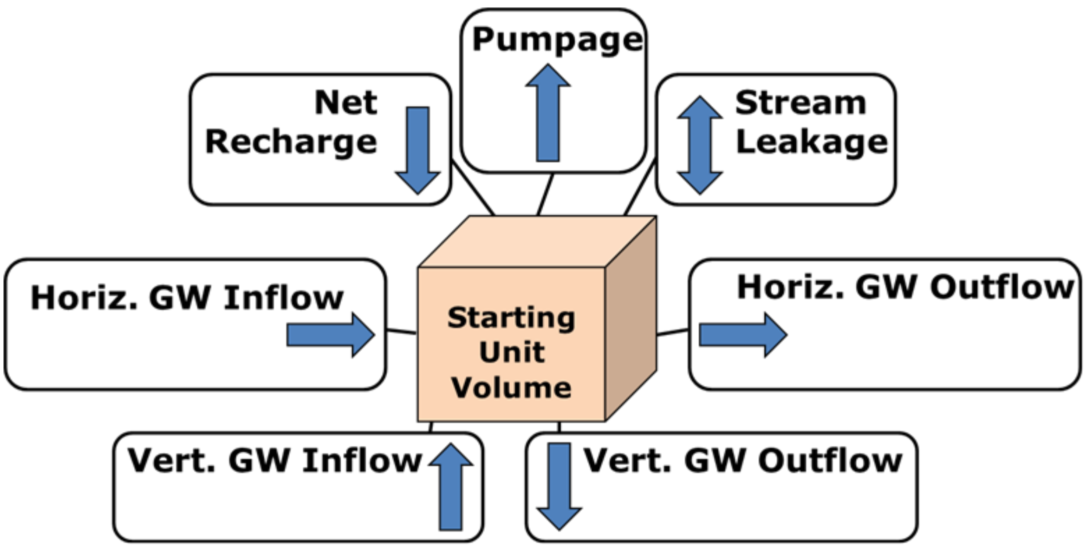


Figure 7-1. Water Budget Components for Shallow Groundwater

[56] In CVHM, the Farm Process (Schmid and Hanson, 2009) is used to simulate landscape recharge. This includes recharge from all land use types, including from urban environments. Because vast majority of land use in the Central Valley is agricultural, and the Farm Process is the only mechanism for providing recharge from the land surface (excluding surface water), we refer to farm net recharge from the Farm Process here as "farm recharge." This represents deep percolation minus any potential direct uptake from groundwater as evapotranspiration.

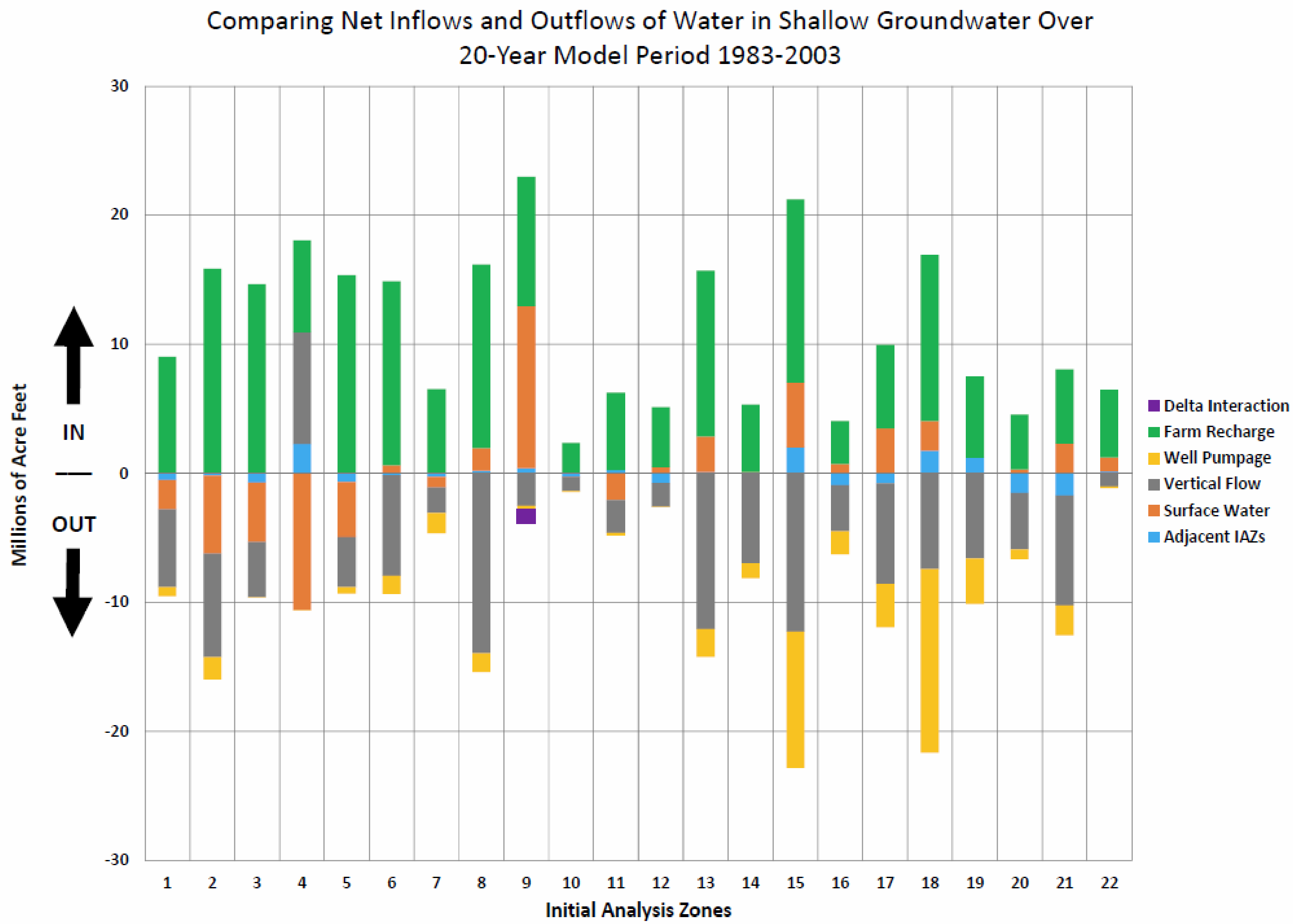
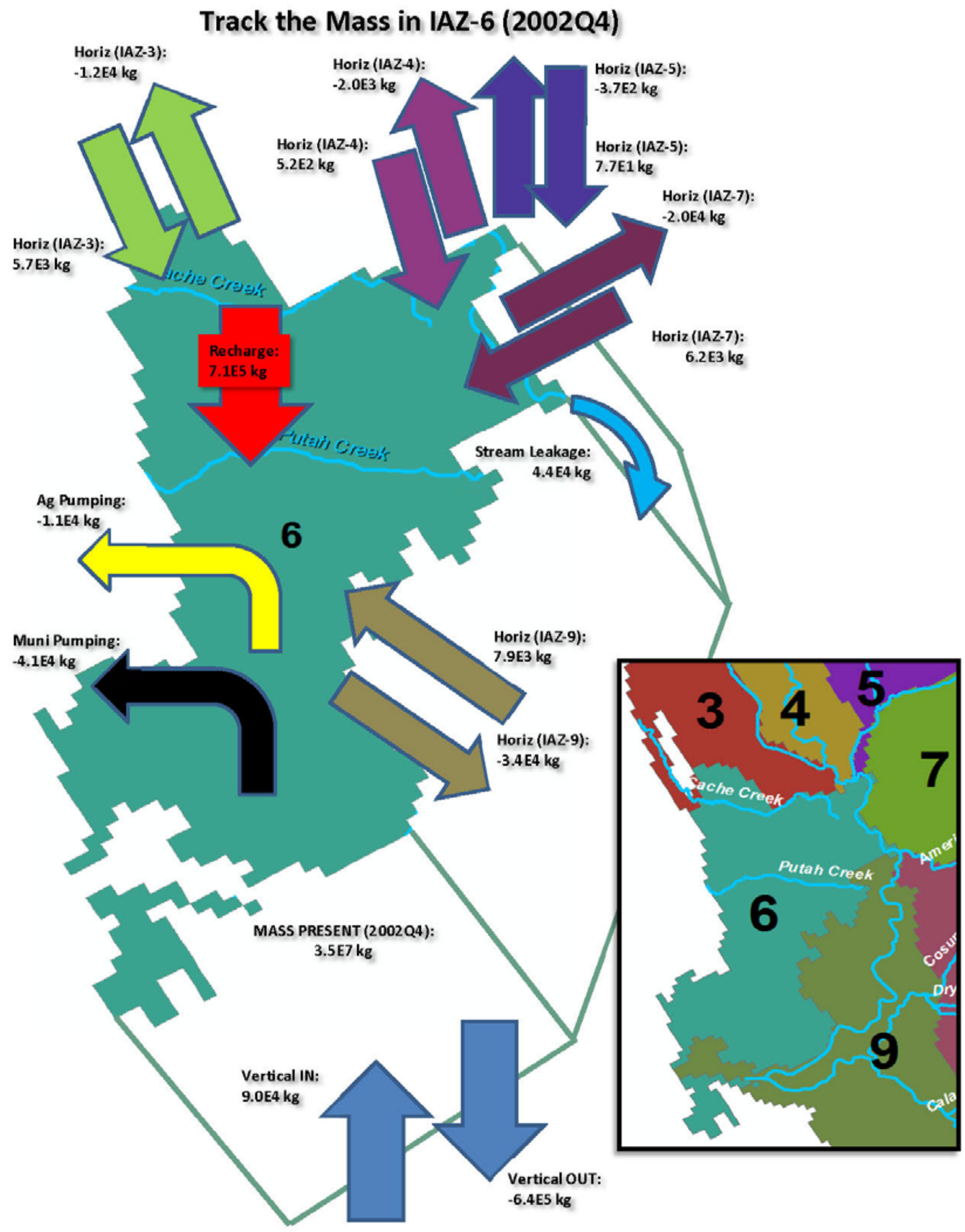


Figure 7-2. CVHM Net Flows

Table 7-1. CVHM Flow Budget, in Millions of Acre-feet.

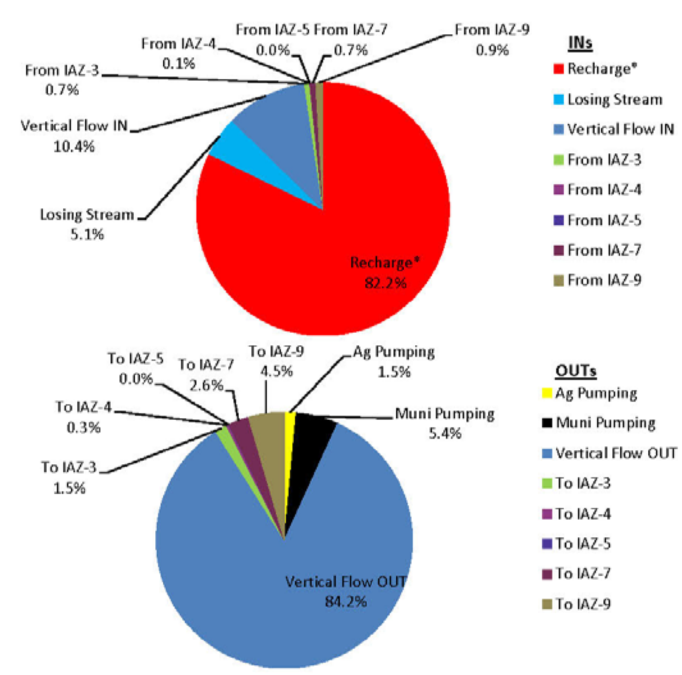
	IAZs	Adjacent IAZs	Surface Water	Vertical Flow	Well Pumpage	Farm Recharge	Delta Interaction
Northern Central Valley	**1**	-0.51	-2.28	-6.03	-0.72	9.02	0.00
	2	-0.16	-6.07	-8.01	-1.74	15.84	0.00
	3	-0.71	-4.60	-4.30	-0.02	14.65	0.00
	4	2.27	-10.62	8.66	0.00	7.12	0.00
	5	-0.65	-4.28	-3.89	-0.51	15.33	0.00
	6	-0.14	0.63	-7.80	-1.41	14.23	0.00
	7	-0.26	-0.83	-1.98	-1.60	6.53	0.00
Middle Central Valley	**8**	0.22	1.73	-13.94	-1.47	14.24	0.00
	9	0.42	12.52	-2.52	-0.24	10.05	-1.10
	10	-0.25	-0.03	-1.10	-0.07	2.35	0.00
	11	0.25	-2.07	-2.56	-0.20	6.02	0.00
	12	-0.75	0.48	-1.85	-0.01	4.64	0.00
	13	0.10	2.76	-12.05	-2.18	12.83	0.00
	22	0.16	1.08	-1.03	-0.12	5.25	0.00
Southern Central Valley	**14**	0.03	0.09	-6.97	-1.16	5.21	0.00
	15	1.97	5.05	-12.26	-10.55	14.20	0.00
	16	-0.93	0.72	-3.57	-1.76	3.32	0.00
	17	-0.76	3.49	-7.81	-3.33	6.46	0.00
	18	1.76	2.30	-7.40	-14.25	12.87	0.00
	19	1.18	0.00	-6.58	-3.53	6.30	0.00
	20	-1.53	0.31	-4.35	-0.77	4.24	0.00
	21	-1.72	2.28	-8.52	-2.29	5.77	0.00



Moving Mass Components in 2002Q4 for IAZ-6 (kg)

Starting Mass		3.53E+07
INs	Recharge*	7.1E+05
	Losing Stream	4.4E+04
	Vertical Flow IN	9.0E+04
	From IAZ-3	5.7E+03
	From IAZ-4	5.2E+02
	From IAZ-5	7.7E+01
	From IAZ-7	6.2E+03
	From IAZ-9	7.9E+03
OUTs	Ag Pumping	-1.1E+04
	Muni Pumping	-4.1E+04
	Vertical Flow OUT	-6.4E+05
	To IAZ-3	-1.2E+04
	To IAZ-4	-2.0E+03
	To IAZ-5	-3.7E+02
	To IAZ-7	-2.0E+04
	To IAZ-9	-3.4E+04
Net Change in Mass		1.1E+05
Ending Mass		3.54E+07

*Recharge mass comes from WARMF analyses and non-WARMF area extrapolation; all other mass components are calculated based on ambient concentrations and CVHM volumes.



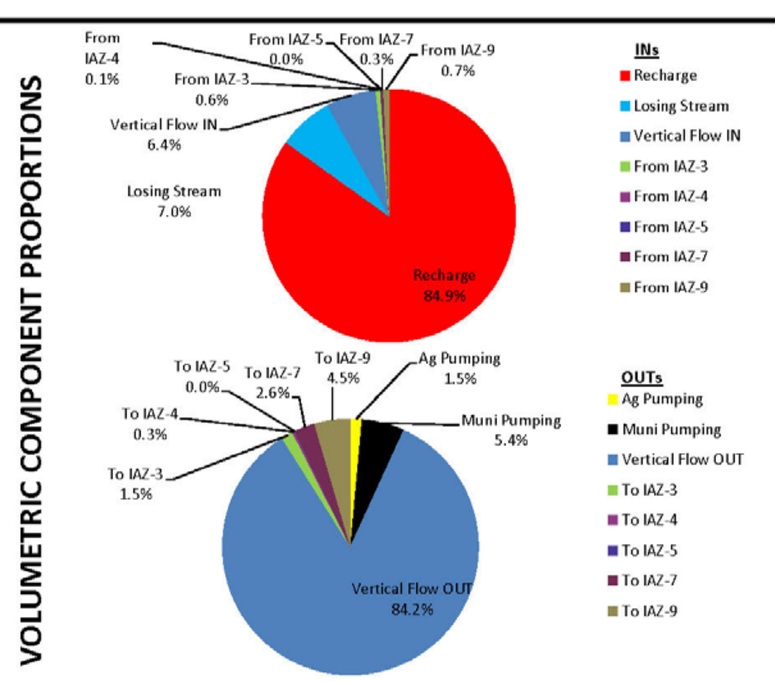
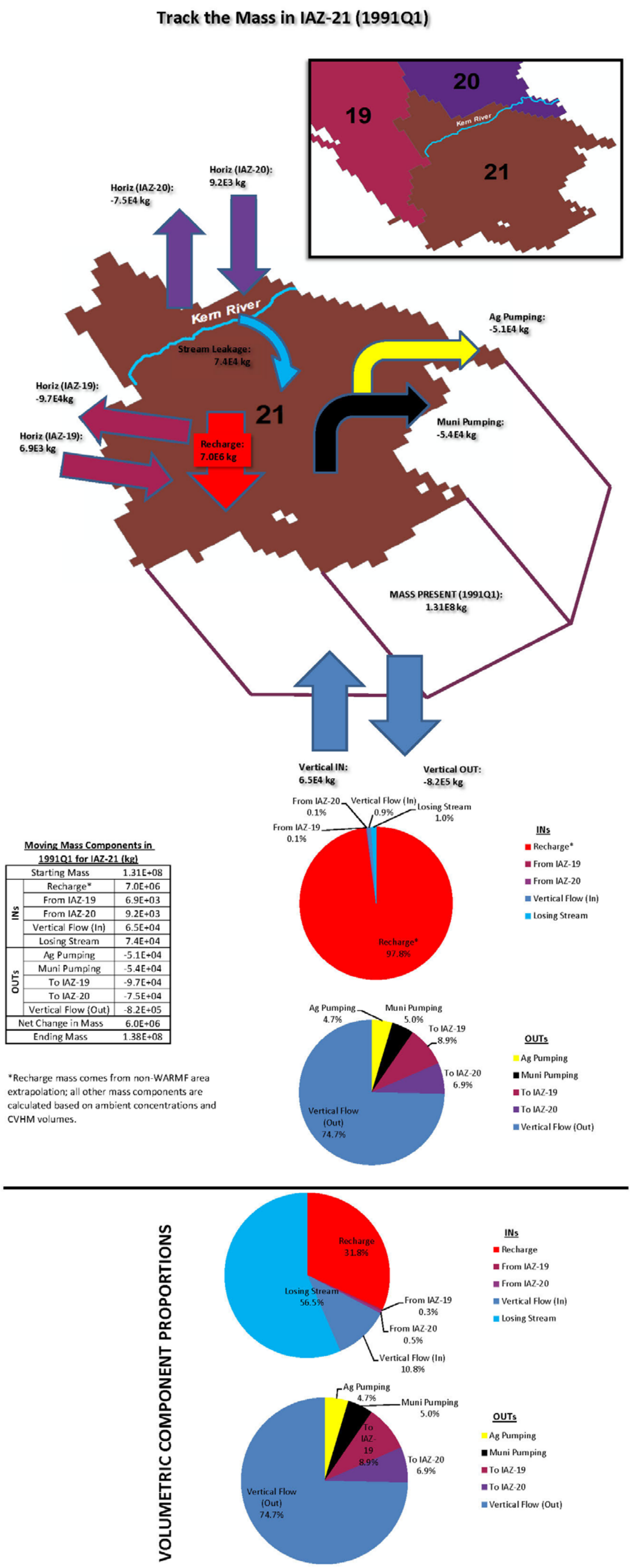


Figure 7-3. Net Sum of Mass Flow Components for IAZ-6



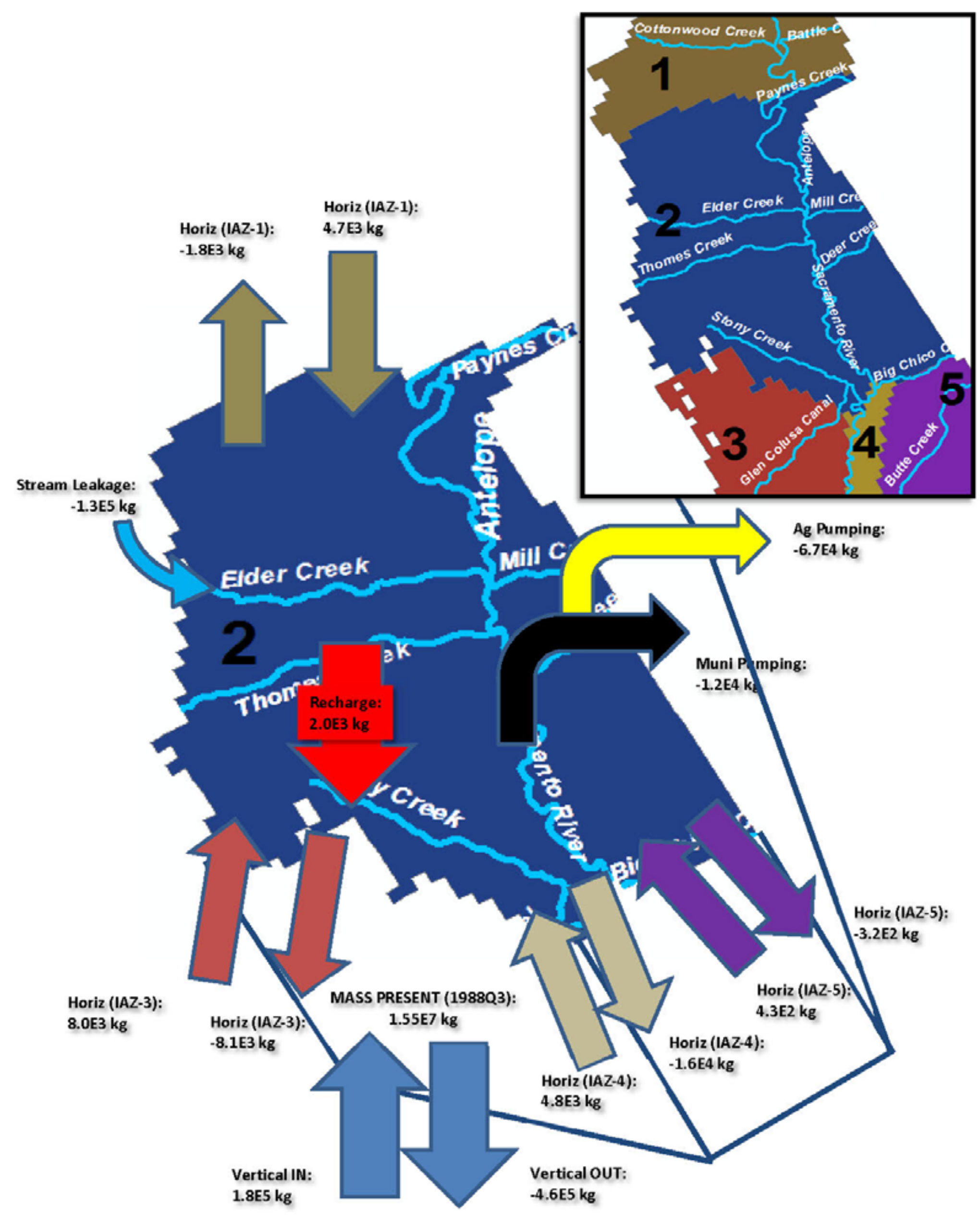
Moving Mass Components in 1991Q1 for IAZ-21 (kg)

Starting Mass		1.31E+08
INs	Recharge*	7.0E+06
	From IAZ-19	6.9E+03
	From IAZ-20	9.2E+03
	Vertical Flow (In)	6.5E+04
	Losing Stream	7.4E+04
OUTs	Ag Pumping	-5.1E+04
	Muni Pumping	-5.4E+04
	To IAZ-19	-9.7E+04
	To IAZ-20	-7.5E+04
	Vertical Flow (Out)	-8.2E+05
Net Change in Mass		6.0E+06
Ending Mass		1.38E+08

*Recharge mass comes from non-WARMF area extrapolation; all other mass components are calculated based on ambient concentrations and CVHM volumes.

Figure 7-4. Net Sum of Flow Components for IAZ-21

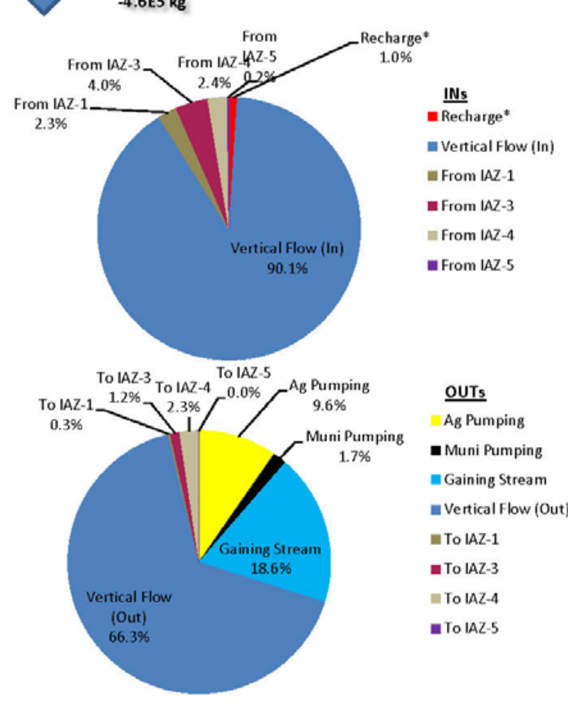
Track the Mass in IAZ-2 (1988Q3)



Moving Mass Components in 1988Q3 for IAZ-2 (kg)

Starting Mass		1.55E+07
Ins	Recharge*	2.0E+03
	Vertical Flow (In)	1.8E+05
	From IAZ-1	4.7E+03
	From IAZ-3	8.0E+03
	From IAZ-4	4.8E+03
	From IAZ-5	4.3E+02
OUTs	Ag Pumping	-6.7E+04
	Muni Pumping	-1.2E+04
	Gaining Stream	-1.3E+05
	Vertical Flow (Out)	-4.6E+05
	To IAZ-1	-1.8E+03
	To IAZ-3	-8.1E+03
	To IAZ-4	-1.6E+04
	To IAZ-5	-3.2E+02
Net Change in Mass		-4.9E+05
Ending Mass		1.50E+07

*Recharge mass comes from WARMF analysis; all other mass components are calculated based on ambient concentrations and CVHM volumes.



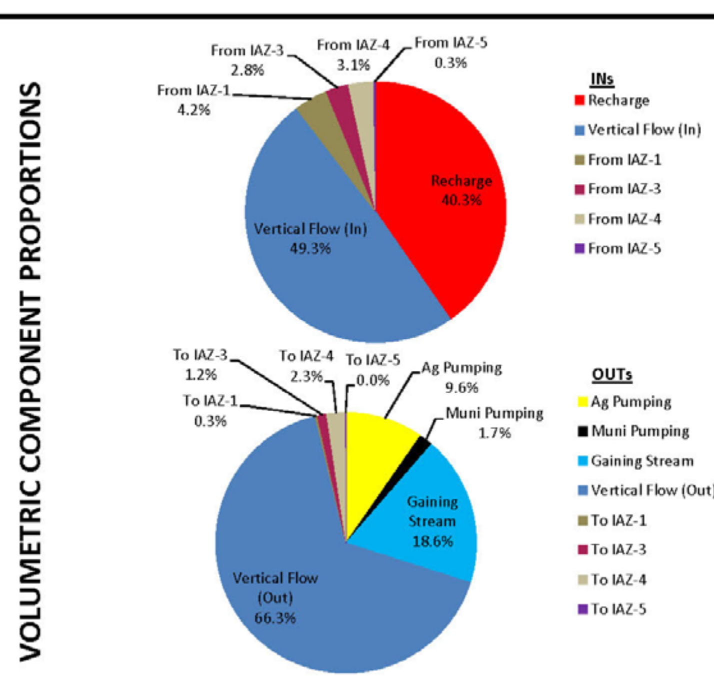


Figure 7-5. Net Sum of Flow Components for IAZ-2

7.2 MASS BUDGETS FOR SHALLOW GROUNDWATER

Quantities of salt and nitrate mass are associated with the inflows and outflows of water to and from shallow groundwater which determine the quality of shallow groundwater. **Figure 7-3** through **Figure 7-5** provide a detailed visualization of the various inflow and outflow components for shallow groundwater for one quarter in three selected IAZs: IAZs 2, 6, and 21. The figures are only an example of a snapshot in time during mixing model simulations and are provided as a visual aid to understanding the various mass flow components. The values represent the output for the third quarter of 1988 for IAZ 2, the first quarter of 1991 for IAZ 21, and the fourth quarter of 2002 for IAZ 6.

Figure 7-6 provides the results of the 20-year sum of mass inflows and outflows to and from shallow groundwater that are associated with the hydrologic flow components. The results for the six nitrate loading scenarios are shown graphically in **Figure 7-7,** and the three TDS loading are shown graphically in **Figure 7-8.** Units of mass are shown in thousands of tons, where a ton equals 2000 pounds. The complete tables of the net inflow and outflows for each IAZ are located in **Appendix F**.

Similar to the flow budget, the results indicate that for both nitrate and TDS, farm recharge is generally the dominant contributor of mass to shallow groundwater. Smaller components contributing mass to shallow groundwater are upward vertical flow from deep groundwater, stream recharge, and horizontal flow from adjacent IAZs. The dominant mechanism for mass leaving shallow groundwater is generally downward vertical flow to deep groundwater for both nitrate and TDS. However, upward vertical flow from deep groundwater provides a significant fraction of TDS mass to shallow groundwater in the northern Central Valley (IAZs 1-7). In IAZ 9, the Delta also provides a significant fraction of TDS mass to shallow groundwater. Discharge to surface water is a significant mechanism in IAZs 2-5 and 11 for both nitrate and TDS.

On a per acre basis, IAZs 14-21 in the southern Central Valley (IAZs 14-21) have relatively greater magnitudes of nitrate loading compared to the northern and middle portions of the Central Valley. For the northern and middle portions of the Central Valley, IAZs 6 and 7 have relatively higher magnitudes of loading compared to the rest of the IAZs in these two regions. Farm recharge is generally the dominant source of nitrate loading to shallow groundwater.

The differences in magnitude of TDS loadings are much more similar between the northern, middle, and southern portions of the Central Valley. In the southern Central Valley IAZs 14 and 19 have highest TDS loading, IAZs 10 and 22 have the highest loading in the middle valley, and in the northern Central Valley, IAZs 3, 4 and 6 have comparatively higher loading.

In general, results show that the higher the magnitude of loading from the surface, the higher the magnitude of mass leaving shallow groundwater. This is largely due to the instantaneous mixing that was simulated for shallow groundwater. Results indicate that the largest fluxes of mass from shallow groundwater occur in the southern Central Valley for both nitrate and TDS, and this is due largely to downward flow to deep groundwater, and to a lesser degree well pumpage. In the middle and northern valleys, discharge to surface water provides a significant fraction of outflow from shallow groundwater for nitrate and TDS. Outflow from IAZ 4 is nearly completely dominated by groundwater discharge to surface water.

Summary of Inflow and Outflow of Nitrate Mass. Units are in Thousands of Tons (1 ton = 2,000 pounds)

Row Labels	Sum of Adjacent IAZs	Sum of Surface Water	Sum of Vertical Flow	Sum of Well Pumpage	Sum of Farm Recharge	Sum of Delta Interaction
1.0						
IN						
High NUE	0.1	0.0	4.0	0.0	3.4	0.0
Moderate NUE	0.1	0.0	4.0	0.0	9.0	0.0
Low NUE	0.2	0.0	4.0	0.0	17.4	0.0
90% of Low NUE	0.2	0.0	4.0	0.0	20.9	0.0
75% of Low NUE	0.2	0.0	4.0	0.0	27.9	0.0
60% of Low NUE	0.3	0.0	4.0	0.0	55.8	0.0
OUT						
High NUE	-0.2	-0.9	-4.6	-0.3	0.0	0.0
Moderate NUE	-0.4	-1.4	-7.3	-0.5	0.0	0.0
Low NUE	-0.6	-2.1	-11.4	-0.8	0.0	0.0
90% of Low NUE	-0.7	-2.4	-13.2	-0.9	0.0	0.0
75% of Low NUE	-0.9	-3.1	-16.6	-1.2	0.0	0.0
60% of Low NUE	-1.6	-5.6	-30.4	-2.1	0.0	0.0
2.0						
IN						
High NUE	1.2	0.0	19.5	0.0	7.7	0.0
Moderate NUE	1.5	0.0	19.5	0.0	13.1	0.0
Low NUE	1.9	0.0	19.5	0.0	21.4	0.0
90% of Low NUE	2.3	0.0	19.5	0.0	26.5	0.0
75% of Low NUE	3.0	0.0	19.5	0.0	36.8	0.0
60% of Low NUE	6.4	0.0	19.5	0.0	84.5	0.0
OUT						
High NUE	-2.0	-8.3	-22.9	-2.3	0.0	0.0
Moderate NUE	-2.2	-9.1	-25.1	-2.5	0.0	0.0
Low NUE	-2.6	-10.3	-28.5	-2.9	0.0	0.0
90% of Low NUE	-2.8	-11.1	-30.6	-3.1	0.0	0.0
75% of Low NUE	-3.1	-12.6	-34.8	-3.5	0.0	0.0
60% of Low NUE	-4.9	-19.7	-54.5	-5.6	0.0	0.0
3.0						
IN						
High NUE	1.8	0.0	11.2	0.0	16.9	0.0
Moderate NUE	2.0	0.0	11.2	0.0	23.8	0.0
Low NUE	2.4	0.0	11.2	0.0	35.0	0.0
90% of Low NUE	2.7	0.0	11.2	0.0	47.8	0.0
75% of Low NUE	3.3	0.0	11.2	0.0	73.3	0.0
60% of Low NUE	6.1	0.0	11.2	0.0	208.3	0.0
OUT						
High NUE	-2.8	-6.9	-16.6	0.0	0.0	0.0
Moderate NUE	-3.2	-8.0	-19.2	0.0	0.0	0.0
Low NUE	-3.9	-9.7	-23.3	0.0	0.0	0.0
90% of Low NUE	-4.6	-11.6	-27.9	-0.1	0.0	0.0
75% of Low NUE	-6.2	-15.3	-37.2	-0.1	0.0	0.0
60% of Low NUE	-14.2	-35.3	-86.0	-0.2	0.0	0.0
4.0						
IN						
High NUE	4.4	0.0	4.1	0.0	5.6	0.0
Moderate NUE	5.0	0.0	4.1	0.0	7.8	0.0
Low NUE	6.0	0.0	4.1	0.0	11.7	0.0
90% of Low NUE	6.9	0.0	4.1	0.0	15.9	0.0
75% of Low NUE	8.7	0.0	4.1	0.0	24.3	0.0
60% of Low NUE	17.8	0.0	4.1	0.0	68.6	0.0
OUT						
High NUE	-1.1	-9.4	-0.8	0.0	0.0	0.0
Moderate NUE	-1.3	-11.0	-1.0	0.0	0.0	0.0
Low NUE	-1.6	-13.6	-1.2	0.0	0.0	0.0
90% of Low NUE	-1.9	-16.3	-1.4	0.0	0.0	0.0
75% of Low NUE	-2.5	-21.8	-1.9	0.0	0.0	0.0
60% of Low NUE	-5.9	-50.4	-4.4	0.0	0.0	0.0
5.0						
IN						
High NUE	1.6	0.0	4.5	0.0	4.0	0.0
Moderate NUE	2.0	0.0	4.5	0.0	7.4	0.0
Low NUE	2.6	0.0	4.5	0.0	12.7	0.0
90% of Low NUE	2.9	0.0	4.5	0.0	16.8	0.0
75% of Low NUE	3.6	0.0	4.5	0.0	25.1	0.0
60% of Low NUE	7.1	0.0	4.5	0.0	66.4	0.0

Figure 7-6. Results of the 20-year Sum of Mass Inflows and Outflows for Shallow Groundwater

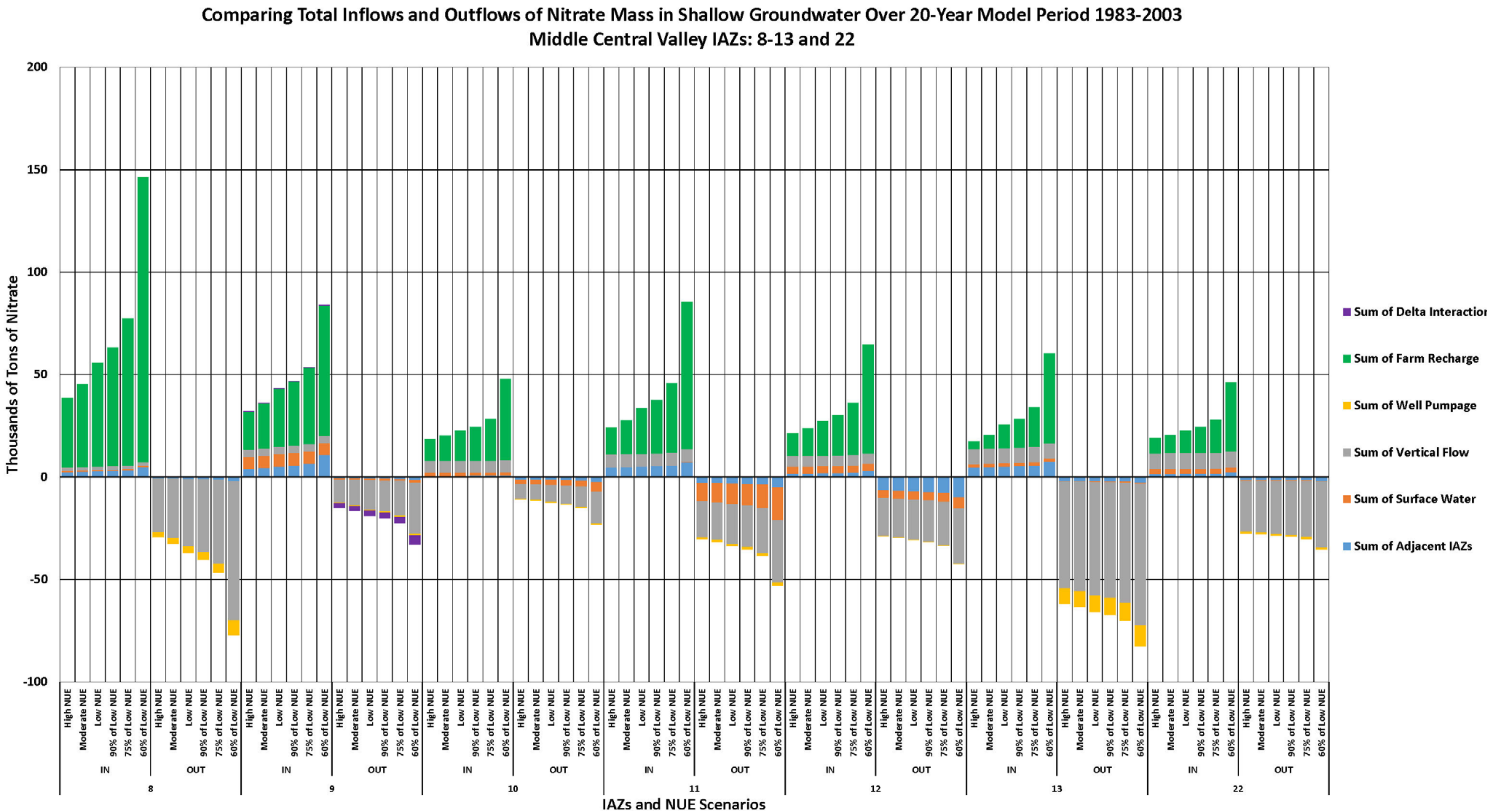


Figure 7-7. Comparison of Total Mass Inflows and Outflows to and from Shallow Groundwater for Nitrate

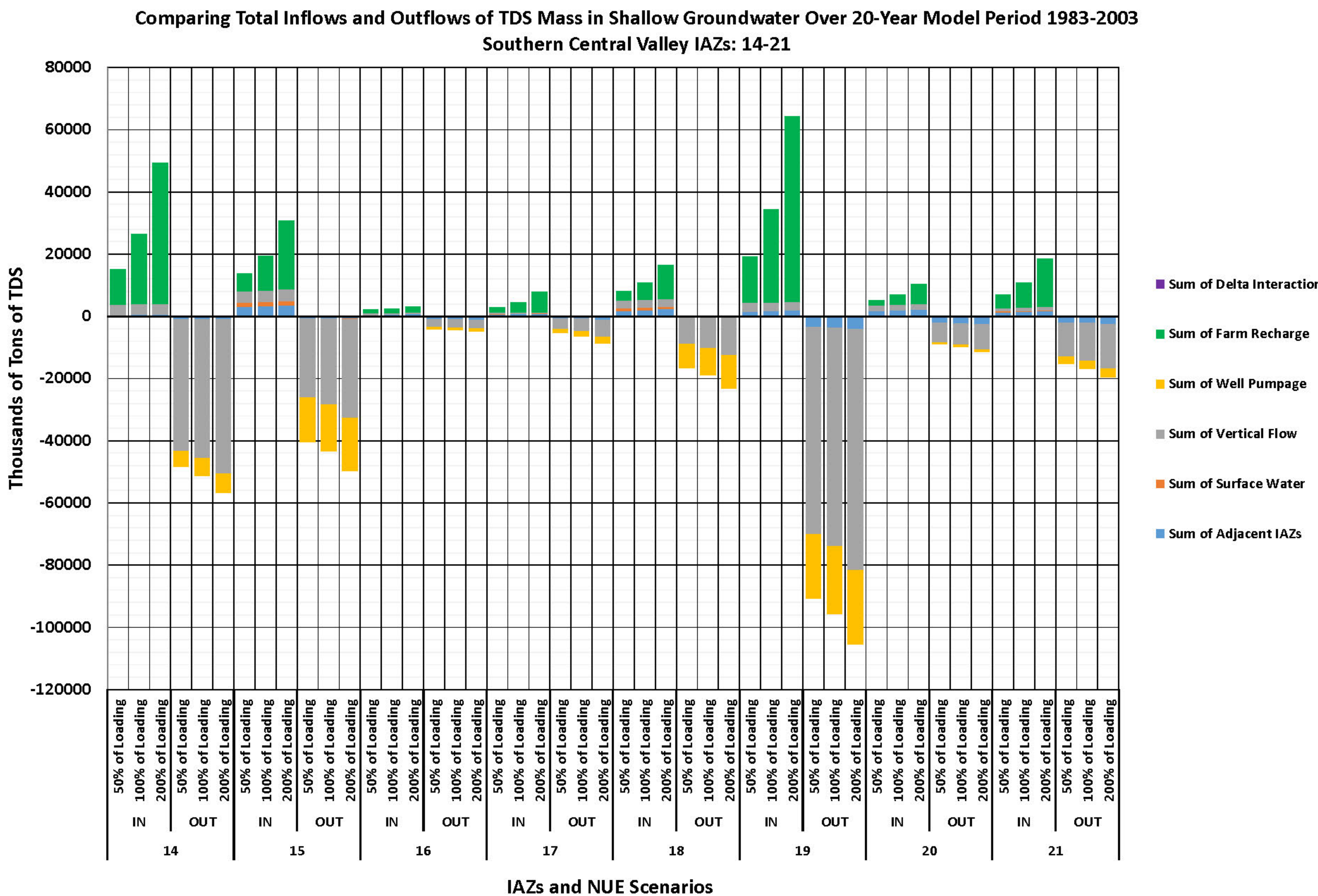


Figure 7-8. Comparison of Total Mass Inflows and outflows to and from Shallow Groundwater for TDS

7.3 COMPARING MASS FLUX TO SHALLOW GROUNDWATER FROM SURFACE AND MASS FLUX FROM SHALLOW TO DEEP.

Figure 7-9 and **Figure 7-10** compare the total nitrate and TDS loading from the surface, and the downward flux from the shallow to the deep aquifer. Here, "surface recharge" is the sum of farm recharge and recharge from surface water. For nitrate, most IAZs have a greater amount of loading to Shallow groundwater from the surface compared to the flux from shallow to deep groundwater. However, IAZs 2, 13, 14, and 22 show a greater flux to deep groundwater compared to loading from the surface for most or all of the nitrogen use efficiency (NUE) scenarios. Conversely, for TDS, most IAZs have a greater flux to deep groundwater compared to loading from the surface. However, IAZs 4, 6, 10, 11, 12, and 22 show greater loading from the surface for most or all of the TDS loading scenarios.

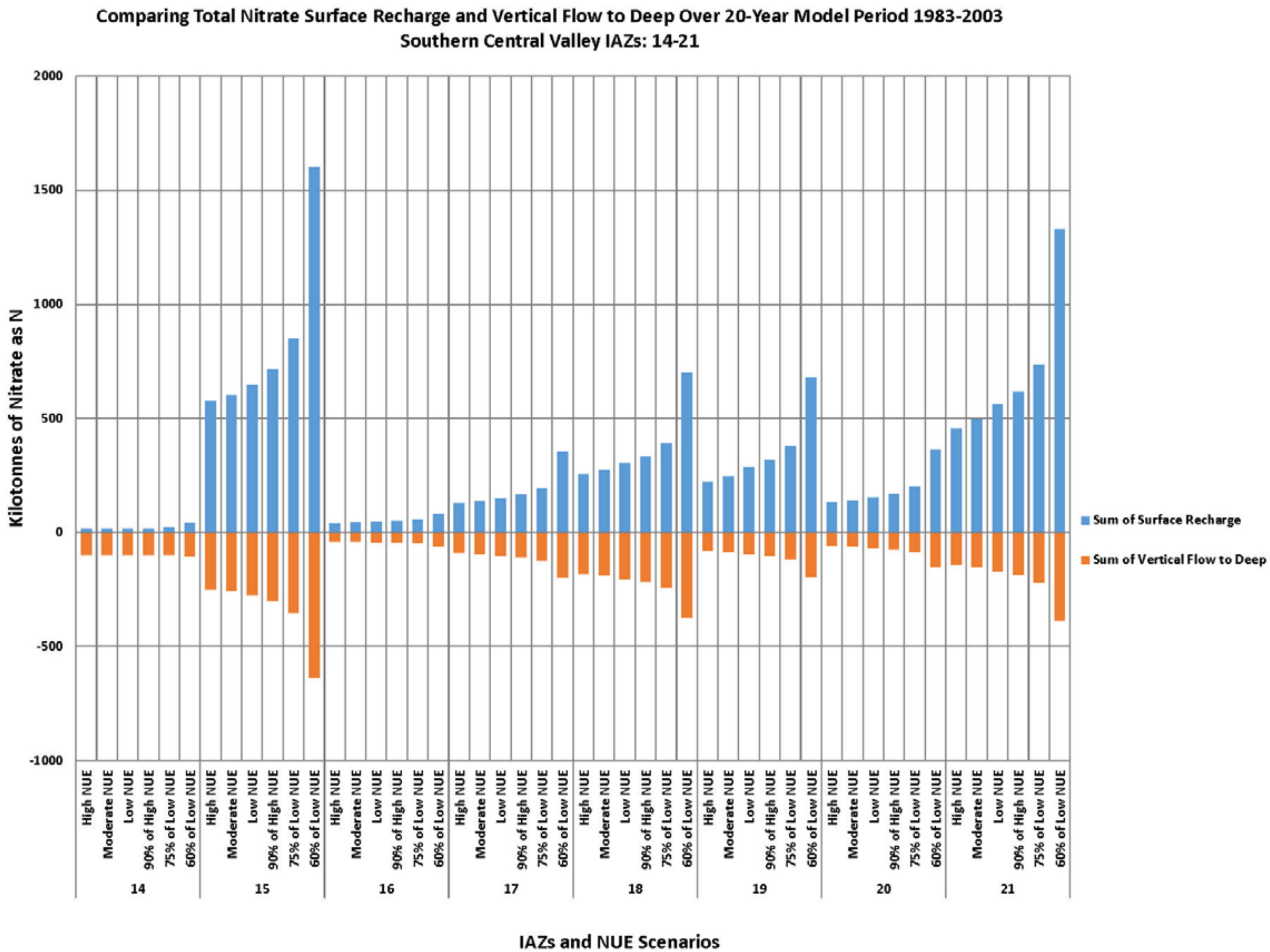


Figure 7-9. Comparison of Total Mass Fluxes from Surface Recharge into Shallow Groundwater and Vertical Flow from Shallow Groundwater to Deep Groundwater for Nitrate

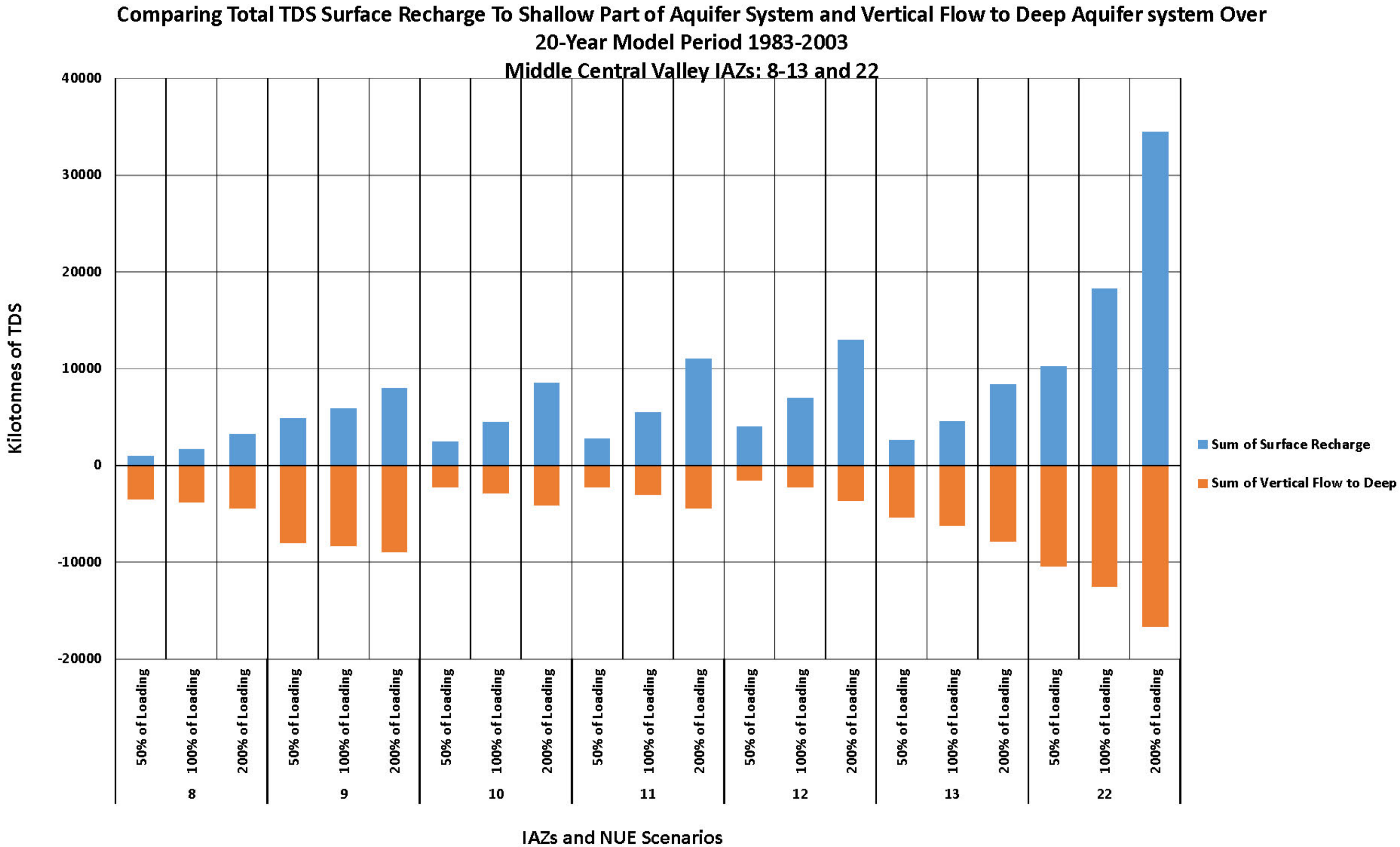


Figure 7-10. Comparison of Total Mass Fluxes from Surface Recharge into Shallow Groundwater and Vertical Flow from Shallow Groundwater to Deep Groundwater for TDS

7.4 STARTING AND ENDING MASS IN SHALLOW GROUNDWATER

Figure 7-11 and **Figure 7-12** compare the estimated initial mass and the final masses from the six nitrate and three TDS loading scenarios. Ambient concentrations estimated for shallow groundwater for each IAZ were converted to mass by assigning the concentration to the calculated volume of water representing shallow groundwater. After the 20-year simulation period for each scenario, the final mass is compared to the initial estimate.

Most nitrate simulations resulted in higher masses after the 20-year simulation period. However, IAZs 13 and 14 show a decrease in total mass for all scenarios. For IAZs 2, 11, 12, 16, 18, and 22, only the higher loading scenarios resulted in an increase in mass.

For TDS, results varied by region. For the northern and southern Central Valley IAZs (1-7 and 14-21), most simulations resulted in less mass compared to the initial estimates. For the middle Central Valley IAZs, the simulations resulted in more mass compared to the initial estimates.

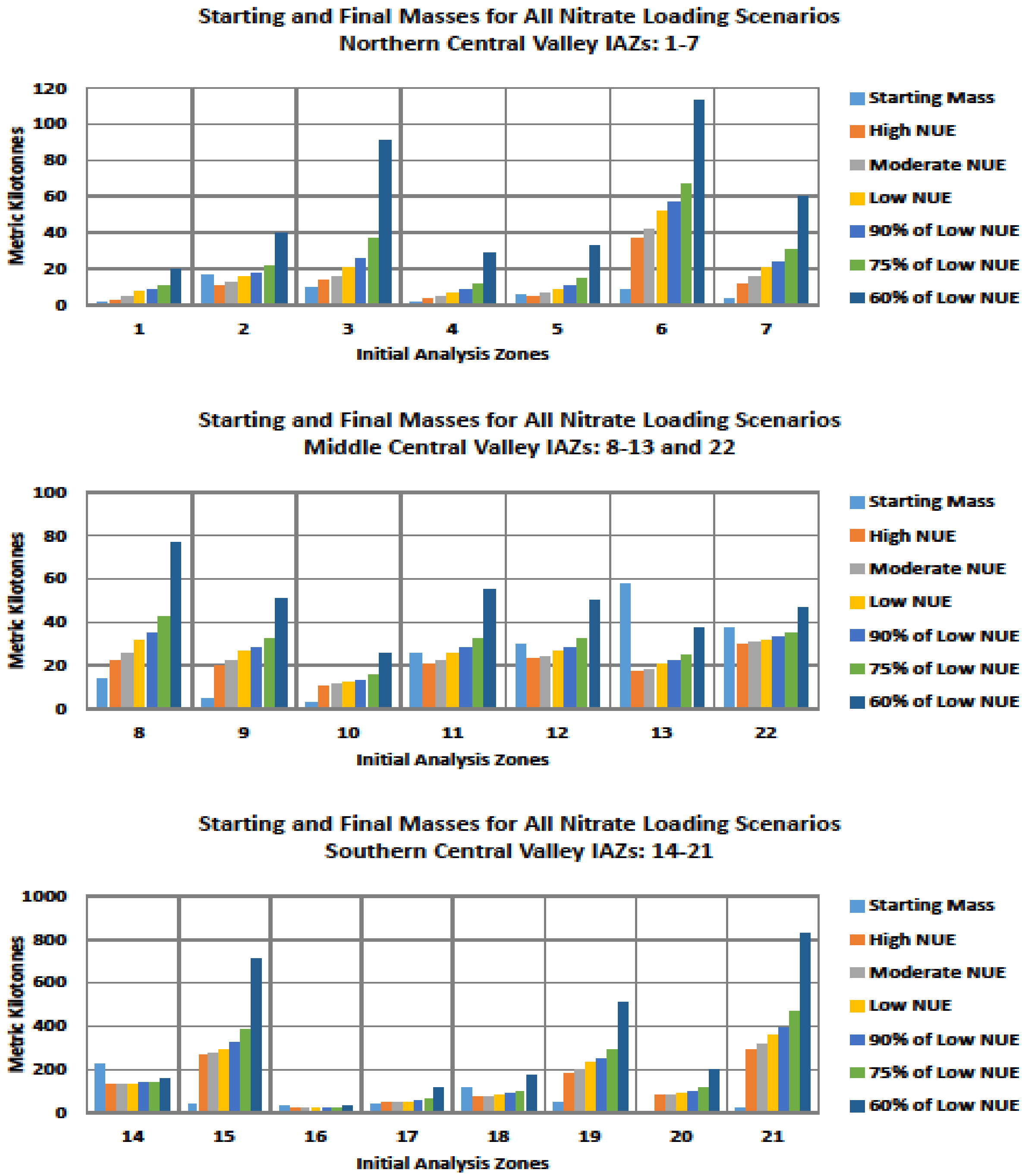


Figure 7-11. Starting and Final Masses for Nitrate Loading Scenarios

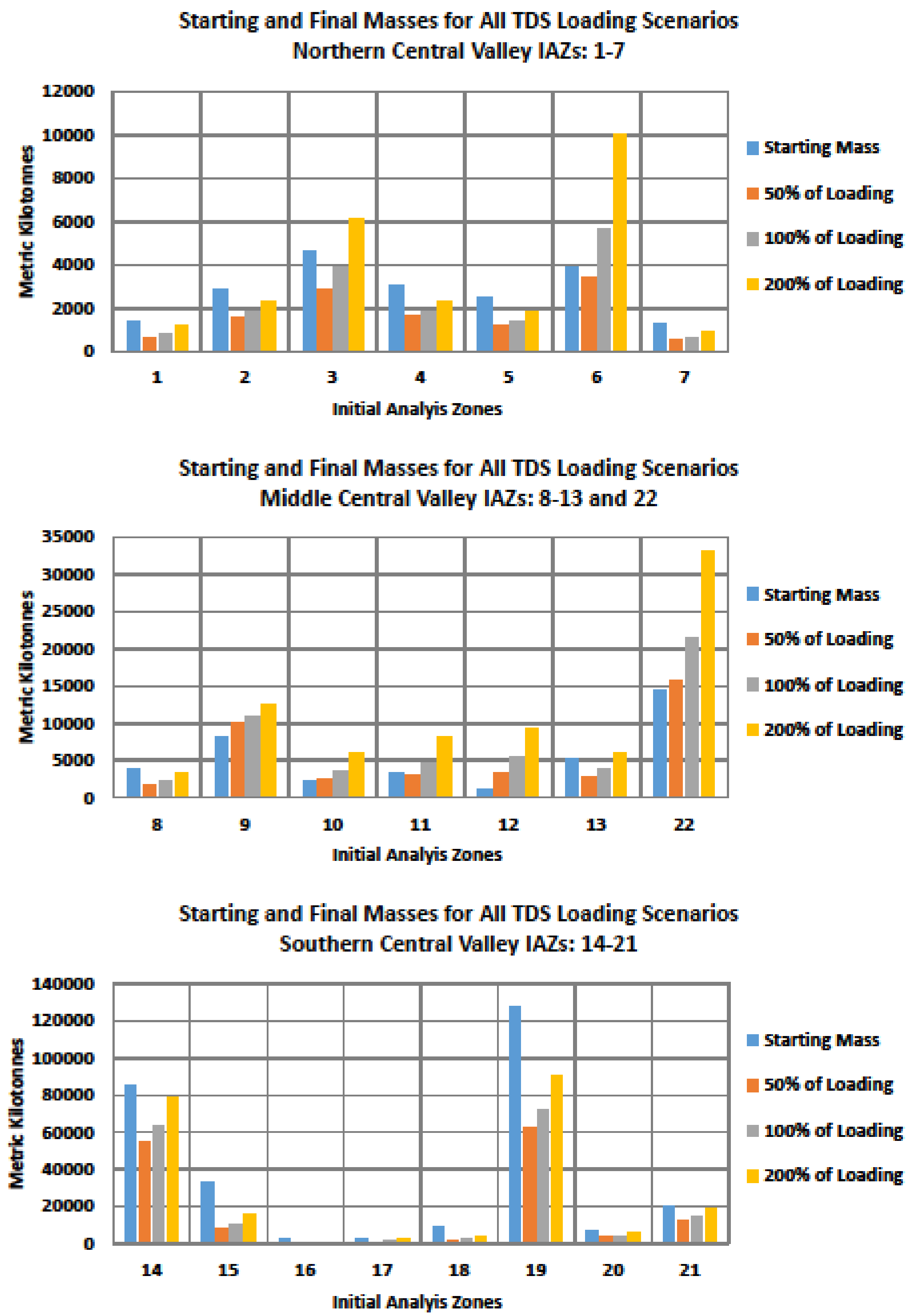


Figure 7-12. Starting and Final Masses for TDS Loading Scenarios

7.5 AMBIENT CONDITIONS, SIMULATED RESULTS, AND IDENTIFYING PRIORITY BASINS

Ambient Concentrations

Groundwater quality has thresholds in terms its use for human consumption. For drinking water, 10 mg/L (nitrate as nitrogen) is the maximum contaminant level (MCL) for nitrate and 500 mg/L is the recommended Secondary Maximum Contaminant Level (SMCL) for TDS. The CVHM grid was used here to distinguish which IAZs more commonly had wells withdrawing water over a drinking water threshold on a spatial scale. Initially, all CVHM grid cells that contained well data were selected. The number of cells that contained a well over a drinking water threshold were compared to the total number of grid cells that contained well data. For this analysis, all well data were included. **Figure 7-13** shows the results as time series plots for the northern, middle, and southern Central Valley regions. **Figure 7-14** and **Figure 7-15** show maps of the results for nitrate and TDS for the 2000-2012 time period. For nitrate, IAZs 10-12 and 18 indicate that 40% or more of their CVHM model grid cells contain a well over 10 mg/L NO3-N for the most recent time period (2000-2012). For TDS, IAZs 9, 10, 14, and 22 indicate that 80% or more of their CVHM model grid cells contain a well over 500 mg/L TDS.

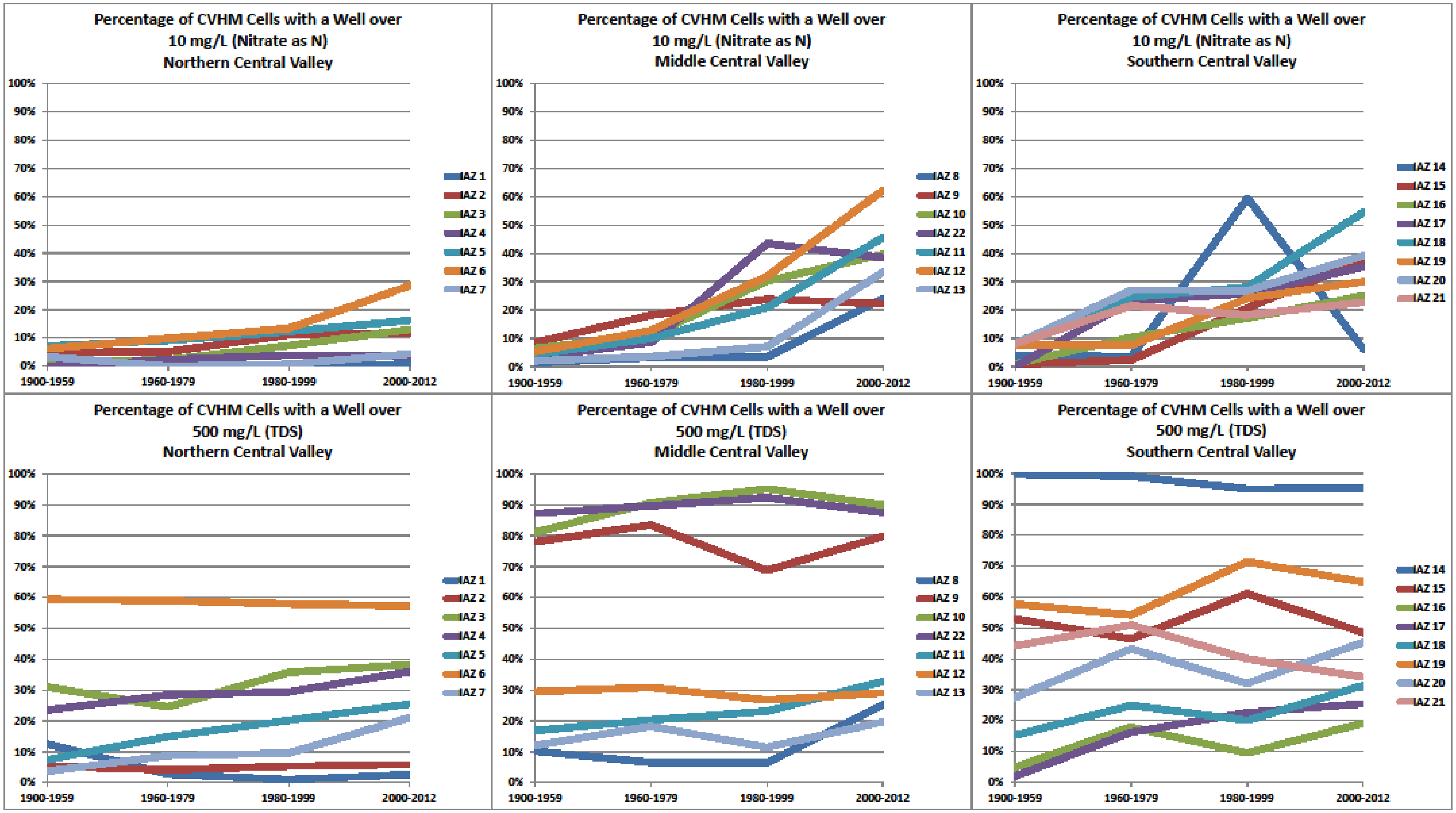


Figure 7-13. Time Series Plots of CVHM Cells

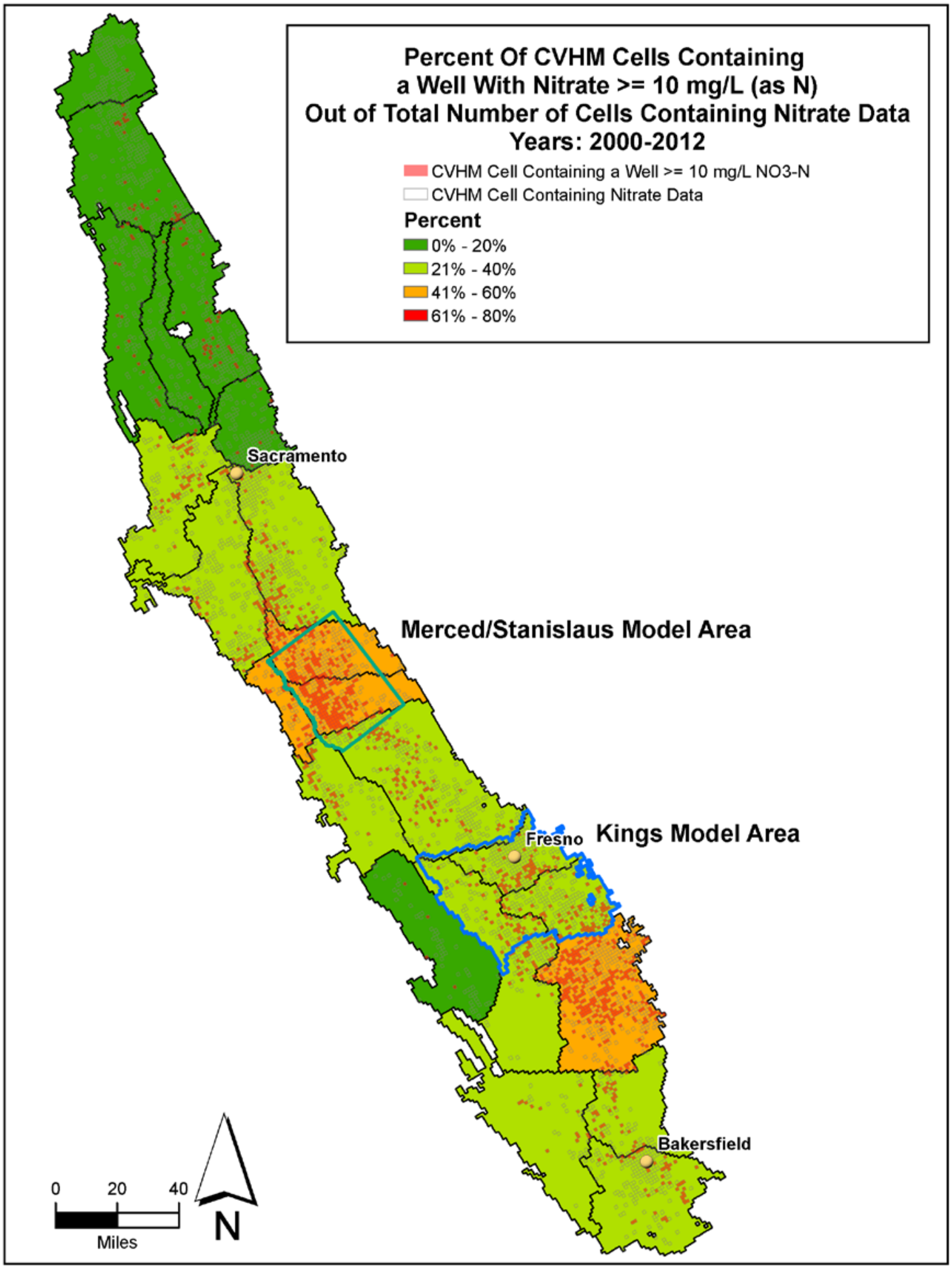


Figure 7-14. Map of CVHM Cells Containing a Well > 10 mg/L NO3-N (2000s)

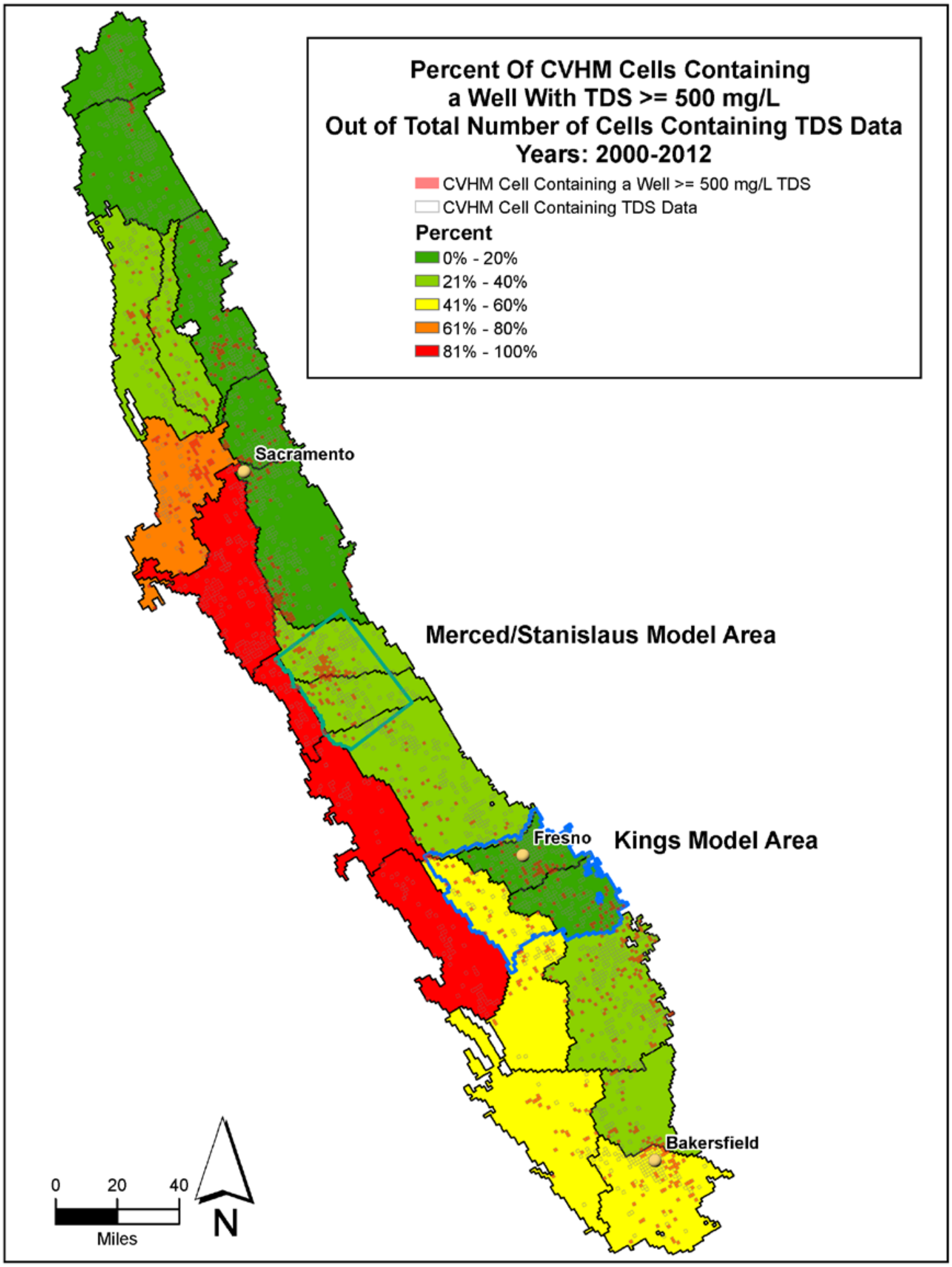


Figure 7-15. Map of CVHM Cells Containing a Well > 500 mg/L TDS (2000s)

Visualizing Spatial Extent of Water Quality Data

The results from the previous analysis were also used to show the spatial extent of the available water quality data. **Figure 7-16, Figure 7-17**, and **Figure 7-18** show the cells that contain well test data, with the red cells containing a well test over a threshold. While the maps provide a useful visualization of spatial water quality trends, two important biases should be noted. The first is that the maps are based on the groundwater quality data that were available at the time of analysis. Some areas may have poor water quality, but the number of wells with groundwater quality data may be limited (for example the western portion of the San Joaquin Valley). Therefore the analysis is limited by the data availability. The second bias is due to the inclusion of the RWQCB (WDR Dairy Data) dataset. This dataset includes more shallow domestic and monitoring wells in rural areas, compared to the other groundwater quality data sources; therefore, these data may over represent water quality in rural areas. Acknowledging these limitations and biases, the maps still provide perspective on groundwater quality trends at a large scale. In addition, the maps provide an important visualization of the spatial extent of available groundwater quality data and where data gaps may exist.

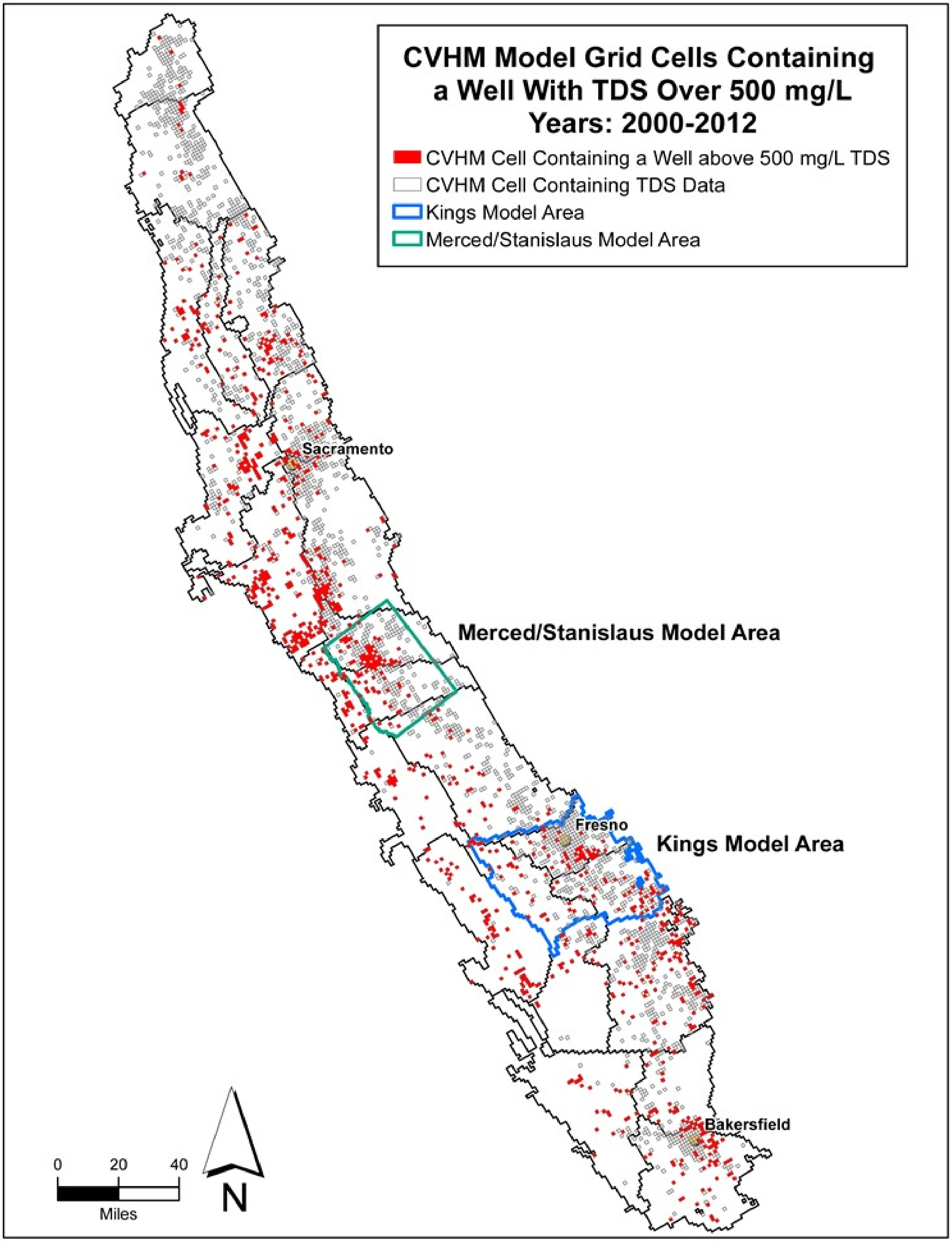


Figure 7-16. Identifying CVHM Model Grid Cells Containing a Well Test Over 500 mg/L TDS

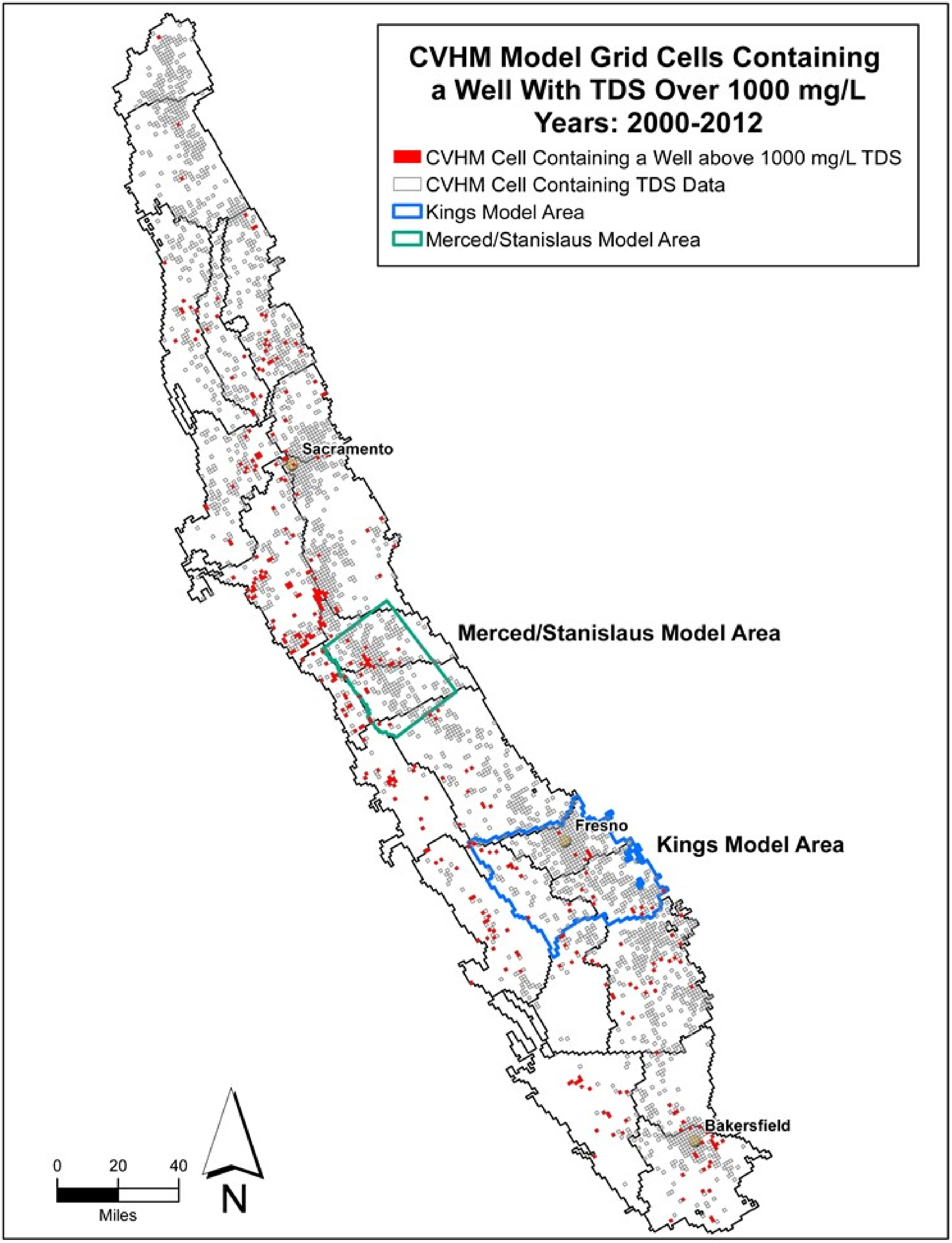


Figure 7-17. Identifying CVHM Model Grid Cells Containing a Well Test Over 1000 mg/L TDS

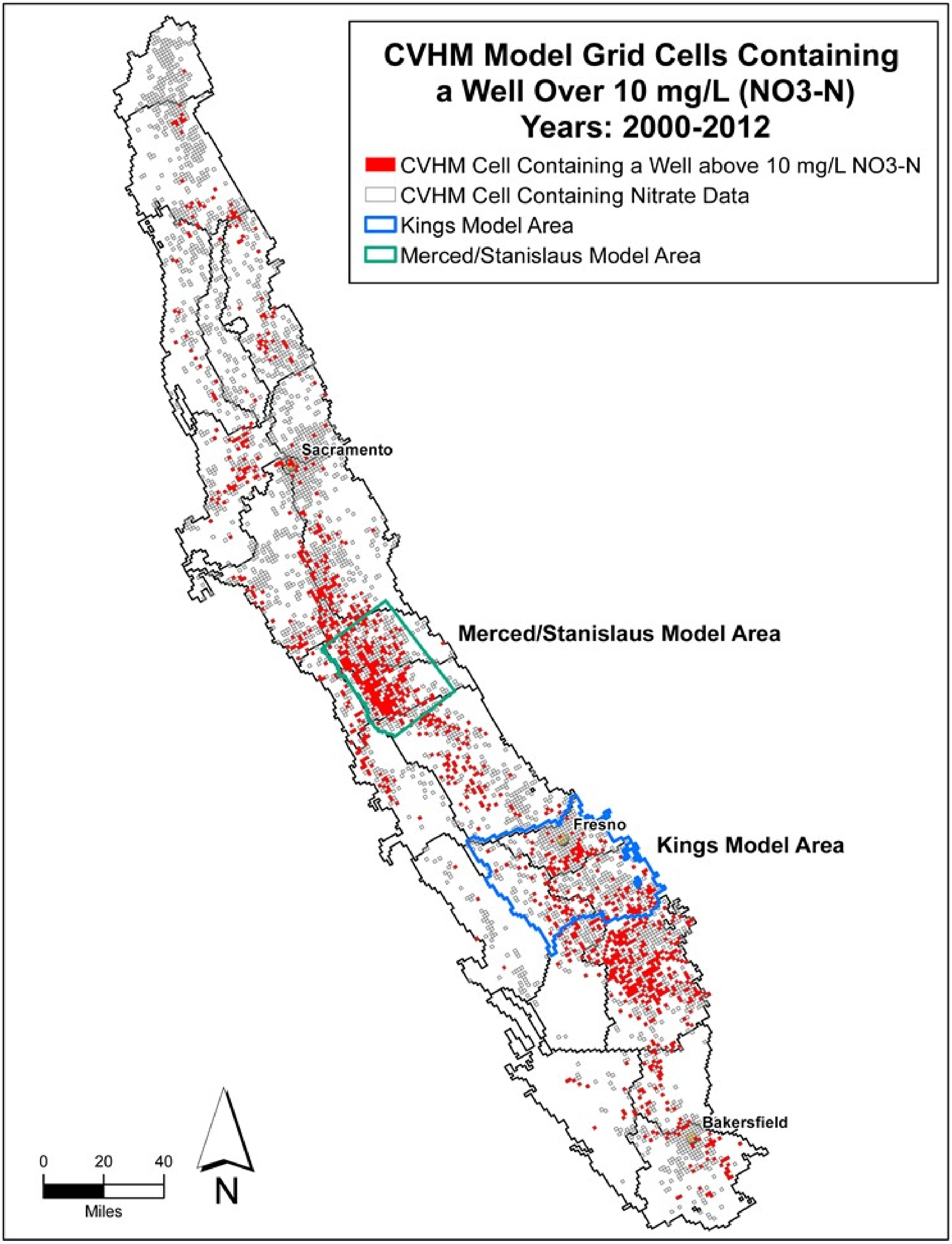


Figure 7-18. Identifying CVHM Model Grid Cells Containing a Well Test Over 10 mg/L NO3-N

Simulated Concentrations, Identifying Priority Basins and Hot Spots

Figure 7-19 and **Figure 7-20** show the results for the nitrate and TDS loading scenarios. Section 8 provides a detailed explanation of how multiple nitrate and TDS loading scenarios were generated[57]. **Figure 7-19** shows the results for the six nitrogen use efficiency (NUE) scenarios, and **Figure 7-20** shows the results of the three TDS loading scenarios. The results (simulation period is from 1983 to 2003) are compared to measured ambient concentrations. Shallow ambient data (annual cell medians) are shown as blue squares. The linear regression of the deep ambient quality for 1980-2012 is shown with a dashed green line, bounded by two dashed red lines, representing the 95% confidence interval of the linear regression. The median Shallow concentration, based on data from 2003-2012 is represented by a green circle, with the 25th and 75th percentiles indicated with red dashes above and below. The map in the center shows the WARMF coverage for the Central Valley and the color scheme indicates if the loading estimated for each IAZ was based wholly or partially on their WARMF coverage, or if the loading was estimated based on adjacent IAZs with WARMF coverage.

[57] As described in Section 8.2.1, the LWA Team ran a sensitivity analysis to evaluate sources of uncertainty in the mixing model results. The sensitivity analysis was conducted for six (6) nitrate loading scenarios using various adjustments to the nitrogen application and uptake parameters and three (3) salinity loading scenarios.

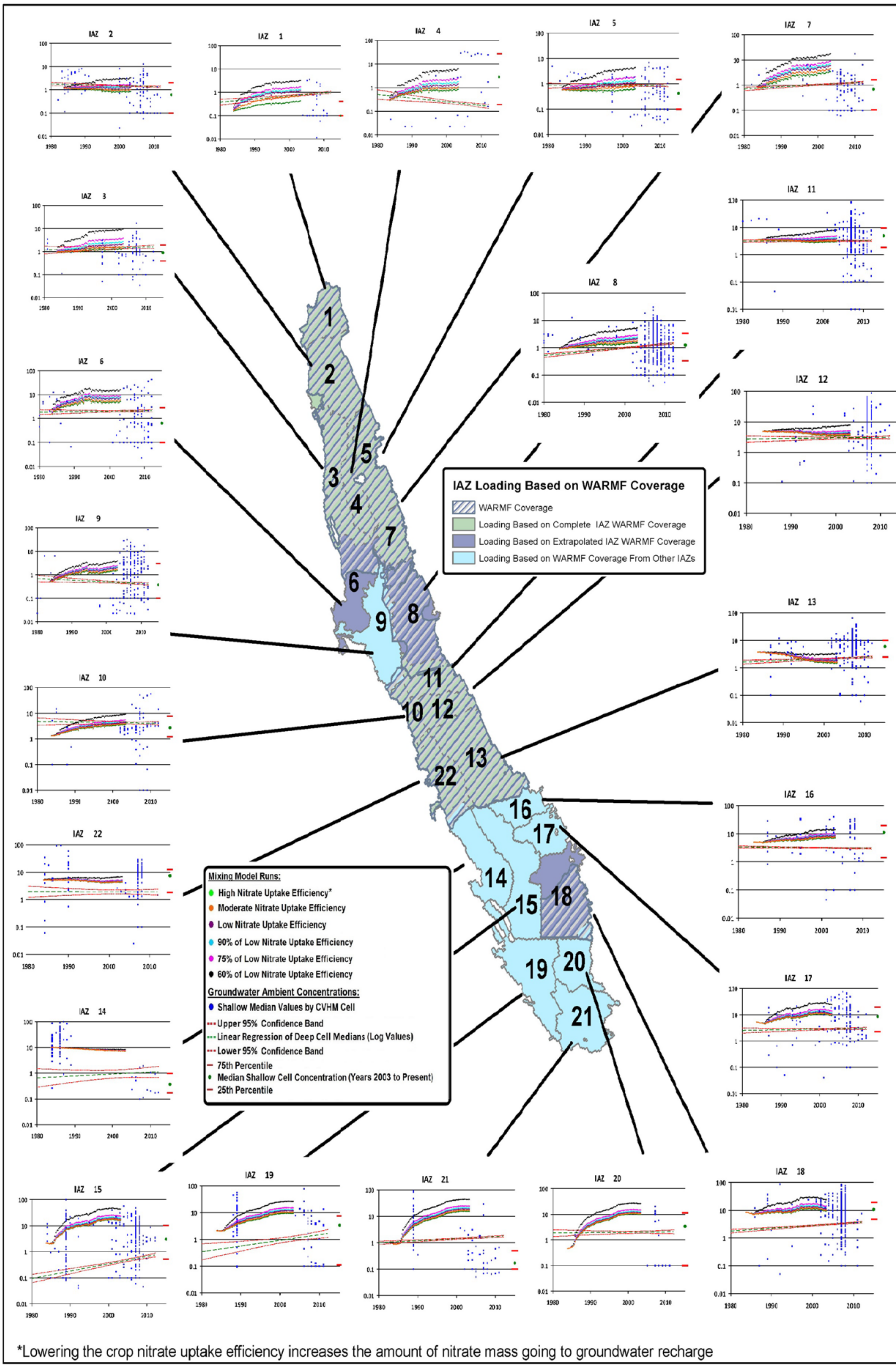


Figure 7-19. Nitrate Groundwater Model Results

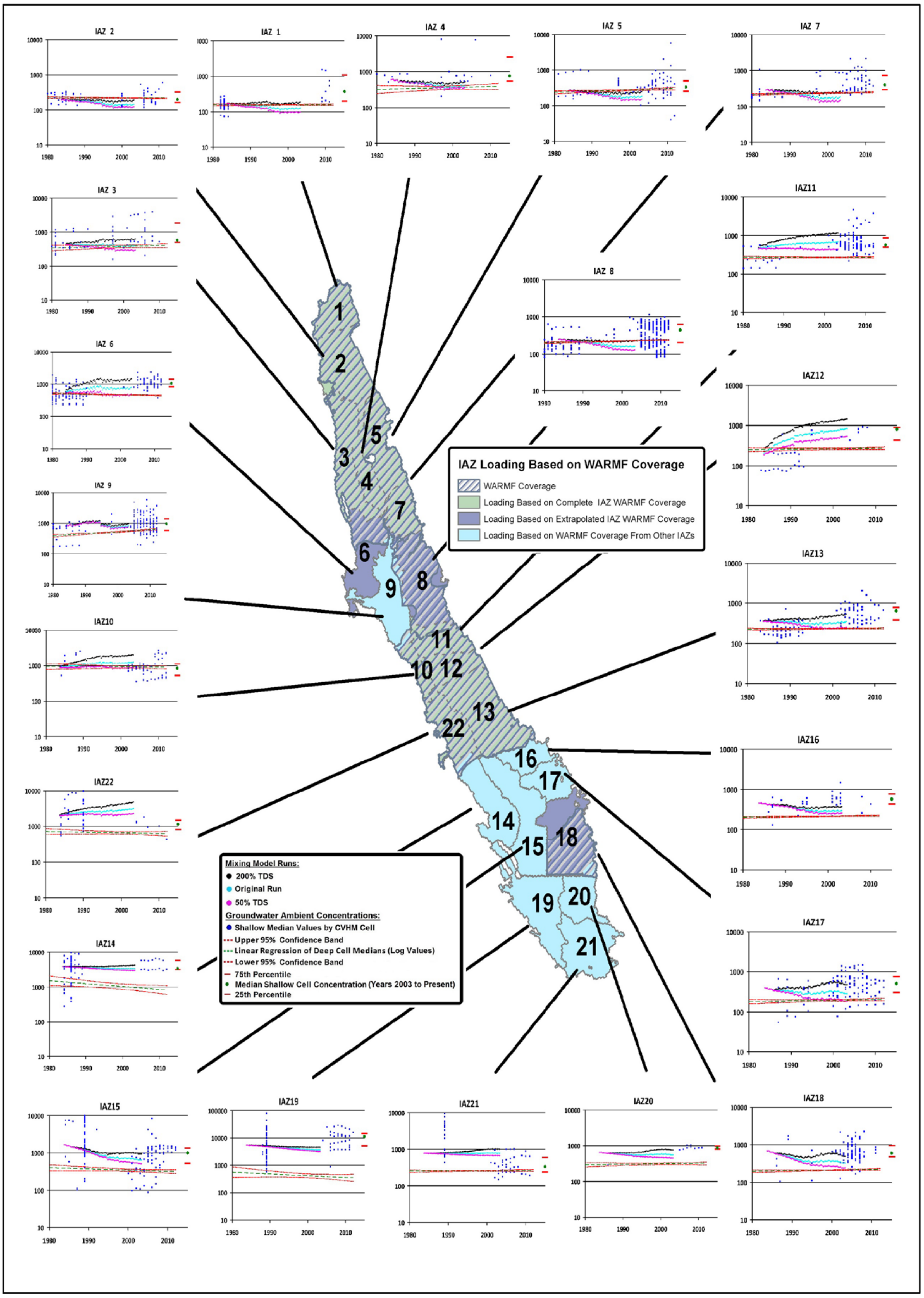


Figure 7-20. TDS Groundwater Model Results

Identifying Priority Basins

Each IAZ was evaluated in terms of the ambient well test data and the simulated mixing model results to rank the IAZs in their level of priority. Three different criteria for ambient data were considered and combined with the simulation results for a total of four criteria. The three criteria for ambient well test data include analyses performed on 1) all the wells within an IAZ, 2) only the shallow wells within an IAZ, and 3) only the deep wells within an IAZ. The fourth criteria relates to the simulation results and how many simulations resulted in concentrations over a given threshold.

For nitrate, the following four criteria were used:

- Does one quarter or more of the CVHM grid cells containing well test data have a well at or above the MCL (10 mg/L NO3-N) in the 2000s?
- Is the median shallow concentration for recent years (2003-2012) at or above half of the MCL (5 mg/L NO3-N)?
- Is the measured 2003 deep concentration at or above 2 mg/L NO3-N?
- Do more than 3 simulations result in shallow groundwater at or above half of the MCL (5 mg/L NO3-N)?

For TDS, two evaluations were made, first using a threshold of 500 mg/L and second using a threshold of 1000 mg/L. The following four criteria for the two threshold levels were used:

- Using a threshold of 500 mg/L
  - Does one quarter or more of the CVHM grid cells containing well test data have a well at or above 500 mg/L TDS in the 2000s?
  - Is the median shallow concentration for recent years (2003-2012) at or above 500 mg/L TDS?
  - Is the estimated 2003 deep concentration at or above 250 mg/L TDS?
  - Do two or more simulations result in shallow groundwater at or above 500 mg/L?

- Using a threshold of 1000 mg/L
  - Does one quarter or more of the CVHM grid cells containing well test data have a well at or above 1000 mg/L TDS in the 2000s?
  - Is the median shallow concentration for recent years (2003-2012) at or above 1000 mg/L TDS?
  - Is the estimated 2003 deep concentration at or above 250 mg/L TDS?
  - Do two or more simulations result in shallow groundwater at or above 1000 mg/L?

Figure 7-21[58] and **Figure 7-22**[59] below show the results from the ambient data analysis and the simulation results from the mixing model. Under the ambient concentrations heading on the left side of the figure, the four green columns display a percentage that represents the number of CVHM cells that contain at least one well over the given threshold (10 mg/L NO3-N, 500 mg/L TDS, 1000 mg/L TDS), divided by the total number of CVHM cells that contain at least one well test for the analyte being evaluated (nitrate or TDS). Four time periods are evaluated: all years before 1960, 1960-1979, 1980-1999, and 2000-2012. The next three orange columns show the calculated median value for shallow groundwater along with the 25th and 75th percentiles, which are based on recent data from 2003-2012. The following three blue columns show the estimated concentrations for deep groundwater in 2003, which is based on the linear regression of deep well test data from 1980-2012. The upper and lower 95% confidence intervals are provided.

Under the simulated concentrations heading, the grey columns show the final (2003) concentration based on the different loading scenarios for nitrate and TDS. These columns are accompanied by two blue columns which count the number of simulation scenarios that resulted in a concentration over the given thresholds for nitrate and TDS. The last column to the right is the relative ranking of priority for the IAZs, based on the ambient and simulation results.

Figure 7-27 through **Figure 7-29** provide a simplified version of the four criteria used to evaluate each IAZ in determining its' priority ranking. **Figure 7-24** through **Figure 7-26** provide maps of the results of the ambient and simulated criteria for ranking the priority of the IAZs. IAZs of top priority are those indicated with a rank of 3 or 4:

<u>Nitrate Priority IAZs:</u>

- <u>IAZ 6</u> Cache-Putah area
- <u>IAZ 12</u> Turlock Basin
- <u>IAZ 13</u> Merced, Chowchilla, and Madera Basins
- <u>IAZ 16</u> Northern Kings Basin
- <u>IAZ 17</u> Southern Kings Basin
- <u>IAZ 18</u> Kaweah and Tule Basins

<u>TDS Priority IAZs (1000 mg/L threshold):</u>

- <u>IAZ 10</u> Delta-Mendota Basin - Northwest Side
- <u>IAZ 14</u> Westside and Northern Pleasant Valley Basins
- <u>IAZ 19</u> Western Kern County and Southern Pleasant Valley Basin
- <u>IAZ 22</u> Delta-Mendota Basin/Grassland area

[58] The "Ranking Priority Basins" column is a relative classification of priority for the IAZs, which is based on measured ambient concentrations and simulated concentrations (darker colored cells represent an exceedance of threshold).

[59] The "Ranking Priority Basins" column is a relative classification of priority for the IAZs, which is based on measured ambient concentrations and simulated concentrations (darker colored cells represent an exceedance of threshold).

	Basin	Ambient TDS Concentrations										Simulated TDS Concentrations					
		Number of CVHM Grid Cells Containing A Well Over 500 mg/L (TDS) Divided By The Number of Grid Cells Containing Well Test Data				Shallow Data (2003-2012)			Deep Data (1980-2012)			IAZ Shallow Groundwater Final (2003) Concentration (mg/L)			Number Of Scenarios Resulting In Concentrations Over A Threshold		
		Before 1960	1960-1979	1980-1999	2000-2012	25th Percentile	Shallow Median mg/L	75th Percentile	Lower 95% Confidence Interval	Estimated 2003 Deep Concentration mg/L	Upper 95% Confidence Interval	50% of Loading	100% of Loading	200% of Loading	Equal To Or Over 500 mg/L (TDS)	Equal To Or Over 1000 mg/L (TDS)	Ranking Priority Basins
Northern Central Valley	1	13%	3%	1%	3%	200	370	1095	153	158	164	97	127	186	0	0	0
	2	5%	4%	5%	6%	164	201	323	218	223	227	124	146	190	0	0	0
	3	31%	25%	36%	38%	497	583	1843	347	381	418	294	408	636	1	0	3
	4	24%	28%	29%	36%	545	761	2548	322	363	410	365	417	521	1	0	3
	5	7%	15%	20%	26%	253	329	495	269	281	293	152	185	249	0	0	2
	6	59%	59%	58%	57%	835	1060	1398	449	461	473	486	805	1442	2	1	4
	7	4%	9%	10%	21%	292	398	743	236	241	247	148	188	267	0	0	0
Middle Central Valley	8	10%	6%	6%	25%	200	438	620	222	226	231	127	161	228	0	0	1
	9	78%	84%	69%	80%	590	961	1375	539	560	583	775	837	962	3	0	4
	10	81%	91%	95%	90%	538	842	1140	853	911	972	880	1268	2044	3	2	4
	11	17%	20%	23%	33%	495	565	888	266	273	282	443	688	1179	2	1	4
	12	30%	31%	27%	29%	432	825	900	255	267	280	536	841	1452	3	1	4
	13	12%	18%	11%	20%	383	648	785	230	236	242	256	351	540	1	0	1
	22	87%	90%	92%	88%	810	1160	1508	591	645	705	2280	3117	4790	3	3	4
Southern Central Valley	14	100%	99%	95%	95%	3150	3375	5700	786	966	1187	2930	3341	4161	3	3	4
	15	53%	46%	61%	48%	523	1000	1350	314	337	361	511	653	936	3	0	4
	16	5%	18%	9%	19%	438	575	771	214	218	223	259	298	374	0	0	1
	17	2%	16%	23%	25%	305	520	755	190	199	208	183	283	483	0	0	2
	18	15%	25%	20%	31%	479	598	937	207	213	219	239	324	493	0	0	2
	19	58%	54%	71%	65%	5075	11300	14500	331	397	475	3225	3686	4608	3	3	4
	20	27%	43%	32%	45%	816	870	975	293	309	327	451	553	756	2	0	4
	21	44%	51%	40%	34%	240	335	598	254	262	271	665	778	1006	3	1	3

Figure 7-21. Ambient and Simulated Results for TDS (500 mg/L Threshold for Priority Ranking)

Region	IAZ	Ambient TDS Concentrations: Number of CVHM Grid Cells Containing A Well Over 1000 mg/L (TDS) Divided By The Number of Grid Cells Containing Well Test Data				Shallow Data (2003-2012)			Deep Data (1980-2012)			Simulated TDS Concentrations: IAZ Shallow Groundwater Final (2003) Concentration (mg/L)			Number Of Scenarios Resulting In Concentrations Over A Threshold		Ranking Priority Basins
		Before 1960	1960-1979	1980-1999	2000-2012	25th Percentile	Shallow Median mg/L	75th Percentile	Lower 95% Confidence Interval	Estimated 2003 Deep Concentration mg/L	Upper 95% Confidence Interval	50% of Loading	100% of Loading	200% of Loading	Equal To Or Over 500 mg/L (TDS)	Equal To Or Over 1000 mg/L (TDS)	
Northern Central Valley	1	8%	2%	0%	1%	200	370	1095	153	158	164	97	127	186	0	0	0
	2	1%	0%	1%	1%	164	201	323	218	223	227	124	146	190	0	0	0
	3	7%	6%	14%	11%	497	583	1843	347	381	418	294	408	636	1	0	1
	4	18%	8%	8%	11%	545	761	2548	322	363	410	365	417	521	1	0	1
	5	0%	2%	5%	10%	253	329	495	269	281	293	152	185	249	0	0	1
	6	6%	15%	12%	14%	835	1060	1398	449	461	473	486	805	1442	2	1	3
	7	0%	1%	2%	5%	292	398	743	236	241	247	148	188	267	0	0	0
Middle Central Valley	8	0%	0%	0%	7%	200	438	620	222	226	231	127	161	228	0	0	0
	9	39%	50%	30%	37%	590	961	1375	539	560	583	775	837	962	3	0	3
	10	26%	45%	45%	53%	538	842	1140	853	911	972	880	1268	2044	3	2	3
	11	5%	4%	3%	11%	495	565	888	266	273	282	443	688	1179	2	1	2
	12	13%	9%	8%	6%	432	825	900	255	267	280	536	841	1452	3	1	2
	13	7%	6%	3%	6%	383	648	785	230	236	242	256	351	540	1	0	0
	22	63%	63%	83%	35%	810	1160	1508	591	645	705	2280	3117	4790	3	3	4
Southern Central Valley	14	28%	17%	45%	22%	3150	3375	5700	786	966	1187	2930	3341	4161	3	3	3
	15	2%	1%	0%	3%	523	1000	1350	314	337	361	511	653	936	3	0	3
	16	0%	1%	0%	6%	438	575	771	214	218	223	259	298	374	0	0	0
	17	5%	5%	6%	7%	305	520	755	190	199	208	183	283	483	0	0	0
	18	46%	40%	53%	49%	479	598	937	207	213	219	239	324	493	0	0	1
	19	9%	17%	16%	11%	5075	11300	14500	331	397	475	3225	3686	4608	3	3	3
	20	21%	25%	17%	13%	816	870	975	293	309	327	451	553	756	2	0	2
	21	64%	53%	66%	56%	240	335	598	254	262	271	665	778	1006	3	1	3

Figure 7-22. Ambient and Simulated Results for TDS (1000 mg/L Threshold for Priority Ranking)

		Ambient Nitrate Concentrations										Simulated Nitrate Concentrations								
		Number of CVHM Grid Cells Containing A Well Over 10 mg/L (NO3-N) Divided By The Number of Grid Cells Containing Well Test Data				Shallow Data (2003-2012)			Deep Data (1980-2012)			IAZ Shallow Groundwater Final (2003) Concentration mg/L NO3-N						Number Of Scenarios Resulting In Concentrations Over A Threshold		
	IAZ	Before 1960	1960-1979	1980-1999	2000-2012	25th Percentile	Shallow Median mg/L NO3-N	75th Percentile	Lower 95% Confidence Interval	Estimated 2003 Deep Concentration mg/L NO3-N	Upper 95% Confidence Interval	High NUE	Moderate NUE	Low NUE	90% of Low NUE	75% of Low NUE	60% of Low NUE	Equal To Or Over 5mg/L (NO3-N)	Equal To Or Over 10mg/L (NO3-N)	Ranking Priority Basins
Northern Central Valley	1	2%	0%	0%	1%	0.1	0.1	0.4	0.7	0.8	0.8	0.4	0.7	1.2	1.4	1.7	3.2	0	0	0
	2	5%	5%	11%	12%	0.1	0.6	2.0	1.4	1.4	1.5	0.8	1.0	1.3	1.4	1.8	3.3	0	0	0
	3	1%	2%	7%	13%	0.4	0.9	1.9	1.3	1.5	1.6	1.4	1.7	2.2	2.7	3.8	9.6	1	0	0
	4	0%	2%	4%	4%	0.2	2.8	27.0	0.2	0.2	0.2	0.9	1.1	1.4	1.8	2.6	6.5	1	0	0
	5	7%	9%	12%	16%	0.1	0.4	1.5	0.8	0.9	0.9	0.6	0.8	1.2	1.4	1.9	4.4	0	0	0
	6	6%	10%	13%	29%	0.1	0.6	2.8	1.9	2.0	2.2	5.2	6.0	7.4	8.1	9.6	16.2	6	1	3
	7	3%	0%	1%	4%	0.1	0.7	1.6	1.1	1.1	1.2	3.4	4.5	6.1	7.0	8.9	17.5	4	1	1
Middle Central Valley	8	1%	3%	3%	24%	0.3	1.2	3.4	1.1	1.1	1.2	1.6	1.8	2.2	2.5	3.0	5.4	1	0	0
	9	8%	18%	24%	22%	0.1	0.4	3.0	0.4	0.5	0.5	1.5	1.7	2.1	2.2	2.5	3.9	0	0	0
	10	6%	11%	30%	40%	1.2	2.7	7.6	3.8	4.2	4.6	3.6	3.9	4.4	4.7	5.4	9.1	2	0	2
	11	4%	10%	21%	46%	1.8	4.9	9.6	3.1	3.2	3.3	3.0	3.3	3.8	4.1	4.8	8.1	1	0	2
	12	5%	13%	32%	62%	2.7	10.4	22.6	2.8	3.0	3.2	3.6	3.8	4.2	4.5	5.0	7.8	2	0	3
	13	2%	4%	7%	33%	2.5	6.1	10.2	2.1	2.2	2.3	1.5	1.7	1.9	2.0	2.2	3.3	0	0	3
	22	3%	9%	43%	38%	1.8	7.4	12.4	1.6	1.9	2.2	4.3	4.4	4.6	4.8	5.1	6.9	2	0	2
Southern Central Valley	14	4%	4%	59%	6%	0.2	0.4	1.0	0.7	1.0	1.4	7.2	7.2	7.2	7.3	7.4	8.3	6	0	1
	15	1%	2%	21%	38%	0.5	3.0	10.2	0.4	0.4	0.5	16.0	16.7	18.0	19.8	23.4	43.5	6	6	2
	16	1%	10%	17%	25%	1.4	11.1	19.5	3.0	3.1	3.2	7.2	7.6	8.3	8.8	9.6	13.8	6	1	4
	17	0%	23%	26%	35%	2.3	8.5	19.4	2.7	2.9	3.1	9.3	9.9	10.9	11.9	13.9	24.4	6	4	4
	18	8%	24%	28%	55%	4.7	10.7	19.2	2.9	3.0	3.2	9.4	10.0	11.1	12.0	14.0	24.2	6	5	4
	19	8%	7%	24%	30%	0.1	3.3	7.5	0.9	1.1	1.3	9.4	10.2	11.7	12.8	15.0	26.0	6	5	2
	20	8%	27%	27%	39%	0.1	3.4	11.3	1.8	2.0	2.2	10.0	10.5	11.4	12.5	14.6	26.0	6	5	3
	21	8%	21%	18%	23%	0.1	0.2	0.5	1.4	1.5	1.6	15.4	16.6	18.7	20.6	24.3	43.4	6	6	1

Figure 7-23. Ambient and Simulated Results for Nitrate (10 mg/L NO3-N Threshold for Priority Ranking)

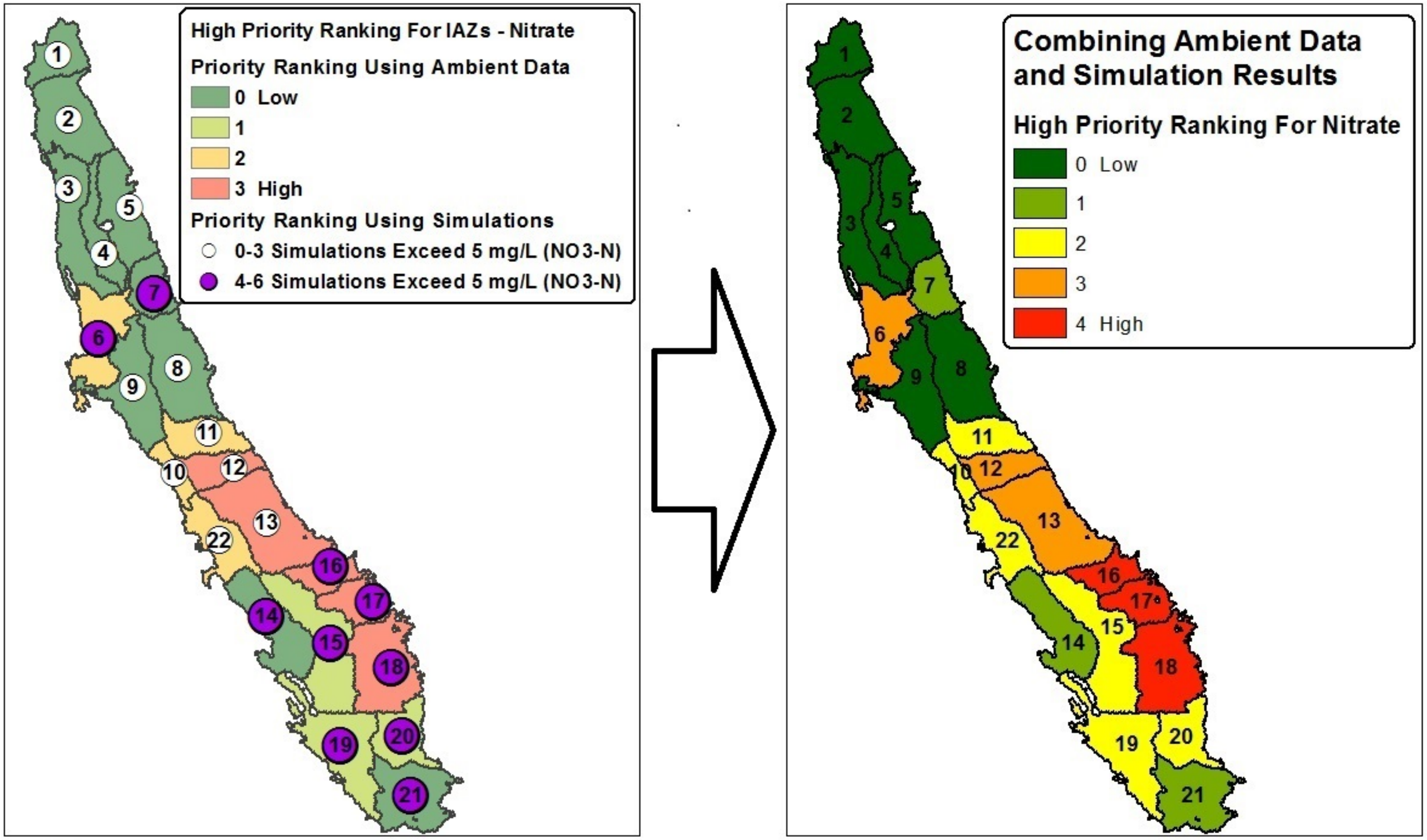


Figure 7-24. Priority Ranking for Nitrate

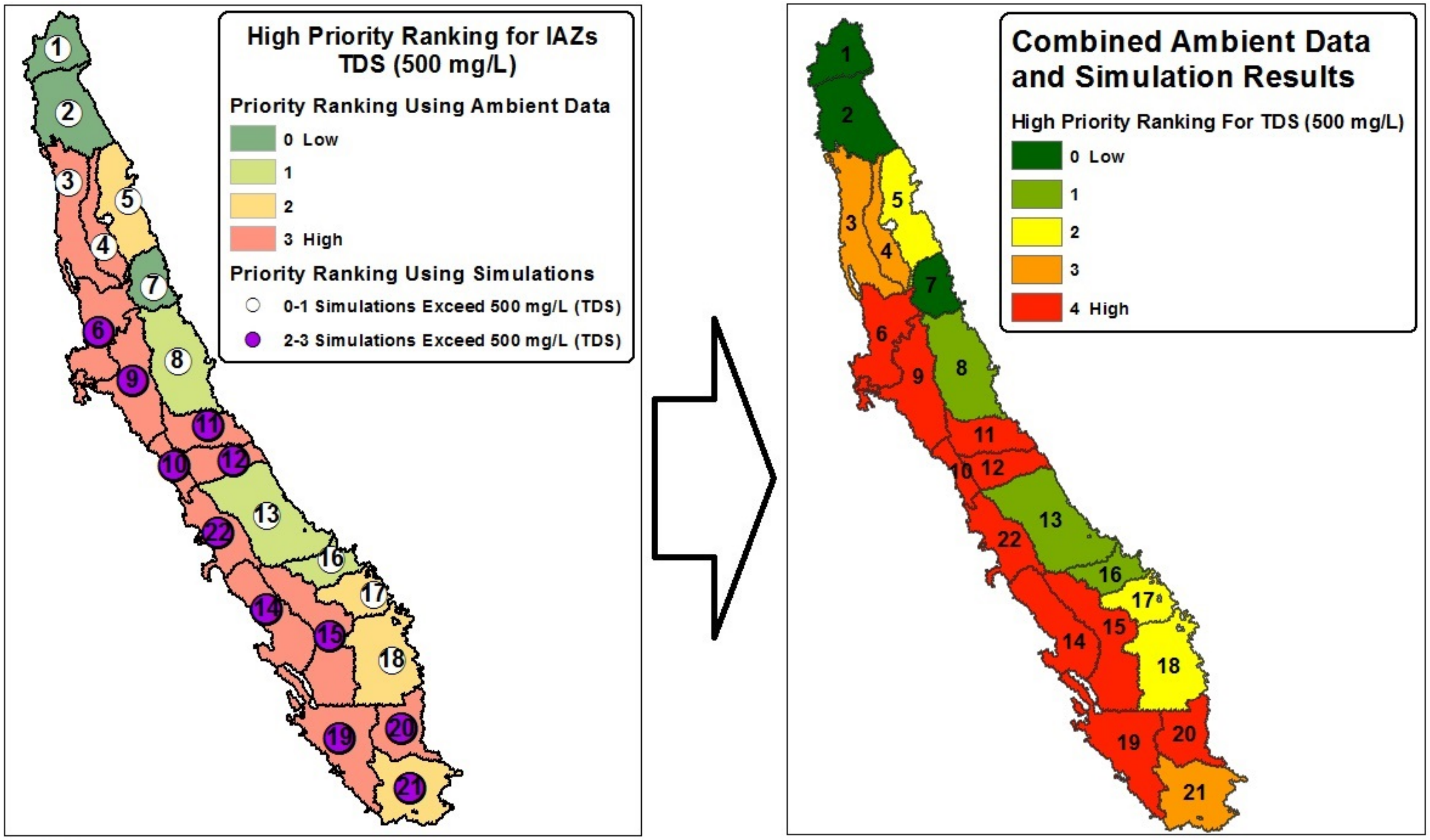


Figure 7-25. Priority Ranking for TDS (500 mg/L)

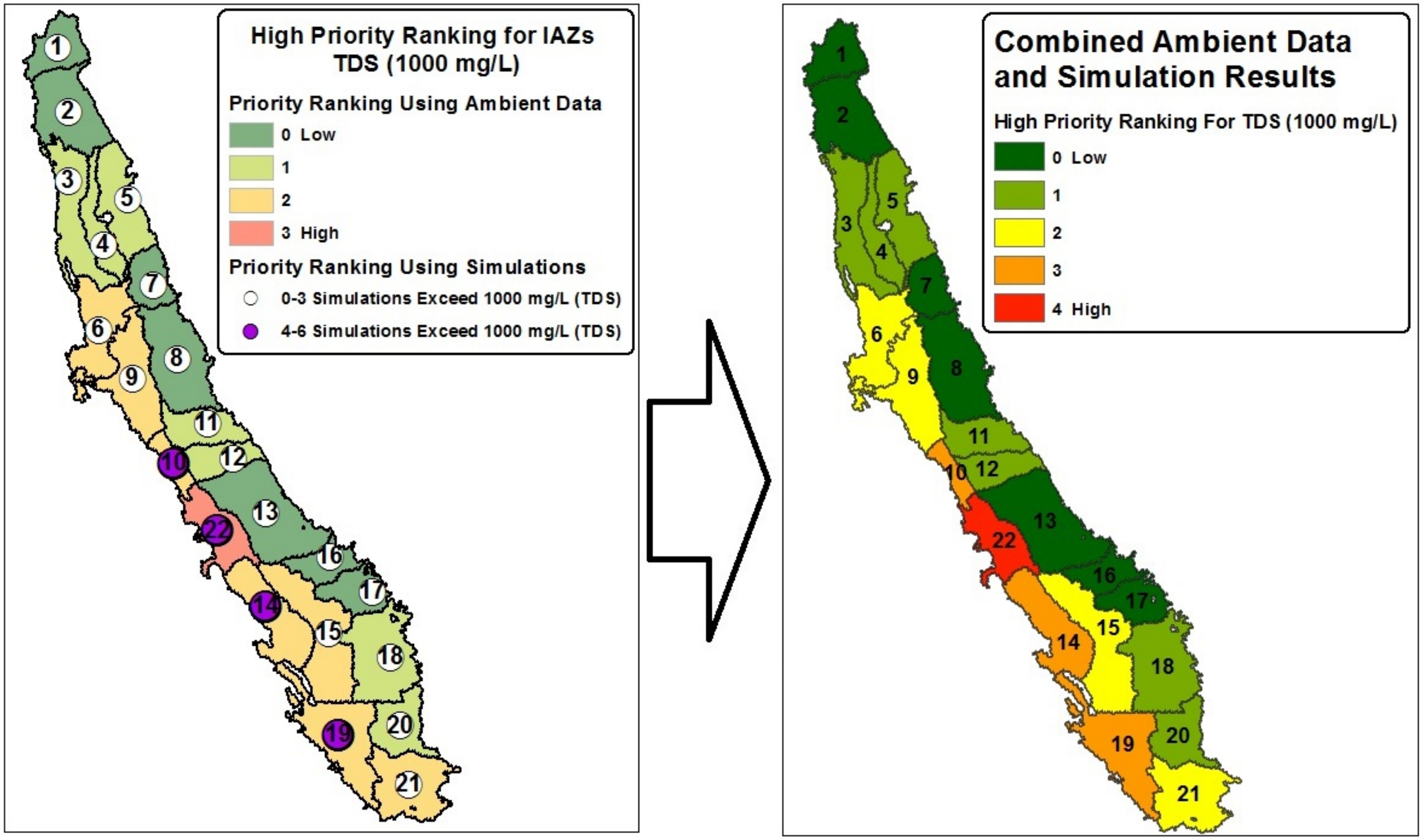


Figure 7-26. Priority Ranking for TDS (1000 mg/L)

	IAZ	Does one quarter or more of the CVHM grid cells containing well test data have a well at or above the MCL (10 mg/L NO3-N) in the 2000s?	Is the median shallow concentration for recent years (2003-2012) at or above half of the MCL (5 mg/L NO3-N)?	Is the estimated 2003 deep concentration at or above 2 mg/L NO3-N?	Priority Basins Based on Ambient Nitrate Data	Do more than three simulations result in shallow groundwater at or above half of the MCL (5 mg/L NO3-N)?	Priority Basins Based on Ambient Nitrate Data and Mixing Model Simulations
Northern Central Valley	1	No	No	No	0	No	0
	2	No	No	No	0	No	0
	3	No	No	No	0	No	0
	4	No	No	No	0	No	0
	5	No	No	No	0	No	0
	6	Yes	No	Yes	2	Yes	3
	7	No	No	No	0	Yes	1
Middle Central Valley	8	No	No	No	0	No	0
	9	No	No	No	0	No	0
	10	Yes	No	Yes	2	No	2
	11	Yes	No	Yes	2	No	2
	12	Yes	Yes	Yes	3	No	3
	13	Yes	Yes	Yes	3	No	3
	22	Yes	Yes	No	2	No	2
Southern Central Valley	14	No	No	No	0	Yes	1
	15	Yes	No	No	1	Yes	2
	16	Yes	Yes	Yes	3	Yes	4
	17	Yes	Yes	Yes	3	Yes	4
	18	Yes	Yes	Yes	3	Yes	4
	19	Yes	No	No	1	Yes	2
	20	Yes	No	No	1	Yes	2
	21	No	No	No	0	Yes	1

Figure 7-27. Establishing Priority Ranking for Nitrate

	IAZ	Does one quarter or more of the CVHM grid cells containing well test data have a well at or above 500 mg/L TDS in the 2000s?	Is the median shallow concentration for recent years (2003-2012) at or above 500 mg/L TDS?	Is the estimated 2003 deep concentration at or above 250 mg/L TDS?	Priority Basins Based on Ambient TDS Data	Do two or more simulations result in shallow groundwater at or above 500 mg/L?	Priority Basins Based on Ambient TDS Data and Mixing Model Simulations
Northern Central Valley	1	No	No	No	0	No	0
	2	No	No	No	0	No	0
	3	Yes	Yes	Yes	3	No	3
	4	Yes	Yes	Yes	3	No	3
	5	Yes	No	Yes	2	No	2
	6	Yes	Yes	Yes	3	Yes	4
	7	No	No	No	0	No	0
Middle Central Valley	8	Yes	No	No	1	No	1
	9	Yes	Yes	Yes	3	Yes	4
	10	Yes	Yes	Yes	3	Yes	4
	11	Yes	Yes	Yes	3	Yes	4
	12	Yes	Yes	Yes	3	Yes	4
	13	No	Yes	No	1	No	1
	22	Yes	Yes	Yes	3	Yes	4
Southern Central Valley	14	Yes	Yes	Yes	3	Yes	4
	15	Yes	Yes	Yes	3	Yes	4
	16	No	Yes	No	1	No	1
	17	Yes	Yes	No	2	No	2
	18	Yes	Yes	No	2	No	2
	19	Yes	Yes	Yes	3	Yes	4
	20	Yes	Yes	Yes	3	Yes	4
	21	Yes	No	Yes	2	Yes	3

Figure 7-28. Establishing Priority Ranking For TDS (500 mg/L)

	IAZ	Does one quarter or more of the CVHM grid cells containing well test data have a well at or above 1000 mg/L TDS in the 2000s?	Is the median shallow concentration for recent years (2003-2012) at or above 1000 mg/L TDS?	Is the estimated 2003 deep concentration at or above 250 mg/L TDS?	Priority Basins Based on Ambient TDS Data	Do two or more simulations result in shallow groundwater at or above 1000 mg/L?	Priority Basins Based on Ambient TDS Data and Mixing Model Simulations
Northern Central Valley	1	No	No	No	0	No	0
	2	No	No	No	0	No	0
	3	No	No	Yes	1	No	1
	4	No	No	Yes	1	No	1
	5	No	No	Yes	1	No	1
	6	No	Yes	Yes	2	No	2
	7	No	No	No	0	No	0
Middle Central Valley	8	No	No	No	0	No	0
	9	Yes	No	Yes	2	No	2
	10	Yes	No	Yes	2	Yes	3
	11	No	No	Yes	1	No	1
	12	No	No	Yes	1	No	1
	13	No	No	No	0	No	0
	22	Yes	Yes	Yes	3	Yes	4
Southern Central Valley	14	No	Yes	Yes	2	Yes	3
	15	No	Yes	Yes	2	No	2
	16	No	No	No	0	No	0
	17	No	No	No	0	No	0
	18	Yes	No	No	1	No	1
	19	No	Yes	Yes	2	Yes	3
	20	No	No	Yes	1	No	1
	21	Yes	No	Yes	2	No	2

Figure 7-29. Establishing Priority Ranking For TDS (1000 mg/L)

7.6 ASSIMILATIVE CAPACITY

The preliminary assimilative capacity[60] was estimated for each IAZ for both nitrate and TDS based on 1) the estimated ambient shallow water quality and 2) for each of the loading scenarios run in the mixing model. For nitrate, the shallow ambient and simulated concentrations are compared to the maximum contaminant level (MCL) of 10 mg/L NO3-N. For TDS, the ambient and simulated concentrations are compared to three thresholds; 500 mg/L, 700 mg/L, and 1000 mg/L. **Table 7-2** shows the estimated assimilative capacities for nitrate and **Table 7-3**, **Table 7-4**, and **Table 7-5** show the estimated assimilative capacities for TDS based on the 500 mg/L, 700 mg/L, and 1000 mg/L thresholds, respectively. Assimilative capacities here are calculated by subtracting the estimated/simulated concentration from the given threshold. For example, IAZ 1 for the Low NUE scenario has a final concentration of 1.2 mg/L NO3-N and the threshold for nitrate is 10 mg/L NO3-N resulting in an assimilative capacity of 8.8 mg/L NO3-N. A red to green color scale (where red is 0 and green is 10) is shown to assist the reader in comparing the IAZ's assimilative capacities.

The assimilative capacities determined for the IAZs are based on a median concentration using data from 2003-2012. Ambient water quality of shallow groundwater for an IAZ, however, is not static and has likely been highly variable through time. Ambient water quality was also estimated using median concentrations for the following time periods: 1910-1964, 1965-1970, 1971-1979, 1980-1989, and 1990-2002. The estimated historical concentrations are plotted in **Figure 7-30** and **Figure 7-31**. **Table 7-8** and **Table 7-9** provide the calculated values and also provide a column labeled "Value Count" which shows how many values the median was based on. The CVHM annual cell medians, used to spatially decluster the data, are the values referred to in calculating the median value for the time period. Section 3 provides details on how the CVHM grid was used to spatially decluster the data.

The median concentrations through time were qualitatively evaluated in terms of water quality trends that might exist in each IAZ. It should be noted, however, that the well test data used for each time period are not from the same wells, and that additionally the overall amount of shallow groundwater quality data through time is very limited. Therefore, it should be noted that there is a high level of uncertainty in any apparent trends at the IAZ scale analysis shown here. In the next section, the two prototype areas, the Stanislaus/Merced region and the Kings

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[60] The SWRCB Recycled Water Policy refers to assimilative capacity, however, an explicit definition is not provided in that guidance document. For ICM purposes, assimilative capacity is defined as the amount of a constituent (contaminant load) that can be discharged to the aquifer system (especially that part of the aquifer system that provides actual or probable beneficial uses) without exceeding water quality standards and/or Basin Plan water quality objectives. Additionally, this term describes the difference between the water quality standards/objectives and average ambient shallow groundwater quality in the basin/subbasin/IAZ/MZ (where shallow does not necessarily mean the uppermost part of the saturated zone directly at the water table, rather "shallow" means the part of the aquifer system that provides actual or probable beneficial uses).

Subbasin, will be evaluated spatially to show the highly variable nature of shallow groundwater across the regions.

Table 7-2. Estimated Assimilative Capacities for Nitrate

		Ambient Groundwater Concentrations		Shallow Groundwater 2003 Simulated Concentrations:						Assimilative Capacity (10 mg/L NO3-N threshold) Based On:						
	IAZ	Shallow Median (2003-2012)	Estimated Deep (2003)	High NUE	Moderate NUE	Low NUE	90% of Low NUE	75% of Low NUE	60% of Low NUE	Shallow Median	High NUE	Moderate NUE	Low NUE	90% of Low NUE	75% of Low NUE	60% of Low NUE
Northern Central Valley	1	0.1	0.8	0.4	0.7	1.2	1.4	1.7	3.2	9.9	9.6	9.3	8.8	8.6	8.3	6.8
	2	0.6	1.4	0.8	1.0	1.3	1.4	1.8	3.3	9.4	9.2	9.0	8.7	8.6	8.2	6.7
	3	0.9	1.5	1.4	1.7	2.2	2.7	3.8	9.6	9.1	8.6	8.3	7.8	7.3	6.2	0.4
	4	2.8	0.2	0.9	1.1	1.4	1.8	2.6	6.5	7.2	9.1	8.9	8.6	8.2	7.4	3.5
	5	0.4	0.9	0.6	0.8	1.2	1.4	1.9	4.4	9.6	9.4	9.2	8.8	8.6	8.1	5.6
	6	0.6	2.0	5.2	6.0	7.4	8.1	9.6	16.2	9.4	4.8	4.0	2.6	1.9	0.4	0.0
	7	0.7	1.1	3.4	4.5	6.1	7.0	8.9	17.5	9.3	6.6	5.5	3.9	3.0	1.1	0.0
Middle Central Valley	8	1.2	1.1	1.6	1.8	2.2	2.5	3.0	5.4	8.8	8.4	8.2	7.8	7.5	7.0	4.6
	9	0.4	0.5	1.5	1.7	2.1	2.2	2.5	3.9	9.6	8.5	8.3	7.9	7.8	7.5	6.1
	10	2.7	4.2	3.6	3.9	4.4	4.7	5.4	9.1	7.3	6.4	6.1	5.6	5.3	4.6	0.9
	11	4.9	3.2	3.0	3.3	3.8	4.1	4.8	8.1	5.1	7.0	6.7	6.2	5.9	5.2	1.9
	12	10.4	3.0	3.6	3.8	4.2	4.5	5.0	7.8	0.0	6.4	6.2	5.8	5.5	5.0	2.2
	13	6.1	2.2	1.5	1.7	1.9	2.0	2.2	3.3	4.0	8.5	8.3	8.1	8.0	7.8	6.7
	22	7.4	1.9	4.3	4.4	4.6	4.8	5.1	6.9	2.6	5.7	5.6	5.4	5.2	4.9	3.1
Southern Central Valley	14	0.4	1.0	7.2	7.2	7.2	7.3	7.4	8.3	9.6	2.8	2.8	2.8	2.7	2.6	1.7
	15	3.0	0.4	16.0	16.7	18.0	19.8	23.4	43.5	7.0	0.0	0.0	0.0	0.0	0.0	0.0
	16	11.1	3.1	7.2	7.6	8.3	8.8	9.6	13.8	0.0	2.8	2.4	1.7	1.2	0.4	0.0
	17	8.5	2.9	9.3	9.9	10.9	11.9	13.9	24.4	1.5	0.7	0.1	0.0	0.0	0.0	0.0
	18	10.7	3.0	9.4	10.0	11.1	12.0	14.0	24.2	0.0	0.6	0.0	0.0	0.0	0.0	0.0
	19	3.3	1.1	9.4	10.2	11.7	12.8	15.0	26.0	6.7	0.6	0.0	0.0	0.0	0.0	0.0
	20	3.4	2.0	10.0	10.5	11.4	12.5	14.6	26.0	6.6	0.0	0.0	0.0	0.0	0.0	0.0
	21	0.2	1.5	15.4	16.6	18.7	20.6	24.3	43.4	9.8	0.0	0.0	0.0	0.0	0.0	0.0

Table 7-3. Estimated Assimilative Capacities for TDS (500 mg/L Threshold)

		Ambient Groundwater Concentrations		Shallow Groundwater 2003 Simulated Concentrations:			Assimilative Capacity (500 mg/L threshold) Based On:			
	IAZ	Shallow Median (2003-2012)	Estimated Deep (2003)	50% of Loading	100% of Loading	200% of Loading	Shallow Median	50% of Loading	100% of Loading	200% of Loading
Northern Central Valley	1	370	158	97	127	186	130	403	373	314
	2	201	223	124	146	190	300	376	354	310
	3	583	381	294	408	636	0	206	92	0
	4	761	363	365	417	521	0	135	83	0
	5	329	281	152	185	249	171	348	315	251
	6	1060	461	486	805	1442	0	14	0	0
	7	398	241	148	188	267	103	352	312	233
Middle Central Valley	8	438	226	127	161	228	62	373	339	272
	9	961	560	775	837	962	0	0	0	0
	10	842	911	880	1268	2044	0	0	0	0
	11	565	273	443	688	1179	0	57	0	0
	12	825	267	536	841	1452	0	0	0	0
	13	648	236	256	351	540	0	244	149	0
	22	1160	645	2280	3117	4790	0	0	0	0
Southern Central Valley	14	3375	966	2930	3341	4161	0	0	0	0
	15	1000	337	511	653	936	0	0	0	0
	16	575	218	259	298	374	0	241	202	126
	17	520	199	183	283	483	0	317	217	17
	18	598	213	239	324	493	0	261	176	7
	19	11300	397	3225	3686	4608	0	0	0	0
	20	870	309	451	553	756	0	49	0	0
	21	335	262	665	778	1006	165	0	0	0

Table 7-4. Estimated Assimilative Capacities for TDS (700 mg/L Threshold)

		Ambient Groundwater Concentrations		Shallow Groundwater 2003 Simulated Concentrations:			Assimilative Capacity (700 mg/L threshold) Based On:			
	IAZ	Shallow Median (2003-2012)	Estimated Deep (2003)	50% of Loading	100% of Loading	200% of Loading	Shallow Median	50% of Loading	100% of Loading	200% of Loading
Northern Central Valley	1	370	158	97	127	186	330	603	573	514
	2	201	223	124	146	190	500	576	554	510
	3	583	381	294	408	636	117	406	292	64
	4	761	363	365	417	521	0	335	283	179
	5	329	281	152	185	249	371	548	515	451
	6	1060	461	486	805	1442	0	214	0	0
	7	398	241	148	188	267	303	552	512	433
Middle Central Valley	8	438	226	127	161	228	262	573	539	472
	9	961	560	775	837	962	0	0	0	0
	10	842	911	880	1268	2044	0	0	0	0
	11	565	273	443	688	1179	135	257	12	0
	12	825	267	536	841	1452	0	164	0	0
	13	648	236	256	351	540	53	444	349	160
	22	1160	645	2280	3117	4790	0	0	0	0
Southern Central Valley	14	3375	966	2930	3341	4161	0	0	0	0
	15	1000	337	511	653	936	0	189	47	0
	16	575	218	259	298	374	125	441	402	326
	17	520	199	183	283	483	180	517	417	217
	18	598	213	239	324	493	102	461	376	207
	19	11300	397	3225	3686	4608	0	0	0	0
	20	870	309	451	553	756	0	249	147	0
	21	335	262	665	778	1006	365	35	0	0

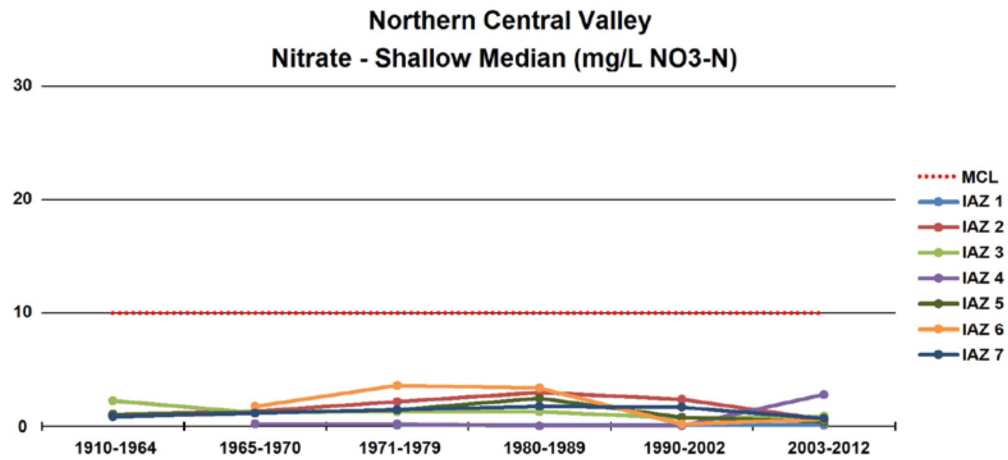
Table 7-5. Estimated Assimilative Capacities for TDS (1000 mg/L Threshold)

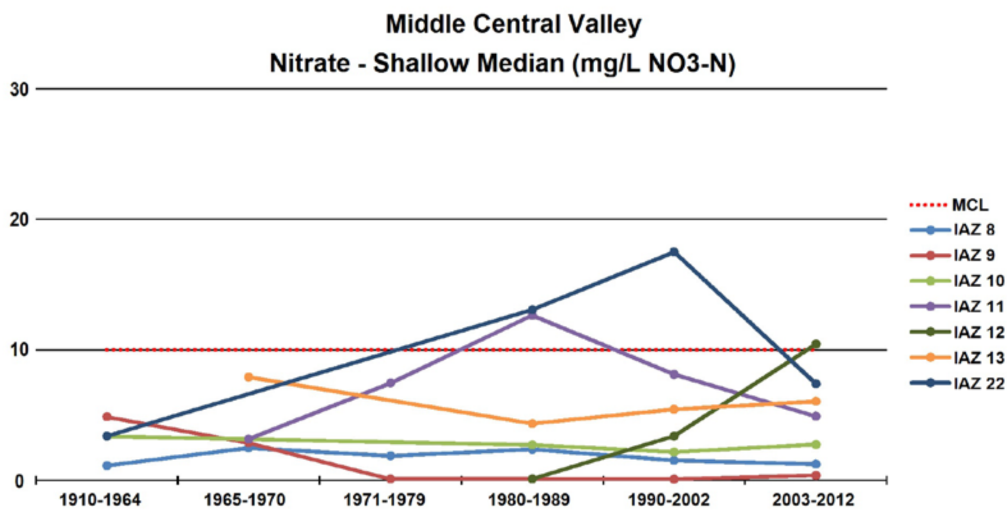
		Ambient Groundwater Concentrations		Shallow Groundwater 2003 Simulated Concentrations:			Assimilative Capacity (1000 mg/L threshold) Based On:			
	IAZ	Shallow Median (2003-2012)	Estimated Deep (2003)	50% of Loading	100% of Loading	200% of Loading	Shallow Median	50% of Loading	100% of Loading	200% of Loading
Northern Central Valley	1	370	158	97	127	186	630	903	873	814
	2	201	223	124	146	190	800	876	854	810
	3	583	381	294	408	636	417	706	592	364
	4	761	363	365	417	521	240	635	583	479
	5	329	281	152	185	249	671	848	815	751
	6	1060	461	486	805	1442	0	514	195	0
	7	398	241	148	188	267	603	852	812	733
Middle Central Valley	8	438	226	127	161	228	562	873	839	772
	9	961	560	775	837	962	40	225	163	38
	10	842	911	880	1268	2044	159	120	0	0
	11	565	273	443	688	1179	435	557	312	0
	12	825	267	536	841	1452	175	464	159	0
	13	648	236	256	351	540	353	744	649	460
	22	1160	645	2280	3117	4790	0	0	0	0
Southern Central Valley	14	3375	966	2930	3341	4161	0	0	0	0
	15	1000	337	511	653	936	0	489	347	64
	16	575	218	259	298	374	425	741	702	626
	17	520	199	183	283	483	480	817	717	517
	18	598	213	239	324	493	402	761	676	507
	19	11300	397	3225	3686	4608	0	0	0	0
	20	870	309	451	553	756	130	549	447	244
	21	335	262	665	778	1006	665	335	222	0

Table 7-6. Median Nitrate Concentrations Through Time and Assimilative Capacity (Based on the 2003-2012 Time Period)

Shallow NO3-N Median Concentration Through Time								
	IAZ	1910-1964	1965-1970	1971-1979	1980-1989	1990-2002	2003-2012	Assimilative capacity 10 mg/L NO3-N Threshold
Nothern Central Valley	1			0.1			0.1	9.9
	2	1.1	1.3	2.2	3.0	2.4	0.6	9.4
	3	2.3	1.2	1.3	1.3	0.7	0.9	9.1
	4		0.2	0.2	0.0	0.1	2.8	7.2
	5	1.1	1.2	1.4	2.5	0.8	0.4	9.6
	6		1.8	3.6	3.4	0.2	0.6	9.4
	7	0.8	1.2	1.5	1.8	1.7	0.7	9.3
Middle Central Valley	8	1.1	2.5	1.9	2.4	1.5	1.2	8.8
	9	4.9	2.9	0.1	0.1	0.1	0.4	9.6
	10	3.4			2.7	2.2	2.7	7.3
	11		3.2	7.5	12.6	8.1	4.9	5.1
	12				0.1	3.4	10.4	0.0
	13		7.9		4.4	5.4	6.1	4.0
	22	3.4			13.1	17.5	7.4	2.6
Southern Central Valley	14	3.4	2.5		23.0		0.4	9.6
	15				1.2	11.3	3.0	7.0
	16	5.7			8.2	7.9	11.1	0.0
	17	6.0		8.1	8.0	10.1	8.5	1.5
	18				14.5	15.0	10.7	0.0
	19	3.6			4.9		3.3	6.7
	20	0.6			1.6		3.4	6.6
	21	0.7		8.6	8.6	0.3	0.2	9.8

Figure 7-30. Median Nitrate Concentrations Through Time for the Northern, Middle, and Southern Central Valley Regions, Shallow Groundwater.





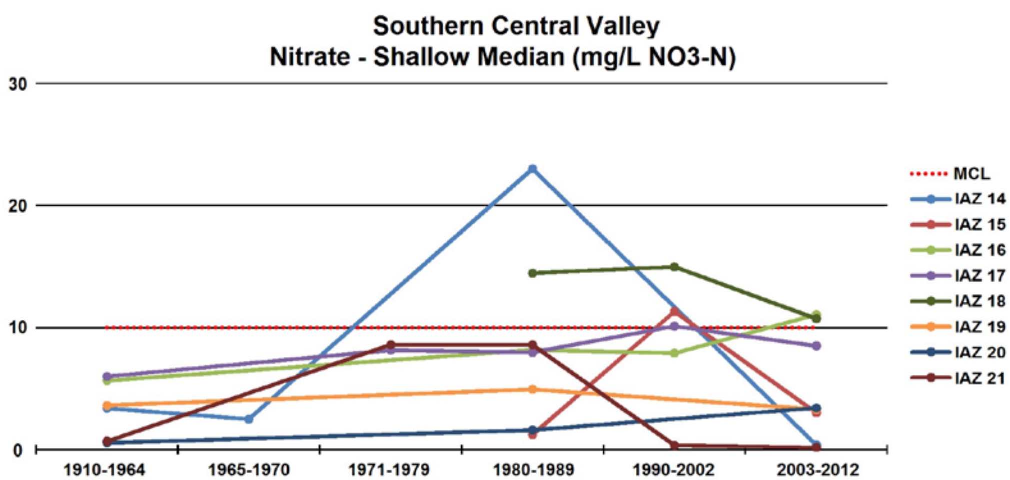


Table 7-7. Median TDS Concentrations Through Time and Assimilative Capacity (Based on the 2003-2012 Time Period)

Shallow TDS Median Concentration Through Time										
	IAZ	1910-1964	1965-1970	1971-1979	1980-1989	1990-2002	2003-2012	Assimilative capacity 500 mg/L TDS Threshold	Assimilative capacity 700 mg/L TDS Threshold	Assimilative capacity 1000 mg/L TDS Threshold
Nothern Central Valley	1			158	150		370	130	330	630
	2	179	145	270	230	195	201	300	500	800
	3	1023	572	347	398	588	583	0	117	417
	4		853	487	806	625	761	0	0	240
	5	164	183	216	219	435	329	0	371	671
	6		381	408	423	528	1060	0	0	0
	7	168	177	186	221	506	398	103	303	603
Middle Central Valley	8	163	164	187	166	336	438	62	262	562
	9	954	995	736	703	714	961	0	0	40
	10	473	870	870	1960	838	842	0	0	159
	11	315	173	257	227	640	565	0	135	435
	12	80	895		83	201	825	0	0	175
	13	235	423	180	204	258	648	0	53	353
	22	962	5630		2575	2410	1160	0	0	0
Southern Central Valley	14	942	836		4310		3375	0	0	0
	15	336	475	315	6490	783	1000	0	0	0
	16	419	124	303	378	497	575	0	125	425
	17	383		352	413	394	520	0	180	480
	18	160		356	1555	648	598	0	102	402
	19	1270			3370		11300	0	0	0
	20	518			290		870	0	0	130
	21	359		353	3420	420	335	165	365	665

Figure 7-31. Median TDS Concentrations Through Time for the Northern, Middle, and Southern Central Valley Regions, Shallow Groundwater

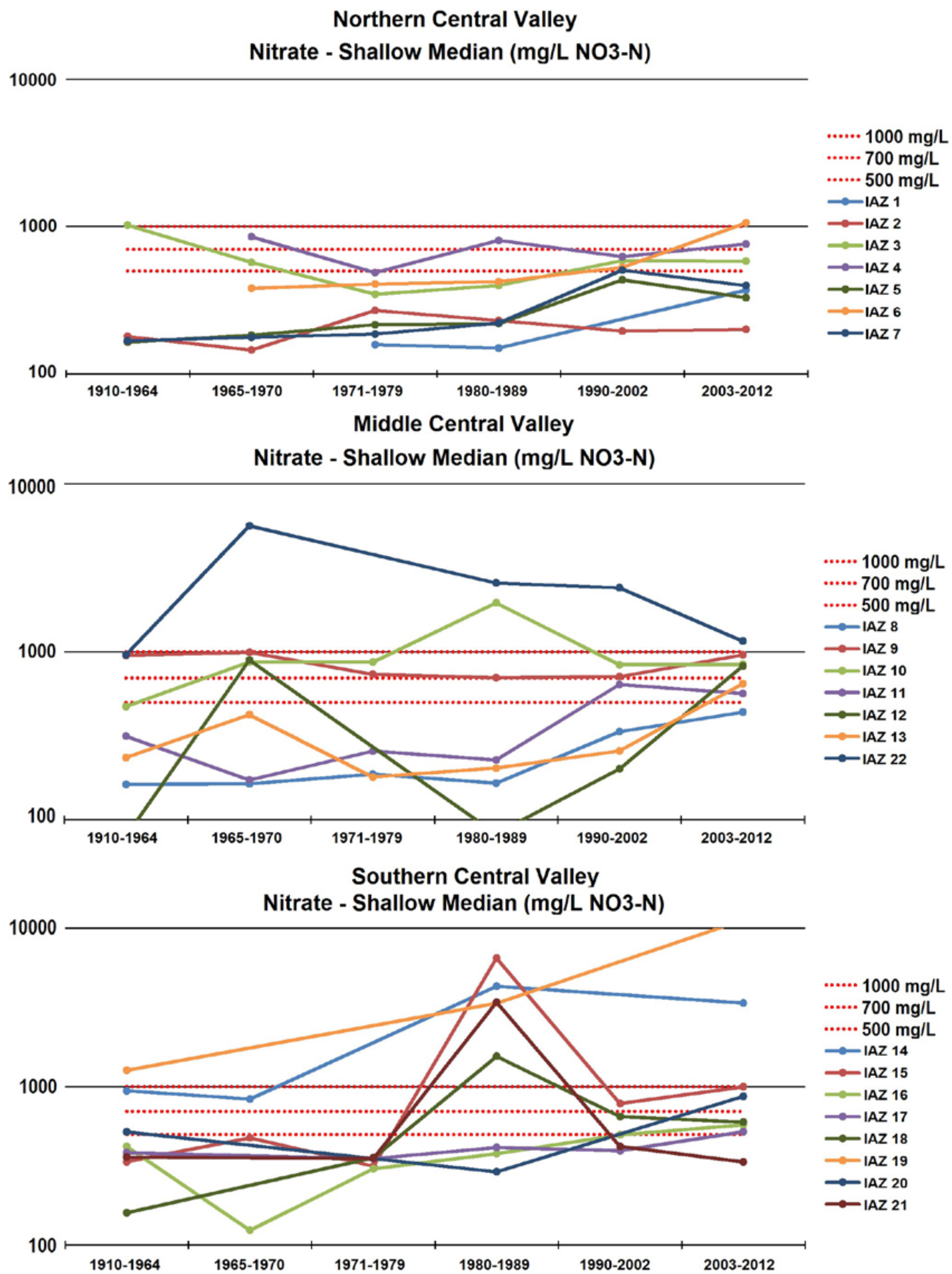


Table 7-8. Shallow Nitrate Median Concentrations and a Qualitative Assessment of Potential Trends

Shallow Nitrate Median Concentration (mg/L NO3-N) Through Time														
		1910-1964		1965-1970		1971-1979		1980-1989		1990-2002		2003-2012		Trend
	IAZ	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	
Nothern Central Valley	1					0.1	1					0.1	41	No apparent trend
	2	1.1	29	1.3	13	2.2	86	3.0	30	2.4	12	0.6	75	No apparent trend
	3	2.3	6	1.2	6	1.3	34	1.3	7	0.7	22	0.9	62	No apparent trend
	4			0.2	7	0.2	11	0.0	2	0.1	7	2.8	17	No apparent trend
	5	1.1	8	1.2	4	1.4	48	2.5	7	0.8	13	0.4	80	No apparent trend
	6			1.8	8	3.6	14	3.4	17	0.2	3	0.6	106	Slightly decreasing
	7	0.8	8	1.2	2	1.5	5	1.8	4	1.7	9	0.7	76	No apparent trend
Middle Central Valley	8	1.1	24	2.5	9	1.9	13	2.4	12	1.5	11	1.2	345	No apparent trend
	9	4.9	8	2.9	4	0.1	7	0.1	7	0.1	10	0.4	218	No apparent trend
	10	3.4	4					2.7	7	2.2	4	2.7	65	No apparent trend
	11			3.2	3	7.5	4	12.6	8	8.1	4	4.9	254	Increasing to decreasing?
	12							0.1	1	3.4	11	10.4	220	Increasing
	13			7.9	3			4.4	8	5.4	21	6.1	195	Slightly increasing
	22	3.4	1					13.1	18	17.5	17	7.4	83	Slightly decreasing
Southern Central Valley	14	3.4	1	2.5	1			23.0	75			0.4	14	No apparent trend
	15							1.2	67	11.3	26	3.0	192	Increasing to decreasing?
	16	5.7	1					8.2	6	7.9	19	11.1	36	Slightly increasing
	17	6.0	2			8.1	1	8.0	10	10.1	33	8.5	100	Slightly increasing
	18							14.5	8	15.0	21	10.7	362	No apparent trend
	19	3.6	3					4.9	40			3.3	42	No apparent trend
	20	0.6	6					1.6	1			3.4	14	Slightly increasing
	21	0.7	8			8.6	1	8.6	23	0.3	5	0.2	45	Increasing to decreasing?

*Value count refers to the number of values the calculated median concentration is based on.

Table 7-9. Shallow TDS Median Concentrations and a Qualitative Assessment of Potential Trends

Shallow TDS Concentrations (mg/L)														
		1910-1964		1965-1970		1971-1979		1980-1989		1990-2002		2003-2012		Trend
	IAZ	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	Median	Value Count	
Nothern Central Valley	1					158	39	149.75	52			370	9	Slightly increasing
	2	179.2	33	145.06	16	269.54	92	230	25	195	9	200.5	26	No apparent trend
	3	1022.8	12	571.52	9	347.26	44	398.26	24	588.25	20	583	21	Slightly increasing
	4			852.5	10	486.5	14	806.4	7	625	8	760.5	6	No apparent trend
	5	164	8	183	9	215.5	52	219	12	435	14	329	59	Slightly increasing
	6			381	7	407.68	63	423.04	99	528	5	1060	55	Increasing
	7	167.5	8	177	5	186.24	14	221.44	24	506.25	8	397.5	52	Slightly increasing
Middle Central Valley	8	162.56	27	164	13	187	73	165.76	57	335.5	8	438	231	Increasing
	9	953.5	12	995.2	12	736	31	702.85	24	713.5	5	960.5	147	No apparent trend
	10	473	8	870.4	1	869.5	2	1960	7	838	4	841.5	47	No apparent trend
	11	315	31	173	7	256.64	18	227.24	16	640	4	565	93	Increasing
	12	80	3	895	3			82.75	12	201.25	12	825	7	Increasing
	13	235	5	423	10	180	3	203.5	27	257.5	23	647.5	49	Increasing
	22	962	13	5630	4			2575	22	2410	17	1160	6	No apparent trend
Southern Central Valley	14	942	3	836	1			4310	74			3375	15	Increasing
	15	335.5	10	475	3	315	2	6490	67	782.5	18	1000	63	Increasing
	16	419	4	124	1	303	3	378	7	496.75	15	575.375	8	Slightly increasing
	17	383	5			351.5	6	413	9	393.75	28	520	63	Slightly increasing
	18	160	3			356	1	1555	8	648	18	597.75	82	No apparent trend
	19	1270	5					3370	39			11300	37	Increasing
	20	518	7					290	1			870	9	No apparent trend
	21	359	10			352.5	2	3420	23	419.5	4	335	32	No apparent trend

*Value count refers to the number of values the calculated median concentration is based on.

Refined Assimilative Capacity for Prototype Areas

For the Merced/Stanislaus region (Modesto Model area) and the Kings Subbasin, assimilative capacity was also estimated at a much finer resolution than what has been shown at the IAZ scale (Section 7.6 Assimilative Capacity). **Figure 7-32** through **Figure 7-39** are maps of the results of the refined analysis of the Merced/Stanislaus and Kings Subbasin areas. In each figure, the top left portion shows the estimated assimilative capacity at the IAZ scale, which is based on the declustered data shown in the lower left (see Section 4.2 regarding declustering method). The IAZ level assimilative capacity value for the IAZs as a whole was based on the median of the cell values shown in the lower left. The map shown on the right side of the figure shows the estimated assimilative capacity at a higher resolution. For the Modesto Model area, this is at the ¼ mile by ¼ mile grid cell level. For the Kings Subbasin, the grid cells have an area of 1 mi^2. Kriging interpolation was used to estimate areas where data are lacking. The MCL of 10 mg/L NO3-N was used to calculate assimilative capacity for nitrate. For TDS, the recommended SMCL of 500 mg/L was used; however, results are also shown using 700 mg/L as well as the upper SMCL for TDS of 1000 mg/L.

The results indicate that the assimilative capacities estimated for an entire IAZ do not apply to all areas of the IAZ, and that considerable variability exists in the groundwater quality (and therefore its' assimilative capacity) within an IAZ. For example, in the Modesto Model area, IAZ 11 as a whole has an estimated assimilative capacity of 5.1 mg/L NO3-N; however, when this analysis is performed at a finer resolution, there exist areas that have no assimilative capacity and areas that have greater assimilative capacity compared to the 5.1 mg/L NO3-N level for the region as a whole.

The purpose of the interpolated maps provided below are to demonstrate that the IAZ scale determination of assimilative capacity is insufficient for developing a final SNMP that would apply at the local scale (e.g., with respect to discharge permits, etc.). The interpolated maps in the following figures are sometimes based on limited data; therefore, there is high uncertainty in areas with limited or no groundwater quality data. While an entire IAZ may have no assimilative capacity when viewed as a whole, locally there may be areas with better groundwater quality. The converse is also true in that IAZs that appear to have a large assimilative capacity when viewed as a whole may have local areas that are affected and further inputs to the aquifer system in the local area should be limited. The spatial resolution of assimilative capacity could be improved with additional data.

Figure 7-32. Refined Assimilative Capacity for Nitrate in the Modesto Model Area Based on a 10 mg/L NO3-N Threshold

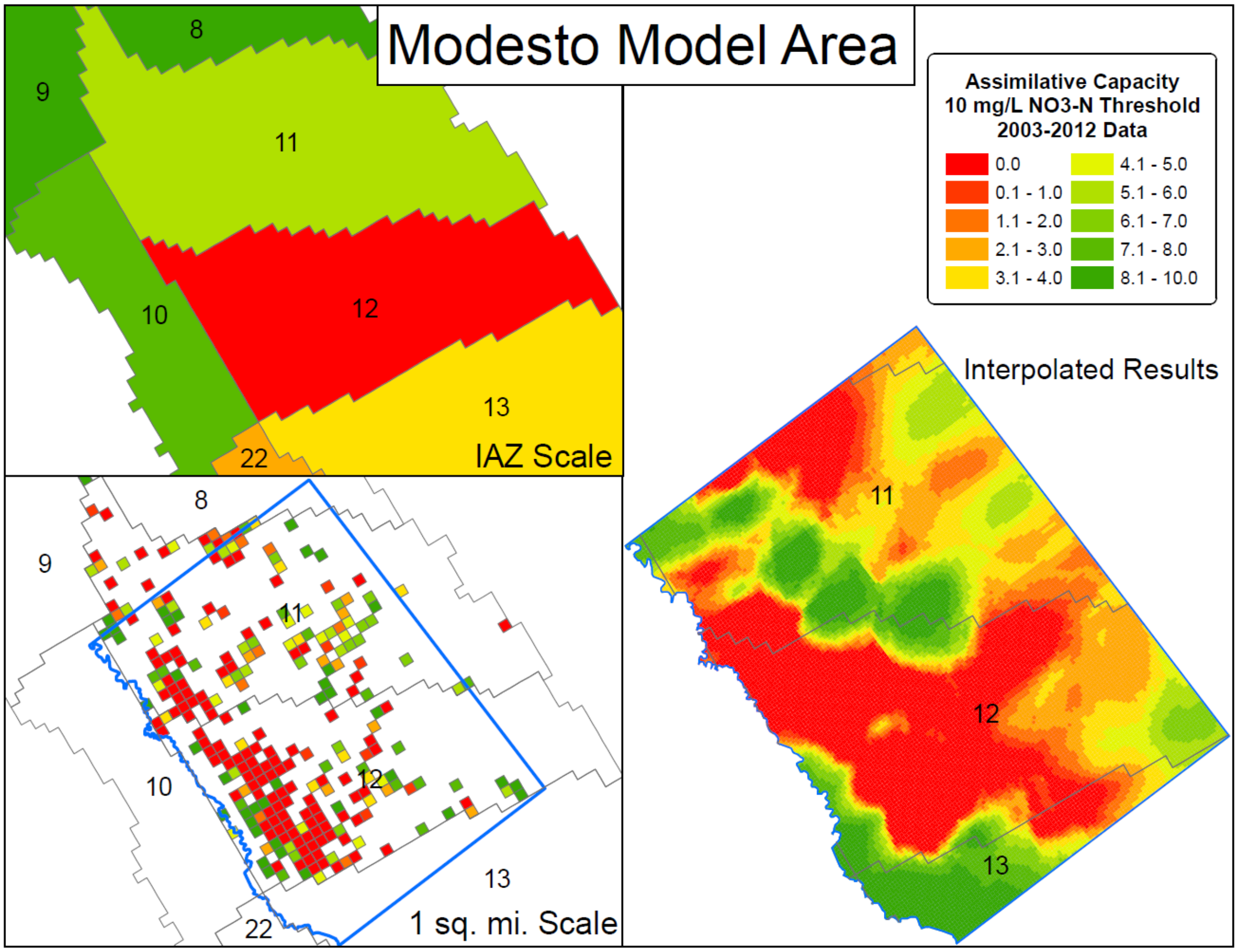


Figure 7-33. Refined Assimilative Capacity for TDS in the Modesto Model Area Based on a 500 mg/L TDS Threshold

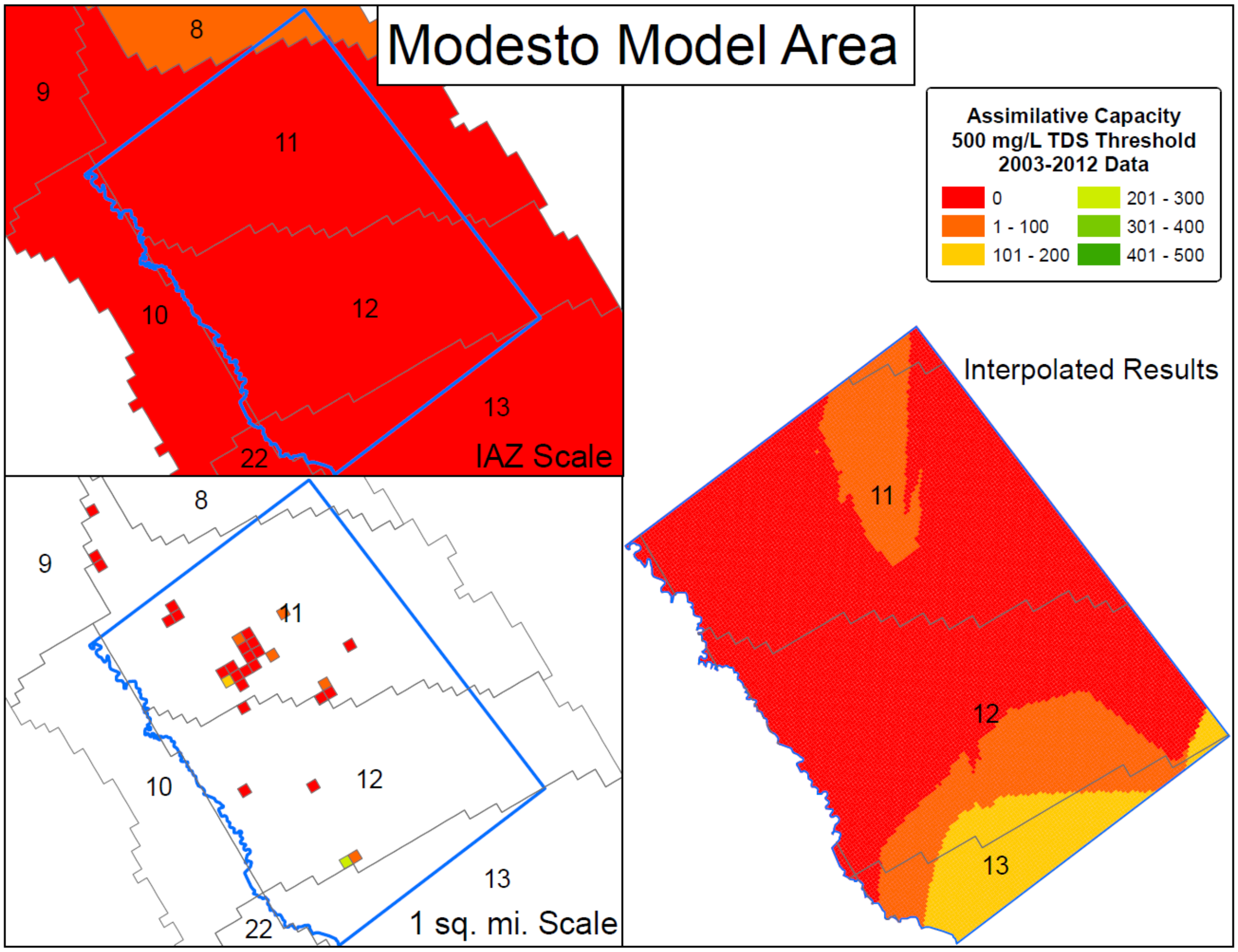


Figure 7-34. Refined Assimilative Capacity for TDS in the Modesto Model Area Based on a 700 mg/L TDS Threshold

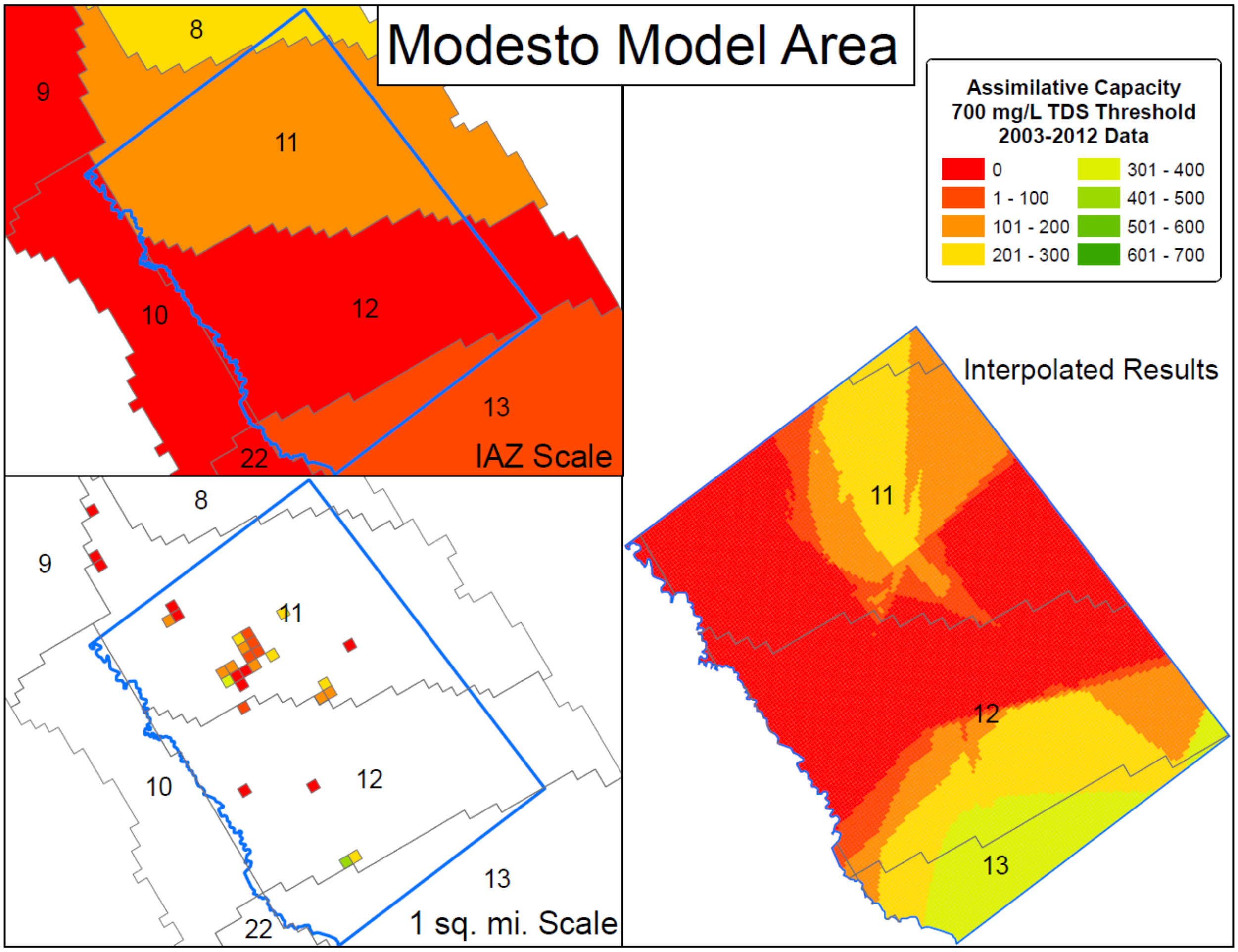


Figure 7-35. Refined Assimilative Capacity for TDS in the Modesto Model Area Based on a 1000 mg/L TDS Threshold

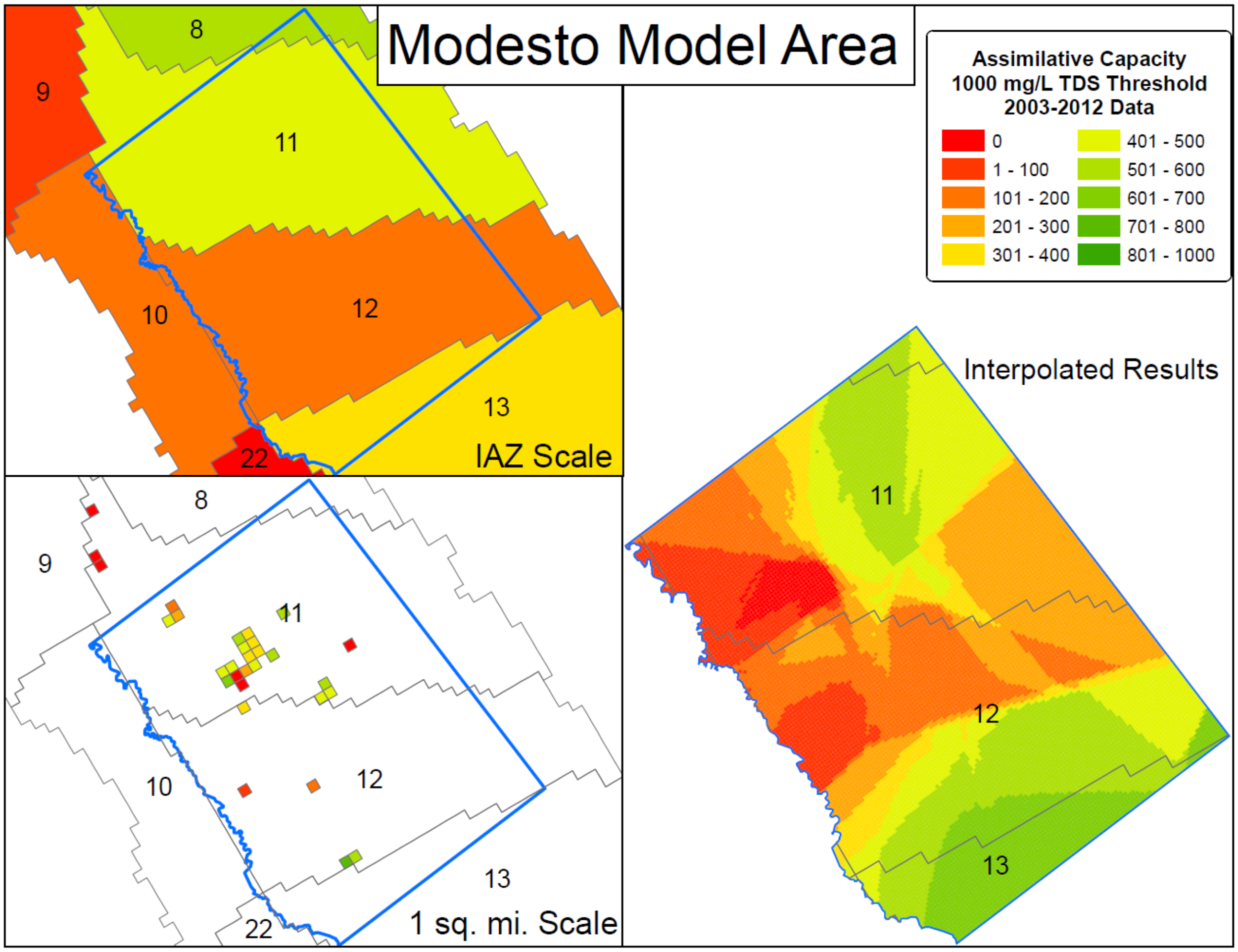


Figure 7-36. Refined Assimilative Capacity for Nitrate in the Kings Model Area Based on a 10 mg/L NO3-N Threshold

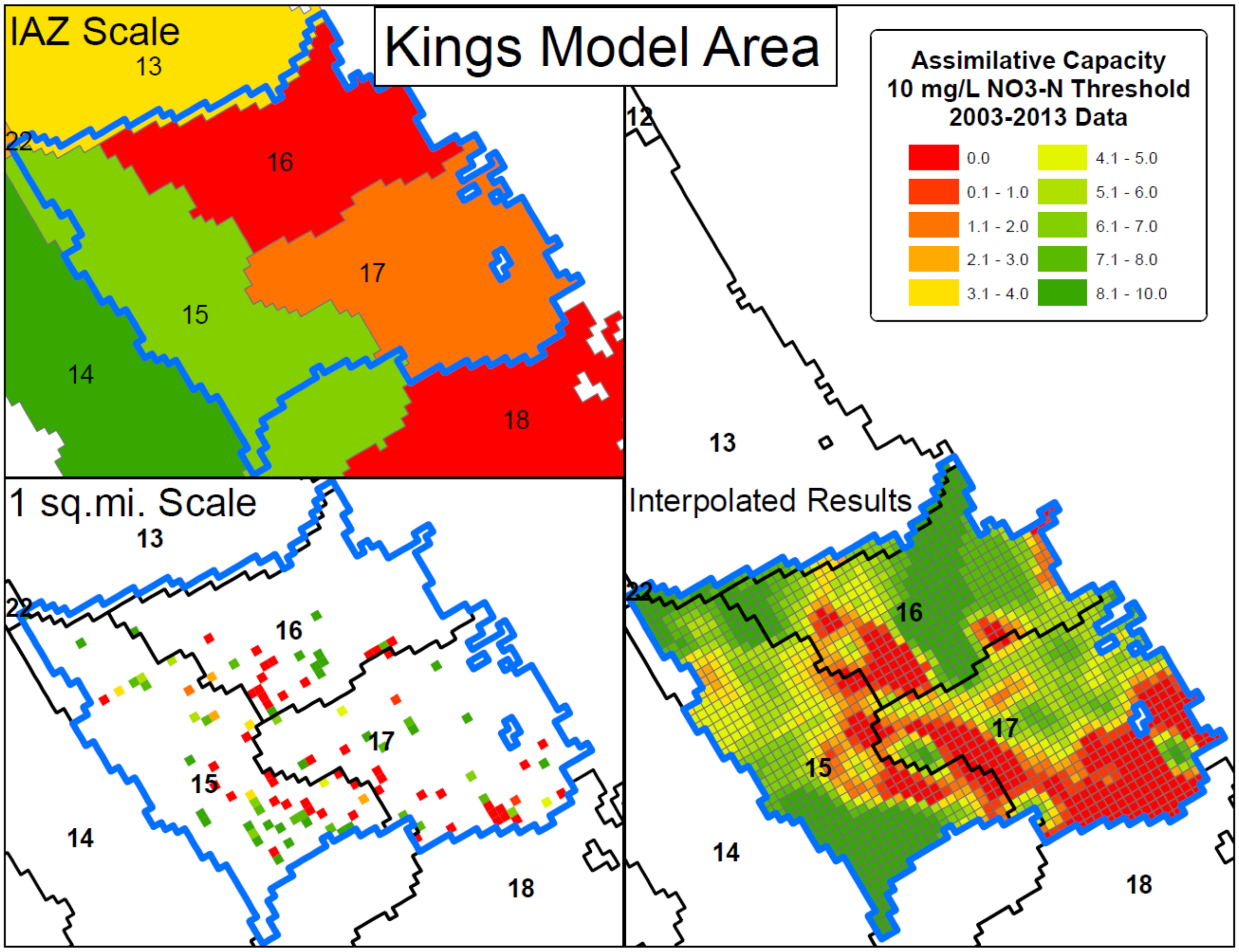


Figure 7-37. Refined Assimilative Capacity for TDS in the Modesto Model Area Based on a 500 mg/L TDS Threshold

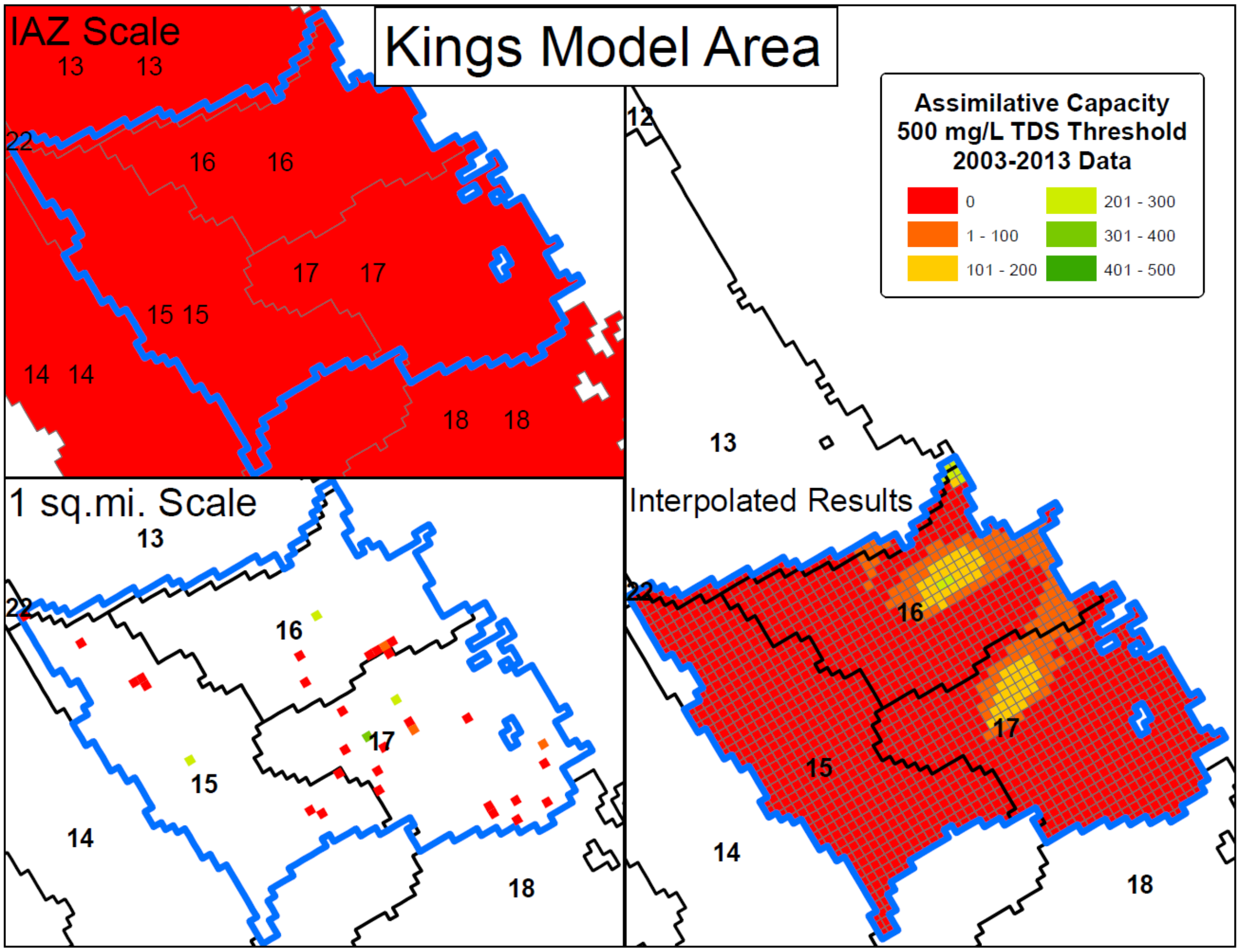


Figure 7-38. Refined Assimilative Capacity for TDS in the Modesto Model Area Based on a 700 mg/L TDS Threshold

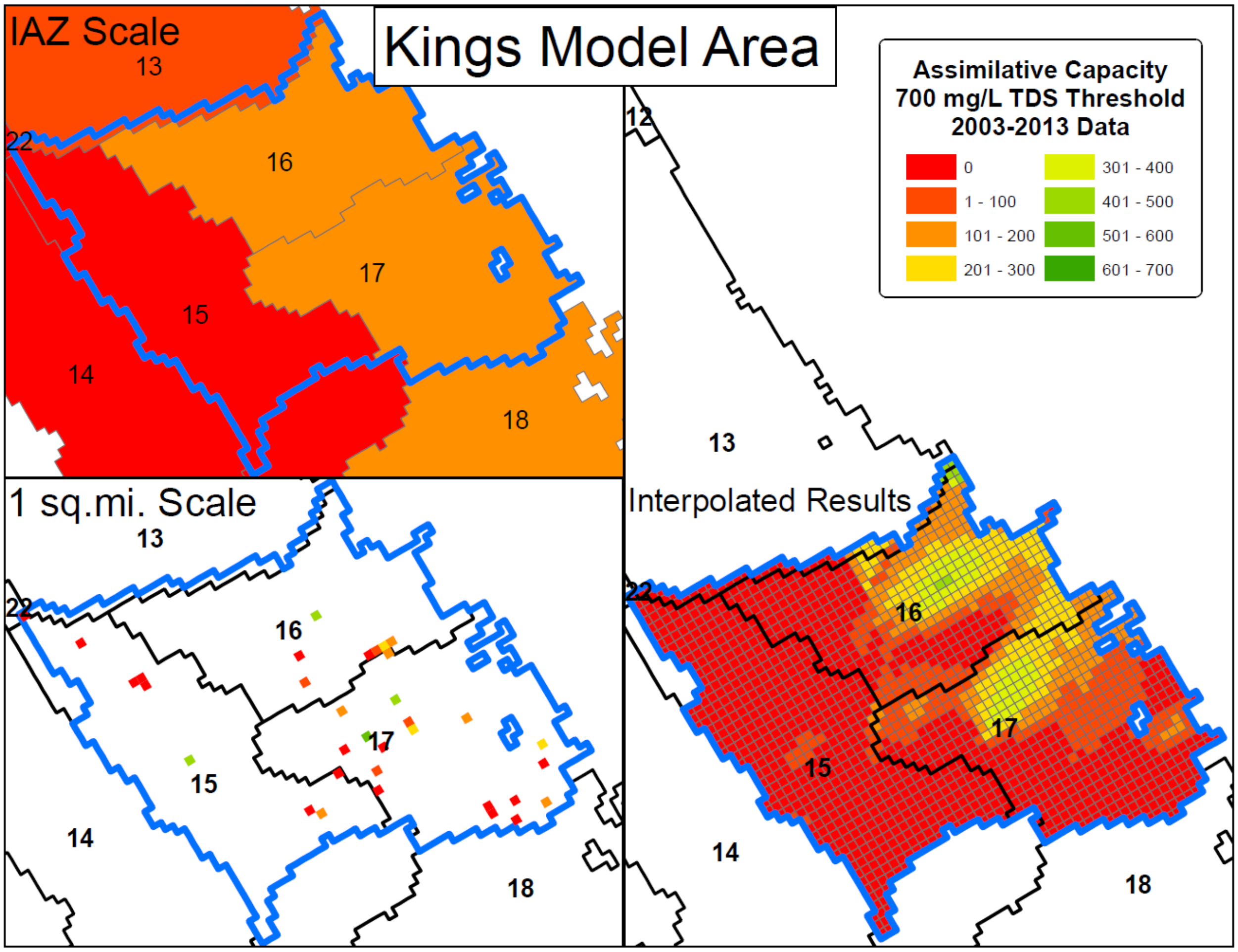
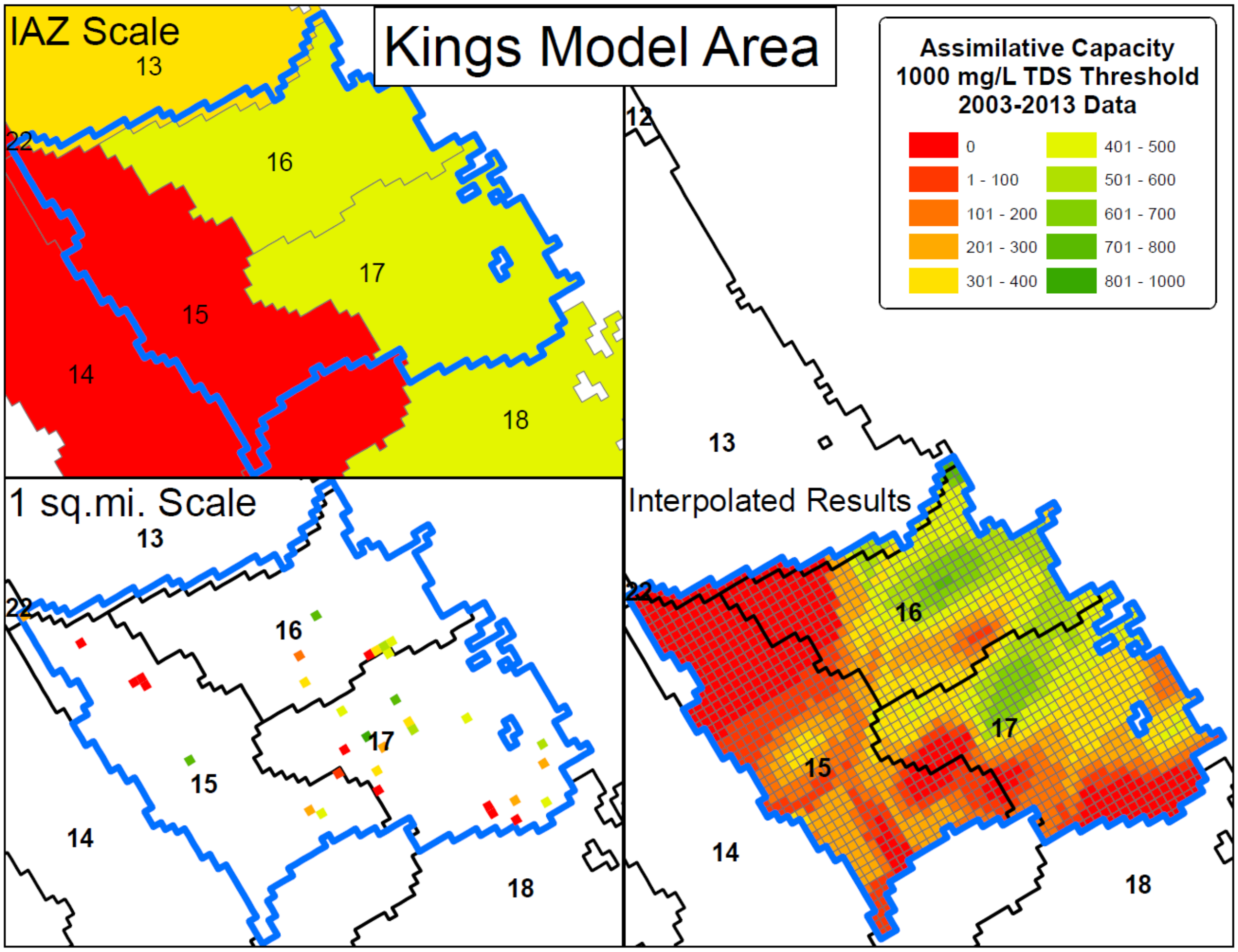


Figure 7-39. Refined Assimilative Capacity for TDS in the Modesto Model Area Based on a 1000 mg/L TDS Threshold



7.7 SUMMARY

Considerable variability exists in shallow groundwater, both in time and space. The analyses presented at the IAZ scale are clearly not adequate to characterize the large regions, and certainly to do not provide sufficient detail to facilitate salt and nitrate management planning at a local scale. The analyses of the prototype areas demonstrate a need for more spatially resolved analyses for all the IAZs. IAZs that appear to have no assimilative capacity when analyzed over the entire region may indeed have areas within the IAZ with higher quality groundwater where there may be some level of assimilative capacity. Similarly, IAZs that appear to have a large assimilative capacity as a whole likely contain areas where shallow groundwater has less assimilative capacity at the local scale (e.g., localized hot spots for TDS or nitrate).

Any apparent trends indicated at the IAZ scale are highly subjective and biased due to the limited data that are available. In most IAZs, the addition of a few dozen well tests from new wells has the possibility to change an analysis significantly. In order to perform adequate salt and nutrient management at a practical (local) scale, datasets should be supplemented with additional data that may not be readily available from public databases. For regions where shallow groundwater data are lacking, local entities such as water quality coalitions, irrigation districts, and county health departments may have collected data that have never been reported to statewide databases. Section 10 provides additional discussion on future recommendations for refinement of the analyses presented in this report.

Surface Water Results

Sources of inflow for surface water include recharge from the land surface, precipitation, diversions, upward flow from shallow groundwater, and horizontal flow from adjacent aquifers. Sources of outflow include evapotranspiration, seepage from surface water, diversions, downward flow to shallow groundwater, and horizontal flow to adjacent aquifers.

Each IAZ was evaluated in terms of the monitoring data and the simulated results. Different situations within the ambient data were considered when combined with the simulation results. These include 1) areal location within the valley (east, west, north, south) 2) source location of ambient data, i.e., WARMF or monitored data 3) magnitude of constituent.

Surface water regulations restrict the levels that constituents may reach; 10 mg/L (nitrate as nitrogen) is the MCL for nitrate and 500 mg/L is the SMCL for TDS. **Figure 7-40** and **Figure 7-41** show representative examples of TDS and nitrate results as time series plots for various regions of the Central Valley. **Appendix G** shows graphs of the results for nitrate and TDS for each IAZ.

Salt (TDS)

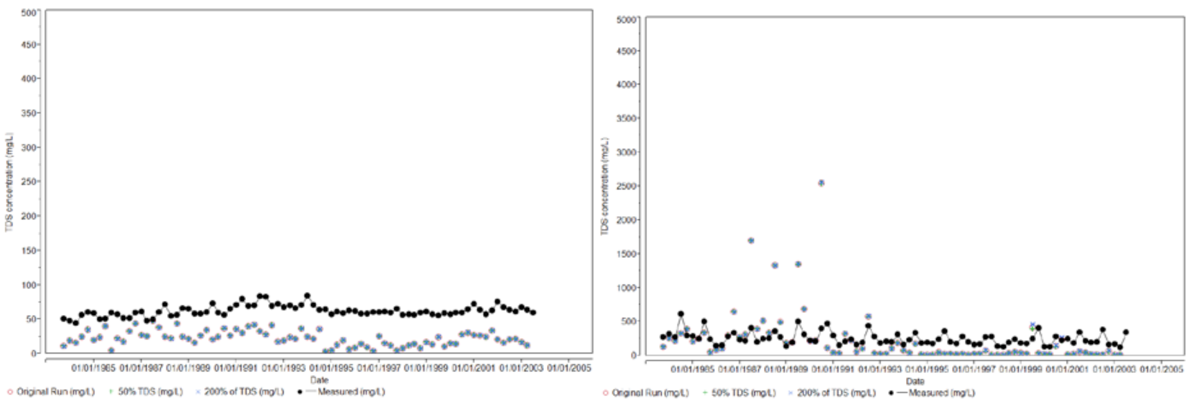


Figure 7-40. Representative Example of TDS Concentrations at IAZ 5 and IAZ 18

Nitrate (NO_3-N)

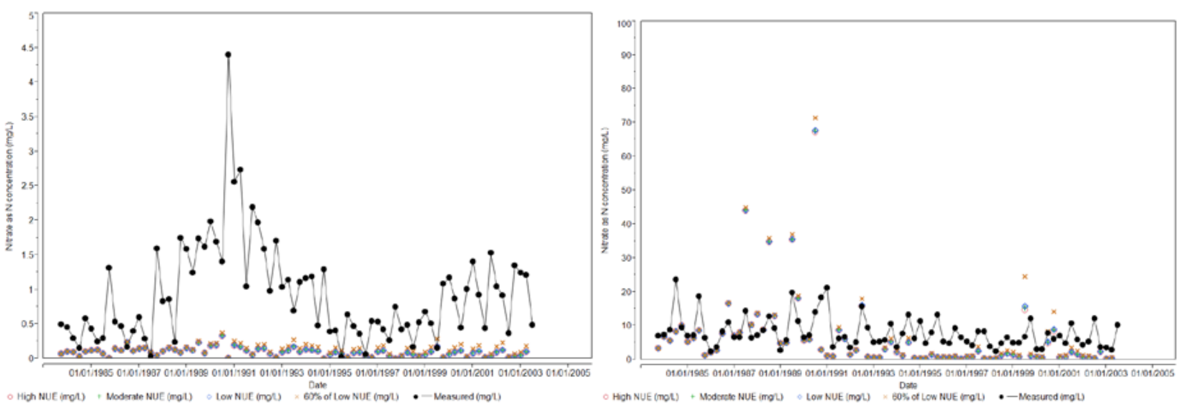


Figure 7-41. Example of Nitrate Concentrations at IAZ3 and IAZ 18

8. Uncertainty Analysis (or Sensitivity Analysis)

The objective of uncertainty analysis is to determine the effect of errors in ICM inputs and formulation on the results of the ICM. Sources of error include uncertainty of model inputs, errors introduced by the assumptions of WARMF and CVHM, and errors in the linkage of the two models. There are thousands of model inputs, but in most cases uncertainty in these inputs has little effect on the ICM results so they do not need to be included in a sensitivity analysis. Sensitivity analysis is an important tool to evaluate the effect of uncertainty in key model inputs. Errors in model representation of actual conditions are minimized by calibration but remain a significant source of error. The linkage between WARMF and CVHM creates a novel usage of both models, and the error introduced by this linkage is difficult to quantify but can be described.

8.1 KEY LIMITATIONS AND ASSUMPTIONS

WARMF Input Parameters

Guidelines for N fertilization are often provided as ranges of values. This is principally to account for variability among the fields and farmers where the guidelines are intended to be employed (Rosenstock, 2013). **Figure 8-1** shows the nitrogen rate guidelines for numerous California crop classes, shown as the size of the range of values given divided by the maximum N rate in the range (the maximum guideline value). Ranges for two crop classes (watermelon and prunes) had no minimum value, and are not shown. Data are from Rosenstock et al. (2013). Ranges of values are in all cases greater than 20% of the maximum guideline value, in excess of 40% for more than half the classes, and greater than 60% for a few classes. These data illustrate one source of uncertainty relative to WARMF input parameters.

Although WARMF is extremely detailed in the breakdown of land cover classes, in mapping of these classes to the individual field level, and in specifying irrigation, salt, and nitrogen loading and transport processes through time as influenced by actual climatic conditions, some variability within land cover classes is not captured. For example, when individual fields are farmed, growers may appropriately select quite different N loading rates for the same crop, as N uptake may vary significantly depending on the amount of crop produced. This is one among many possible examples of variability within land cover classes that would be challenging to characterize accurately based on available data. As a result, the most reasonable, modal conditions are those that characterize land cover classes in WARMF (and for that matter, in CVHM). While these simplifications would be extremely challenging to avoid in a large-scale study at the present time, they must be acknowledged as sources of uncertainty.

Figure 8-1. Nitrogen Rate Guidelines for Crop Classes in California, Shown as the Size of the Range of Values Given, Divided by the Maximum N Rate in the Range

WARMF Data Coverage and Areas without Coverage

Another acknowledged source of uncertainty is the lack of WARMF models for substantial areas of the Central Valley (IAZs 6 (part), 9, and 14-17, 18 (part), 19, and 21). This necessitates estimates and approximations to generate comparable mixing model inputs, based on WARMF results for nearby reference areas (see previous discussion). While this procedure is the best currently available, it lacks the rigor and analytical underpinning of an actual WARMF model run.

Land Cover Updates

Land cover consideration in CVHM is more general, in that the predominant land cover in each cell drives hydrology. The implications of this approach for hydrology are unknown. However, it would probably introduce substantial uncertainty were it applied to water quality parameters such as fertilization rates.

WARMF employs field-by-field land cover data (in agricultural areas), and datasets with comparable granularity for other areas. Parameters for each catchment are area-weighted averages that depend on the blend of land cover classes found within the catchment. This averaging also introduces some uncertainty, but unlike the CVHM approach, WARMF allows each class to influence the manner in which a catchment is represented, whether that class is predominant in the catchment or not.

Real land cover is dynamic, but data on land cover are less so. Both models employ DWR land cover data to represent most irrigated lands that comprise most of the Central Valley acreage. These areas are mapped approximately every 7 years, limiting the amount of resolution that is available. Models further simplify land cover change over time. WARMF uses recent land cover for its entire, 20-year analysis period, whereas CVHM shifts land cover each decade. Use of the most recent land cover is acceptable in that the goal of the analysis emphasizes a need to understand the influence of contemporary land and water management on salt and nitrate balances.

While irrigation method and soil variability can influence salt and nitrate load, fate, and transport, land cover schemes employed do not take these explicitly into account. WARMF has the capacity to consider varied soil conditions, but inputs do not reflect this variability. So, while the most important drivers of salt and nitrate load, fate, and transport *are* captured in land cover classes employed, secondary factors are not represented. This too is an acknowledged source of imprecision and uncertainty in the current work.

Actual land cover can evolve relatively quickly. For example, in parts of the San Joaquin Valley, large areas of cropland and non-cropland have been converted to permanent crops (e.g., almonds and grapes), largely under drip or microspray irrigation. These conversions may not be reflected in the most recent DWR data for a county, but are known and can be mapped through analysis of remote sensing data. These lands will likely remain in these land cover classes for a long period. Development of refined land cover mapping was beyond the scope of the current work. Nevertheless, future refinements of water, salt, and nitrate balances should update the representation of recently converted land cover classes, especially when changes are likely to have influence results.

Other Data Needs

As mentioned previously, loading of salt and nitrate are primary drivers in this type of analysis. Therefore, more accurate data regarding this loading will usually make the analysis more reliable. Specifically, it would be helpful to develop better data regarding the following:

- Actual applied water quality (surface and groundwater qualities applied to lands, and the proportions of each source employed for irrigation).
- Actual (organic and inorganic) fertilizer and amendments applied to each land cover class. The amount of N is the most critical parameter, but as analyses become more refined, it would become helpful to know field-specific rates, forms, and timing of application.

WARMF Model Error

The WARMF model is designed for simulation of surface water and near-surface groundwater in and just below the root zone. It is populated with data to the extent it is available, then the model is calibrated by adjusting coefficients not known with precision so simulated hydrology and water quality match measured data collected from rivers and lakes. Calibration statistics are available in the calibration reports for the various WARMF applications (Systech 2011a, Systech 2011b, LWA 2009). The model generally produces simulation results within the maximum error goals used to guide calibration, but there are specific known sources of modeling error beyond those typically used for calibration.

WARMF simulations of the central agricultural zone of the Sacramento River watershed produce too little surface agricultural drainage. This issue is believed to be caused by input applied water rates for rice which are too low but could not be corrected during previous uses of the Sacramento WARMF model. The second known WARMF simulation issue is in IAZ 13, which is part of the San Joaquin River WARMF application. This region is characterized by little surface water and infrequent hydrologic connection to the lower San Joaquin River. The WARMF model has not been fully developed for this region because it did not reflect the priorities of the prior applications of the WARMF model to the San Joaquin River. The model also has not been calibrated in this region, although there is little data with which to do so regardless. WARMF still simulates the soil processes and performs mass balances of inputs and outputs to generate mass fluxes for the mixing model. The incomplete representation of irrigation in IAZ 13 may underestimate salinity loading to groundwater recharge, with a lesser underestimate for nitrate. The Tule River WARMF application is fully developed but there is little calibration data to evaluate the model's accuracy.

8.2 WARMF/CVHM LINKAGE ISSUES

The linkage of two very different models is similarly a source of acknowledged uncertainty. CVHM hydrology was the early choice of CV-SALTS for the Initial Conceptual Model.

However, since CVHM contains no water quality component, this implied that water quality information would need to be drawn in from another source. WARMF models being available for much of the Central Valley, and without a comparable source of water quality model output, WARMF became the obvious choice. While this is the best available approach at this time, it would nevertheless be more ideal to perform these analyses with a single model capturing both hydrology and water quality in a manner acceptable to CV-SALTS. This would have the following advantages:

- No linkage model would need to be developed or run;
- Hydrology and water quality aspects of the analysis could be calibrated and more readily studied together; and
- Mismatches between flow and load components would be easier to avoid, and when they arose, to address.

Because WARMF bases its simulations on mass balance and inputs to the soil are approximately equal to outputs over the long term, the total mass outflux determined by WARMF can be expected to be unaffected by the reapportionment of outflows in the WARMF-CVHM linkage for conservative substances like TDS. The linkage introduces a potential source of error for nitrate, however. Denitrification occurs when dissolved oxygen drops to near zero. Nitrate is converted to nitrogen gas, which evades out of the soil. Denitrification occurs when there is ample organic carbon to consume oxygen and a long retention time so there is time for organic carbon decay to deplete all the oxygen. Since CVHM has much higher net outflow from the near-surface soil, primarily to groundwater recharge, the retention time would be shorter than under the hydrologic regime predicted by WARMF. If WARMF were run with CVHM hydrology, it likely would predict less denitrification and therefore higher nitrate concentrations.

The potential extent of this source of error can be seen in **Table 8-1** and **Table 8-2**, which identify nitrate source and sink fluxes. Denitrification is over half the total sinks in WARMF simulations of IAZs 18 and 20, so significantly less denitrification would be possible if WARMF had the same hydrology as CVHM. Denitrification is 21% of the sinks in IAZ 22 and over 10% in IAZ 7 and the rest of the San Joaquin River watershed, so slightly higher nitrate mass flux would be possible if WARMF were run with CVHM hydrology in these areas as well.

Table 8-1. WARMF Simulated Nitrate Mass Fluxes, IAZs 1-8 (all in kg N per day)

IAZ	1	2	3	4	5	6	7	8
Precipitation	314	490	551	372	804	298	402	764
Dry Deposition	216	407	654	429	802	400	485	1,134
Irrigation	2	3	94	29	13	3,356	46	2,544
Land Application	2,249	2,396	2,306	1,112	2,867	1,515	3,675	5,603
Point Sources	65	-	-	-	-	19	-	-
Nitrification	504	2,018	10,140	2,918	2,368	4,753	10,252	26,381
TOTAL SOURCES	3,350	5,313	13,745	4,860	6,854	10,341	14,861	36,426
Uptake	2,825	4,312	11,874	4,208	6,154	3,853	8,746	17,990
Denitrification	0	4	114	29	0	211	1,371	1,361
Runoff	340	412	533	383	455	123	1,543	1,519
Lateral Flow	84	60	681	22	97	209	368	107
Recharge	0	0	0	0	0	6,277	0	0
TOTAL SINKS	3,249	4,788	13,202	4,642	6,707	10,673	12,028	20,977

Table 8-2. WARMF Simulated Nitrate Mass Fluxes, IAZs 9-22

IAZ	10	11	12	13	18	20	22
Precipitation	75	234	205	730	183	19	236
Dry Deposition	199	649	611	2,052	950	92	981
Irrigation	3,743	1,822	4,723	640	18,781	653	10,712
Land Application	1,255	3,740	4,898	6,803	62,704	2,943	3,543
Point Sources	0	1,406	492	33	84	0	0
Nitrification	3,497	4,613	1,740	0	37,251	844	5,562
TOTAL SOURCES	8,769	12,463	12,669	10,257	119,952	4,551	21,033
Uptake	5,643	8,691	8,998	8,706	22,595	1,295	16,061
Denitrification	1,453	1,346	2,086	1,135	44,890	1,596	4,727
Runoff	248	151	741	245	1,353	141	761
Lateral Flow	631	163	198	94	15	2	303
Recharge	148	395	265	11	7,251	0	226
TOTAL SINKS	8,123	10,746	12,289	10,191	76,105	3,034	22,078

An error in the groundwater recharge flows used in the WARMF-CVHM model linkage was discovered too late to perform a correction[61]. Instead, this source of error is described here and in

[61] An intermediate value of groundwater recharge flow was used instead of the net farm recharge term.

Chapter 5 to improve the interpretation of the ICM results. In all IAZs, this error resulted in too much mass flux of salt and nitrate, in equal proportion, being apportioned to groundwater rather than runoff and leakage to stream. The estimated error is expressed as a percent in **Table 8-3.** However, the effects of this error are reduced especially in IAZs with gaining stream conditions where shallow groundwater is leaving the aquifer system via leakage to stream, so extra mass is removed.

Table 8-3. Estimated Excess Salt and Nitrate Mass Flux Load Apportioned to Recharge

IAZ	**1***	**2***	**3***	**4***	**5***	**6**	**7***	**8**
Error	27%	33%	17%	70%	12%	8%	11%	7%
IAZ	**10***	**11***	**12**	**13**	**18**	**20**	**22**	
Error	36%	18%	25%	8%	4%	4%	1%	

*IAZs with net gaining stream conditions

Sensitivity Analysis

Initial mixing model results were reviewed by the team. In some areas, trends matched observed shallow groundwater quality reasonably well. In others, trends appeared quite different. In evaluating sources of uncertainty that could lead to these mismatches, the team identified salt and nitrogen loading rates as predominant. The WARMF Peer Review Report (Keller 2000) reported that the simulations were generally moderately sensitive to land application rates, but WARMF flux output indicated that land application was generally the largest source of nitrate in Central Valley watersheds. A sensitivity analysis was implemented to assess the affect varying nitrate and salt land application rates.The general approach to the sensitivity analysis was to post-process mixing model inputs for each IAZ, adjusting them in proportion to alterations in fertilizer or salinity loading parameters. The nature of loading parameter alterations, and the manner in which they were translated into alternative sets of mixing model inputs, are described.

Nitrate Loading

Several of the land cover classes for which nitrogen application and uptake parameters were updated for this analysis had exceptionally high (>90%) nitrogen use efficiency (NUE = uptake/application mass of N). Several loading scenarios were thus produced:

- Low: This is the original set of inputs that were employed
- Medium: In this scenario, NUE was reduced to 70% for land cover classes in which NUE was > 80% for the Low scenario. An exception was the Perennial forages class (largely alfalfa), which was reduced from 95% to 90%
- High: In this scenario, NUE was reduced to 50% for land cover classes in which NUE was > 80% for the Low scenario. An exception was the Perennial forages class (largely alfalfa), which was reduced from 95% to 85%

- High 90: In this scenario, NUE of each land cover class was reduced to 90% of its level in the “High” scenario
- High 75: In this scenario, NUE of each land cover class was reduced to 75% of its level in the “High” scenario
- High 60: In this scenario, NUE of each land cover class was reduced to 60% of its level in the “High” scenario

The aggregate change in for each scenario loading was calculated based on the blend of land cover classes in each IAZ. Uptake was in all cases assumed to remain fixed across scenarios.

Detailed N balances were developed from WARMF output for each IAZ, for the Low scenario (which was analyzed in WARMF) (**Table 8-1** and **Table 8-2**). Results for reference WARMF areas were employed for areas without WARMF analyses. The balances were then adjusted to account for the greater input levels in each of the other five scenarios. In this way, WARMF outputs were estimated without re-running WARMF for each scenario. These outputs were employed to scale mixing model inputs that also reflected each scenario.

Nitrogen balances are shown in **Table 8-4**, containing the following terms:

Table 8-4. Nitrogen Balance Components

Component	Nitrate	Ammonia
Sources	Precipitation	Precipitation
	Dry Deposition	Dry Deposition
	Irrigation	Irrigation
	Land Application	Land Application
	Point Sources	Point Sources
	Nitrification	Reaction Product
Sinks	Uptake	Uptake
	Denitrification	Reaction Decay
	Runoff	Runoff
	Lateral Flow	Lateral Flow
	Recharge	Recharge

Salinity Loading

Sensitivity to salinity loading was illustrated by altering salinity loads estimated for WARMF and non-WARMF areas in the original analysis (by methods previously discussed). The resulting three scenarios were as follows:

- High TDS: Double the originally estimated loads
- Moderate TDS: The originally estimated loads
- Low TDS: Half the originally estimated loads

8.3 SUMMARY AND RECOMMENDATIONS

Given the complex and varied nature of Central Valley lands and waters, uncertainty will need to be managed at some reasonable level. The key will be identification of factors whose refinement will generate the greatest benefit, given the goals of the particular phase or analysis. Information provided in previous sections should be helpful in this regard.

In future work phases, priority areas for reducing uncertainty should be identified and addressed. The approach taken here of bracketing uncertain factors by developing varied scenarios was instructive and may prove helpful in the future for factors that remain uncertain (such as variability in actual farming practices).

Factors that could be addressed mainly by providing time and budget to refine tools include the following, noting the timeframes needed to address each:

- Refinement of applied water quality estimates, especially for non-WARMF areas (short);
- Expansion of WARMF modeling throughout the study area (moderate);
- Developing a unified model to handle hydrology and water quality, retaining the best aspects of the CVHM and WARMF models (long); and
- Incorporation of soils (short) and irrigation (moderate) factors into modeling.

Factors that might require non-technical, supporting processes include the following:

- Improvement of data on actual fertilizer and amendment application (long); and
- Development of more current land cover class data, especially for areas thought to be changing rapidly (moderate).

9. Analyses for Two Prototype Areas

Two prototype areas were selected by the CV-SALTS for further refinement. The Merced/Stanislaus County area and the Kings Subbasin were identified as areas of interest to develop templates for data analysis methods and modeling tools to characterize water, salt, and nitrate balances, including accumulation and depletion, on a more spatially refined level compared to the IAZ-scale for the ICM. The purpose of these analyses is to provide potential tools to be employed on a level more detailed than the IAZ level, in which management decisions may be based on.

The methodology for the prototype analysis is described in the Task 5 Methodology Report and summarized here. The prototype templates are to demonstrate methods to:

- Characterize the hydrology and hydrogeology of the prototype areas based on existing groundwater flow model platforms;
- Identify major sources and sinks of salt and nitrate, based on available data sets as developed from Task 3 and incorporated in the models used in Task 7;
- Identify zones of high, moderate, and low groundwater quality;
- Establish and quantify salt and nitrate transport patterns; and
- Preliminarily describe further data needs and/or recommend analyses relating to the concepts of assimilative capacity that will be conducted as part of the Phase II Draft SNMP.

The Stanislaus/Merced prototype area was based on a publicly available steady-state[62] regional USGS MODFLOW model created for the greater Modesto area (containing most of Stanislaus County and a portion of northern Merced County) (**Figure 9-1**). WARMF coverage exists in this area and so existing nitrate (as N) and TDS mass loadings are available on a catchment basis.

The Kings Subbasin overlays the greater Fresno area, where the publicly available transient[63] Central Valley-wide USGS CVHM MODFLOW model was selected for analysis. A subset of CVHM model cells was selected to represent the Kings Subbasin for this prototype analysis (**Figure 9-2**). There is no existing WARMF coverage for this area, so mass loadings were

[62] The term "steady-state" refers to inputs and outputs (including pumping, climatic conditions, and magnitude and direction of flow) remaining constant for the duration of the model. This can represent an average of a period of years' environmental conditions or one selected year of conditions. In the case of the Modesto Regional USGS Model, the model simulates a steady-state condition for water-year 2000 (Phillips et al., 2000).

[63] The term "transient" refers to the inputs and outputs changing for different stress periods in the MODFLOW model. The CVHM model is setup to have monthly stress periods over the period of time from April 1961 to September 2003. Inputs and outputs vary across these 510 stress periods representing 42.5 years of climatic and anthropogenic variability.

estimated using similar tactics as non-WARMF areas in the IAZ analysis except on a cell-by-cell basis, as described in later sections below.

The prototype analyses presented in this report have been developed as a “proof of concept” that is designed to demonstrate particular tools and techniques that can be applied to future work in local or regional areas. It is therefore not intended to be a final, calibrated, site-specific analysis of salt and nitrate for the Modesto regional area nor the Kings Subbasin. The prototype analysis is crafted around existing groundwater flow models (using the publicly available MODFLOW source code) and incorporates a new USGS module MODPATH-OBS (Hanson et al., 2013) to estimate salt and nitrate constituent concentrations. This module has been used internally by the USGS (not yet published) and provided to the LWA Team in a “beta testing” capacity in advance of its public release. The code advances the particle tracking capabilities of the existing MODPATH module, allowing chemical concentrations to be tracked with flow.

Two main tools were developed for the prototype areas. For the Modesto Regional Model area, a method to estimate the age and concentration of particles reaching particular observation locations was developed. For the Kings Subbasin, a method that tracks concentrations over time within each model cell was developed to observe the change in concentration in all cells. The two methodologies are different and answer different questions, but both are used to help identify and determine the movement of water, salt, and nitrate on a much finer scale compared to the IAZ approach.

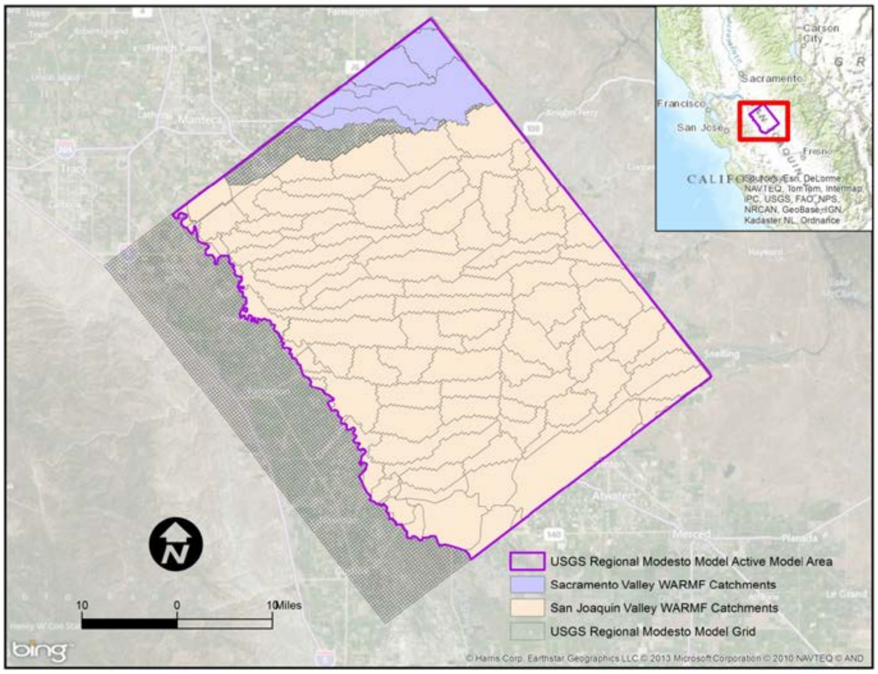


Figure 9-1. Stanislaus/Merced Subarea: USGS Modesto Regional Model and WARMF Catchments

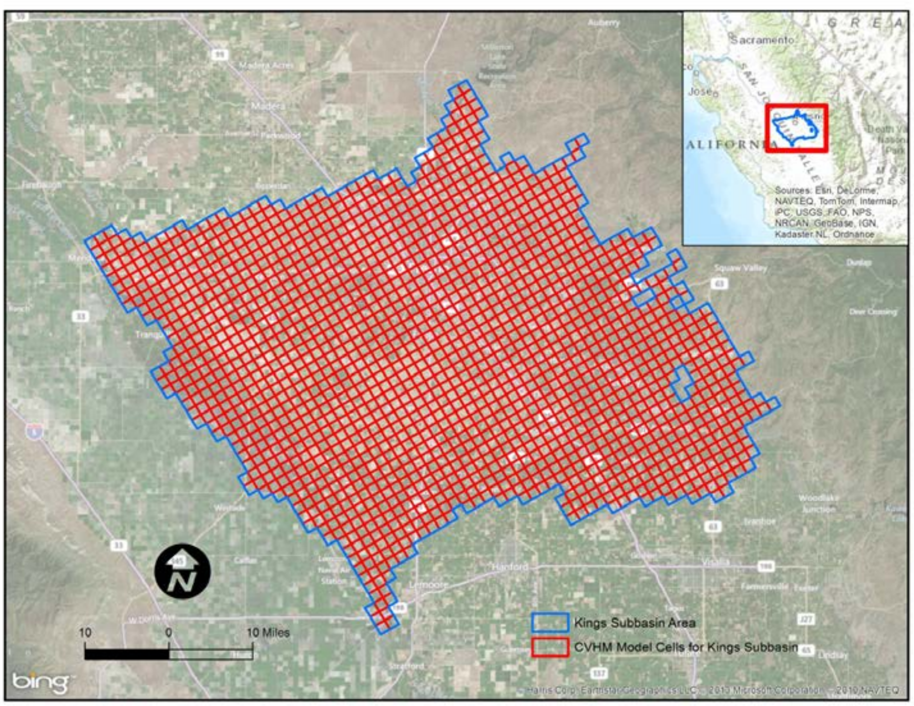


Figure 9-2. Kings Subbasin Subarea and CVHM Model Cells

9.1 MERCED/STANISLAUS AREA ANALYSIS

Three main techniques were developed for the Merced/Stanislaus area analysis incorporating the USGS Modesto Regional Model[64], WARMF, and groundwater quality data developed in earlier ICM tasks.

- The first technique involves determining groundwater recharge concentrations from mass loadings on a more refined level compared to the IAZ analysis.
- The second technique involves characterizing groundwater quality for salt and nitrate in order to identify hotspots in the Merced/Stanislaus area.
- The third technique is the development of a tool that simulates the concentration of observation wells based on recharge areas and historical groundwater recharge concentrations. This last technique utilizes the mass loadings from WARMF and converts the masses into concentrations of salt and nitrate to be associated with particles of water moving from the surface and water table down through the subsurface to enter a well. This technique may be useful for developing future management practices that consider the travel times and recharge areas of particular wells or areas of potentially vulnerable groundwater.

Modesto Regional Mass Loadings

Mass loadings developed from WARMF were compiled and assigned spatially to their underlying groundwater flow model cells using the location of each model cell centroid (**Figure 9-3**). This included nitrate and TDS mass associated with WARMF terms of groundwater recharge and 'leakage to stream'. In this area of the Central Valley, as seen in the IAZ analysis, streams are gaining, which means that for this analysis, the WARMF term of "leakage to stream" was added to the WARMF mass associated with groundwater recharge to achieve the total mass loading to groundwater (mass is conserved using this technique using the assumption that the portion of mass associated with the WARMF mass term of "leakage to stream" returns to the stream via stream leakage within the groundwater modeling platform). Another reason for combining the two WARMF mass terms is to be generous with the mass loading coming from WARMF data, as the mass associated with WARMF's groundwater recharge term is severely diminished and not supported by observations of concentration when converted to concentration.

WARMF is set up to calculate mass balances on a catchment basis. Each catchment has an irregular shape based on watershed delineation. In order to assign mass to groundwater model cells, the mass loading associated with each WARMF catchment was divided equally to the model cells underlying it. When catchments were only partially within the active model area, a

[64] A new transient version of the USGS Modesto area model is being completed for the Modesto Irrigation District by the USGS that uses the Farm Process (Randy Hanson, USGS, personal communication, August 2013).

spatially weighted average was applied to calculate the portion of mass associated with the area of catchment within the model. That portion of mass was then divided equally into the number of model centroids within the catchment.

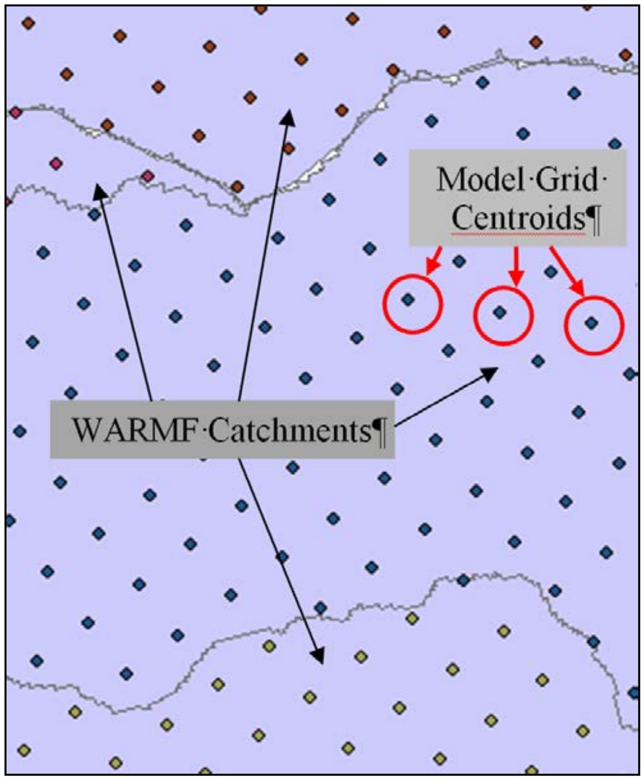


Figure 9-3. WARMF Catchment and Model Cell Centroid for Mass Loading Assignment

Once all of the active model cells have a mass associated with them, a concentration is calculated using the volume of recharge estimated by post-processing the groundwater flow model's cell-by-cell water budget output file. Recharge volumes calculated for each cell are used along with the assigned WARMF catchment portion of mass for each cell to calculate concentration using the formula: concentration = mass/volume. These recharge concentrations are shown below for nitrate (as N) (**Figure 9-4**) and TDS (**Figure 9-5**). These two figures show the relatively low concentrations of recharge water quality, as seen by the majority of the model area having a recharge concentration of less than 2.5 mg/L nitrate as N and zero TDS (0 mg/L) in the eastern portion of the Modesto model where irrigated agriculture exists and recharge concentrations would be expected to be greater than zero. As observed in the IAZ analysis, WARMF tends to underestimate the mass of nitrate in groundwater recharge, and therefore the calculated concentration of groundwater recharge quality will be unrealistically low. This prototype analysis does not attempt to address this imbalance.

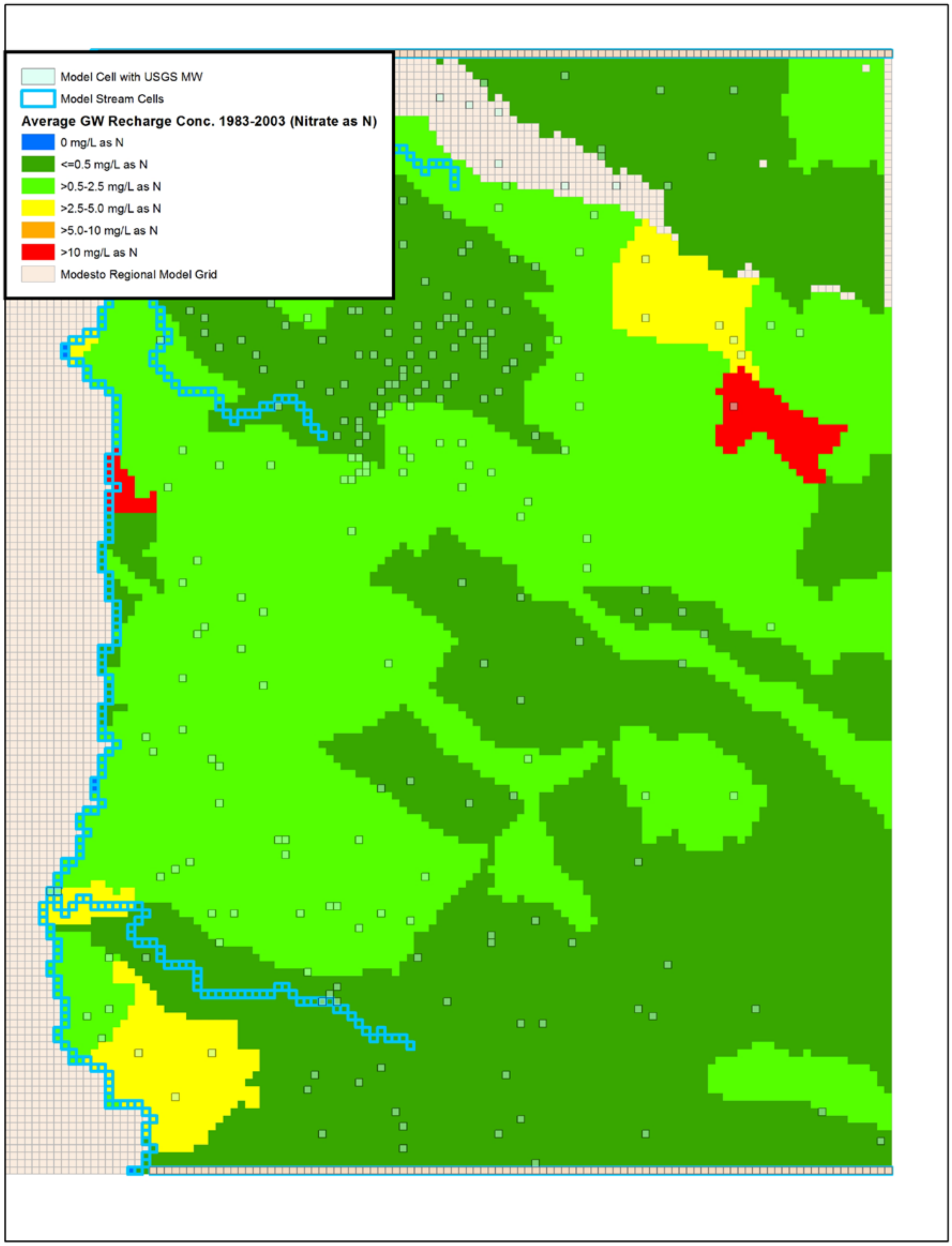


Figure 9-4. Average Groundwater Recharge Nitrate Concentration for the Modesto Regional Model Area (1983-2003, in mg/L as N)

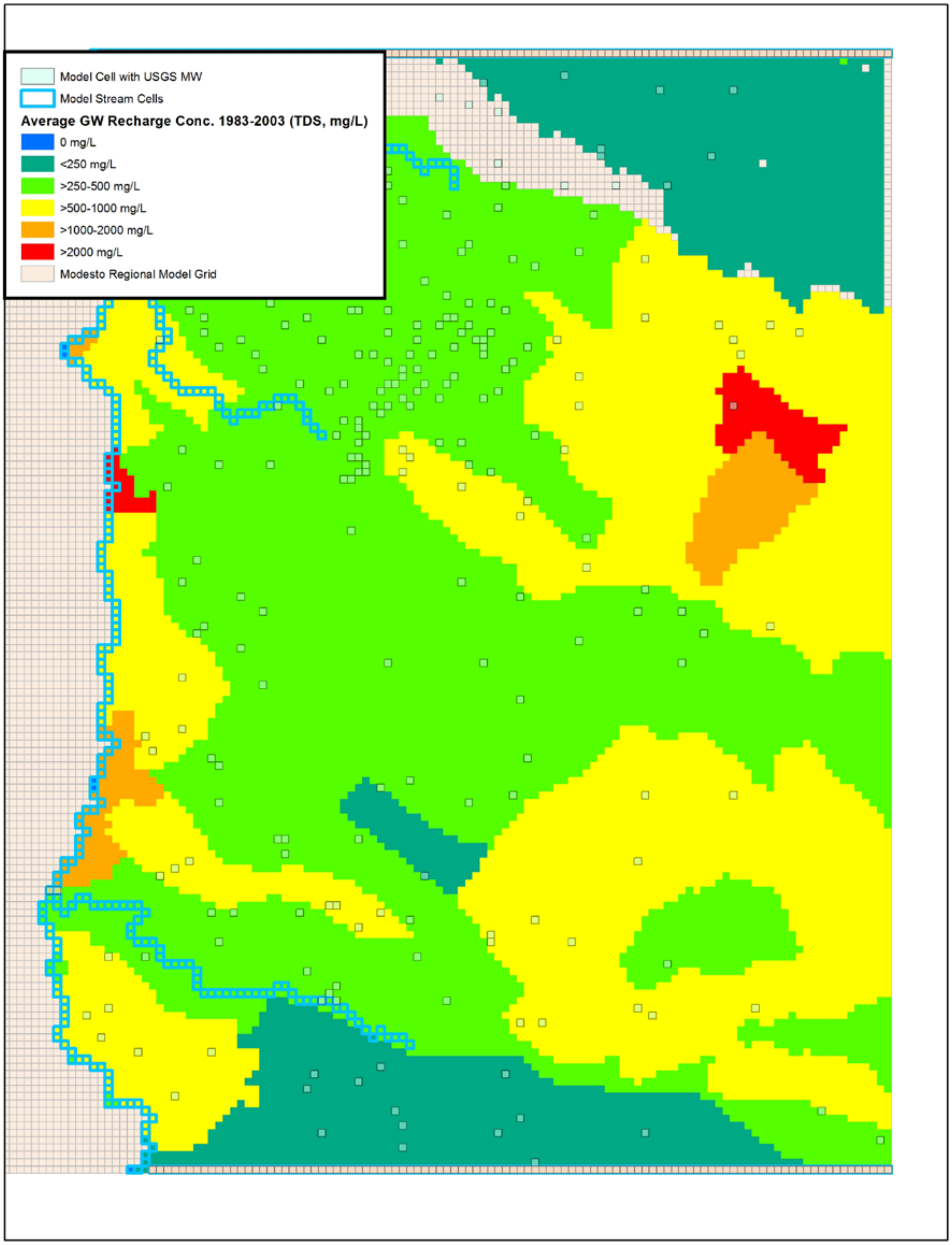


Figure 9-5. Average Groundwater Recharge TDS Concentration for the Modesto Regional Model Area (1983-2003, in mg/L)

Despite this limitation, concentrations of groundwater recharge are assigned to cells within each WARMF catchment. WARMF mass loadings were readily available for 1983 to 2003. Since groundwater takes more than 20 years to reach some observation wells, especially observation wells that are completed at great depths, assumptions were made to estimate the concentrations historically through time[65]. Current mass loadings from 1983 to 2003 were repeated into the future to see what effect the mass loadings have over time. Ideally, this step would be more thoroughly investigated to reduce uncertainty in historical mass loading, and future mass loadings would be applied based on expected future management practices.

Observation wells were selected for this prototype methodology example that had reported well depth (**Figure 9-6**). These 322 wells represent a subset of the wells originating from the USGS NWIS dataset from Task 3. 58 wells are multiple completion monitoring wells meaning that at the same location (16 locations) there are wells completed in different depths of the subsurface. Well depths ranged from 5 feet to 675 feet below ground surface, with most wells between 100 and 200 feet depths (**Figure 9-7**).

[65] To estimate historical groundwater recharge concentrations for salt, the main variable is irrigation: how much water is being applied and how much of that water is evaporating. According to WARMF simulations, unirrigated catchments in the vicinity (west side foothills) have TDS of about 500-550 mg/L in the lowest soil layer since those areas are relatively dry. There are no unirrigated catchments on the east side of the valley floor to make a more direct comparison. Irrigated catchments on the east side have a TDS in the bottom soil layer of about 1100 mg/L. Based on this, the TDS concentration multiplier for pre-1900 would be about 0.5.

The diversion dam for the Modesto and Turlock Irrigation Districts was built in 1893, and water has been diverted at current levels since about 1920. The concentration of salt from 1920 to present might be in large part a function of irrigation efficiency. Higher efficiency in recent years relates to higher concentration with less volume. The TDS concentration multiplier for 1900-1920 is estimated to be 0.6; for 1920-1960 the multiplier is estimated to be 0.8; for 1960-1983 the multiplier is estimated to be 0.9.

Estimating historical nitrate recharge concentrations is more difficult and has more uncertainty associated with it. Land application is the largest modern source, although irrigation from groundwater and atmospheric deposition are also important. Atmospheric deposition of nitrate has declined in the last 30 years, while it most likely gradually increased from pre-industrial values near zero to a peak in around 1980. Nitrate in unirrigated catchments (where atmospheric deposition would present the primary source) has a concentration of about 0.5 mg/L as N in the bottom WARMF soil layer. WARMF indicates that irrigated catchments on the east side of the Modesto area have lower concentrations than that. Based on these competing factors and ignoring changes in land application, it is estimated that the multiplier for nitrate for the Modesto area is 0.8 for pre-1920; 1 from 1920-1960; and 1.2 from 1960-1980.

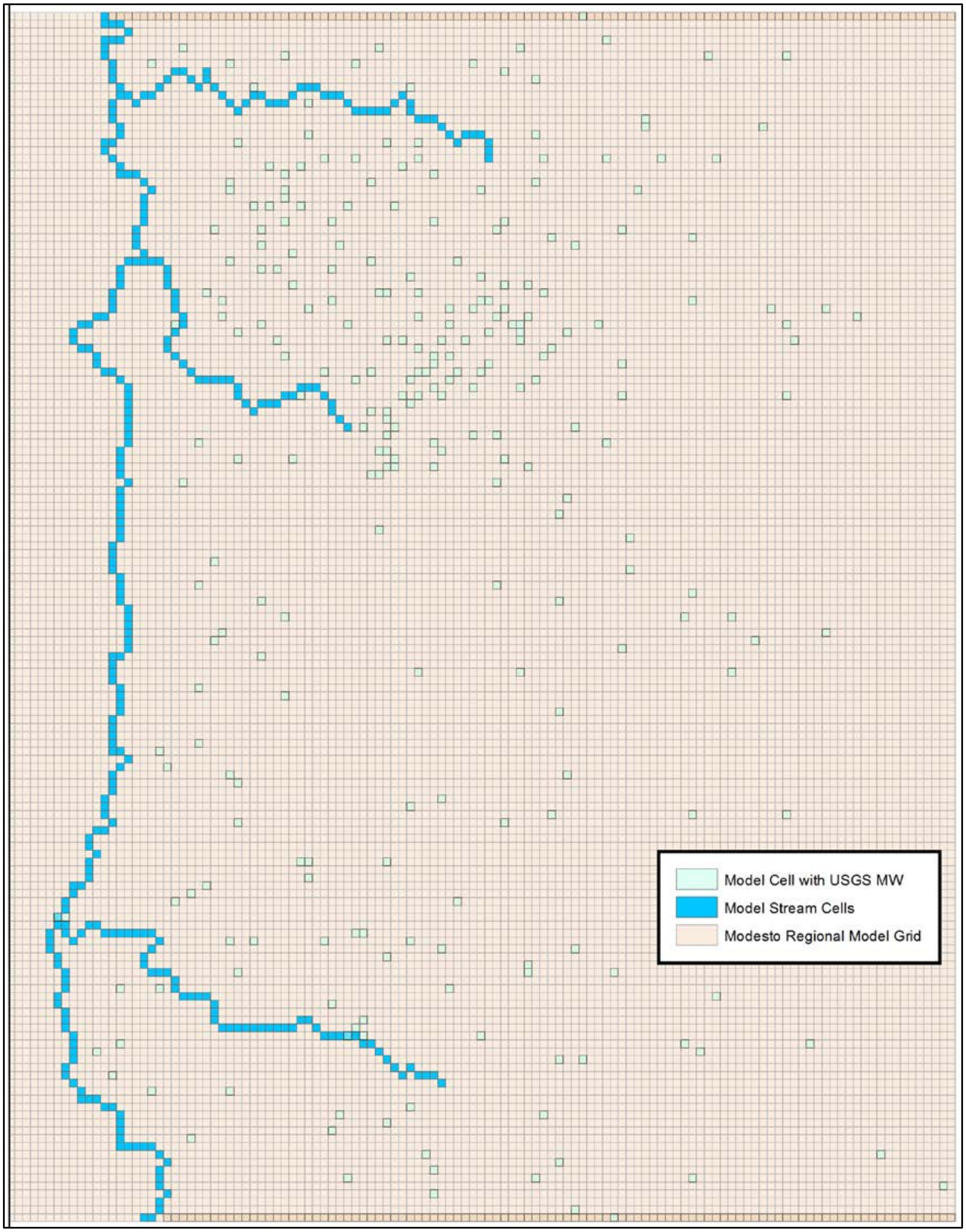


Figure 9-6. USGS Observation Well Locations used for Modesto Regional Prototype Analysis

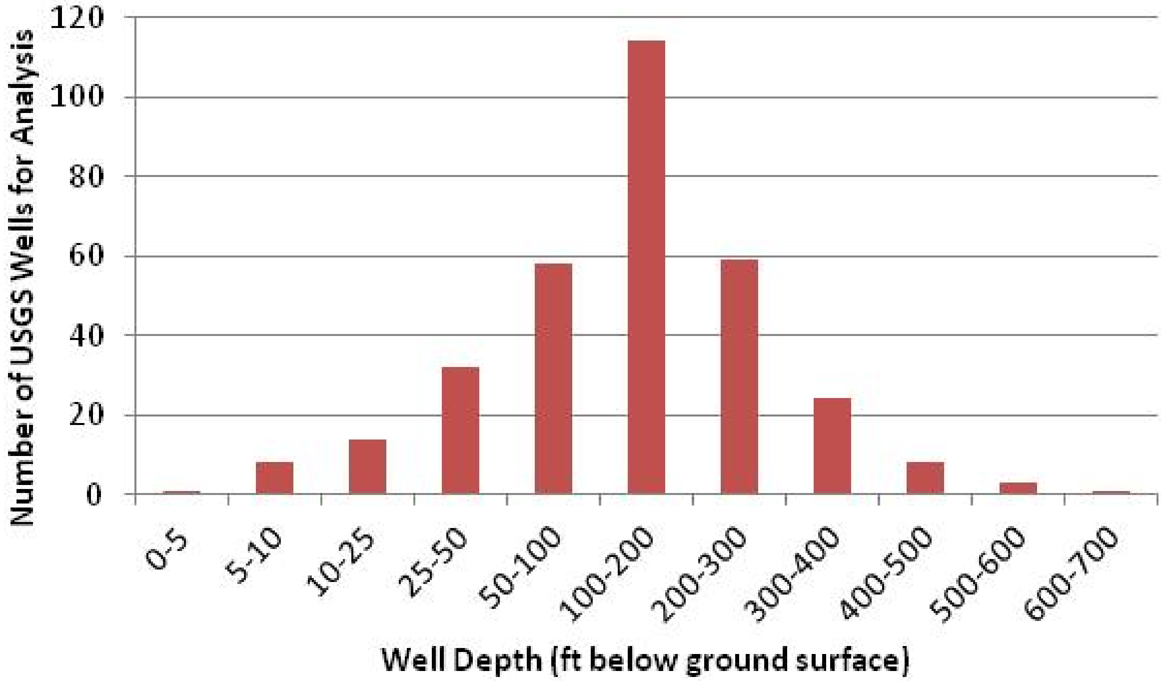


Figure 9-7. USGS Well Depth Histogram for Wells Used in Modesto Regional Prototype Analysis

Identify Zones of High, Low, and Moderate Groundwater Quality

For the Stanislaus/Merced and Kings Subbasin model areas, GIS mapping techniques are used to categorize zones where the groundwater is considered to be of high quality (low concentrations of salt and nitrate), low quality (high concentrations of salt and/or nitrate), and moderate quality. The mapping includes depiction of higher to lower quality in the relatively shallower part of the aquifer system and the relatively deeper part of the aquifer system, as available. The delineation of the relatively shallower part of the aquifer system is coordinated with the 20-year travel distance and vertical delineation of the IAZs.

Modesto Hot Spots

Two hot spots were identified for the Stanislaus/Merced model region, as shown in **Figure 9-8**. The hot spots were based on the density of CVHM grid cells that contained at least one well that had exceeded the MCL for nitrate in the 1980s and 1990s. Hot spot 1 is identified as an area that contained at least 15 red grid cells within a 5-mile radius, and hot spot 2 is identified as an area that contained between 10 and 14 red grid cells within a 5-mile radius.

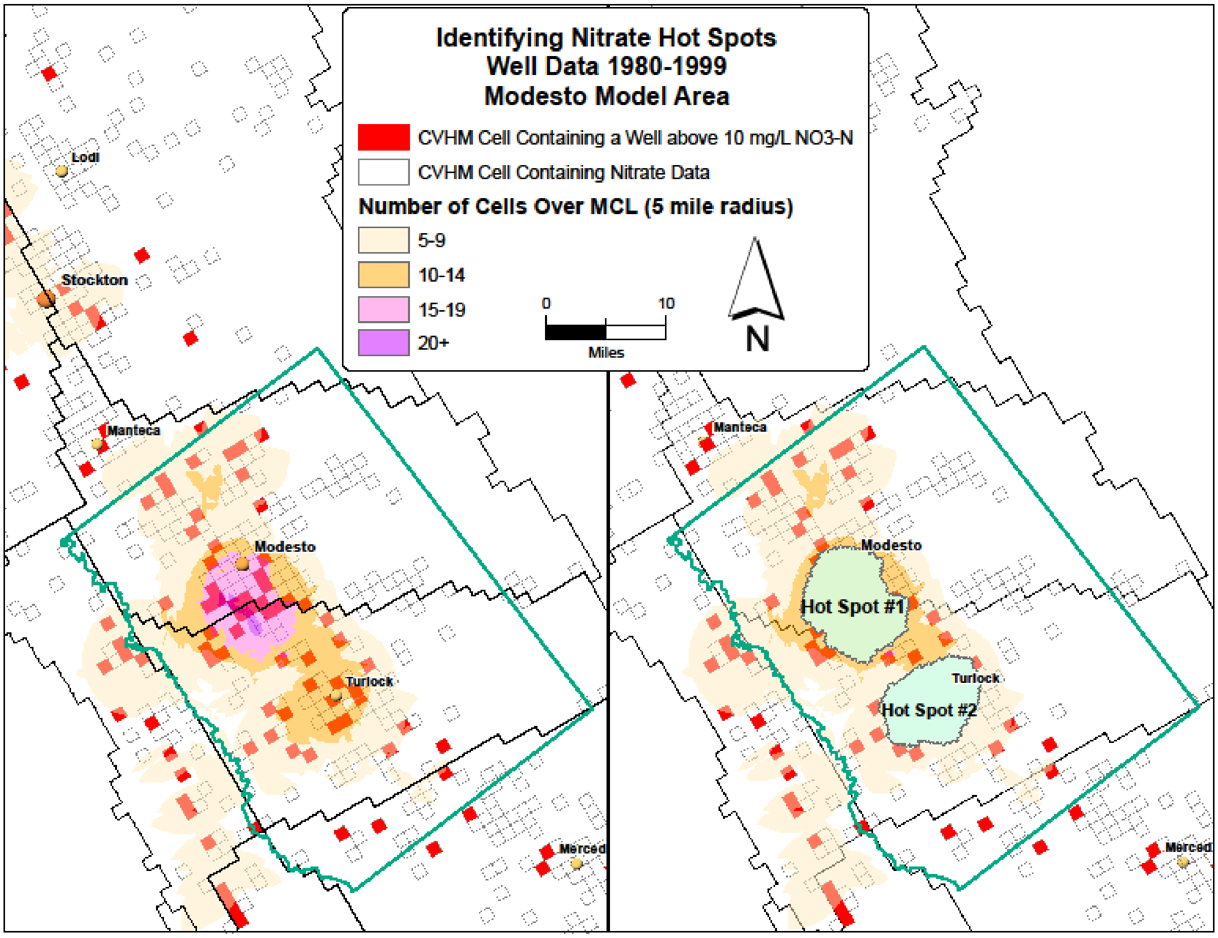


Figure 9-8. Identifying Nitrate Hot Spots, Modesto Model Area

Establish and Quantify Transport Patterns and Simulate Concentrations of Salt and Nitrate in Wells Over Time in the Modesto Regional Area

The first "proof of concept" tool for establishing and quantifying transport patterns involves simulating the concentration of groundwater in observation wells over time using estimated surface mass loadings. The methodology of this first example was implemented on the Modesto Regional USGS groundwater flow model. The advantage of using this model is its steady state construction. This means that one could simulate the movement of particles either forward or backward in time for an infinite amount of time. In order to estimate the concentrations of water quality in particular wells of interest, particles of water are sent backwards in time out from their well screen until they reach their appropriate simulated recharge area. The recharge area must have a value of recharge concentration for the time when the particle hits that surface.

No screened interval information was available, so it was assumed that the wells had 20-foot screens. 100 particles were placed in the assumed 20-foot screened interval for each well, and these particles were sent backwards in time to reach their termination point (or endpoint) at the water table where they were recharged. This process of assigning particle starting points associated with well screens and backward tracking these particles utilizes the MODPATH module, which runs independently of the existing completed MODFLOW model. MODPATH determines the travel time, path, and endpoints for each particle released from the well screen reaching the water table (**Figure 9-9**)[66]. For this demonstration of methodology, the particles were released every year between 1983 and 2023. The travel times for particles sent back from the well screen to the water table where they were recharged ranges from about two days to over 2,500 years (**Figure 9-10**). Many particles reached the surface at a simulated boundary condition such as a stream cell. In that case, the travel times associated with those particles is much greater (>10,000 years) but is not useful for the prototype analysis. The particle pathlines and travel times indicate that groundwater generally flows from the east to the west toward streams and the center of the Central Valley axis. Travel times are longer for particles at depth and are effected by aquifer parameters, including hydraulic conductivity and porosity (**Table 9-1**).

The travel distances for particles reaching their recharge surface (usually the water table) vary with depth and location based on modeled hydrogeologic aquifer parameters (**Table 9-1**). The particle pathlines are plotted based on the starting locations of each particle in the maps below (**Figure 9-11 - Figure 9-14**). The model grid in these maps are ¼ mile by ¼ mile, and these maps are helpful to show that the shallow particles (from observation wells completed in layers 1 through 6, for example in **Figure 9-11** and **Figure 9-12**) have relatively shorter lateral distances from their recharge area compared to deeper particles that travel a much longer lateral distance from their recharge area (**Figure 9-13** and **Figure 9-14**). This observation supports the notion that shallow wells are more susceptible to surface activities close by, whereas deeper wells are affected by surface activities at farther distances.

[66] Note, some pathlines appear to be thicker due to a greater density of pathlines occurring in some areas.

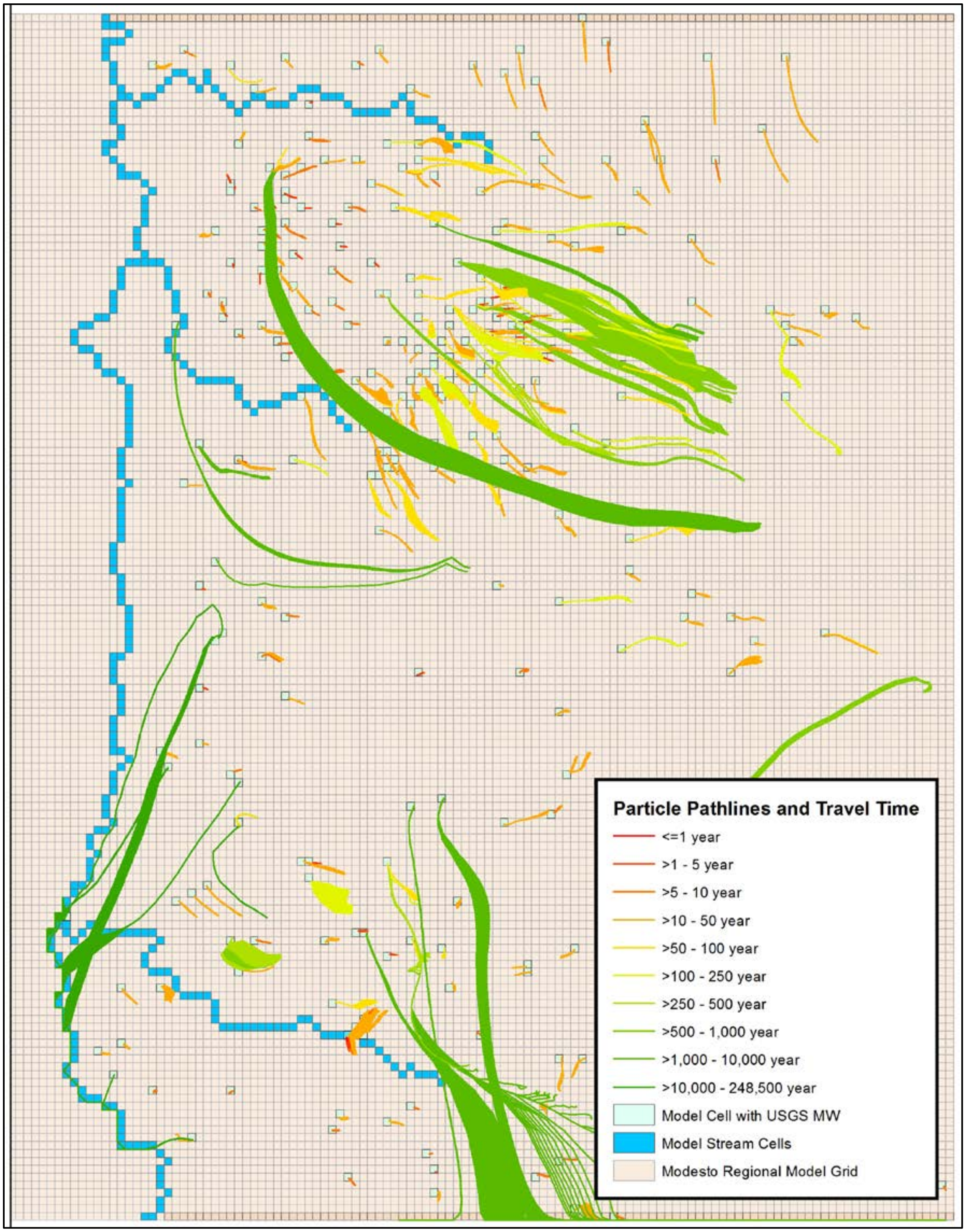


Figure 9-9. Modesto Regional Model Particle Pathlines and Travel Times for USGS Observation Wells

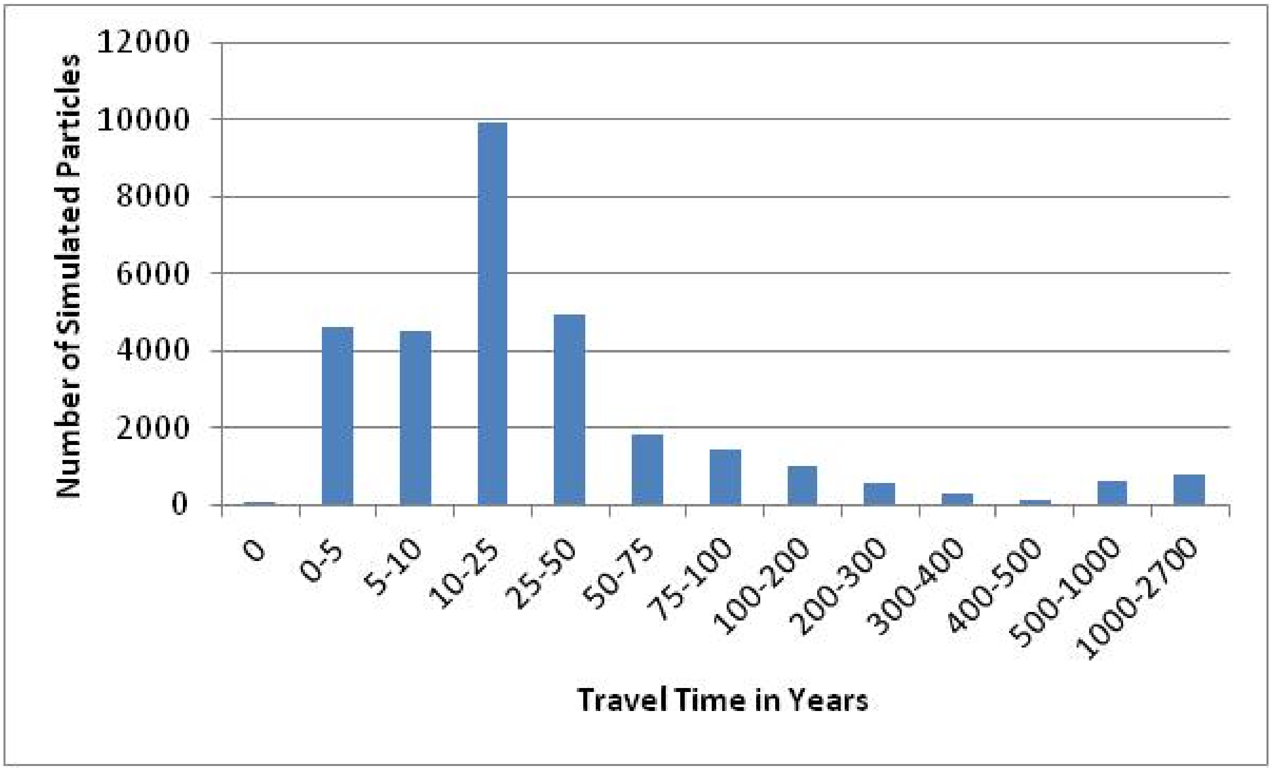


Figure 9-10. Histogram of Particle Travel Times Simulated in the Modesto Regional Prototype Area

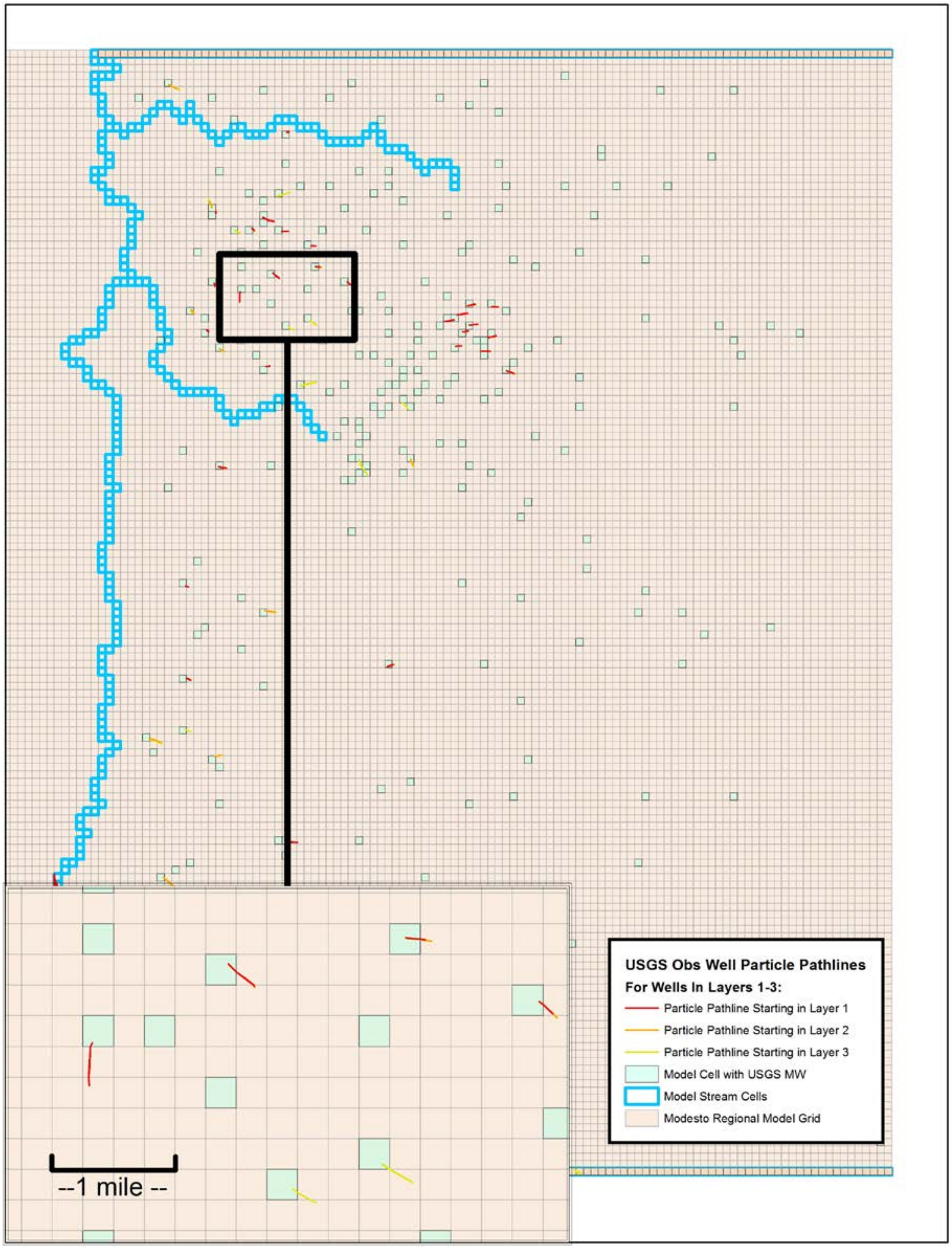


Figure 9-11. Particle Pathlines for Observation Wells in Layers 1-3 (Pathlines Correspond to 100 Particles from Each Cell)

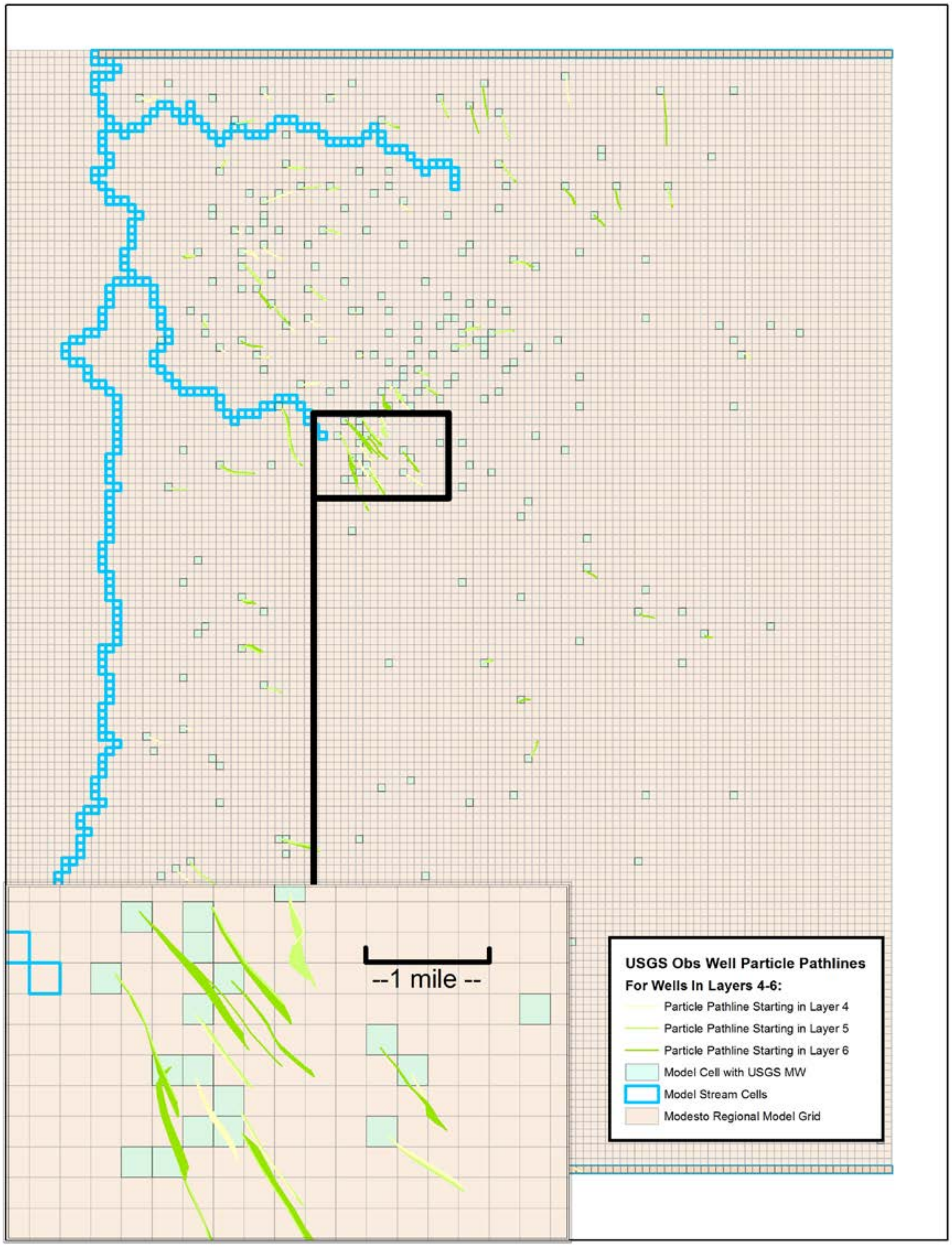


Figure 9-12. Particle Pathlines for Observation Wells in Layers 4-6 (Pathlines Correspond to 100 Particles from Each Cell)

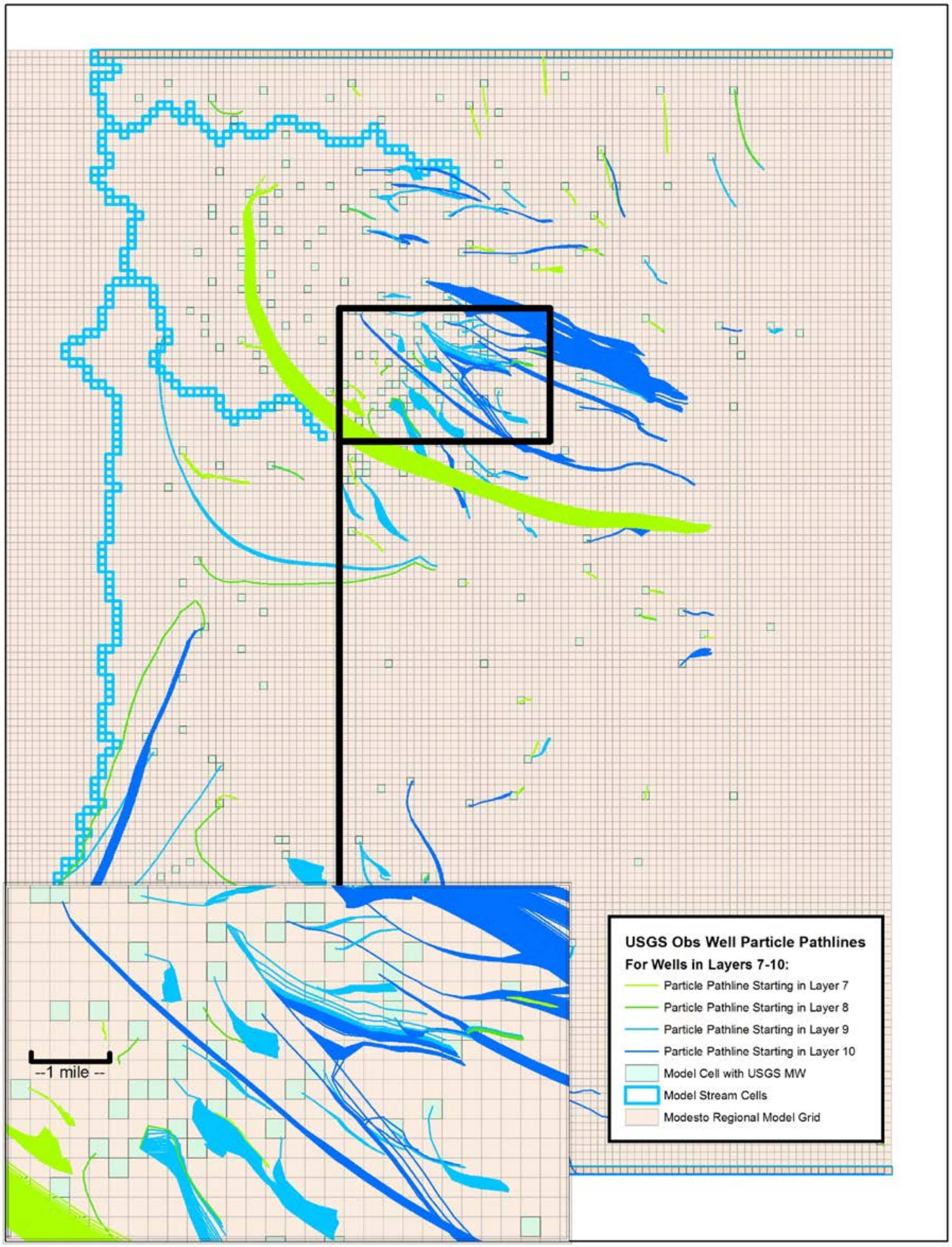


Figure 9-13. Particle Pathlines for Observation Wells in Layers 7-10 (Pathlines Correspond to 100 Particles from Each Cell)

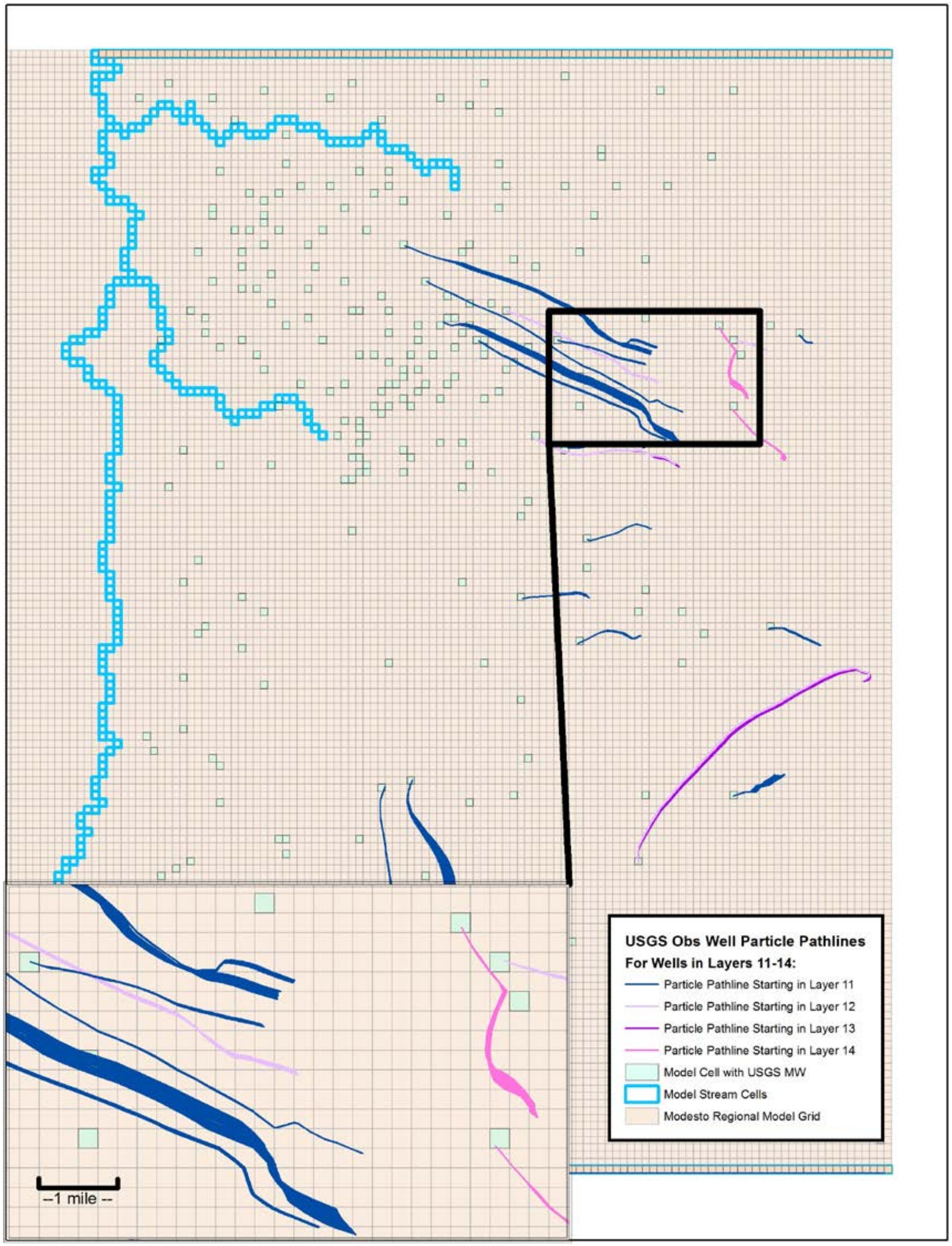


Figure 9-14. Particle Pathlines for Observation Wells in Layers 11-14 (Pathlines Correspond to 100 Particles from Each Cell)

Table 9-1. USGS Modesto Regional Model Layering and Travel Time Associated with Observation Wells

Layer of Particle Origination	Average Particle Travel Time (Years)	Minimum Particle Travel Time (Years)	Maximum Particle Travel Time (Years)
1	3	0	29
2	7	2	27
3	9	3	31
4	12	5	42
5	15	7	44
6	20	8	66
7	69	8	1983
8 (Corcoran Clay where exists)	184	8	1527
9	88	12	1675
10	257	28	2683
11	669	41	2880
12	275	50	634
13	504	230	636
14	197	145	251

MODPATH-OBS connects concentrations to each particle based on the concentration history of the recharge area location[67] (Hanson et al., 2013). MODPATH-OBS uses the concentration history inputs developed from the historical recharge and repeated current recharge mass loading concentrations for each catchment and uses the travel time of each particle to assign a concentration value to each particle. MODPATH-OBS takes an average concentration of all of the particles in each of the observation wells for the years identified.

A comparison between simulated concentrations and measured concentrations is a good way to test that the recharge concentrations are appropriate. In this example, the simulated recharge concentrations for nitrate are low compared to measured data (**Figure 9-15**), which is due to the low concentrations of groundwater recharge for nitrate in the model area. To fix this, the concentration of nitrate in groundwater recharge should be increased. The TDS simulated concentrations compare better to the measured TDS concentrations in the USGS observation

[67] For example, if a particle is sent backward in time from 1995, and it takes 50 years for that particle to reach the water table, the recharge concentration associated with 1945 is assigned to that particle. The other particles associated with the same well sent backward from 1995 get assigned recharge concentrations based on their travel times and historic recharge concentration. An average concentration of all of the particles in the well is calculated for 1995.

wells (**Figure 9-16**). **Appendix H** contains plots for nitrate and TDS only in wells where the results matched relatively well: for nitrate, plots are included in the appendix only for wells where the simulated nitrate concentration was within 50% of the measured or actual nitrate concentration; for TDS, plots are included for wells where the simulated TDS concentration was within 10% of the measured or actual TDS concentration. This filtering results in the reduction from over 300 wells with data to only 13 wells that qualify for nitrate data and 11 wells that qualify for TDS.

The methodology described above can be used to estimate the effects of mass loading over time and relate it to concentrations in observation wells. Observation wells do not have to be monitoring wells, but could represent domestic, irrigation, and public supply wells, or a general vicinity of proposed supply wells for future development.

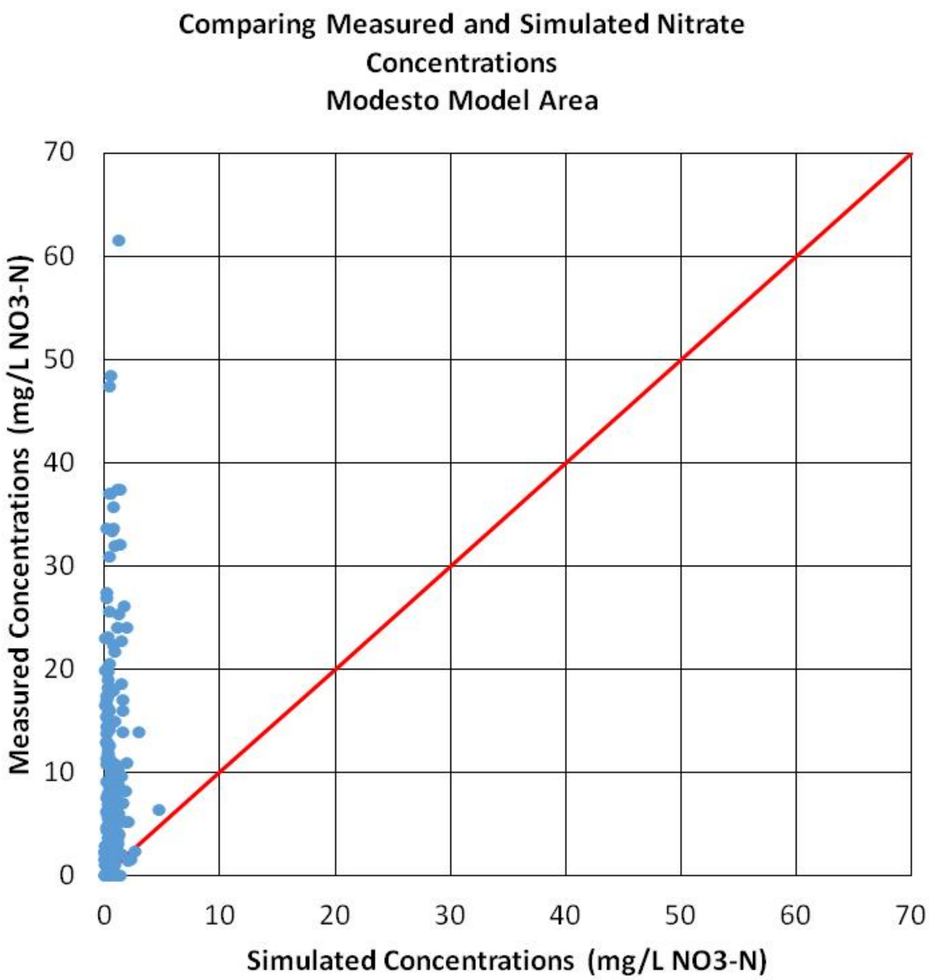


Figure 9-15. Simulated and Measured Nitrate as N Concentrations in USGS Observation Wells

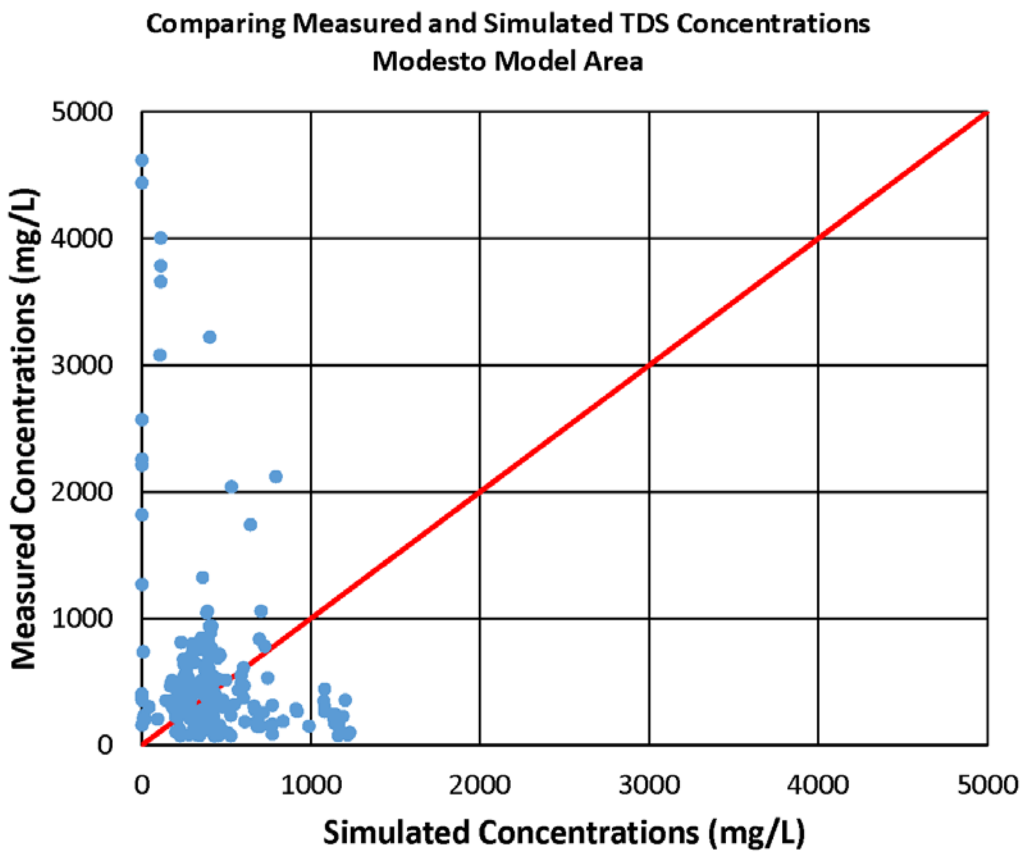


Figure 9-16. Simulated and Measured TDS Concentrations in USGS Observation Wells

Further Data Needs and Recommended Analyses

The uncertainty of recharge concentrations is an inherent limitation in the Modesto Regional analysis. WARMF mass loadings paired with USGS flow model recharge volumes results in an inability to determine assimilative capacity. This is due to WARMF's imbalance of groundwater recharge mass and lack of time in this "proof of concept" timeframe to resolve this deficiency. It is noteworthy, however, that WARMF provides "better" TDS mass loadings compared to nitrate.

9.2 KINGS SUBBASIN ANALYSIS

The Kings Subbasin analysis utilized three main techniques to assess the movement of water, salt, and nitrate. The first technique involves estimating mass loadings on a more refined cell-by-cell basis, using the CVHM cell grid of 1 square mile as the unit for analysis instead of the catchment scale used above for Modesto, or the bulk IAZ scale for the water, salt, and nitrate balance calculations described in previous sections of this report. The second technique involves determining ambient groundwater quality on a more refined scale compared to the IAZ scale, including more vertical definition to identify zones of high, low, and moderate groundwater quality for nitrate and TDS. The third and final technique combines the first and second techniques and establishes and quantifies transport patterns and simulates concentrations of salt and nitrate for a 20-year time period on a cell-by-cell basis.

Kings Subbasin Mass Loadings

No WARMF analysis exists for the Kings Subbasin (**Figure 9-17**), other than a sliver along the northern edge. Thus, an approach analogous to that employed for non-WARMF areas in Task 6 was needed to provide water quality inputs to the more detailed modeling of groundwater quality in this area. The greater spatial resolution of these inputs (1,656 cells in an area made up of parts of four IAZ's (**Figure 9-17**), or more than 500 fold spatial resolution; see **Figure 9-18**) requires that inputs be generated at a much greater level of detail.

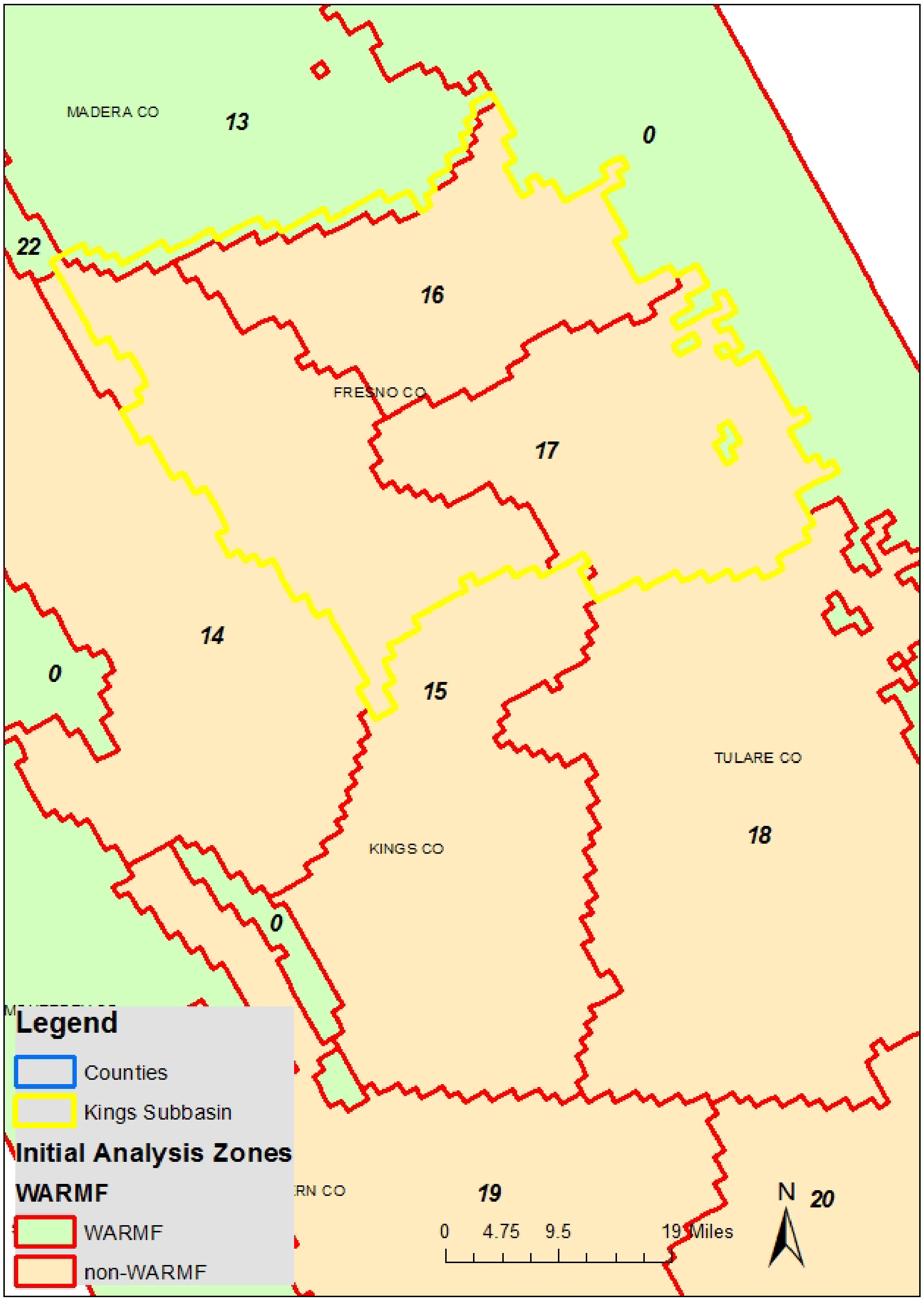


Figure 9-17. Correspondence Among Kings Subbasin and IAZ Boundaries

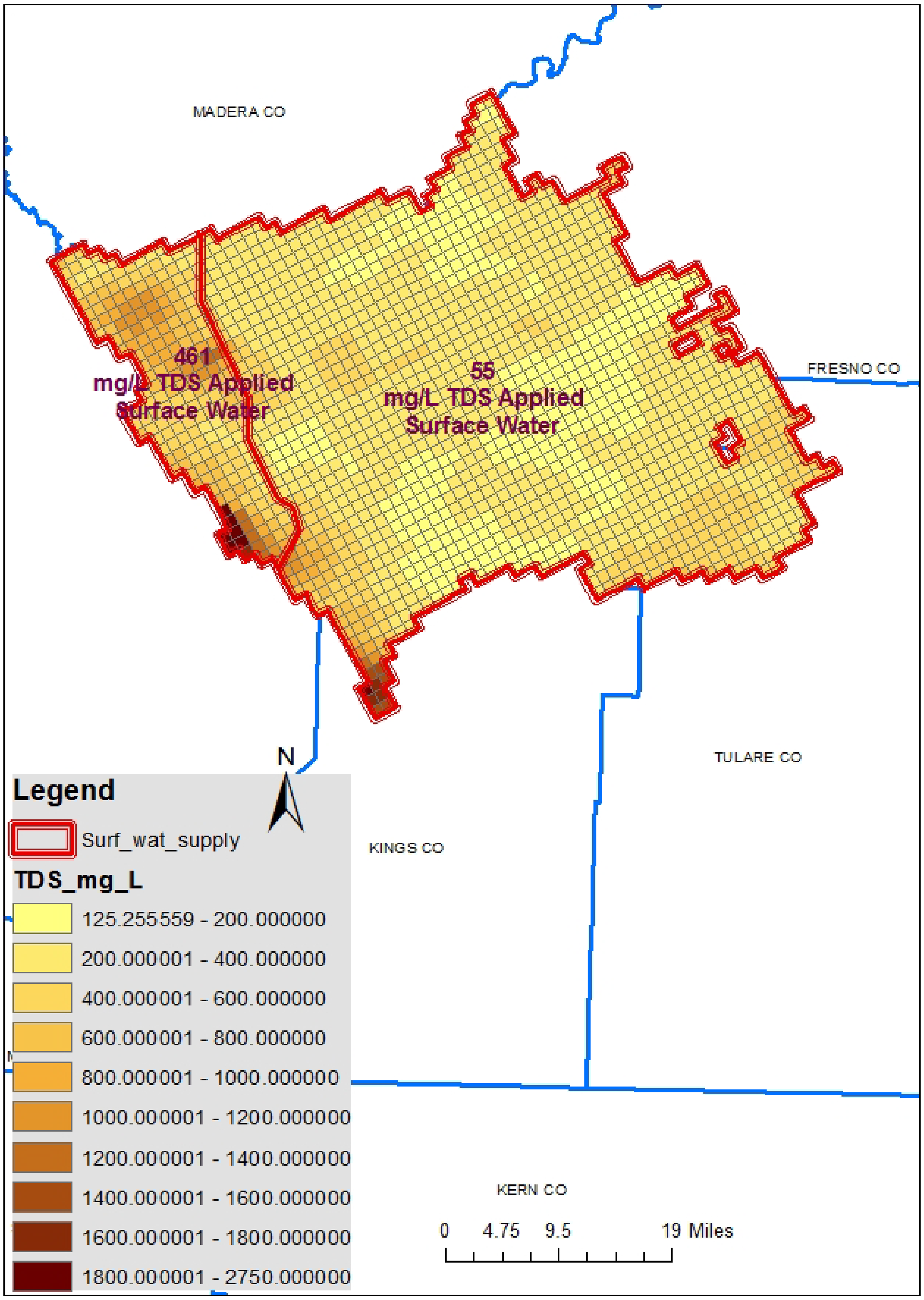


Figure 9-18. CVHM Cell Grid in Kings Subbasin. Surface Water Quality Subdivision of Kings Subbasin. Applied Water Salinity Estimate, by Grid Cell.

Refinement of Loads in Applied Water

Applied water data were procured with the assistance of the Kings River Conservation District (KRCD). Two key references and one essential piece of water supply information were provided:

- A map of irrigation and water districts within KRCD (**Figure 9-19**).
- Documentation and maps of groundwater quality within KRCD (Page and LeBlanc, 1969; **Figure 9-20**).
- Indication that most districts to the east draw water from the Friant-Kern Project or Kings River, and that this water averages about 55 mg/L TDS. Further indication that some districts on the west side draw from Mendota Pool via Fresno Slough. Water quality in this water body is documented in a report (LSCE, 2003), which was used along with local CIMIS data to derive a flow-weighted average surface water supply quality for these districts. Employing a water quality blending proportion from CVHM, the applied water weighted average (of applied surface and groundwater) salinity during an average year, was estimated for each grid cell (**Figure 9-18**).

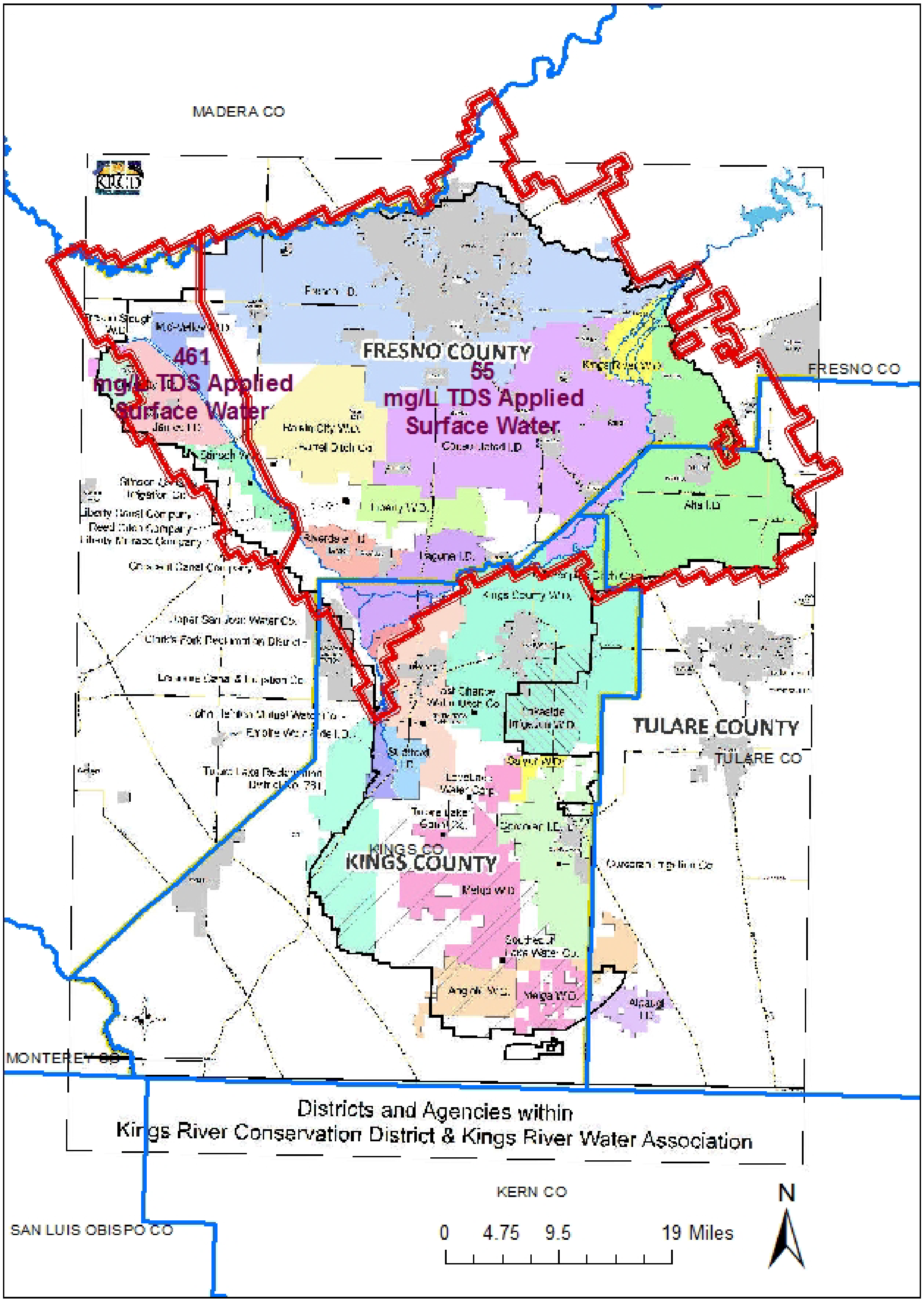


Figure 9-19. Water and Irrigation Districts Within Kings Subbasin (courtesy of KRCD)

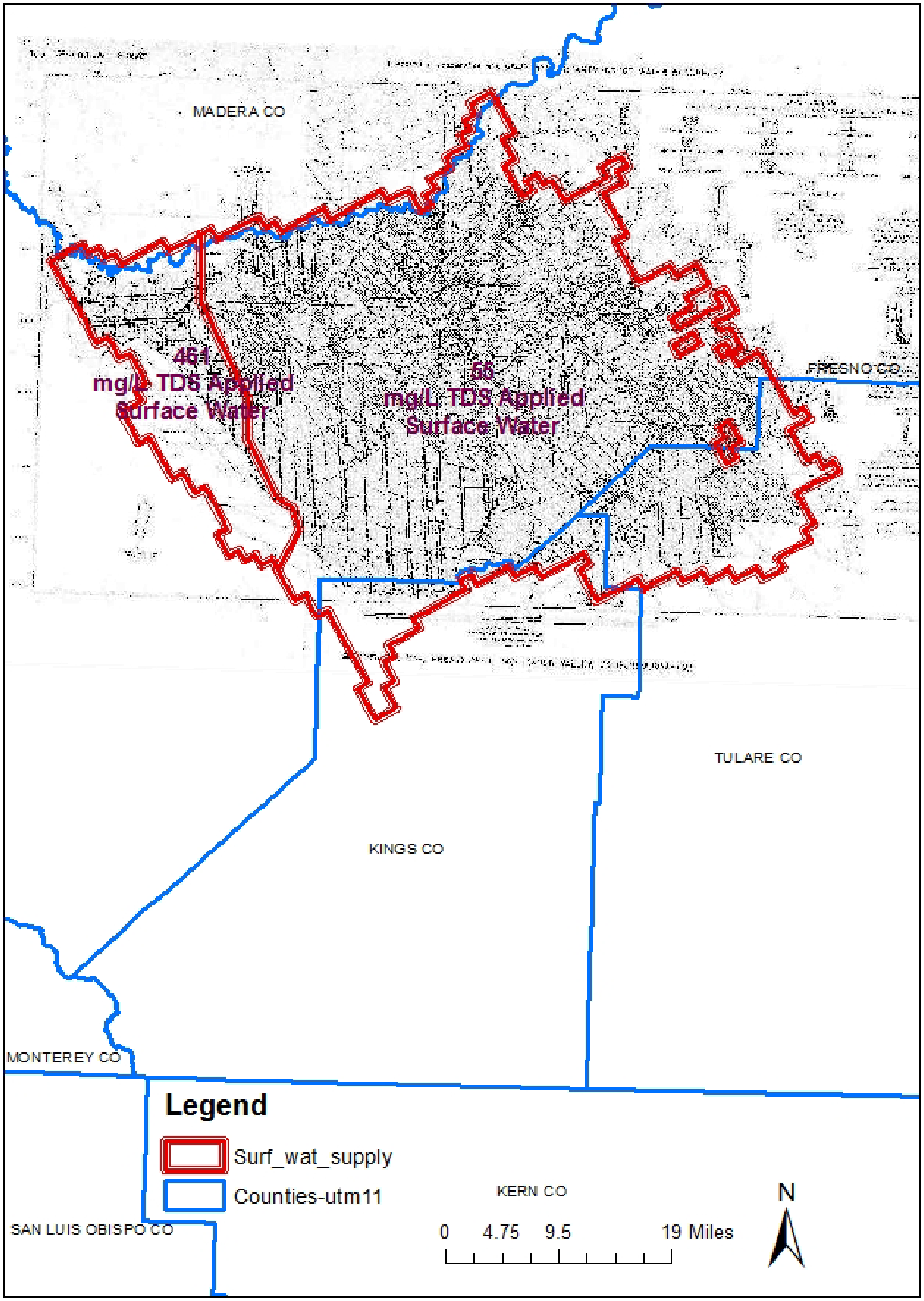


Figure 9-20. Groundwater Contours in Kings Subbasin (from Page and LeBlanc, 1969)

Loading Estimate Basis and Land Cover

Land cover on each cell was assessed with the most recent DWR land cover data for each county, translated into the land cover classes employed in the Tule River WARMF model (**Figure 9-21**)[68]. Fertilization rates for each land cover polygon depended on 1) the land cover class of the polygon, and 2) the fertilization zone in which the polygon was situated (**Figure 9-22**). Fertilization rates were similar to those employed in the most recent Tule River WARMF model runs (also the "Low" scenario under Task 6) which had in general performed best in matching underlying groundwater quality.

[68] Areas shown as "Kings_dairy_parcels" were analyzed as the land cover class representing dairy manure land application at agronomic rates from the Tule River WARMF model.

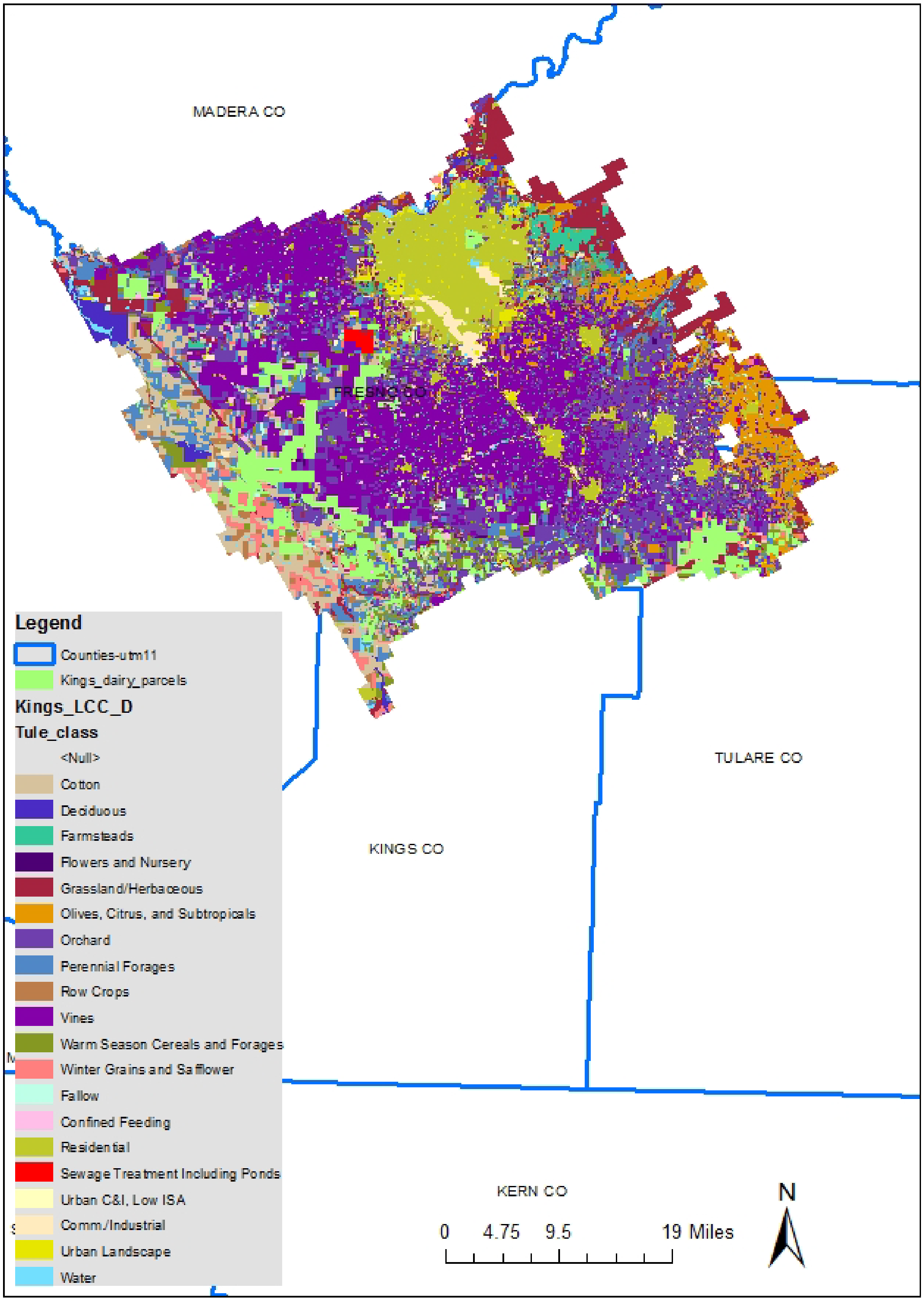


Figure 9-21. Land Cover Classes in Kings Subbasin

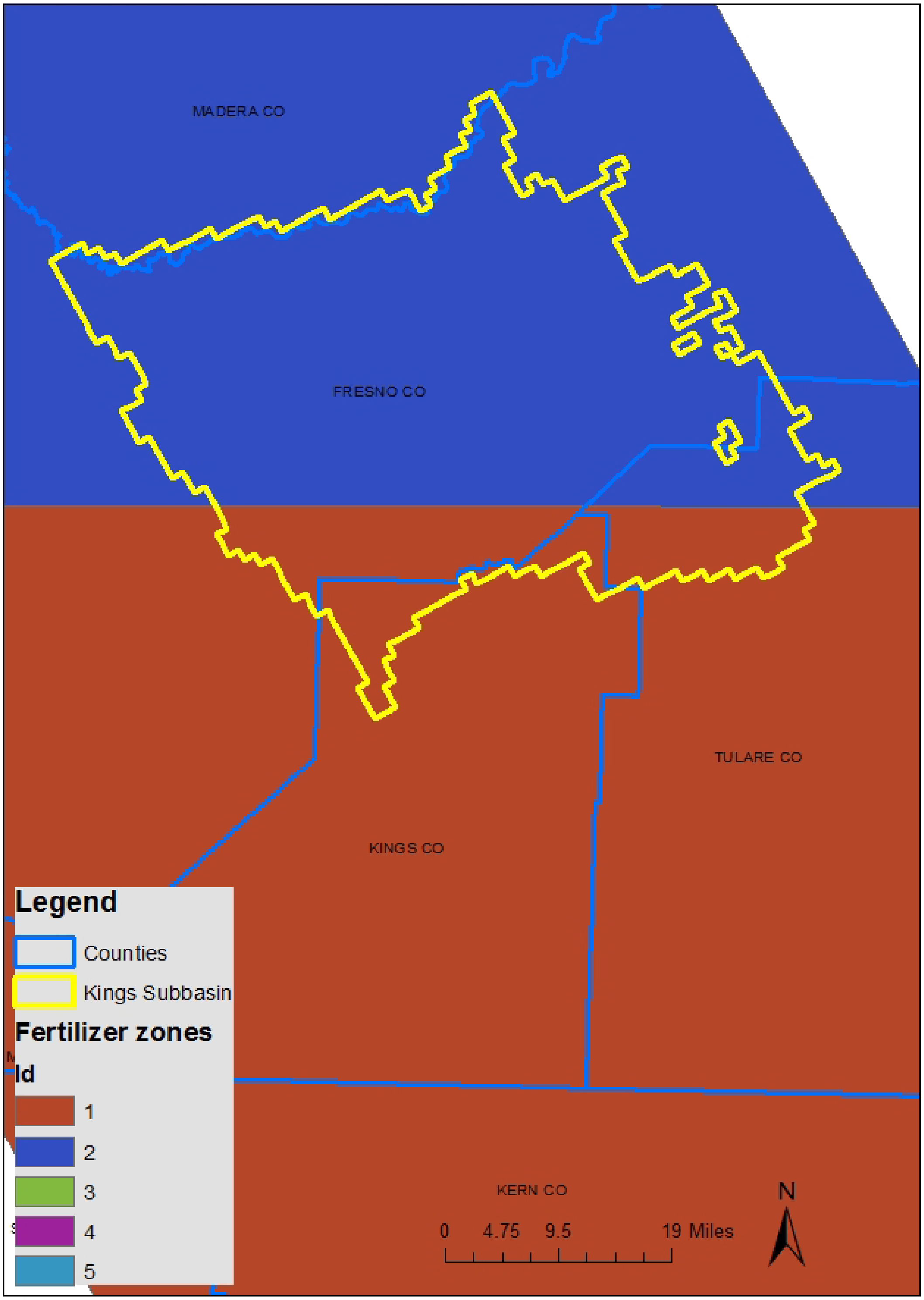


Figure 9-22. Fertilizer Zones Developed Under Task 6, Showing Zones 1 and 2 Overlapping Kings Subbasin

The Tule River WARMF model was selected as the reference WARMF area for IAZ’s 15, 16, and 17 that make up almost all of the Kings Subbasin. The small strip of IAZ 13, lying as it does along the northern borders of IAZs 15 and 16, can be handled similarly. WARMF results can be expressed as loads per acre of each individual land cover class, for each modeled period. These provided the basic results for each land cover class polygon in the Kings Subbasin, from which loading for individual cells was estimated as follows:

- Proportional adjustments were made to the Tule River WARMF nitrate results for polygons lying in Fertilizer Zone 2, to account for the difference in fertilization rates and uptake from Zone 1 (where the Tule River WARMF domain is situated).
- Proportional adjustments were made to the Tule River WARMF salinity results for polygons to account for the differences between applied water salinity to the polygon (determined by the CVHM cell in which the polygon lies) and that assumed for the WARMF model area.
- Land application loads from Task 6 were similarly calculated on a per-acre, per-time-step basis, and applied to lands classified as POTWs (generally ponds).
- Constituent loads coming from each land cover polygon (or portion thereof) in each cell were summed for each model time step.
- Loads were apportioned among outflow components in the same manner as they were for non-WARMF areas in Task 6.
- These apportioned loads, per cell and per time step, were employed as input to the Task 7 groundwater model.

Due to the large size of the data set, it is not presented in tabular format in this report, but rather will be provided digitally along with other project materials. A map of the mass loadings for nitrate and TDS are below (**Figure 9-23** and **Figure 9-24**).

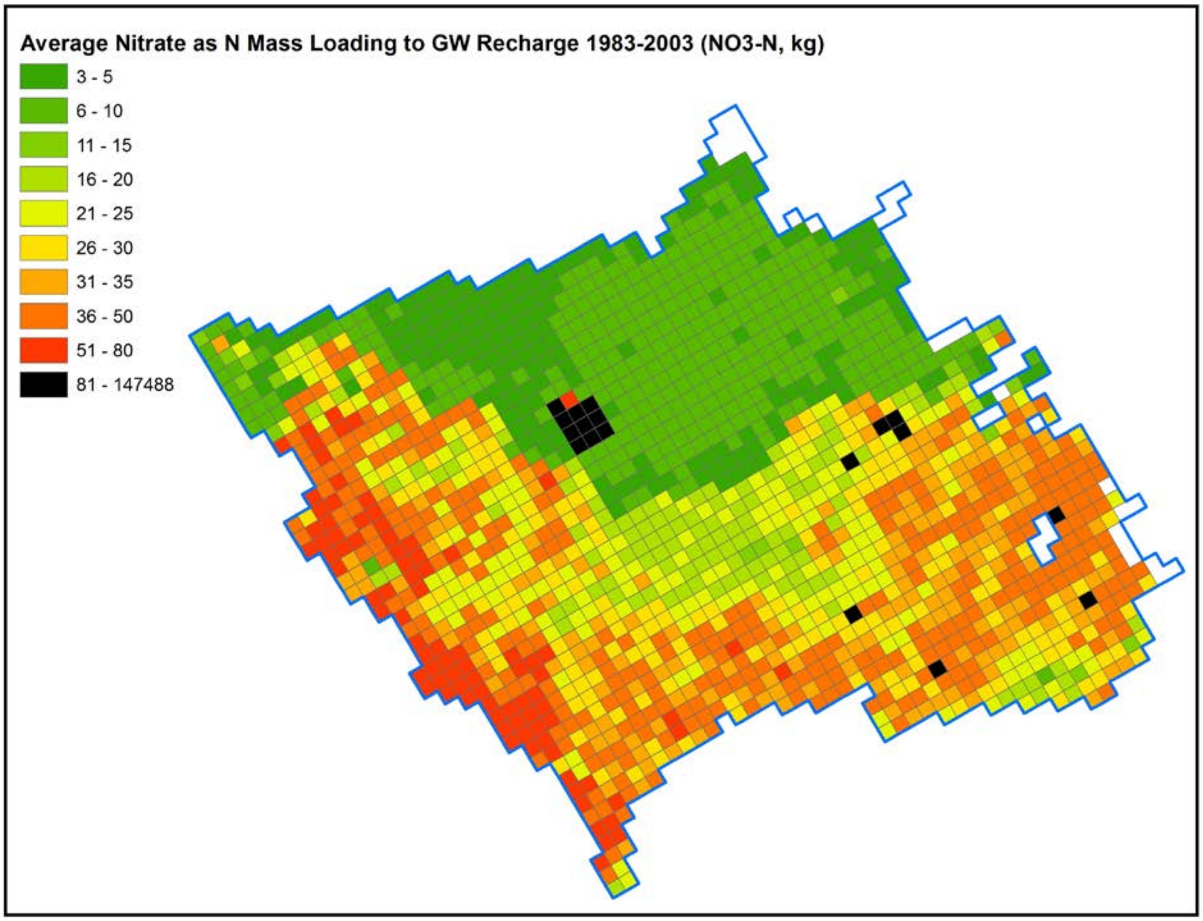


Figure 9-23. Average Nitrate as N Mass Loading to Groundwater Recharge, 1983-2003 (kg per square mile per quarter)

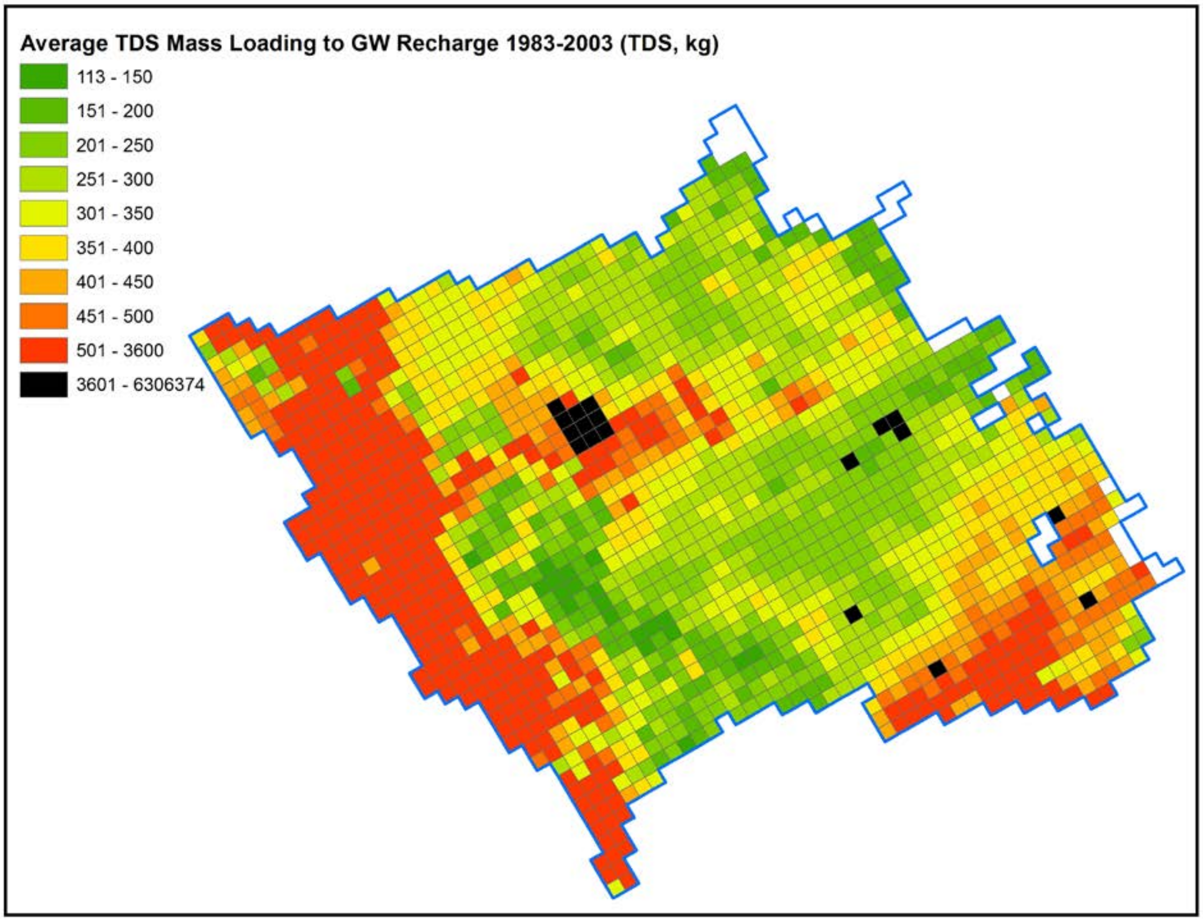


Figure 9-24. Average TDS Mass Loading to Groundwater Recharge, 1983-2003 (kg per square mile per quarter)

Identify Zones of High, Low, and Moderate Groundwater Quality for the Kings Subbasin

Ambient water quality was established for the Kings Subbasin model area. Ambient conditions were assigned to the model layering using well types, and when available, well depths. Monitoring and domestic wells were assigned to Layers 1 and 2, domestic wells were assigned to Layer 3, and public supply and irrigation wells were assigned to Layers 6-10.

Kriging was used to estimate concentrations over the entire model domain. In order to interpolate over the entire model domain, a large search radius was used in order to capture sufficient data, as large portions of the domain contain no data. This resulted in a minor amount of smoothing of the data. The interpolated domains were then contoured and 8to10 water quality zones were established based on the distribution of values. **Figure 9-25** through **Figure 9-30** show the kriged fields along with the original data and the subsequent water quality zones.

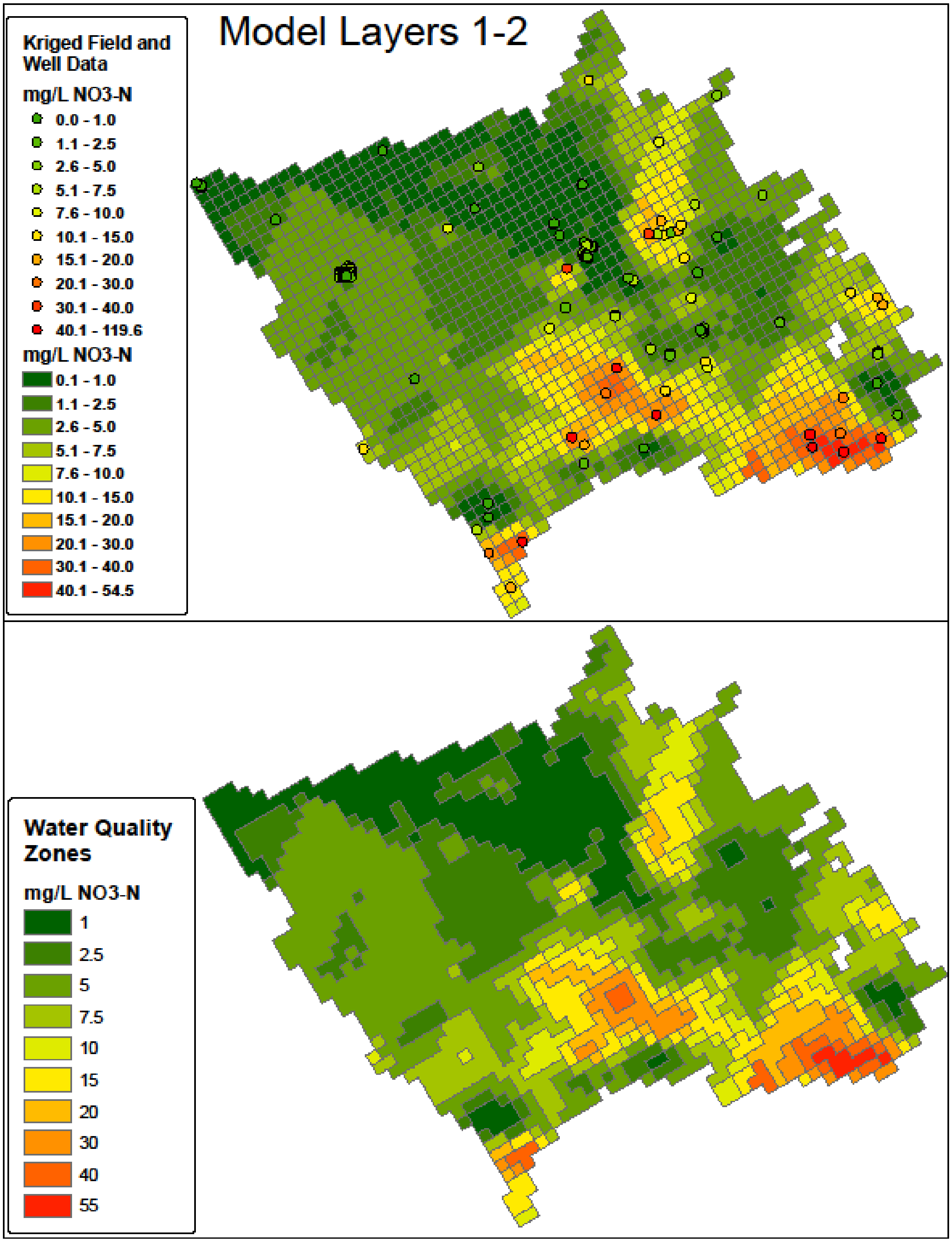


Figure 9-25. Kriged Field, Nitrate Model Layer 1-2

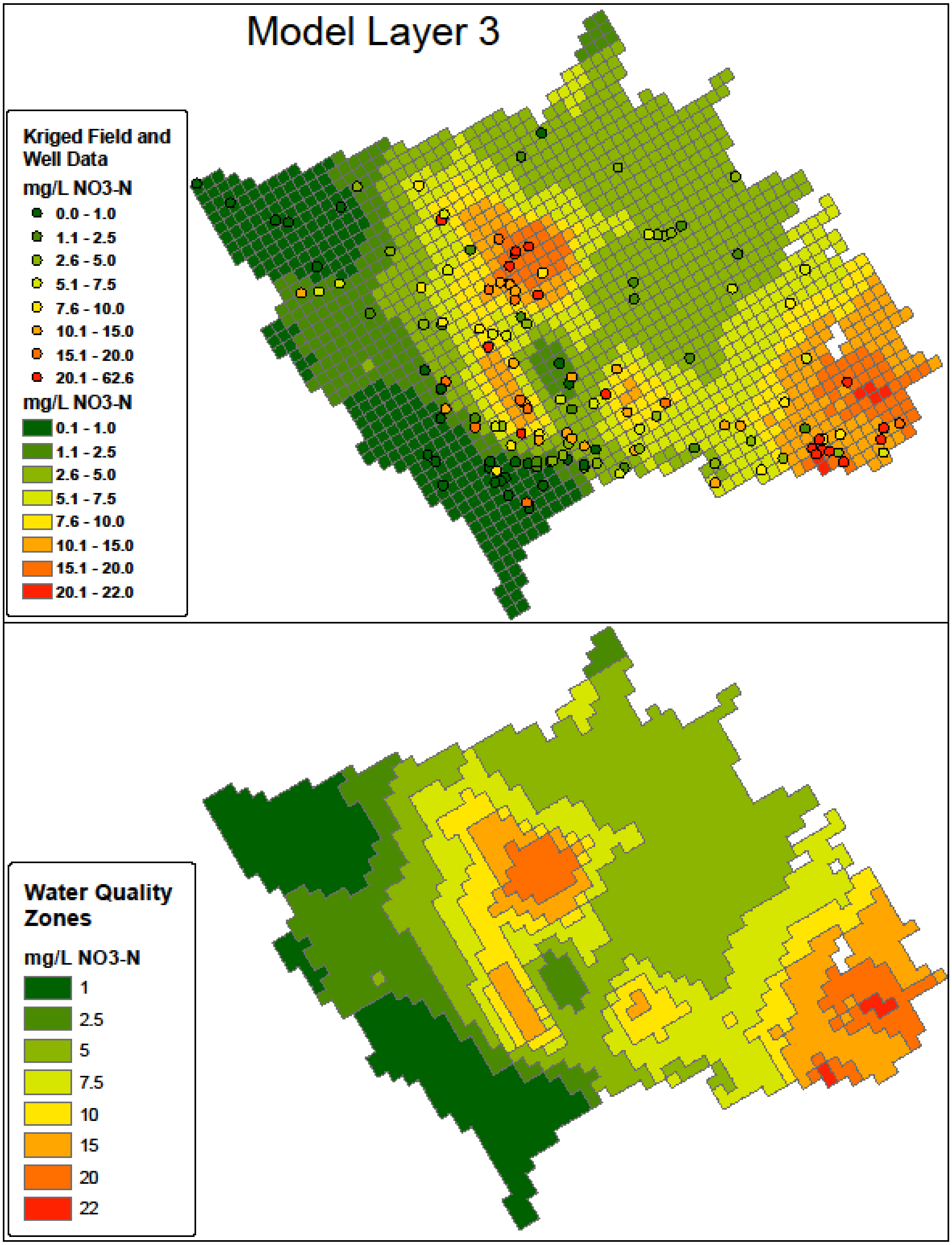


Figure 9-26. Kriged Field, Nitrate Model Layer 3

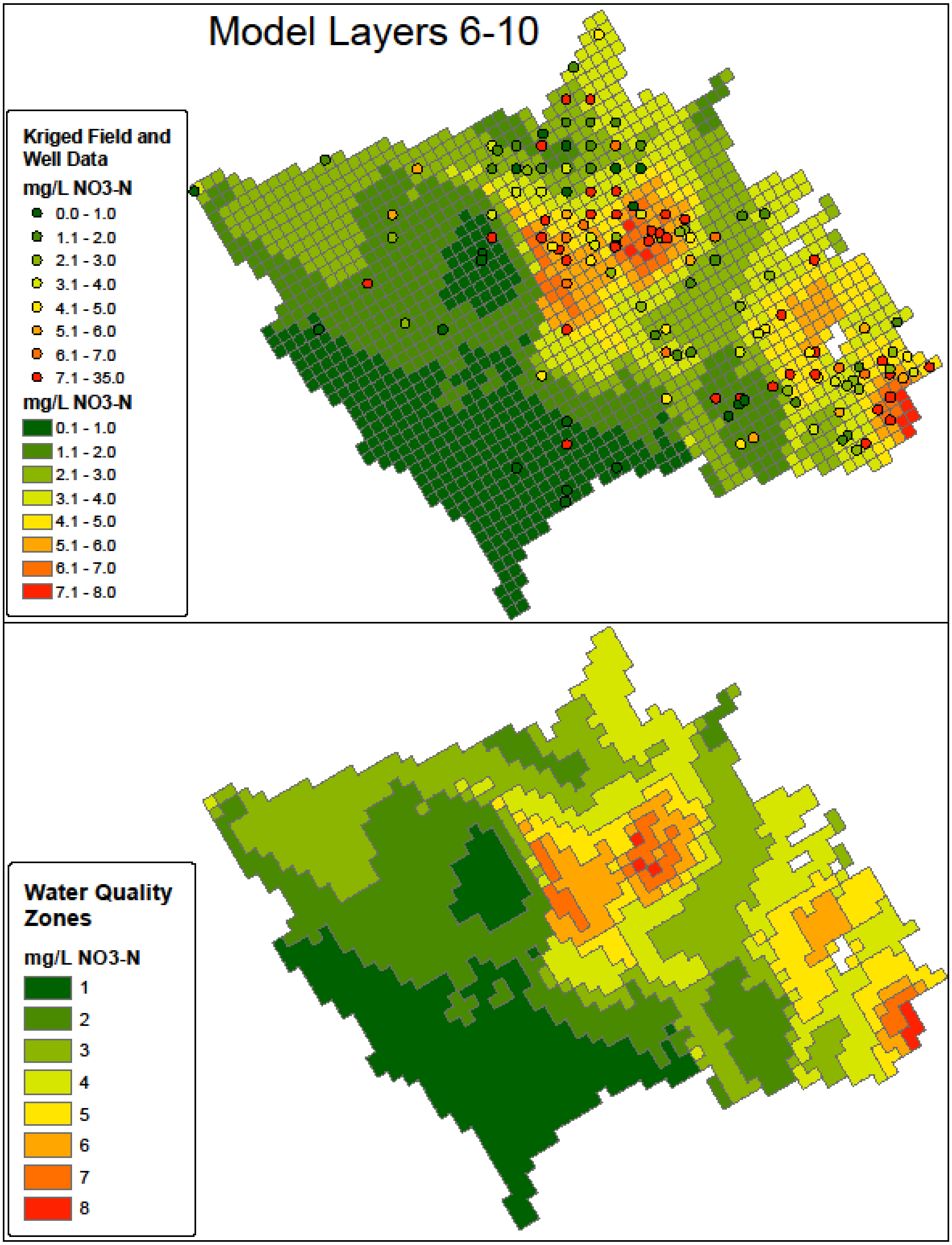


Figure 9-27. Kriged Field, Nitrate Model Layer 6-10

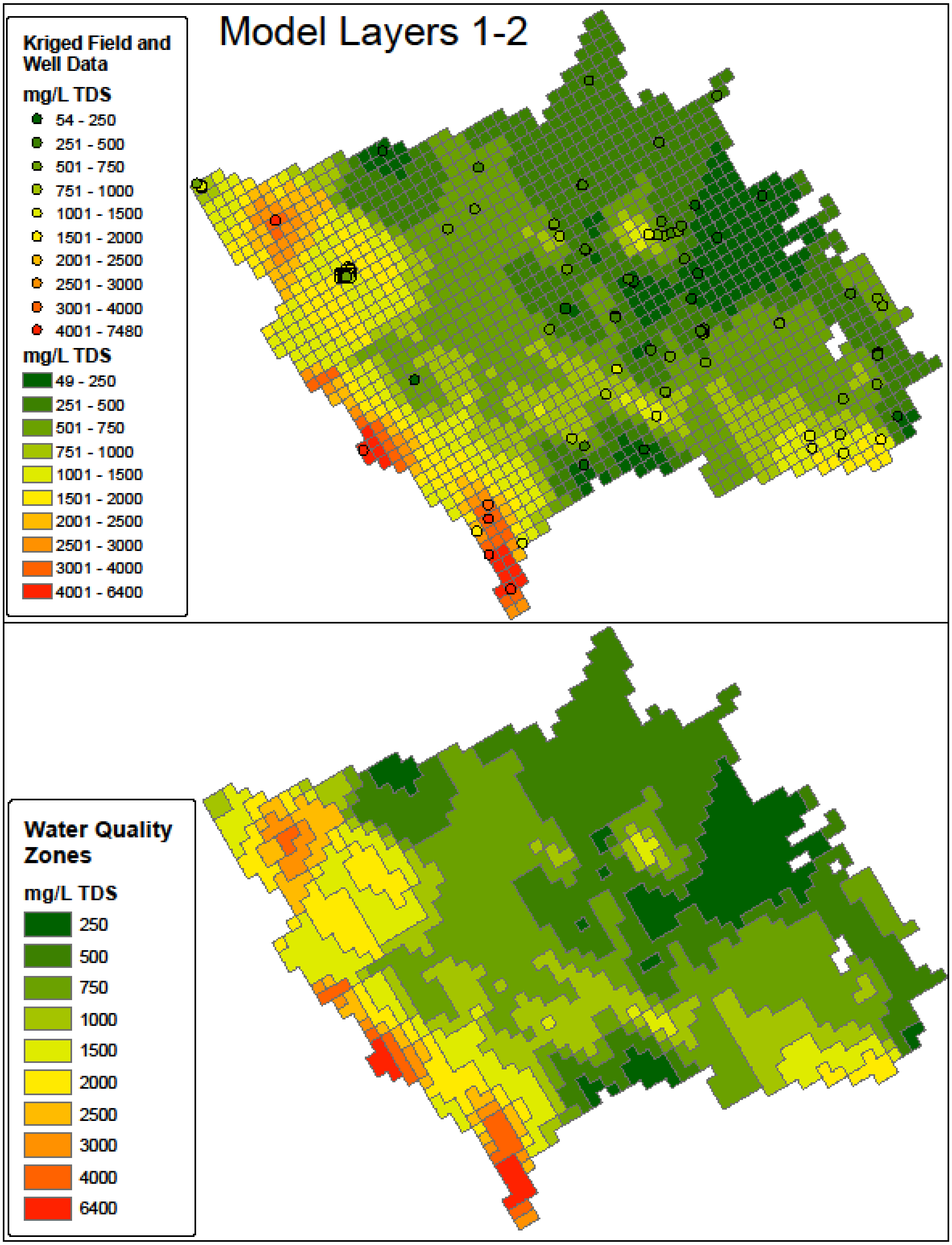


Figure 9-28. Kriged Field, TDS Model Layer 1-2

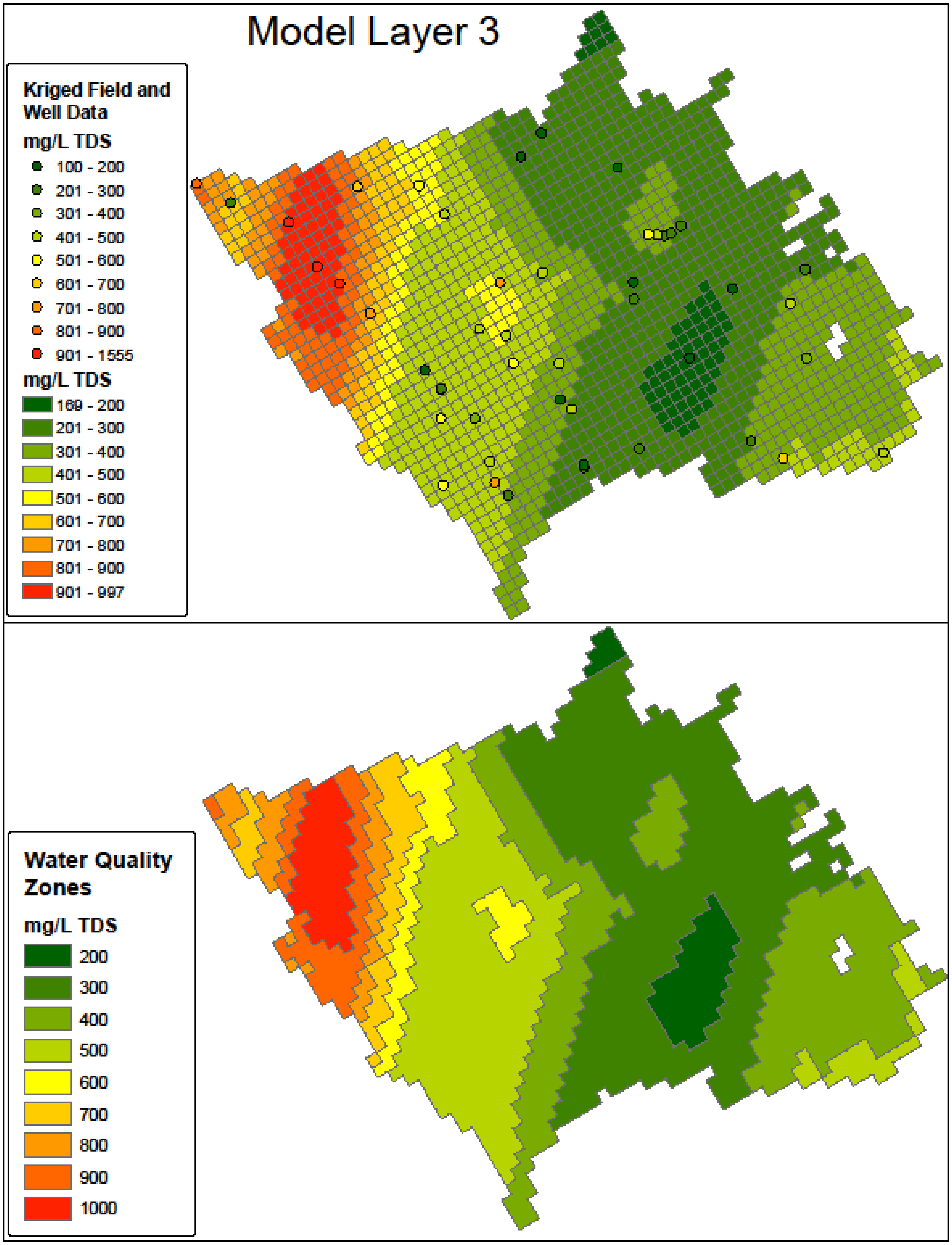


Figure 9-29. Kriged Field, TDS Model Layer 3

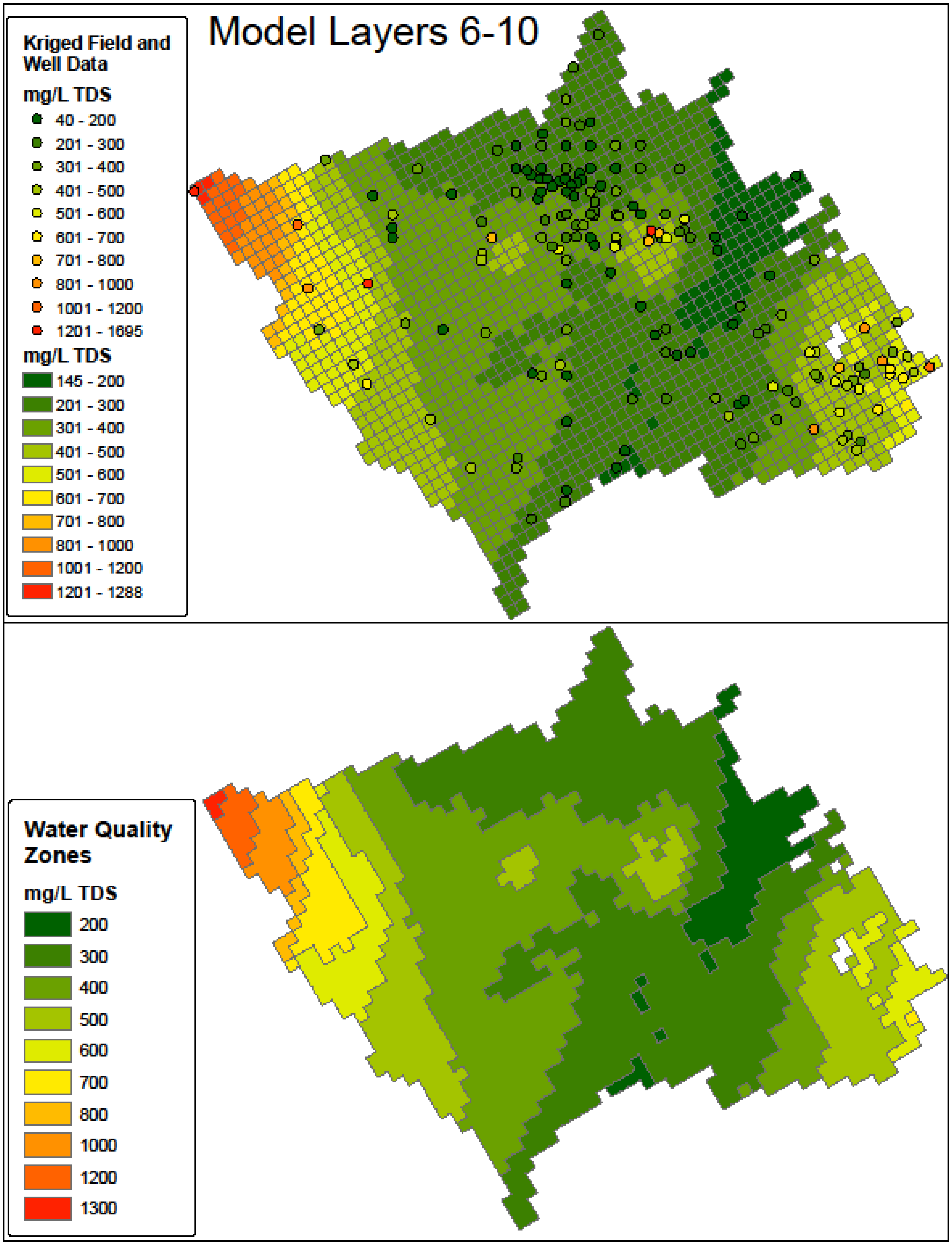


Figure 9-30. Kriged Field, TDS Model Layer 6-10

Establish and Quantify Transport Patterns and Simulate Concentrations of Salt and Nitrate in Areas Over Time for the Kings Subbasin

The prototype methodology developed for the Kings Subbasin is different from the simulated concentration of wells analysis for the Modesto Regional Area. The methodology developed for the Kings Subbasin attempts to use estimated concentrations of salt and nitrate of groundwater recharge along with measured groundwater quality data, distributed spatially over the entire Kings Subbasin. The movement of the varying concentrations of water is then tracked over a twenty-year period, including recharge concentrations, to see where areas of high and low water quality are travelling and what effect those concentrations have on groundwater quality through time.

The CVHM model was chosen as the foundation for this application. The CVHM model is a transient model with monthly stress periods for a total of 42.5 years of simulation. Similar to the IAZ analysis, the methodology for this prototype area utilizes the last 20-years of the CVHM simulation (1983 to 2003). Groundwater recharge mass loadings were developed as described above, and converted to concentrations on a cell-by-cell basis using the MODFLOW post-processer Zonebudget to extract the flow and volume of groundwater recharge for each of the 1,628 CVHM cells in the Kings Subbasin (**Figure 9-31**). The recharge map identifies areas of low recharge volume in the northern portion of the area, which corresponds to the urban area of Fresno. When the masses developed above are combined with the CVHM volumes, the average concentrations of groundwater recharge can be seen in the map below for nitrate as N (**Figure 9-32**) and TDS (**Figure 9-33**). Some of the high groundwater recharge concentrations are a remnant of high mass loadings based on the permits for Fresno’s wastewater percolation ponds combined with relatively low volumes of CVHM recharge on those 1 mile by 1 mile grid cell locations, rendering unsupported high water quality concentrations (seen in cells colored black in the mass loading **Figures 9-23** and **9-24**). Other high concentrations seen in the urban Fresno area might also be unreasonably high due to the proportional inconsistencies between CVHM recharge and mass loadings: a relatively low amount of CVHM recharge is combined with a modest amount of nitrate and TDS mass for that area to result in a high concentration.

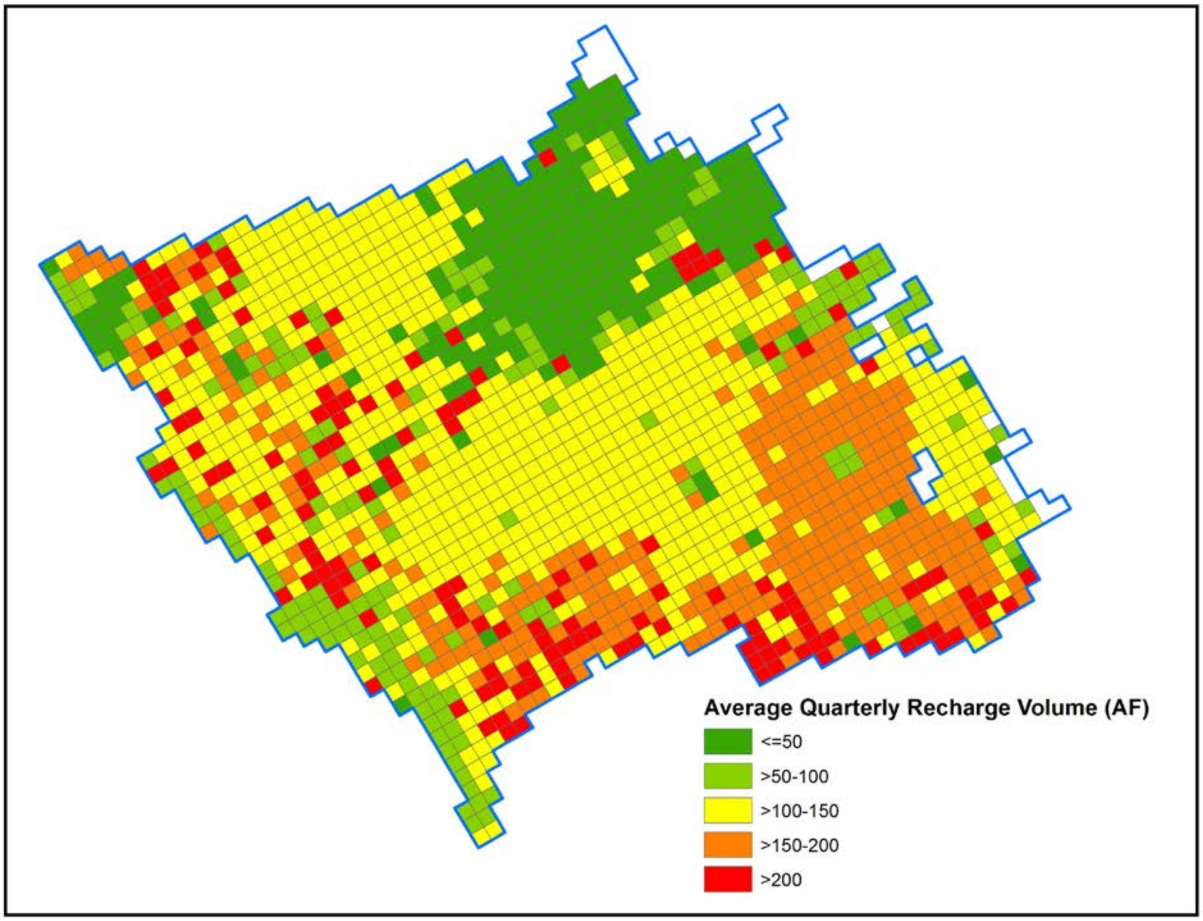


Figure 9-31. Kings Subbasin Average Quarterly Recharge Volume (AF)

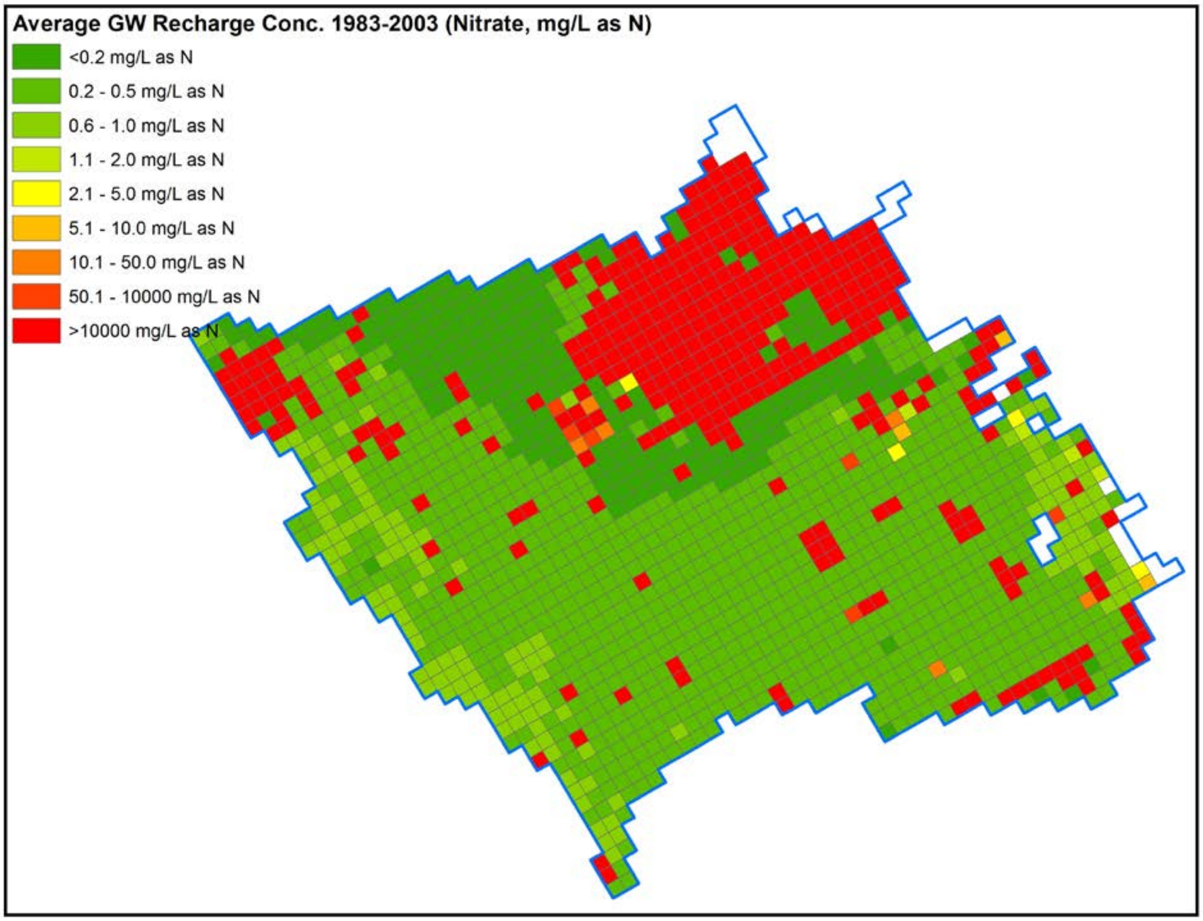


Figure 9-32. Kings Subbasin Average Groundwater Recharge Nitrate (as N) Concentration (1983-2003)

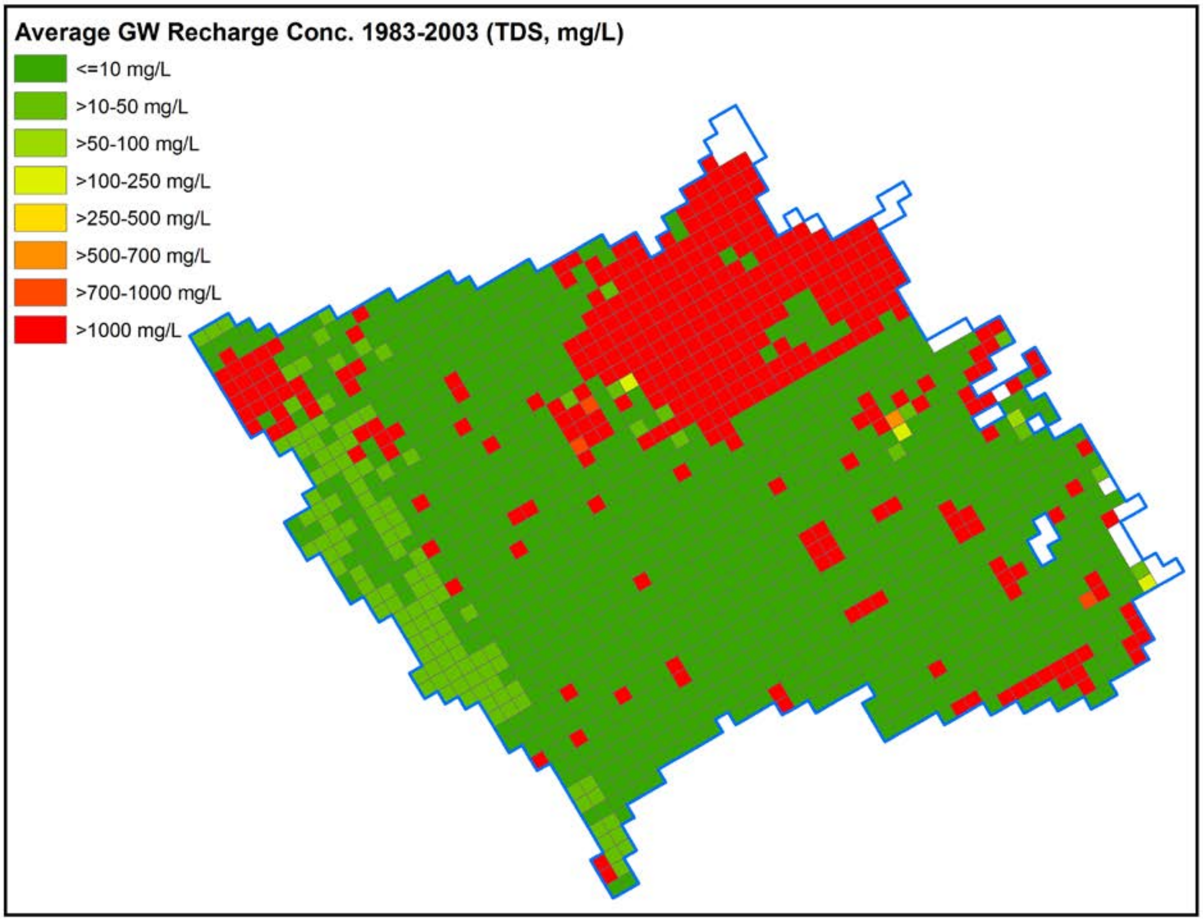


Figure 9-33. Kings Subbasin Average Groundwater Recharge TDS Concentration (1983-2003)

The subsurface in the Kings Subbasin was split into three depth categories based on CVHM layering. Layers 1 and 2 are grouped together and are assigned groundwater quality based on monitoring wells. Layer 3 is assigned groundwater quality based on domestic wells. Layers 4 and 5 are CVHM placeholders for the Corcoran Clay and were not assigned groundwater quality. Layers 6 through 10 were grouped together and assigned groundwater quality based on public supply and irrigation wells. USGS wells that had a well depth were assigned to the model layer that corresponded with the well depth. Groundwater quality zones were assigned using a range of values for salt and nitrate. **Figure 9-25**, **Figure 9-26**, and **Figure 9-27** show the nitrate as N concentrations and quality zones assigned to Layers 1 and 2, Layer 3, and Layers 6 through 10 respectively for the 1983-2003 time period. **Figure 9-28, Figure 9-29**, and **Figure 9-30** show the TDS concentrations and quality zones assigned to Layers 1 and 2, Layer 3, and Layers 6 through 10 respectively for the 1983-2003 time period.

In order to track the movement of water within these different zones, particle tracking was employed on the CVHM model using MODPATH. Particles were placed in 1) the center of every cell in the Kings Subbasin and 2) in each cell on the top of the model representing the groundwater recharge surface. These particles were continuously assigned to their cells and sent forward in time every quarter (3 months) for the duration of the 20-year simulation period (resulting in the accumulation of over 1.4 million simulated particles).

Observations of groundwater quality were made on an annual basis at each cell of the model based on the MODPATH-OBS module. In order to make annual observations, MODPATH was run 20 times to create endpoints for each particle released every quarter during the 20-year period. This approach uses the locations of each particle's starting point and endpoint and assigns the water quality concentration of the starting point based on its original water quality zone (**Figure 9-25** through **Figure 9-30**) or recharge concentration, and takes an average of all particles ending up in each cell at the particular year of interest. These simulated observations represent an estimated concentration in each cell in the model as they are affected by water, salt, and nitrate movement through the 20-year period.

Kings Results

The results of this "proof of concept" approach can be used to illustrate and quantify the concentration of salt and nitrate in groundwater and identify areas where concentrations are increasing, decreasing, or remaining stable. Time series of plots can be produced for particular cells or areas of interest that show the simulated concentration over time. Maps can be created and animated to present the simulated movement of groundwater quality "hotspots" through time.

Specifically in the Kings Subbasin, this approach was limited by the transient nature of the CVHM model, which constrains the distance water can move and take with it a particular concentration of salt and nitrate. The movement of groundwater is relatively slow, and when looking on a 1-mile by 1-mile grid, some particles of water/salt/nitrate barely leave the cell they originated from within one year.

A summary of the particle statistics showing the vertical and horizontal movement of water/salt/nitrate is provided below for all of the particles released every quarter for the Kings Subbasin, using the CVHM hydrology for 1983 to 2003.

The following table (**Table 9-2**) summarizes the vertical movement of all particles over the 20-year period by the number of layers the particle travels through either up or down:

Table 9-2. Summary of Vertical Movement of Particles in 20 Years

	Number of Layers Traveled[69]	Number of Particles
Upward	-2	294
	-1	7472
	0	1227752
Downward	1	166517
	2	52481
	3	374
	4	134
	5	16

A small portion of particles move upward, while the majority of particles move downward, most moving down into the layer below them, and some moving down five CVHM model layers in 20 years. Many particles stay in the same layer and although may have some vertical movement, are not able to pass into a higher or lower layer within their travel time. A subset of these particles represent those assigned to recharge. The following table (**Table 9-3**) summarizes the vertical movement of recharge particles that were released every quarter for the 20-year period.

Table 9-3. Summary of the Vertical Movement of Recharge Particles

	Final Layer	Number of Layers Traveled	Number of Particles	Minimum Travel Time (years)	Maximum Travel Time (years)	Average Travel Time (years)
Layer 1 Recharge Particles	1	0	4756	0	20	9
	2	1	34266	0	20	9
	3	2	47946	0.1	20	10
	4	3	89	7	20	14
	5	4	47	11	20	16
	6	5	16	16	20	18

[69]The “Number of Layers Traveled” represents the particle’s final layer minus the particle’s initial layer.

Layer 2 Recharge Particles	1	-1	440	6.2	20	15
	2	0	3535	0	20	9
	3	1	27526	0	20	10
	4	2	161	9	20	16
	5	3	18	18	20	19
Layer 3 Recharge Particles	3	0	4928	0.2	20	9
	4	1	6512	0.2	20	11

Most recharge particles move downward, but as seen by the recharge particles that travel vertically down past Layer 4, it takes many years for recharge to get that far deep (minimum travel time of at least 7 years). A complete summary of the vertical movement of all particles for each layer released during the 20-year period, including the travel times and vertical distances are in the table below (**Table 9-4**)

Table 9-4. Vertical Movement of All Particles (Travel Times and Vertical Distances)

	Number of Layers Traveled	Number of Particles	Travel Time (years)			Vertical Distance (ft)		
			Min	Max	Avg	Min	Max	Avg
Layer 1 Particles	0	122296	0	20	5	-96	125	7
	1	47483	0	20	10	-24	159	32
	2	49553	0	20	10	-5	318	32
	3	162	7	20	13	106	305	256
	4	90	11	20	16	115	306	278
	5	16	16	20	18	266	320	293
Layer 2 Particles	-1	4321	0	20	11	-96	62	-13
	0	78304	0	20	7	-17	89	12
	1	81019	0	20	10	-44	226	28
	2	399	6	20	16	106	227	162
	3	73	10	20	16	113	216	181
	4	44	13	20	17	214	297	250
Layer 3 Particles	-2	57	7	19	9	-134	-93	-110
	-1	688	6	20	14	-166	-69	-110
	0	135111	0	20	9	-161	129	10
	1	7587	0	20	11	-7	105	10
	2	338	8	20	15	53	106	77
	3	139	12	20	17	67	176	116
Layer 4	-1	1287	4	20	15	-182	52	-30

Particles	0	114926	0	20	8	-4	16	1
	1	14076	2	20	14	0	27	8
	2	2191	5	20	16	1	164	33
Layer 5 Particles	-2	237	12	20	17	-71	26	-29
	-1	1047	5	20	15	-1	0	-1
	0	114942	0	20	8	-4	16	1
	1	16254	2	20	14	0	192	17
Layer 6 Particles	-1	129	14	20	18	-107	-92	-99
	0	132253	0	20	9	-105	112	3
	1	98	14	20	18	77	131	109
Layer 7 Particles	0	132480	0	20	9	-108	73	1
Layer 8 Particles	0	132480	0	20	9	-23	27	0
Layer 9 Particles	0	132480	0	20	9	-91	7	0
Layer 10 Particles	0	132480	0	20	8	-5	2	0

The table above emphasizes the decrease of vertical movement of particles at depth (particles in deeper layers travel a small vertical distance compared to shallower layer particles). **Table 9-4** also shows that 1) particles in Layers 4 and 5, which CVHM uses to represent the Corcoran Clay, remain in that layer, 2) there is very little vertical movement out of Layer 6, and 3) particles originating in Layers 7 through 10 remain in those layers during the 20-year simulation period.

In terms of horizontal or lateral movement, the following table (**Table 9-5)** summarizes the movement of particles laterally across cells in the x- direction and the y-direction, which in the CVHM model platform corresponds to an east-southeast to west-northwest direction and a north-northwest to south-southeast direction, due to the fact that the CVHM model grid is tilted or rotated by 34 degrees west of north.

Table 9-5. Summary of Lateral Particle Movement in 20 Years

X-direction

# of 1-mi² Cells Traveled		Number of Particles	Travel Time (years)			X-direction Travel Distance (ft)		
			Min	Max	Avg	Min	Max	Avg
westward	-5	4	19	20	20	7359	7686	7543
	-4	145	13	20	18	5635	7037	6031
	-3	1323	9	20	17	4023	5632	4614
	-2	10009	5	20	16	2414	4022	2968
	-1	96305	1	20	14	805	2414	1314
0		1337743	0	20	8	-805	805	70
eastward	1	9507	4	20	15	-2410	-805	-1071
	2	4	20	20	20	-2454	-2422	-2433

Y-direction

# of 1-mi² Cells Traveled		Number of Particles	Travel Time (years)			Y-direction Travel Distance (ft)		
			Min	Max	Avg	Min	Max	Avg
southward	-3	82	12	20	18	-4785	-4026	-4261
	-2	2073	4	20	16	-4022	-2414	-2943
	-1	58982	1	20	15	-2413	-805	-1180
0		1380583	0	20	8	-805	805	-60
northward	1	11573	1	20	14	805	2412	1227
	2	1469	3	20	15	2415	4023	3052
	3	210	7	20	16	4026	5624	4489
	4	58	11	20	15	5634	7218	6288
	5	10	17	20	19	7242	7401	7307

Particles move laterally in all directions (north, south, east, and west). The following tables show how particles in each layer move laterally (**Table 9-6**).

Table 9-6. Lateral Particle Movement in the X-Direction by Layer for the 20-Year Period

	# of 1-mi² Cells Traveled		Number Of Particles	Travel Time (years)			X-direction Travel Distance (ft)		
				Min	Max	Avg	Min	Max	Avg
Layer 1 Particles	westward	-5	4	19	20	20	24139	25208	24741
		-4	119	13	20	18	18499	23080	19889
		-3	517	9	20	15	13197	18472	15576
		-2	2612	5	20	15	7918	13189	9545
		-1	26646	1	20	14	2639	7917	4259
	0		184751	0	20	6	-2639	2639	212
	eastward	1	4951	4	20	14	-7860	-2639	-3441
Layer 2 Particles	westward	-4	22	17	20	19	18483	20761	19360
		-3	541	11	20	17	13200	18471	14945
		-2	4583	6	20	16	7918	13192	9803
		-1	30594	1	20	13	2639	7917	4551
	0		125829	0	20	7	-2638	2639	362
	eastward	1	2591	4	20	15	-7849	-2639	-3479
Layer 3 Particles	westward	-4	4	19	20	20	18625	19246	18934
		-3	265	12	20	18	13199	18420	14656
		-2	2797	7	20	16	7918	13191	9806
		-1	25255	2	20	14	2639	7917	4359
	0		113647	0	20	8	-2639	2639	374
	eastward	1	1948	7	20	16	-7904	-2639	-3739
		2	4	20	20	20	-8050	-7943	-7981
Layer 4 Particles	westward	-1	341	11	20	17	2642	7657	3988
	0		132134	0	20	9	-2610	2635	11
	eastward	1	5	19	20	19	-2909	-2641	-2790
Layer 5 Particles	westward	-1	739	9	20	16	2639	6620	3783
	0		131741	0	20	9	-1947	2638	34
Layer 6 Particles	westward	-2	17	17	20	19	7918	8849	8133
		-1	12730	5	20	16	2639	7907	3772
	0		119721	0	20	8	-2613	2639	574
	eastward	1	12	17	20	19	-3156	-2722	-2942
Layer 7 Particles	0		132480	0	20	9	-1972	2613	350
Layer 8 Particles	0		132480	0	20	9	-1296	1686	243
Layer 9 Particles	0		132480	0	20	9	-15	911	134

Layer 10 Particles	0	132480	0	20	8	0	616	73

Table 9-7. Lateral Particle Movement in the Y-Direction by Layer for the 20-Year Period

	# of 1-mi2 Cells Traveled		Number of Particles	Travel Time (years)			X-direction Travel Distance (ft)		
				Min	Max	Avg	Min	Max	Avg
Layer 1 Particles	southward	-3	36	16	20	19	-15693	-13207	-14220
		-2	952	4	20	16	-13191	-7919	-9740
		-1	23034	1	20	15	-7912	-2639	-3851
	0		190308	0	20	7	-2639	2635	-459
	northward	1	3911	1	20	12	2639	7912	4196
		2	1089	3	20	14	7921	13195	10123
		3	202	7	20	16	13206	18445	14767
		4	58	11	20	15	18479	23676	20625
		5	10	17	20	19	23755	24274	23969
Layer 2 Particles	southward	-3	42	12	20	17	-14621	-13225	-13819
		-2	688	5	20	16	-13186	-7923	-9570
		-1	18310	1	20	15	-7913	-2639	-3973
	0		140541	0	20	8	-2639	2639	-386
	northward	1	4195	3	20	14	2639	7900	3971
		2	376	9	20	16	7920	13079	9705
		3	8	18	20	19	13230	13877	13607
Layer 3 Particles	southward	-3	4	19	20	20	-13562	-13214	-13402
		-2	429	12	20	17	-13006	-7929	-9607
		-1	15055	3	20	15	-7905	-2639	-3853
	0		125646	0	20	9	-2639	2639	-478
	northward	1	2782	5	20	15	2639	7907	4106
		2	4	19	20	20	7980	8191	8086
Layer 4 Particles	southward	-2	4	19	20	20	-8380	-8062	-8243
		-1	231	11	20	16	-7855	-2644	-4853
	0		132241	0	20	9	-2637	2632	-5
	northward	1	4	19	20	20	2673	2746	2713
Layer 5 Particles	southward	-1	260	12	20	18	-4575	-2639	-3203
	0		132154	0	20	9	-2639	2638	-3
	northward	1	66	16	20	18	2639	3553	2970
Layer 6	southward	-1	2092	8	20	17	-5668	-2639	-3296
	0		129782	0	20	9	-2639	2638	-263

Particles	northward	1	606	7	20	15	2639	5438	3078
Layer 7 Particles	0		132471	0	20	9	-2410	2636	-126
	northward	1	9	17	18	18	2639	2747	2698
Layer 8 Particles	0		132480	0	20	9	-1363	2367	-88
Layer 9 Particles	0		132480	0	20	9	-548	1006	-33
Layer 10 Particles	0		132480	0	20	8	-206	595	-3

The above two tables (**Table 9-6** and **Table 9-7**) show the general direction and magnitude of water (and therefore salt and nitrate) associated with each model layer representing the subsurface. The two above tables also indicate the very subtle movement of groundwater at depth in the horizontal direction (layers 7 through 10 have very little lateral movement, most particles do not exit the 1-square-mile cell they originated in within the 20-year time period).

The overall net change in concentration on a cell-by-cell basis over the 20-year simulation period is shown in the following difference maps for nitrate (as N) and TDS for the shallow aquifer (Layers 1, 2, and 3), and Layer 6 (**Figure 9-34** and **Figure 9-35**). These difference maps show areas of simulated stability (no change in concentration) in yellow; simulated worsening conditions are shown in orange and red; and simulated improving conditions are shown in shades of green.

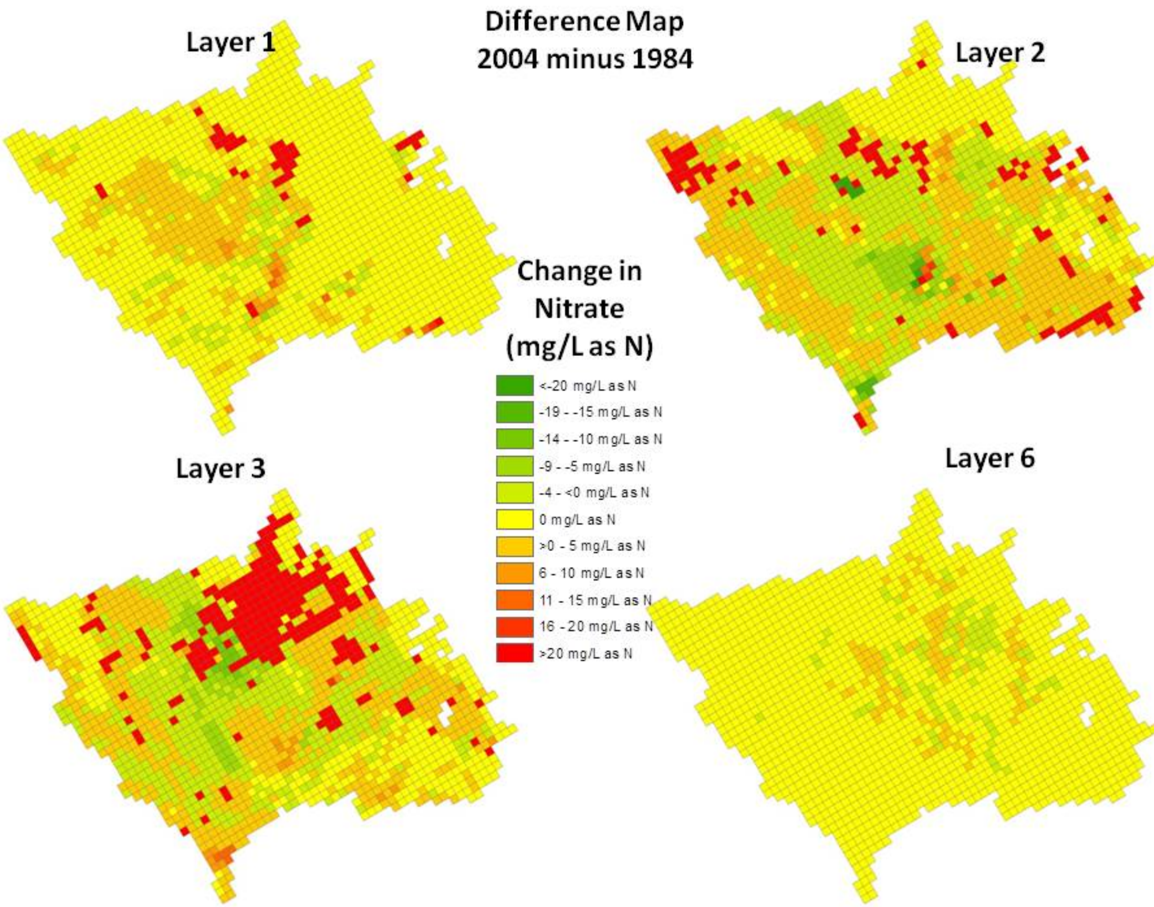


Figure 9-34. Simulated Difference Map Between 2004 and 1984 Nitrate Concentrations, Selected Layers

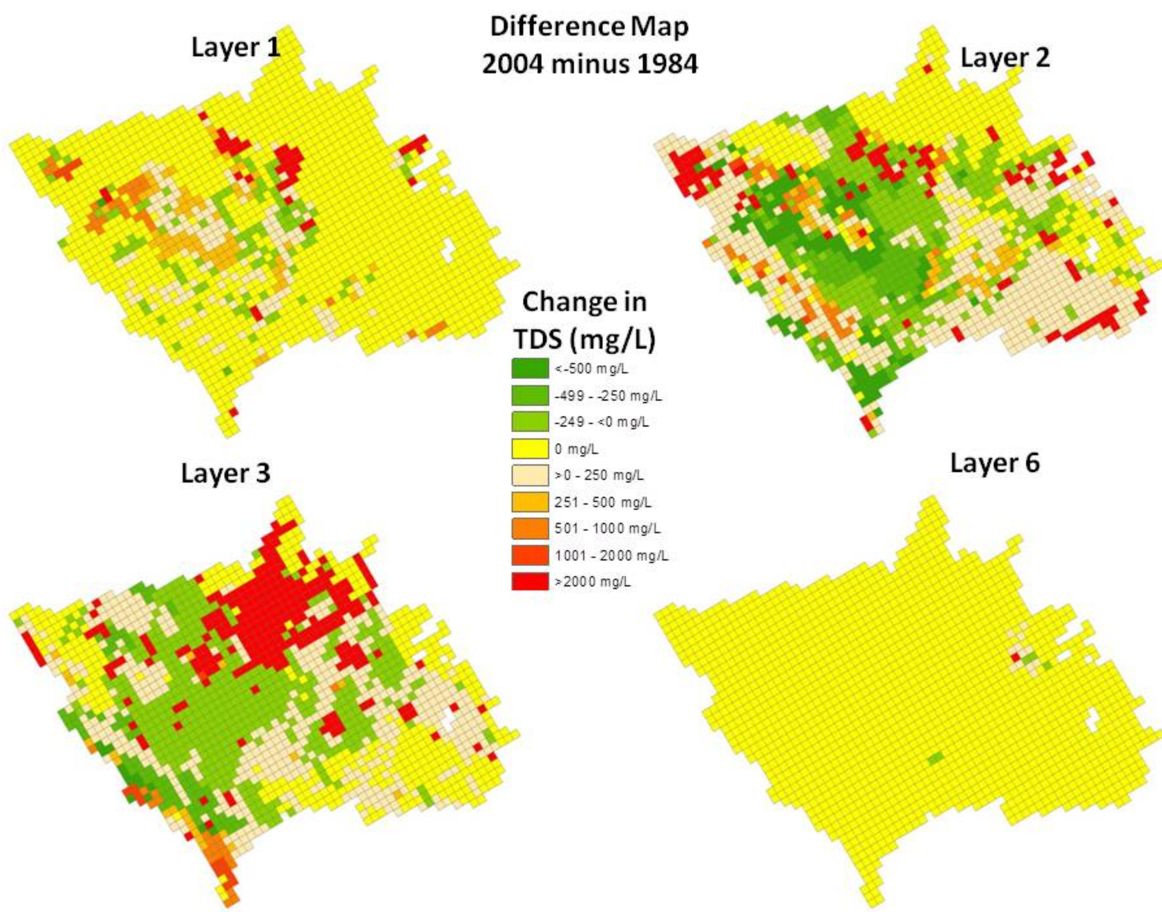


Figure 9-35. Simulated Difference Map Between 2004 and 1984 TDS Concentrations, Selected Layers

Comparison of Two Groundwater Flow Models

The Kings Subbasin prototype area is comprised of model cells from CVHM. The KRCD also developed an Integrated Groundwater Surface Water Model (IGSM) model for the same main footprint. A comparison of the general properties of the two models is provided below as an example of the differences and similarities between two different model platforms. Particle tracking capabilities are not available for IGSM models with concentrations at this time, and so the CVHM model was selected for this analysis.

The IGSM model consists of 32 zones and three model layers. The zones were overlain upon the CVHM grid in order to match up the CVHM grid cells and layers that correspond to the IGSM zones. Zonebudget was then used to extract the water budget for the matching areas from the CVHM model in order to compare the water budgets between the two models. **Figure 9-36** shows the model zones for the King's IGSM on the left, with the approximate coverage of the zones in the CVHM model on the right. The water budget results are shown in **Table 9-8**, showing the average annual flow component from each model.

On a zone-by-zone basis, the models differ in the amount of flow simulated for each component of the water budget. However, as a whole, both models simulate roughly similar amounts of water flow. Results show that CVHM simulates 20% more pumpage from urban environments compared to the King's IGSM, and 38% less pumpage from agriculture. As a whole, CVHM simulates 30% less groundwater pumpage than the King's IGSM. For surface water, CVHM simulates 39% more leakage to groundwater from streams and rivers in the King's subbasin. Lastly, the amount of recharge from the land surface (Farm Recharge) is very similar between the models, with CVHM simulating only 8% less than the King's IGSM.

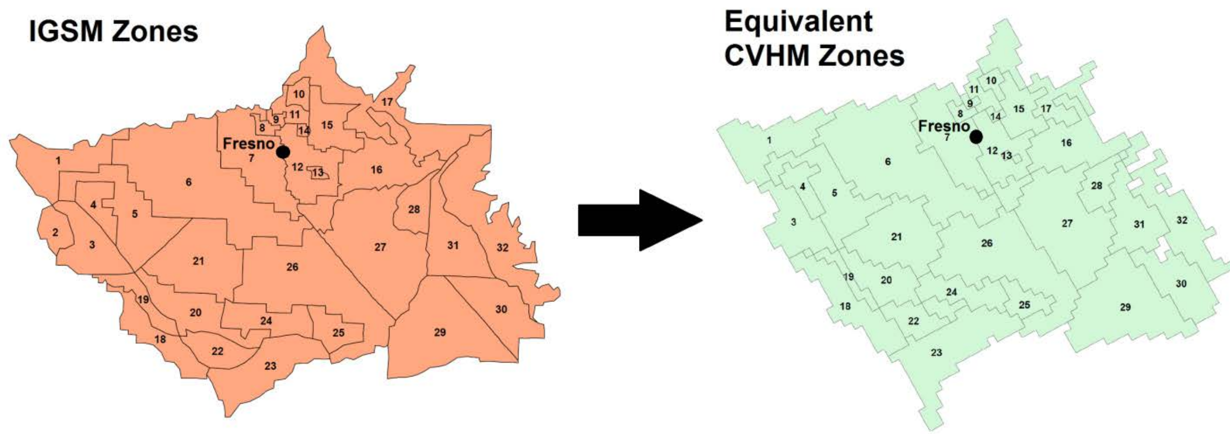


Figure 9-36. IGSM and Equivalent CVHM Model Zones

Table 9-8. Comparison of Water Budgets for the Kings IGSM and Equivalent Kings Subbasin Model Area from CVHM

Units in Thousands of Acre-feet	IGSM					CVHM				
Zones	Urban Pumpage	Ag Pumpage	Total Pumpage	Stream Leakage	Farm Recharge	Urban Pumpage	Ag Pumpage	Total Pumpage	Stream Leakage	Farm Recharge
1	0.00	73.13	73.13	54.21	16.08	1.12	39.91	41.03	57.45	27.80
2	0.14	8.37	8.51	0.00	6.62	0.00	0.00	0.00	0.00	0.00
3	0.53	12.76	13.29	4.45	17.58	13.66	40.51	54.17	44.08	25.29
4	0.00	47.49	47.49	0.00	8.94	4.02	8.45	12.46	0.00	11.84
5	0.00	168.26	168.26	3.34	27.38	1.79	93.03	94.81	0.00	36.30
6	3.13	132.86	135.99	55.90	113.75	10.14	124.77	134.91	1.34	90.46
7	56.20	20.10	76.30	28.24	16.81	58.82	9.21	68.03	0.77	19.08
8	8.38	0.31	8.69	0.00	0.18	9.09	0.00	9.09	0.00	1.21
9	3.25	0.23	3.48	2.00	0.13	4.55	0.00	4.55	0.12	0.63
10	4.43	1.64	6.07	0.77	2.78	2.60	0.35	2.95	0.00	2.48
11	13.95	2.79	16.74	4.16	2.05	7.01	0.65	7.66	0.41	2.88
12	86.71	14.85	101.55	22.98	13.25	48.79	1.12	49.91	0.00	10.53
13	19.52	0.50	20.02	1.51	0.76	2.31	0.01	2.32	0.00	0.34
14	6.08	2.54	8.63	0.20	3.68	3.11	0.02	3.12	0.00	0.61
15	18.31	14.84	33.15	7.84	13.26	16.30	1.26	17.56	0.00	7.57
16	5.08	59.11	64.19	35.13	46.34	3.44	6.80	10.24	-1.25	33.35
17	11.22	5.25	16.47	-43.98	27.39	3.95	1.07	5.02	0.40	7.10
18	0.00	61.06	61.06	9.46	9.58	31.29	8.45	39.74	10.38	28.83
19	0.00	26.45	26.45	12.91	5.09	7.59	0.01	7.60	18.74	9.89
20	0.00	64.17	64.17	1.05	23.83	4.16	0.05	4.21	24.33	27.35
21	0.03	191.74	191.77	0.00	41.33	15.61	238.95	254.56	0.00	40.74
22	0.62	46.36	46.97	0.00	11.47	0.00	6.80	6.80	8.29	15.67
23	0.31	92.03	92.34	39.89	43.45	12.29	39.48	51.77	33.10	59.61
24	0.00	82.74	82.74	0.00	22.51	7.41	35.89	43.30	0.00	20.85
25	0.00	59.30	59.30	22.64	16.07	7.56	21.71	29.27	0.00	12.81
26	2.78	140.43	143.22	28.14	100.78	3.52	127.77	131.29	6.07	75.21
27	15.73	91.18	106.91	-3.50	90.87	22.95	102.92	125.87	9.01	72.18
28	2.04	10.38	12.24	-14.94	20.17	0.00	17.78	17.78	191.12	9.17
29	2.54	128.22	130.75	22.39	68.42	2.75	70.29	73.04	4.75	83.46
30	5.73	53.94	59.67	6.88	33.53	7.25	8.37	15.63	0.00	33.88
31	6.20	63.22	69.41	2.37	40.19	11.33	29.70	41.03	4.86	31.05
32	1.22	16.28	17.49	-4.11	43.76	3.24	18.08	21.33	1.71	22.98
Total:	**274.13**	**1692.50**	**1966.43**	**299.94**	**888.02**	**327.63**	**1053.41**	**1381.04**	**415.68**	**821.17**
					CVHM/IGSM	**120%**	**62%**	**70%**	**139%**	**92%**

9.3 SUMMARY

This section describes the methodology and results of the prototype area analyses. Two prototype areas were analyzed for the ICM (Merced/Stanislaus area and the Kings Subbasin). The two prototype areas were unique and the tools developed for their analysis were also unique, using a much more refined resolution interpretation. The Merced/Stanislaus area covered the area of an existing USGS groundwater flow model, called the "Modesto Regional Model". This model is different from CVHM, which was used for the IAZ analysis (and the Kings Subbasin analysis). The Merced/Stanislaus area also had WARMF coverage to achieve mass values for groundwater recharge. The Kings Subbasin, on the other hand, had no publicly available local groundwater flow model, so CVHM was elected to be used. Also, the Kings Subbasin did not have any WARMF coverage, so recharge masses and concentrations were interpolated from other nearby WARMF areas on a cell-by-cell basis.

The scale of the prototype analyses was either ¼ mile square for the Modesto Regional Model grid, or 1 square mile for the Kings Subbasin (CVHM grid size), which means that all of the groundwater quality and mass loading information was also developed at this finer scale. The Modesto Regional Model was used in conjunction with particle tracking and the USGS MODPATH-OBS package to attach concentrations to particles. Particles were assigned to monitored wells and sent backwards in time until they reached their recharge area (at the water table). Recharge concentrations associated with that recharge area were used to simulate expected concentration of TDS and nitrate as N in each well. These simulated concentrations were compared with measured concentrations in the same well to determine how well they compare.

For the Kings Subbasin, CVHM was paired with particle tracking, except instead of a well-specific analysis, each cell was assigned a particle during each quarterly time step to determine the movement of salt and nitrate in the subsurface. At each quarter, particles present in each cell were averaged together to achieve a simulated concentration associated with each cell. These concentrations change over time as particles with various concentrations move in or out of cells.

The Modesto Regional Model simulation results were compared to measured concentrations. The simulated NO_3-N concentrations were low compared to the measured NO_3-N concentrations in the USGS observation wells. The simulated TDS concentrations compared better to the measured TDS concentrations in the USGS observation wells. Unlike the IAZ analyses in Task 6, the Task 7 Modesto area analysis did not include multiple mass loading scenarios to assess whether increasing the nitrate mass would result in a better correlation between simulated results and actually observed nitrate concentrations. The "proof of concept" level of analysis also did not include recalibrating the model for either groundwater flow or mass transport.

Kings Subbasin simulation results illustrated the "proof of concept" approach can be used to illustrate and quantify concentration of salt and nitrate in groundwater and identify areas where concentrations are increasing, decreasing, or remaining stable. It was learned that this approach was limited by the transient nature of the CVHM model, which constrains the distance water can move and take with it a particular concentration of salt and nitrate. Future local area model simulations would benefit from a model that allows for a sufficiently long simulation period.

10. Phase I Findings and Recommendations for Phase II

The purpose of this section is to identify the required elements of the SNMP, describe how CV-SALTS is phasing the development of the necessary SNMP elements, summarize the key findings from the Phase I - ICM work effort, and provide recommendations for Phase II – the development of the initial draft SNMP so that it meets the Recycled Water Policy requirements.

10.1 DEVELOPMENT OF THE CENTRAL VALLEY SALT AND NITRATE MANAGEMENT PLAN (SNMP)

The State Water Resources Control Board (SWRCB), in its Recycled Water Policy (Policy)[70], established the requirement to develop regional or subregional salt and nutrient management plans (SNMPs)[71]. The Policy states:

> *"It is the intent of this Policy that salts and nutrients from **all sources be managed on a basin-wide or watershed-wide basis** in a manner that ensures attainment of water quality objectives and protection of beneficial uses. The State Water Board finds that the appropriate way to address salt and nutrient issues is through the **development of regional or subregional salt and nutrient management plans** rather than through imposing requirements solely on individual recycled water projects." [emphasis added]*

The SNMPs must be completed and proposed to the Board by May 2014, unless the Regional Board finds that the stakeholders are making substantial progress towards the completion of a plan[72]. In those cases the SNMPs must be completed and proposed to the Board by approximately May 2016.

The key elements of an SNMP, as defined in the Policy, must include the following:

- A basin/subbasin wide monitoring plan with an appropriate network of monitoring locations;
- A provision for annual monitoring of Constituents of Emerging Concern (CECs);
- Water recycling and stormwater recharge/use goals and objectives;
- Salt and nutrient source identification, basin/subbasin assimilative capacity and loading estimates, together with the fate and transport of salts and nutrients;

[70] SWRCB Resolution 2009-0011 was adopted February 2009. The Office of Administrative Law (OAL) approved the Policy in May 2009. SWRCB Resolution 2013-003, an amendment to the Policy, was approved April 2013. http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2013/rs2013_0003_a.pdf

[71] Section 6.a.(2)

[72] This determination will likely be subject to a formal Board action.

- Implementation measures to manage salt and nutrient loading in the basin on a sustainable basis; and
- An antidegradation analysis[73].

In addition to those elements required pursuant to the Policy, the SNMP may also include additional information such as introduction and purpose, groundwater basin characteristics, water balance, and a comprehensive implementation plan.

Consistent with the Policy, CV-SALTS is developing an SNMP for the Central Valley Regional Water Quality Control Board's jurisdictional boundaries. The SNMP will identify the approach and establish the basis for the management of salt and nitrate[74] in the Central Valley region. In order to develop the SNMP, a phased approach is being used. The phases of development and the corresponding schedules are identified in **Figure 10-1** and include the following:

- Phase I – Initial Conceptual Model: The goal of the ICM is to produce a 30,000 foot level, 'c*oncept level'* analysis of water balance, and to estimate salt and nitrate load balances for the Central Valley floor in 22 areas of analysis that, for purposes of the ICM, are referred to as Initial Analysis Zones (IAZs).

- Phase II - Development of the Draft SNMP: Phase II will utilize the data collected and/or organized as well as the methods and results developed as a part of the ICM. The Phase II SNMP will provide refined spatial detail in some locations for the water balance, salt, and nitrate modeling of the Central Valley floor, as represented by the mid-size puzzle pieces. This phase will also be informed by the work that is completed under ICM Task 7, the prototype "proof of concept" analyses of the Stanislaus/Merced area and Kings Subbasin.

- Phase III – Regulatory Approval Process: During Phase III the SNMP will be finalized and the documents that are necessary for the regulatory approval process for the adoption of the SNMP will be developed and submitted as a part of the BPA. This will include the development of the California Environmental Quality Act (CEQA) equivalent documents, the economic analysis of implementation alternatives, an antidegradation analysis, and the proposed BPA and staff report[75].

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[73] In order for the Regional Water Board to issue a new NPDES permit the Board must determine whether the discharges comply with the antidegradation provisions of 40 CFR 131.12 and State Water Board Resolution 68-16.

[74] The Central Valley SNMP will focus on salt and nitrate. "Nutrients" will be addressed within the Central Valley through other regulatory mechanisms using technical approaches currently under development, such as the nutrient numeric endpoints process.

[75] For the purposes of this Report, Phase III includes the following items from the CV-SALTS Workplan budget: Phase III (surveillance and implementation 13242, economic analysis, antidegradation analysis) and Documentation Basin Plan Amendment (CEQA equivalent SED and Basin Plan Staff Report, Final SNMP documentation and changes).

- Development of the Local SNMPs: It is anticipated that, upon completion of Phase III and the adoption of the comprehensive SNMP, local-scale SNMPs (Local SNMPs) may be developed and implemented by local and/or regional entities as needed. The Local SNMPs will be informed by prototype and archetype methods as well as the implementation measures recommended in the SNMP.

The SNMP will be the salt and nitrate management plan adopted for the entire Central Valley Regional Board jurisdiction. The SNMP will utilize information from the Phase I work and supplements that information with additional work performed under Phases II and III. The relationship between the phased work being conducted for the SNMP and the Policy required elements of the SNMP as described above are outlined in **Table 10-1**.

While the Phase I work completed the analyses at the IAZ scale for the CV floor and tested prototype tools for two subareas with refined spatial analysis, additional work is necessary during Phase II, based on the findings from Phase I, in order to develop the background information, continue the refined analyses in prioritized and/or archetype areas, and/or to develop the approach/methods that are necessary for the various components of the SNMP. This is further detailed in sections below.

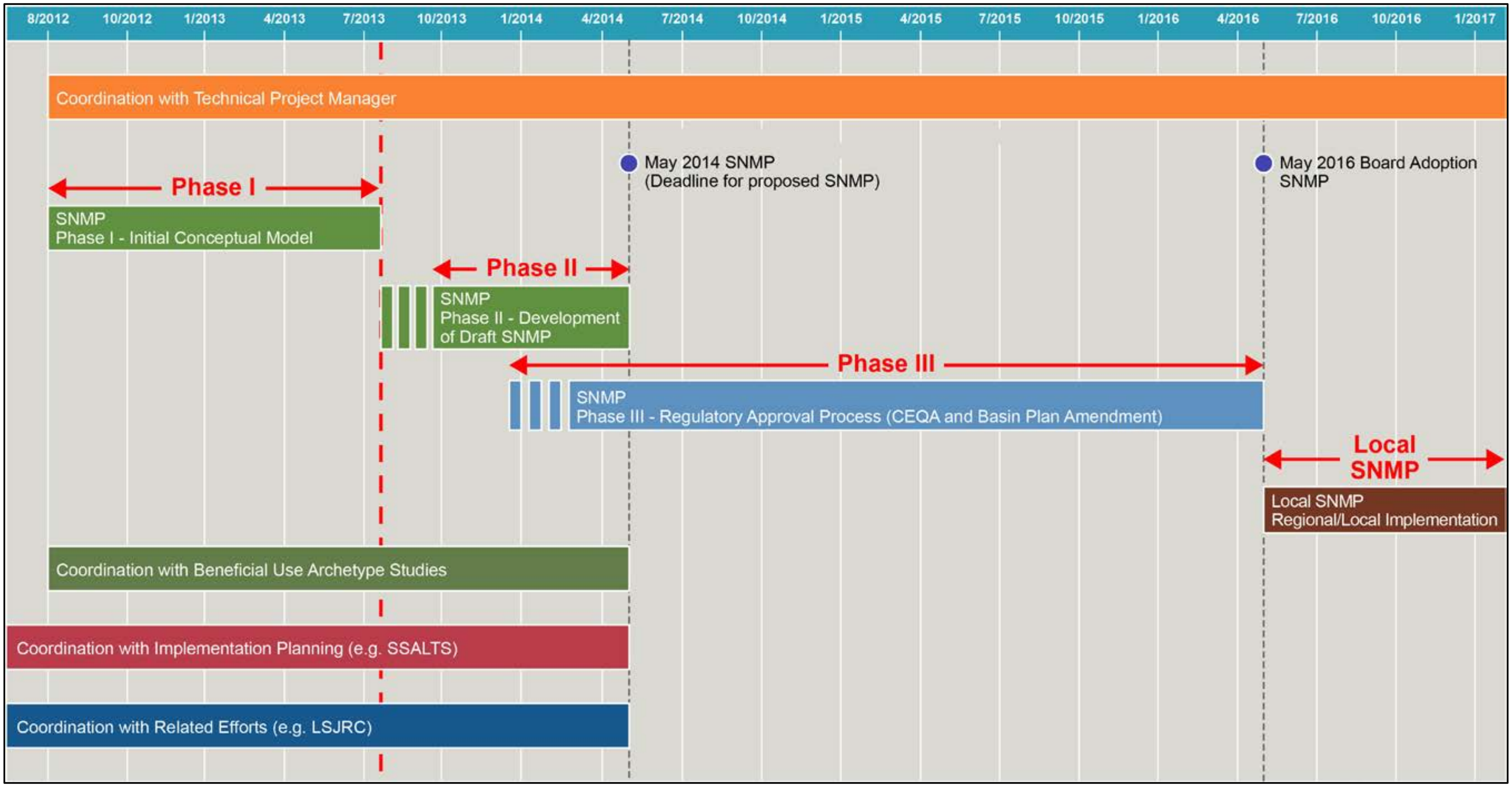

Figure 10-1. CV-SALTS Timeline for the Development of the SNMP

Table 10-1. Comparison of the Recycled Water Policy Requirements and the Phased Development of the Central Valley SNMP[76]

<table>
<tr><th colspan="2">Recycled Water Policy Requirements – The SNMP Must Include the Following:</th><th colspan="3">Development of the Central Valley Salt and Nitrate Management Plan (SNMP)</th><th rowspan="2">Regional/Local Implementation</th></tr>
<tr><th>General Requirements</th><th>Sub-elements</th><th>Phase I – Initial Conceptual Model (ICM)</th><th>Phase II – Development of the Draft SNMP</th><th>Phase III – Regulatory Approval Process</th></tr>
<tr><td colspan="2">Recycled Water Policy and Background Information</td><td>No activity</td><td>The SNMP will include additional information such as:
• Background
• Basin Characterization
• Water Balance
• Comprehensive Implementation Plan</td><td>No activity planned</td><td>SNMP: The baseline information is provided in the SNMP.

Local SNMP Developed: Local SNMPs may provide additional, local information.</td></tr>
<tr><td colspan="2">Water recycling and stormwater recharge/use goals and objectives [6.b.(3)(c)]</td><td>No activity</td><td>The goals and objectives will be included in the SNMP.</td><td>No activity planned</td><td>SNMP: General activities to support the goals and objectives are specified.

Local SNMP Developed: Local SNMPs will include specific activities to support the goals and objectives.</td></tr>
<tr><td rowspan="4">Salt and Nutrient Characterization [6.b.(3)(d)]</td><td>Source Identification</td><td rowspan="3">Completed at IAZ scale for CV floor and preliminarily at refined scale in two subareas</td><td rowspan="3">Continued refinement in prioritized and/or archetype areas</td><td rowspan="3">No activity planned</td><td rowspan="4">SNMP: The methodologies and information are provided in the SNMP.

Local SNMP Developed: Local SNMPs may complete additional analyses to further refine the information</td></tr>
<tr><td>Loading Estimates</td></tr>
<tr><td>Fate and Transport</td></tr>
<tr><td>Basin/subbasin Assimilative Capacity (AC)</td><td>Initiated at IAZ scale for CV and at refined scale in two subareas</td><td>Develop methods for evaluating AC; use in prioritized and/or archetype areas</td><td>No activity planned</td></tr>
<tr><td colspan="2">Implementation measures to manage salt and nutrient loading in the basin on a sustainable basis [6.b.(3)(e)]</td><td>No activity</td><td>The SNMP will include the implementation measures currently being evaluated by SSALTS.

Additional measures may be identified as a part of the archetypes.</td><td>No activity planned</td><td>SNMP: General implementation measures are specified.

Local SNMP Developed: Local SNMPs will include specific implementation measures.</td></tr>
<tr><td>Basin/Subbasin Monitoring Plan (MP) [6.b.(3)(a)]</td><td>Must address salts, nutrients, and other constituents of concern as identified in the SNMP</td><td>Groundwater and surface water data were obtained. This will support the development of the MP.</td><td rowspan="2">General approach for monitoring will be described. More detailed monitoring plans will be submitted by local stakeholders consistent with the approach in the SNMP.</td><td rowspan="2">No activity planned</td><td rowspan="2">SNMP: The general monitoring approach and plan is specified.

Local SNMP Developed: Detailed monitoring plan is submitted to along with Local SNMP.</td></tr>
<tr><td colspan="2">Monitoring of Constituents of Emerging Concern (CECs) [6.b.(3)(b)]</td><td>No activity</td></tr>
<tr><td colspan="2">Antidegradation analysis demonstrating that the projects included within the plan will collectively satisfy the requirements of Resolution No. 68-16 [6.b.(3)(f)]</td><td>No activity</td><td>Develop methods for antidegradation analysis.</td><td>Complete analysis to satisfy SNMP requirements.</td><td>No activity planned</td></tr>
</table>

[76] For the purposes of this Report, Phase III includes the following items from the CV-SALTS Workplan budget: Phase III (surveillance and implementation 13242, economic analysis, antidegradation analysis) and Documentation Basin Plan Amendment (CEQA equivalent SED and Basin Plan Staff Report, Final SNMP documentation and changes). The phasing as described in this Report is consistent with the previous work products completed pursuant to the ICM Workplan.

10.2 KEY PHASE I - INITIAL CONCEPTUAL MODEL (ICM) FINDINGS AND OUTCOMES

As part of the ICM, two approaches were used to assess salt and nitrate sources, trends, and transport in the Central Valley.

- One approach, the 30,000 foot conceptual approach (Task 6), examined the salt and nitrate loading and transport mechanisms on the scale of the entire Central Valley floor. Twenty-two IAZs were evaluated to assess salt and nitrate accumulation, depletion, or stable trends in surface water and groundwater over a twenty-year period for each IAZ as well as transport between IAZs (**Figure 10-2** and **Table 10-2**).
- The other approach (Task 7) examined two prototype areas, the Merced/Stanislaus area and the Kings Subbasin, which were identified as areas of interest by CV-SALTS, to develop templates for data analysis methods and modeling tools to characterize water, salt, and nitrate balances, including accumulation and depletion, on a more spatially refined level compared to the IAZ-scale (**Figure 10-2**).

Key findings and outcomes derived from the IAZ-scale and spatially-refined prototype scale are summarized below.

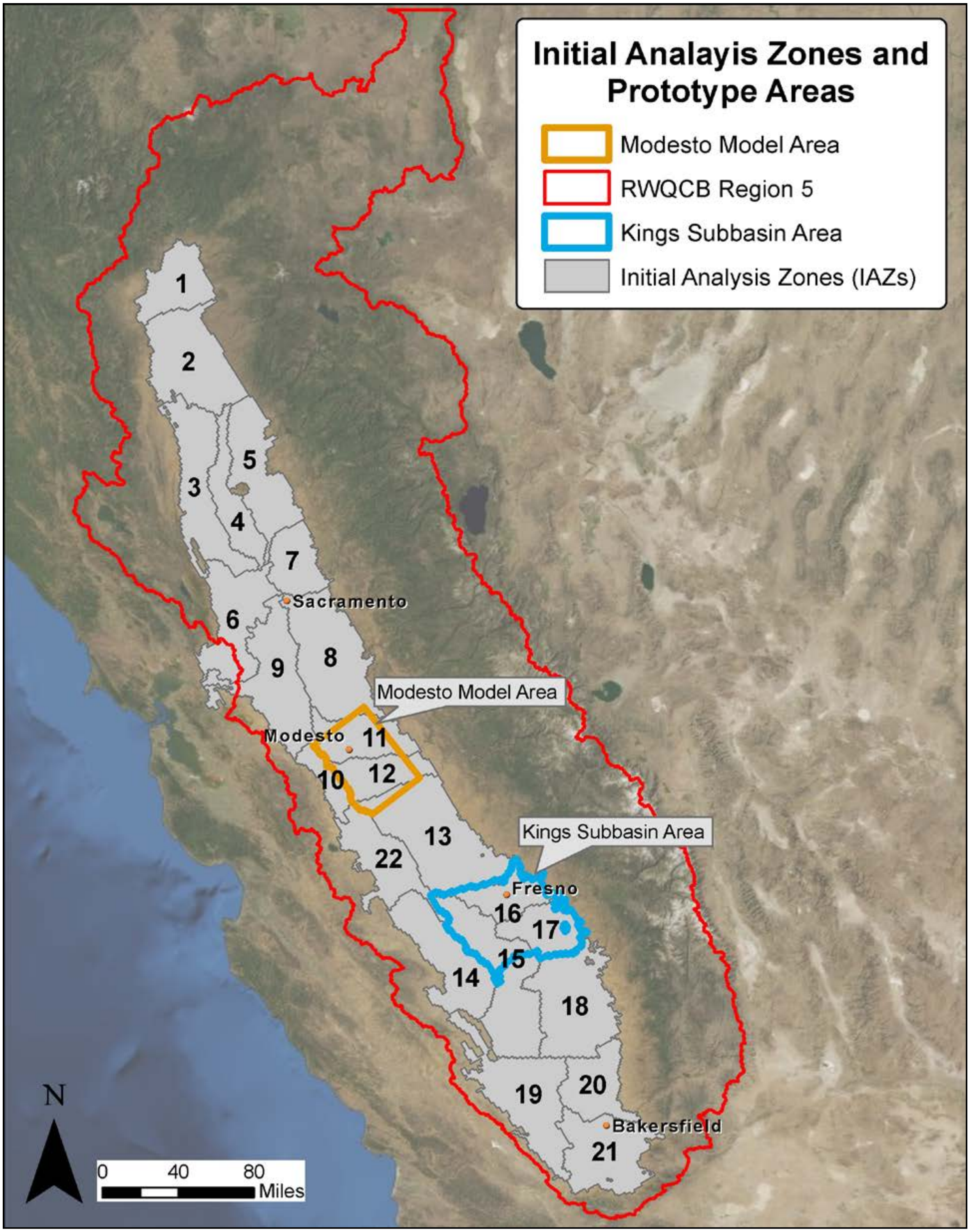

Figure 10-2. Initial Analysis Zones and Prototype Areas

Table 10-2. IAZ Descriptions

	IAZ	Initial Analysis Zone Description
Northern Central Valley	1	Sacramento River above Red Bluff
	2	Red Bluff to Chico Landing
	3	Colusa Trough
	4	Chico Landing to Knights Landing proximal to the Sacramento River
	5	Eastern Sacramento Valley foothills near Sutter Buttes
	6	Cache-Putah area
	7	East of Feather and South of Yuba Rivers
Middle Central Valley	8	Valley floor east of the Delta
	9	Delta
	10	Delta-Mendota Basin - Northwest Side
	11	Modesto and southern Eastern San Joaquin Basin
	12	Turlock Basin
	13	Merced, Chowchilla, and Madera Basins
	22	Delta-Mendota Basin - Grassland
Southern Central Valley	14	Westside and Northern Pleasant Valley Basins
	15	Tulare Lake and Western Kings Basin
	16	Northern Kings Basin
	17	Southern Kings Basin
	18	Kaweah and Tule Basins
	19	Western Kern County and Southern Pleasant Valley Basin
	20	Northeastern Kern County Basin
	21	Southeastern Kern County Basin

Task 6 Highlights – Key Water, Salt, and Nitrate Balance Findings for the Initial Analysis Zones

It is important to recognize that the effort undertaken during the development of the ICM is the first time that water quality (salt and nitrate) and quantity (surface water and groundwater, including their interaction) has been simulated for the entirety of the Central Valley floor. It is also important to recognize the benefits and limitations of simulations made at this aggregated or coarser IAZ scale. For example, any apparent trends indicated at the IAZ scale are subject to change based on the limited data that are available. In most IAZs, the addition of a few dozen well tests from new wells has the possibility to change an analysis significantly. In order to perform adequate salt and nutrient management at a practical (local) scale, datasets should be supplemented with additional data that may not be readily available from public databases.

At the outset of Task 6, decisions made, with the concurrence of the Project Committee, provided the foundation for the IAZ-scale modeling approach. The key decisions included:

- It was agreed that the USGS groundwater flow model, CVHM, would provide the basis for the hydrologic components for the simulation effort.
- It was understood that the compressed schedule for the ICM work effort dictated the need to use existing CVHM inputs, i.e., no new hydrologic inputs and recalibration could be accommodated.
- Since the quality (mass) components were not a part of CVHM and, since WARMF domains had been developed and utilized for other purposes over a large part of the Central Valley, it was agreed that WARMF along with non-WARMF extrapolation approaches would be used to provide the mass loading recharge inputs for the IAZ-scale simulations.
- It was agreed that the spatial boundary of the IAZs would be acceptable for the ICM work effort. As described in Section 2, these boundaries have a hydrologic basis as they relate directly to the water balance regions that have been used by DWR. In addition, similar boundaries were also employed by the USGS for the 2009 CVHM (additional smaller regions are being developed by the USGS for a new version, CVHM-2).

The key findings and results from Task 6 are listed below.

- <u>Post Processing Databases Were Developed</u> - At the outset of the project, it was determined that the individual spreadsheet approach for computing flow and mass balances for each IAZ would not suffice; it would not adequately account for the interplay between IAZs. The massive amount of mass inputs and hydrologic information that needed to be computed for a quarterly 20-year period not only for each IAZ, but accounting for movement between IAZs on a temporal basis, necessitated the development of a database used in conjunction with a series of tables and queries to perform all of the groundwater, salt, and nitrate calculations. A separate database was developed to do the same for surface water. Multiple databases were also developed for each nitrate (six databases) and TDS (three databases) scenario as well.

- <u>Mixing Volume was Individually Computed for each IAZ</u> - Based on discussions with the Project Committee, the IAZ mixing volume for shallow groundwater was individually computed for each IAZ, and on a 1-square mile cell-by-cell basis, using aquifer properties assigned in CVHM. A twenty-year vertical travel distance was computed for each active CVHM model cell. With this approach, each IAZ had an irregular bottom surface computed which resulted in greater spatial resolution compared to qualitatively selecting one or more CVHM layers to represent the entire IAZ. The average thickness of the IAZs ranged from 55 to 481 feet, while the average saturated thickness of the IAZs ranged from 58 to 180 feet. The selection of the IAZ volume is important as the ambient salt and nitrate groundwater quality and simulation results computed for this volume also serve as the basis for the relative prioritization of the IAZs with respect to future salt and nitrate management efforts and also for the preliminary assessment of assimilative capacity.

- <u>Available Ambient Groundwater Quality Data Varied</u> - Ambient groundwater quality was established using available online data from a number of sources. It was found that the available data ranged from "adequate" to "somewhat adequate" for the 22 IAZs when all well types and depths are considered. For all tested well depths, 16 IAZs were considered to have adequate areal salt and nitrate data, while data were somewhat adequate for salt in 6 IAZs and for nitrate in 9 IAZs. The suitability of areal and temporal data for shallow[77] wells was more problematic with no IAZs considered to have adequate data; rather data were considered either somewhat adequate or not adequate (IAZs 1, 10 and 20 especially lacked shallow nitrate data).
- <u>Estimating Ambient Shallow Groundwater was Problematic Due to Limited Amount of Shallow Groundwater Data</u> - Shallow ambient groundwater quality data were very limited for the Task 6 analysis. Shallow groundwater quality is highly variable and the spatial extent of available data did not permit the use of interpolation techniques (shallow well data can be 10s of miles apart). The annual median concentrations for shallow wells located within a CVHM cell were used to estimate ambient shallow groundwater quality (see Section 4.2 regarding declustering method). Initially, starting masses for each IAZ were calculated using only data from around the 1983 starting period. This resulted in many of the estimated initial masses to be either very large, or very small, as the calculations were based only a very small amount of well test data. Due to the limited shallow groundwater quality data in space and in time, all shallow data within an IAZ were included in estimating a starting concentration for the mixing model. The initial concentration for shallow groundwater was estimated by taking the average of the shallow annual CVHM grid cell median concentrations for each IAZ over all time periods. When data were included from all time periods, the initial masses better reflected the overall water quality for each IAZ, and thus provided an appropriate initial starting point for the mixing model. Additionally, the shallow groundwater volumes used in the mixing model were established using a 20-year vertical travel distance. Therefore, the final concentration and mass calculated at the end of the 20-year mixing model should

[77] Shallow is based on known well types that are likely of shallower completion (as described in Section 3) and/or well depths, as available. The latter was evaluated with respect to each IAZs vertical dimension as calculated for the 20-year vertical travel time.

only be a reflection of the loading inputs to the model during 20 years. Only the final concentration and final mass were used for identifying priority basins in Section 7.

- The Hydrology and Mass Fluxes Between CVHM and WARMF Needed to be Considered and/or Reapportioned - Since the CVHM hydrology served as the basis for the IAZ simulations, the hydrology associated with the mass fluxes calculated by WARMF had to be considered to ensure that overlap and double counting of mass inputs did not occur. The fluxes calculated by WARMF also needed to be reapportioned among the flow pathways based on CVHM components. CVHM contains significant groundwater recharge as part of the water budget for all IAZs; WARMF has less recharge in some IAZs and does not include recharge in others. This imbalance was found to affect the mass loading apportioned by WARMF for input to the initial simulations; so mass loading for many IAZs was initially underestimated. CVHM is a calibrated groundwater flow model, whereas WARMF achieves mass balance across a watershed domain based on calibrations using surface water data.

Ambient Conditions Contributed in Identifying Potential High Priority Areas - Ambient groundwater quality was ultimately based on recent shallow median TDS and nitrate data from 2003-2012. Ambient conditions, when considered on the IAZ scale and using all well depths, showed IAZs 10, 11, 12, and 18 as having 40% or more of the CVHM cells (out of those that did contain well test data for nitrate) with a well NO_3-N concentration over 10 mg/L, and IAZs 9, 10, 22, 14, and 19 having more than 60% of the CVHM cells (out of those that did contain well test data for TDS) with a well TDS concentration over 500 mg/L (**Table 10-3**)[78]. The results from the previous analysis were also used to show the spatial extent of the available water quality data.**Figure 7-18**, **10-3** and **Figure 10-4** show the cells that contain well test data, with the red cells containing a well test over a threshold. While the maps provide a useful visualization of spatial water quality trends, two important biases should be noted. The first is that the maps are based on the groundwater quality data that were available at the time of analysis. Some areas may have poor water quality, but the number of wells with groundwater quality data may be limited (for example the western portion of the San Joaquin Valley). Therefore, the analysis is limited by the data availability. The second bias is due to the inclusion of the RWQCB (WDR Dairy Data) dataset. This dataset includes more shallow domestic and monitoring wells in rural areas, compared to the other groundwater quality data sources; therefore, these data may over represent water quality in rural areas. Acknowledging these limitations and biases, the maps still provide perspective on groundwater quality trends at a large scale. The maps also provide an important visualization of the spatial extent of available groundwater quality data and where data gaps may exist.

[78] The ratio is the number of cells with a well over a threshold, divided by the total number of cells that contained data. This analysis estimates the spatial extent of the elevated concentrations, or the overall fraction of the IAZ that is elevated in either nitrate or TDS without allowing clusters of wells bias the analysis.

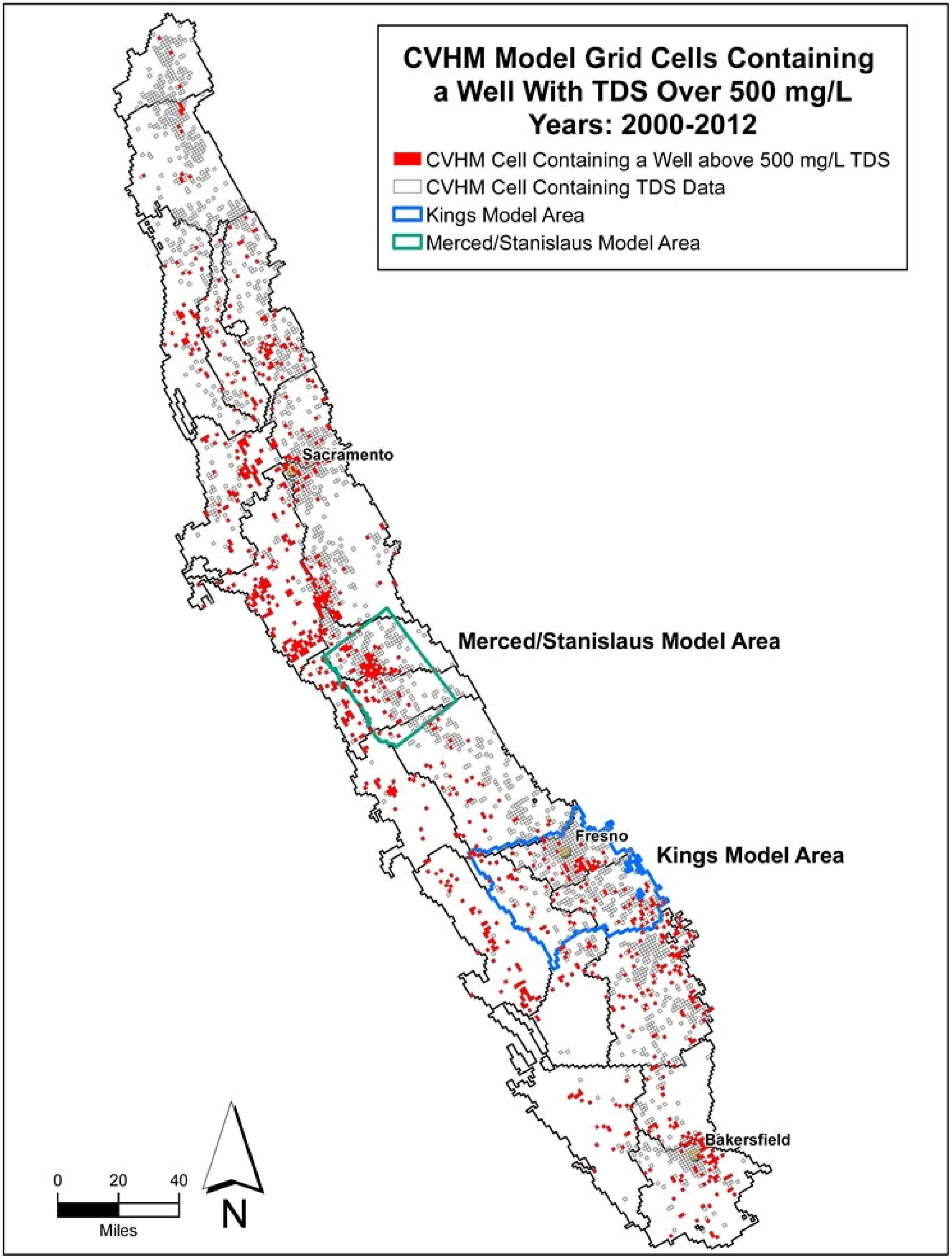

Figure 10-3. Identifying CVHM Model Grid Cells Containing a Well Test Over 500 mg/L TDS from 2000-2012

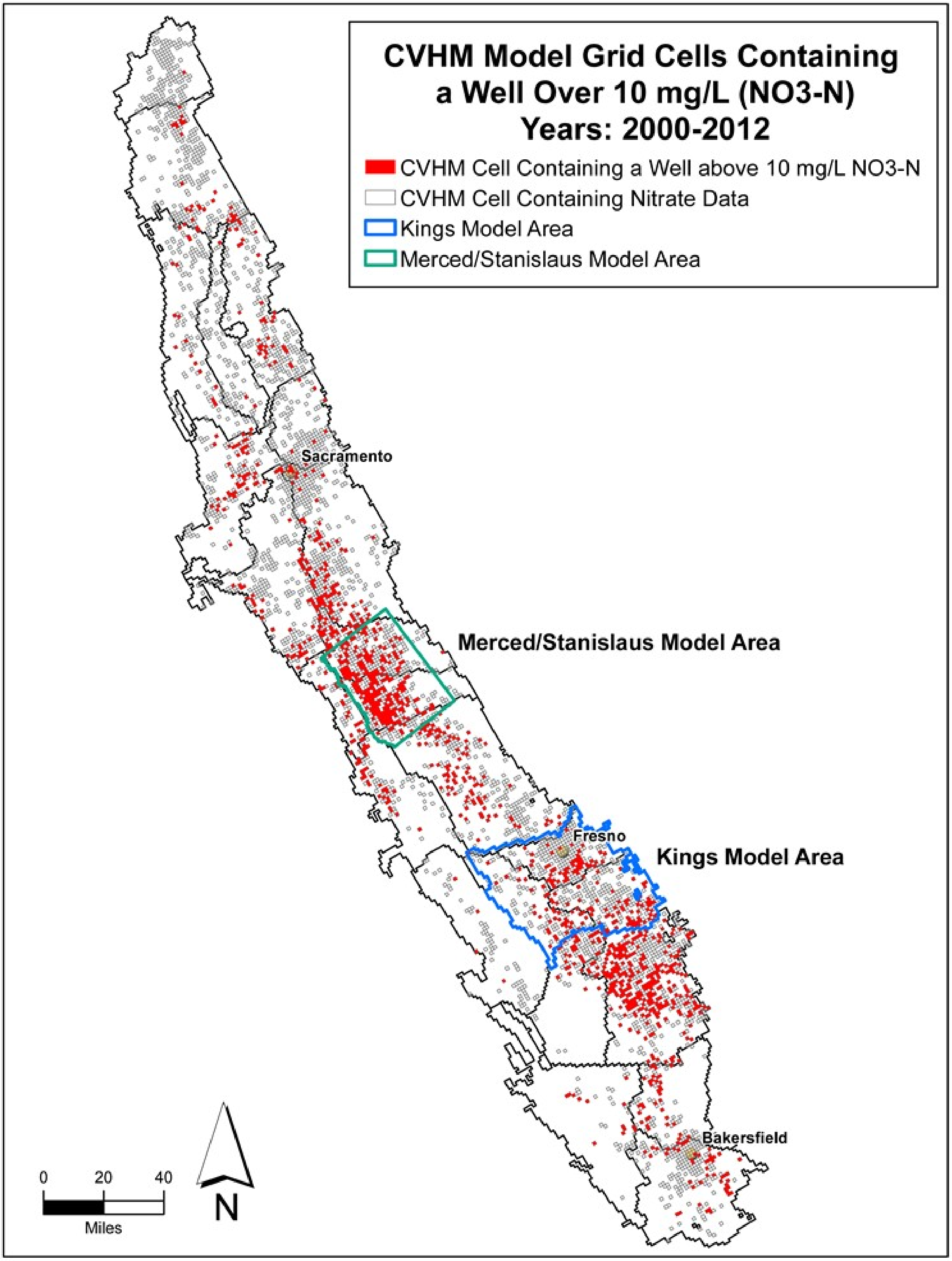

Figure 10-4. Identifying CVHM Model Grid Cells Containing a Well Test Over 10 mg/L NO3-N from 2000-2012

Table 10-3. Percent of CVHM Grid Cells Containing a Well over a Threshold

		Ambient Nitrate Concentrations				Ambient TDS Concentrations							
		Number of CVHM Grid Cells Containing A Well Over 10 mg/L (NO3-N) Divided By The Number of Grid Cells Containing Well Test Data				Number of CVHM Grid Cells Containing A Well Over 500 mg/L (TDS) Divided By The Number of Grid Cells Containing Well Test Data				Number of CVHM Grid Cells Containing A Well Over 1000 mg/L (TDS) Divided By The Number of Grid Cells Containing Well Test Data			
	IAZ	Before 1960	1960-1979	1980-1999	2000-2012	Before 1960	1960-1979	1980-1999	2000-2012	Before 1960	1960-1979	1980-1999	2000-2012
Northern Central Valley	1	2%	0%	0%	1%	13%	3%	1%	3%	8%	2%	0%	1%
	2	5%	5%	11%	12%	5%	4%	5%	6%	1%	0%	1%	1%
	3	1%	2%	7%	13%	31%	25%	36%	38%	7%	6%	14%	11%
	4	0%	2%	4%	4%	24%	28%	29%	36%	18%	8%	8%	11%
	5	7%	9%	12%	16%	7%	15%	20%	26%	0%	2%	5%	10%
	6	6%	10%	13%	29%	59%	59%	58%	57%	6%	15%	12%	14%
	7	3%	0%	1%	4%	4%	9%	10%	21%	0%	1%	2%	5%
Middle Central Valley	8	1%	3%	3%	24%	10%	6%	6%	25%	0%	0%	0%	7%
	9	8%	18%	24%	22%	78%	84%	69%	80%	39%	50%	30%	37%
	10	6%	11%	30%	40%	81%	91%	95%	90%	26%	45%	45%	53%
	11	4%	10%	21%	46%	17%	20%	23%	33%	5%	4%	3%	11%
	12	5%	13%	32%	62%	30%	31%	27%	29%	13%	9%	8%	6%
	13	2%	4%	7%	33%	12%	18%	11%	20%	7%	6%	3%	6%
	22	3%	9%	43%	38%	87%	90%	92%	88%	63%	63%	83%	35%
Southern Central Valley	14	4%	4%	59%	6%	100%	99%	95%	95%	28%	17%	45%	22%
	15	1%	2%	21%	38%	53%	46%	61%	48%	2%	1%	0%	3%
	16	1%	10%	17%	25%	5%	18%	9%	19%	0%	1%	0%	6%
	17	0%	23%	26%	35%	2%	16%	23%	25%	5%	5%	6%	7%
	18	8%	24%	28%	55%	15%	25%	20%	31%	46%	40%	53%	49%
	19	8%	7%	24%	30%	58%	54%	71%	65%	9%	17%	16%	11%
	20	8%	27%	27%	39%	27%	43%	32%	45%	21%	25%	17%	13%
	21	8%	21%	18%	23%	44%	51%	40%	34%	64%	53%	66%	56%

- The Simulations Identified the Dominant Groundwater Hydrologic Mechanisms Throughout the Central Valley Floor - For most IAZs, recharge from the land surface provides the majority of flow into shallow groundwater. IAZs 4 and 9 are unique in this respect as the majority of flow to shallow groundwater in these areas comes from upward vertical flow from deep groundwater (IAZ 4) and recharge from surface water (IAZ 9). Outflow from shallow groundwater for all IAZs is largely composed of downward vertical flow to deep groundwater and groundwater pumping. For most IAZs, downward vertical flow outpaces groundwater pumping with the exception of IAZs 15 and 18 which show significant amounts of groundwater pumped from shallow groundwater. Results for IAZs 1 through 5 in the northern portion of the Central Valley indicate that a large fraction of outflow from shallow groundwater is to surface water under gaining stream conditions. These hydrologic mechanisms are significant; for the northern part of the Central Valley, this means there is mass that moves from the shallow aquifer to surface water via gaining stream conditions. This lessens the potential for downward vertical flow into the deeper part of the aquifer system in these areas; therefore, there is less potential for accumulating mass and decreasing groundwater quality over time. However, for most other IAZs, the cumulative mass recharged to the shallow aquifer is very similar to the cumulative mass transported via downward vertical flows to the deeper part of the aquifer system. In IAZs where this is the predominant mechanism, the water quality condition of the shallow aquifer may, barring thick low permeability intervening units such as the Corcoran Clay member, indicate the trends that may ultimately also occur in the deeper portion of the aquifer system (**Figure 10-5)**.
- Southern Central Valley has a Relatively Greater Magnitude of Nitrate Loading - On a per acre basis, IAZs 14 through 21 in the southern Central Valley have relatively greater magnitudes of nitrate loading compared to the northern and middle portions of the Central Valley (**Table 10-4**). For the northern and middle portions of the Central Valley, IAZs 6 and 7 have relatively higher magnitudes of loading compared to other IAZs in these two regions. Groundwater recharge is generally the dominant source of nitrate loading to shallow groundwater.

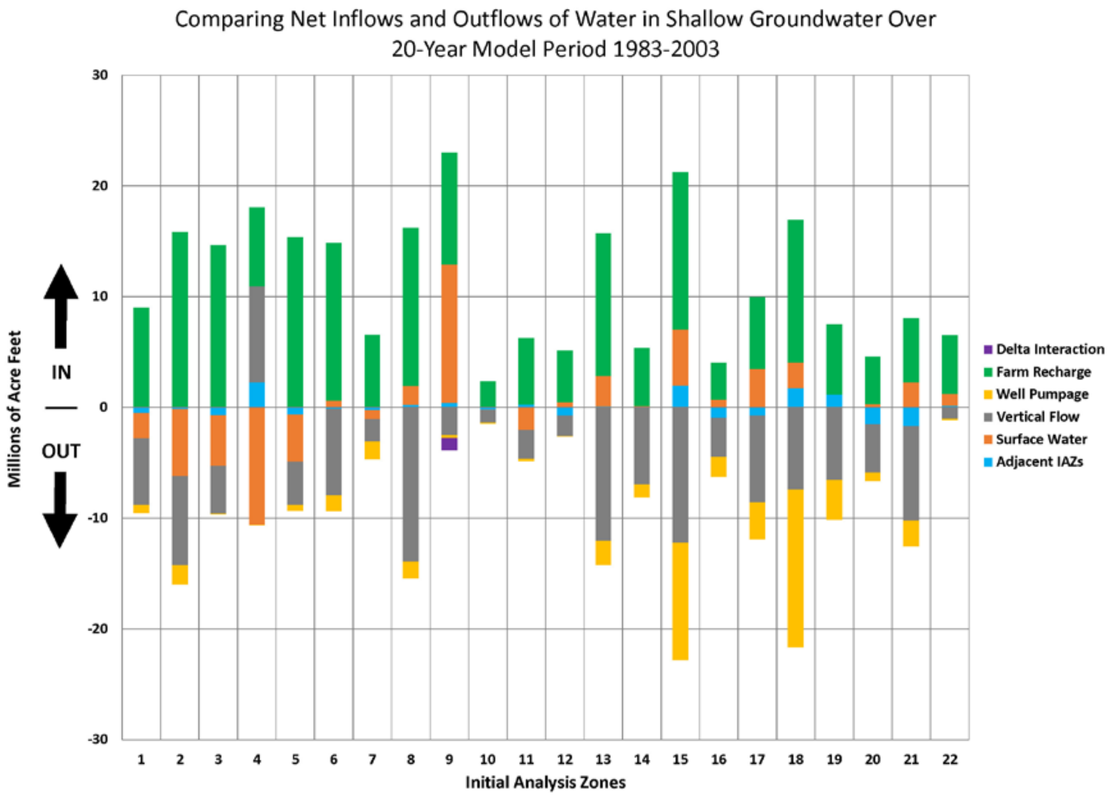

Figure 10-5. CVHM Net Flow Components for Shallow Groundwater form 1983-2003

- <u>The Magnitude of the TDS Loadings Throughout the Valley are Relatively Similar</u> - The magnitude of TDS loading is much more similar between the northern, middle, and southern portions of the Central Valley, compared to the variability seen in nitrate loading. In the southern Central Valley IAZs 14 and 19 have the highest TDS loading, IAZs 10 and 22 have the highest loading in the middle valley, and in the northern Central Valley, IAZs 3, 4 and 6 have comparatively higher loading. In general, a higher magnitude of loading from the surface translates to a higher magnitude of mass leaving shallow groundwater. This is largely due to the instantaneous mixing that was simulated for shallow groundwater. The largest fluxes of mass leaving shallow groundwater occur in the southern Central Valley for both nitrate and TDS, and this is due largely to downward flow to deep groundwater and to a lesser degree to groundwater pumping. In the middle and northern valleys, discharge to surface water provides a significant fraction of outflow from shallow groundwater for nitrate and TDS. Outflow from IAZ 4 is nearly completely dominated by discharge to surface water (via the Sacramento River) (**Table 10-4**).

Table 10-4. Annual Mass Loading of a Per Acre Basis for the Six (6) Nitrate and Three (3) TDS Loading Scenarios[79]

		Northern Central Valley							Middle Central Valley							Southern Central Valley							
IAZ NUMBER		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**22**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Acres (Thousands)		391	744	712	358	612	668	342	872	756	180	425	346	1,055	513	685	911	306	364	869	874	451	707
Square Miles		611	1163	1112	560	957	1044	534	1362	1181	282	664	540	1648	801	1071	1423	478	569	1358	1365	705	1105
Annual Loading per Acre (Kg/Acre per year) – Nitrate Scenarios	High NUE	0.4	0.5	1.1	0.7	0.3	6.8	3.3	1.8	1.1	2.7	1.4	1.4	0.2	0.7	1.1	28.3	6.3	17.2	12.8	12.7	14.2	30.9
	Moderate NUE	1.0	0.8	1.5	1.0	0.5	7.9	4.5	2.1	1.3	3.1	1.8	1.7	0.3	0.8	1.1	29.5	6.9	18.4	13.8	14.0	15.0	33.6
	Low NUE	2.0	1.3	2.2	1.5	0.9	9.9	6.2	2.6	1.7	3.7	2.4	2.2	0.5	1.0	1.2	31.8	7.8	20.3	15.6	16.4	16.4	38.0
	90% of Low NUE	2.4	1.6	3.0	2.0	1.2	11.0	7.2	3.0	1.9	4.2	2.8	2.6	0.6	1.1	1.3	35.1	8.2	22.3	17.2	18.1	18.0	41.9
	75% of Low NUE	3.2	2.2	4.7	3.1	1.9	13.0	9.3	3.7	2.2	5.1	3.6	3.3	0.8	1.4	1.5	41.8	9.1	26.4	20.4	21.6	21.3	49.7
	60% of Low NUE	6.5	5.1	13.3	8.7	4.9	22.4	18.8	7.2	3.8	10.0	7.7	7.0	1.9	3.0	2.9	78.9	12.9	48.0	37.4	38.8	39.0	89.9
Annual Loading per Acre (Kg/Acre per year) – TDS Scenarios	50% of Original	62	41	176	70	39	435	36	43	68	557	323	434	91	788	749	119	175	194	125	773	145	208
	Original TDS Loading	124	83	351	140	79	870	72	86	136	1113	646	868	182	1575	1498	238	206	388	239	1546	283	390
	200% of Original	249	165	702	280	158	1739	144	172	272	2226	1292	1736	363	3151	2997	476	269	775	467	3093	560	755

[79] A red to green color scale (where red is the maximum value and green is minimum value) is shown to assist the reader in comparing the loading scenarios for nitrate and TDS. Separate scales are used for nitrate and TDS.

- Each IAZ was Prioritized for Future Salt and/or Nitrate Management Based on Four Criteria - Each IAZ was evaluated in terms of the ambient groundwater quality data along with the simulated mixing model results to rank the IAZs in their level of relative priority for attention to future salt and/or nitrate management.

  Three different criteria for ambient data were considered and combined with the simulation results for a total of four criteria. The three criteria for ambient groundwater quality data included analyses performed on:

  1) All the wells within an IAZ;
  2) Only the shallow wells within an IAZ; and
  3) Only the deep wells within an IAZ.

  The fourth criteria related to the simulation results and to how many simulations resulted in concentrations over a given threshold.

  Based on these criteria, the following areas ranked as relatively higher priorities (**Figure 10-6**):

  - Nitrate:
    - IAZs 16 and 17 (Kings Subbasin)
    - IAZ 18 (Kaweah and Tule Basins)
  - TDS:
    - IAZ 22 (Delta-Mendota Basin/Grassland)
    - IAZ 14 (Westside and Northern Pleasant Valley Basins)
    - IAZ 19 (Western Kern County and Southern Pleasant Valley Basin)

- Preliminary Assimilative Capacities Were Estimated for Each IAZ - Preliminary assimilative capacities were estimated for each IAZ for both nitrate and TDS based on:

  1) The estimated ambient shallow groundwater quality using data from 2003-2012; and
  2) Using the final concentration (Fall 2003) for each of the loading scenarios run in the mixing model.

  For nitrate, the shallow ambient groundwater quality and simulated concentrations were compared to the NO_3-N MCL of 10 mg/L. For TDS, the ambient groundwater quality and simulated concentrations were compared to three thresholds, including 500 mg/L, 700 mg/L, and 1000 mg/L.

  Based on these criteria, the following areas indicated relatively less available assimilative capacity (as based only on the recent (2003-2012) median shallow groundwater quality:

  - Nitrate: 4 IAZs exceed the NO_3-N MCL threshold of 10 mg/L, including:
    - IAZ 12 (Turlock Basin)
    - IAZs 16 and 17 (Kings Subbasin)

- IAZ 18 (Kaweah and Tule Basins)

- TDS: Most exceed the assimilative capacity for the 500 mg/L threshold (IAZs 3, 4, 6, 9-20, and 22); 5 IAZs exceed the 1,000 mg/L TDS threshold, including:
  - IAZ 6 (Cache-Putah area)
  - IAZ 22 (Delta-Mendota Basin/Grassland area)
  - IAZ 14 (Westside and Northern Pleasant Valley Basins)
  - IAZ 15 (Tulare Lake and Western Kings Basin)
  - IAZ 19 (Western Kern County and Southern Pleasant Valley Basin)

Considerable variability exists in the water quality (and therefore its' assimilative capacity) within an IAZ. The results showed that there can be areas that have no assimilative capacity, while there may also be areas that have greater assimilative capacity compared to the IAZ as a whole (**Table 10-5**).

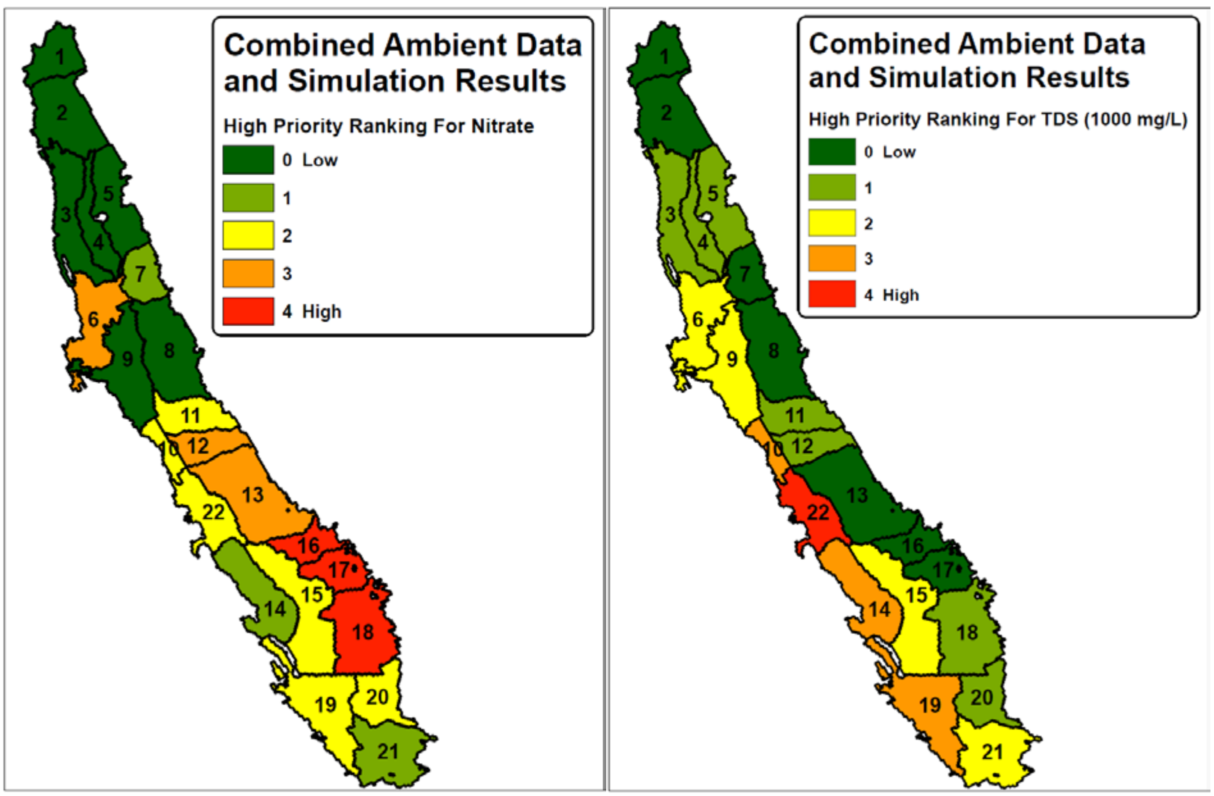

Figure 10-6. Priority Ranking of IAZs for Nitrate and TDS

Table 10-5. Assimilative Capacity[1] Based on Recent (2003-2012) Shallow Data for Nitrate and TDS

		Nitrate			TDS				
		Ambient Data (mg/L NO3-N)		Assimilative Capacity	Ambient Data (mg/L)		Assimilative Capacity		
	IAZ	Shallow Median (2003-2012)	Estimated Deep (2003)	10 mg/L NO3-N Threshold	Shallow Median (2003-2012)	Estimated Deep (2003)	500 mg/L Threshold	700 mg/L Threshold	1000 mg/L Threshold
Northern Central Valley	1	0.1	0.8	9.9	370	158	130	330	630
	2	0.6	1.4	9.4	201	223	300	500	800
	3	0.9	1.5	9.1	583	381	0	117	417
	4	2.8	0.2	7.2	761	363	0	0	240
	5	0.4	0.9	9.6	329	281	171	371	671
	6	0.6	2.0	9.4	1060	461	0	0	0
	7	0.7	1.1	9.3	398	241	103	303	603
Middle Central Valley	8	1.2	1.1	8.8	438	226	62	262	562
	9	0.4	0.5	9.6	961	560	0	0	40
	10	2.7	4.2	7.3	842	911	0	0	159
	11	4.9	3.2	5.1	565	273	0	135	435
	12	10.4	3.0	0.0	825	267	0	0	175
	13	6.1	2.2	4.0	648	236	0	53	353
	22	7.4	1.9	2.6	1160	645	0	0	0
Southern Central Valley	14	0.4	1.0	9.6	3375	966	0	0	0
	15	3.0	0.4	7.0	1000	337	0	0	0
	16	11.1	3.1	0.0	575	218	0	125	425
	17	8.5	2.9	1.5	520	199	0	180	480
	18	10.7	3.0	0.0	598	213	0	102	402
	19	3.3	1.1	6.7	11300	397	0	0	0
	20	3.4	2.0	6.6	870	309	0	0	130
	21	0.2	1.5	9.8	335	262	165	365	665

[1] - Assimilative capacity is calculated by subtracting the median value over an IAZ from the given threshold. A red to green color scale (where red is 0 and green is the threshold value) is shown to assist the reader in comparing the IAZ's assimilative capacities.

- Overall Trends were Evaluated for the IAZs - Using available historical measured groundwater quality data, trends in shallow median groundwater quality were considered for data ranging from the early 1900's to 2012. The following qualitative trends were apparent for NO_3-N and TDS (**Table 10-6**):
  - Nitrate:
    - Slightly decreasing trend - IAZ 6, 22
    - No apparent trend - IAZs 1, 2, 3, 4, 5, 7, 8, 9, 10, 14, 19
    - Possible increasing to decreasing trend - IAZs 11, 15, 21
    - Slightly increasing trend – IAZ 13, 17, 20
    - Increasing trends and/or were above the MCL in recent years - IAZs 12, 16, 18
  - TDS:
    - No apparent trend - IAZs 2, 4, 9, 10, 18, 20, and 21
    - Slightly Increasing - IAZs 1,3, 5, 7, 16, and 17
    - Increasing trends and/or were above the 1,000 mg/L threshold in recent years- IAZs 6, 8, 11, 12, 13, 14, 15, 19, and 22

Table 10-6. Shallow Median Concentrations for Nitrate and TDS Through Time, with a Qualitative Assessment of Potential Trend

	IAZ	1910-1964	1965-1970	1971-1979	1980-1989	1990-2002	2003-2012	Trend	1910-1964	1965-1970	1971-1979	1980-1989	1990-2002	2003-2012	Trend
Nothern Central Valley	1			0.1			0.1	No apparent trend			158	150		370	Slightly increasing
	2	1.1	1.3	2.2	3.0	2.4	0.6	No apparent trend	179	145	270	230	195	201	No apparent trend
	3	2.3	1.2	1.3	1.3	0.7	0.9	No apparent trend	1023	572	347	398	588	583	Slightly increasing
	4		0.2	0.2	0.0	0.1	2.8	No apparent trend		853	487	806	625	761	No apparent trend
	5	1.1	1.2	1.4	2.5	0.8	0.4	No apparent trend	164	183	216	219	435	329	Slightly increasing
	6		1.8	3.6	3.4	0.2	0.6	Slightly decreasing		381	408	423	528	1060	Increasing
	7	0.8	1.2	1.5	1.8	1.7	0.7	No apparent trend	168	177	186	221	506	398	Slightly increasing
Middle Central Valley	8	1.1	2.5	1.9	2.4	1.5	1.2	No apparent trend	163	164	187	166	336	438	Increasing
	9	4.9	2.9	0.1	0.1	0.1	0.4	No apparent trend	954	995	736	703	714	961	No apparent trend
	10	3.4			2.7	2.2	2.7	No apparent trend	473	870	870	1960	838	842	No apparent trend
	11		3.2	7.5	12.6	8.1	4.9	Increasing to decreasing?	315	173	257	227	640	565	Increasing
	12				0.1	3.4	10.4	Increasing	80	895		83	201	825	Increasing
	13		7.9		4.4	5.4	6.1	Slightly increasing	235	423	180	204	258	648	Increasing
	22	3.4			13.1	17.5	7.4	Slightly decreasing	962	5630		2575	2410	1160	No apparent trend
Southern Central Valley	14	3.4	2.5		23.0		0.4	No apparent trend	942	836		4310		3375	Increasing
	15				1.2	11.3	3.0	Increasing to decreasing?	336	475	315	6490	783	1000	Increasing
	16	5.7			8.2	7.9	11.1	Slightly increasing	419	124	303	378	497	575	Slightly increasing
	17	6.0		8.1	8.0	10.1	8.5	Slightly increasing	383		352	413	394	520	Slightly increasing
	18				14.5	15.0	10.7	No apparent trend	160		356	1555	648	598	No apparent trend
	19	3.6			4.9		3.3	No apparent trend	1270			3370		11300	Increasing
	20	0.6			1.6		3.4	Slightly increasing	518			290		870	No apparent trend
	21	0.7		8.6	8.6	0.3	0.2	Increasing to decreasing?	359		353	3420	420	335	No apparent trend

Task 7 Highlights – Key Water, Salt and Nitrate Balance Results for the Two Subareas

The prototype analyses presented for Task 7 (Section 9) were developed as a "proof of concept" designed to demonstrate particular tools and techniques that can be applied to future work in local or regional areas. These prototypes are not intended to be a final, calibrated, site-specific analysis of salt and nitrate for the Modesto regional area nor the Kings Subbasin. The prototype analyses were crafted around existing groundwater flow models (using the publicly available MODFLOW source code) and incorporated a new USGS module MODPATH-OBS (Hanson et al., 2013) to estimate salt and nitrate constituent concentrations.

Two main tools were developed for the prototype areas.

- For the Modesto Regional Model, a method to estimate the age and concentration of particles reaching particular observation locations was developed.
- For the Kings Subbasin, a method that tracks concentrations over time within each model cell was developed to observe the change in concentration in all cells.

The two methodologies are different and answer different questions, but both are used to help identify and determine the movement of water, salt, and nitrate on a much finer scale compared to the IAZ-scale approach.

Key findings and results from Task 7 are listed below.

- <u>GIS Mapping Techniques were used to Categorize Zones</u> –
  - GIS mapping techniques were used to categorize zones where the groundwater is considered to be of high quality (low concentrations of salt and nitrate), low quality (high concentrations of salt and/or nitrate), and moderate quality. The mapping included depictions of higher to lower quality in the relatively shallower part of the aquifer system and the relatively deeper part of the aquifer system, as available.
- <u>Ambient Groundwater Quality Was Established</u>
  - In the Modesto area, ambient groundwater quality was established using well test data from wells classified as shallow. However, the Modesto prototype modeling effort focused on tracking particle travel times and concentrations relative to actual USGS observation wells in the model area, including those classified as deep.
  - In the Kings Subbasin, ambient groundwater quality was established for model layers 1-2, 3, and 6-10 based on well types and, when available, well depths (layers 4-5 were placeholders for the Corcoran Clay).

- The Two Different Approaches to Evaluating Salt and Nitrate Concentrations and Subsurface Transport
    - Modesto Regional Model: The approach of this model application was to simulate the concentration of water quality within observation wells using recharge concentrations. This model had an advantage of faster computation time because of its steady state construction. This meant that the movement of particles could be simulated either forward or backward in time for an infinite amount of time. Particles were assigned starting points associated with well screens, and backward tracking these particles utilized the MODPATH module, which runs independently of the existing MODFLOW model. MODPATH determines the travel time, path, and endpoints for each particle released from the well screen reaching the water table. The travel times for particles sent back from the well screen to the water table where they were recharged ranged from about two days to over 2,500 years. MODPATH-OBS was then used to connect concentrations to each particle based on the concentration history of the recharge area location, repeated current recharge mass loading concentrations for each catchment, and the travel time of each particle to assign a concentration value to each particle. MODPATH-OBS takes an average concentration of all of the particles in each of the observation wells for the years identified. Computations times were relatively shorter for the Modesto Regional Model because there were significantly less particles to be managed during the analysis compared to the Kings Subbasin.
    - Kings Subbasin: The CVHM model is a transient model with monthly stress periods for a total of 42.5 years of simulation. The methodology for this prototype area utilizes the last 20-years of the CVHM simulation (1983 to 2003). Groundwater recharge mass loadings were developed and converted to concentrations on a cell-by-cell basis using the MODFLOW post-processer Zonebudget to extract the flow and volume of groundwater recharge for each of the 1,628 CVHM cells in the Kings Subbasin. Particle tracking was employed on the CVHM model using MODPATH. Particles were placed in the center of every cell and in each cell on the top of the model representing the groundwater recharge surface. These particles were continuously assigned to their cells and sent forward in time every quarter (3 months) for the duration of the 20-year simulation period (resulting in over 1.4 million particles simulated). Observations of groundwater quality were made on an annual basis at each cell of the model cells.

- The Simulation Results were Evaluated
  - The Modesto Regional Model simulation results were compared to measured concentrations. This comparison further emphasized the imbalance in the low recharge concentrations for NO_3-N computed by WARMF; the simulated NO_3-N concentrations were low compared to the measured NO_3-N concentrations in the USGS observation wells. The simulated TDS concentrations compared better to the measured TDS concentrations in the USGS observation wells.
  - The Kings Subbasin simulation results illustrated that this "proof of concept" approach can be used to illustrate and quantify the concentration of salt and nitrate in groundwater and identify areas where concentrations are increasing, decreasing, or remaining stable. It was learned that this approach was limited by the transient nature of the CVHM model, which constrains the distance water can move and take with it a particular concentration of salt and nitrate. The movement of groundwater is relatively slow, and for a 1-mile by 1-mile grid, some particles of water/salt/nitrate barely leave the cell they originated from within one year. It takes many years for recharge to get as deep as Layer 4 (minimum travel time of at least 7 years). The Corcoran Clay is represented by Layers 4 and 5, and this Clay member extends across part of the model area. The concentrations of salt and nitrate associated with the particles whose movements are represented on maps that compare the movement and impact of groundwater recharge particles and associated concentrations in the shallow upper model layers (Layers 1, 2 , and 3). There was very little impact on the deeper model layers (Layers 6 through 10) for the 20-year simulation period.
- Preliminary Assimilative Capacities Were Developed Based on Ambient Shallow Groundwater Quality Data
  - Preliminary assimilative capacity analyses were developed for the Modesto area based on shallow ambient groundwater quality data, which was analyzed on a much finer resolution than for the IAZ scale.
  - Preliminary assimilative capacity analyses were also developed for the Kings Subbasin based on shallow ambient groundwater quality data; similar to the Modesto area, this was analyzed on a much finer resolution than for the IAZ scale.

The results for the assimilative capacities at the finer resolution were found to be quite different than those estimated for an entire IAZ. Considerable variability exists in the water quality (and therefore its' assimilative capacity) within an IAZ. The results showed that there can be areas that have no assimilative capacity, while there may also be areas that have greater assimilative capacity compared to the IAZ as a whole.

Summary of Key Findings from Phase I

Key findings from Phase I are summarized below.

- The available groundwater quality data were generally adequate for purposes of the ICM. Refinements to the spatial and temporal characteristics of groundwater quality data will improve analyses relating to the determination of available assimilative capacities at refined spatial scales.
- The IAZ-scale analysis shows areas where NO_3-N and TDS are accumulating in the Central Valley.
- TDS (salt) shows the most definitive pattern of transport across the Central Valley. Specifically, the salt load to groundwater increases in a southerly direction in the Central Valley. Of the 8 IAZs located generally in the southern part of the Central Valley, 7 of these IAZs show increasing historical trends in salinity of the shallow part of the aquifer system (i.e., trends based on actual groundwater quality observations). The average thickness of these IAZs ranges from 128 to 481 feet, and the saturated thickness ranges from 67 to 180 feet. Therefore, although there is a significant unsaturated zone thickness in these IAZs, the salt load is affecting at least the upper part of the aquifer system and is not isolated to the first-encountered groundwater.
- On an IAZ scale, preliminary analyses show relatively less available assimilative capacity with respect to NO_3-N.
  - Nitrate: 4 IAZs exceed the NO_3-N MCL threshold of 10 mg/L, including:
    - IAZ 12 (Turlock Basin)
    - IAZs 16 and 17 (Kings Subbasin)
    - IAZ 18 (Kaweah and Tule Basins)
  - TDS: Most exceed the assimilative capacity for the 500 mg/L threshold (IAZs 3, 4, 6, 9-20, and 22); 5 IAZs exceed the 1,000 mg/L TDS threshold, including:
    - IAZ 6 (Cache-Putah area)
    - IAZ 22 (Delta-Mendota Basin/Grassland area)
    - IAZ 14 (Westside and Northern Pleasant Valley Basins)
    - IAZ 15 (Tulare Lake and Western Kings Basin)
    - IAZ 19 (Western Kern County and Southern Pleasant Valley Basin)
- Hydrologic mechanisms have a significant influence on the potential for surface mass loads (i.e., the salt and/or nitrate mass) to affect groundwater quality. For the northern part of the Central Valley, mass that moves from the shallow aquifer to surface water via gaining stream conditions lessens the potential for downward vertical flow into the deeper part of the aquifer system. In these areas (IAZs 1-5), there is less potential for accumulating mass and decreasing groundwater quality over time. IAZs 6 and 7 have relatively higher magnitudes of loading compared to the other IAZs in the northern part of the Central Valley. IAZ 9 is unique in that the majority of flow to shallow groundwater in this area comes from recharge from surface water. For most other IAZs, the

cumulative mass recharged to the shallow aquifer is very similar to the cumulative mass transported via downward vertical flows to the deeper part of the aquifer system. In IAZs where this is the predominant mechanism, the water quality condition of the shallow aquifer may, barring thick low permeability intervening units such as the Corcoran Clay member, indicate the trends that may ultimately also occur in the deeper portion of the aquifer system.

- Due to the influence that hydrologic mechanisms impart on groundwater quality conditions and trends, it will be important to consider water quality and quantity interrelationships as part of future water resources management scenarios.
- The WARMF model tracks all constituents from all sources and creates input and output mass balances. A significant imbalance exists in WARMF's computation of adequate groundwater recharge volumes and the associated mass loading as compared to other models' physical conceptualization of the hydrologic system (i.e., CVHM water budget components) and indications of actual recharge effects based on available groundwater quality data.
- The available data for the Modesto and Kings model areas allowed for the prototype applications to be implemented. Additional data, particularly inputs relating to TDS and nitrate groundwater recharge concentrations would improve the certainty and accuracy of the results.
- The analytical tools and methods developed for this study would be applicable to all parts of the Central Valley. Although, the utility of and applications with MODPATH-OBS are still in the process of being examined. The primary data needed to run the mass balance calculations on local models are meteorologic, hydrologic, and land cover data that are readily available for all regions. The accuracy of the mass balance calculations will vary depending on the amount and accuracy of other input data, such as groundwater quality data and groundwater pumping and recharge volumes. Reasonable values for data that are missing or limited can be estimated.
- In future work phases, priority areas for reducing uncertainty should be identified and addressed. Factors that could be addressed include the following:
    - Refinement of applied water quality estimates, especially for non-WARMF areas. This necessitates coordination with and cooperation from local entities that may have gathered such data.
    - Incorporation of soils characteristics and irrigation factors into future modeling efforts. The latter information again would necessitate cooperation from local entities that are knowledgeable about such practices.
    - Improvement of data on actual fertilizer and amendment application. This is likely to be developed over a longer period of time in coordination with the Irrigated Lands Regulatory Program.

10.3 RECOMMENDATIONS FROM PHASE I FOR PHASE II AND/OR DEVELOPMENT OF LOCAL SNMPS[80]

Based on the ICM results, recommendations are provided for further refinements and additional approaches that could be useful during Phase II and/or the development and/or implementation of Local SNMPs, pending regional plan objectives.

Key recommendations regarding the topics of land cover and soils, groundwater data, groundwater flow and quality modeling, and analysis tools are summarized below. The recommendations provided below, in part, relate to Phase II and /or refinements that could be made for purposes of Local SNMPs to improve access to certain data types and to improve the certainty and accuracy of results using the methodology employed in the study. None of these recommended actions would likely impact the basic results or conclusions derived from the Phase I ICM work effort.

Land Cover and Soils

Real land cover is dynamic, but data on land cover are less so. The CVHM and WARMF models both employ DWR and cover data to represent most irrigated lands that comprise most of the Central Valley acreage. Future refinements of water, salt, and nitrate balances should update the representation of recently converted land cover classes, especially when changes are likely to have a strong influence on results.

1. Refine land use classes for mixed or blended classes of crops (e.g., other row crops)
2. Aggregate land use class with small percentages of total land use and loading where possible
3. Refine nitrogen loading parameters for dairy solids to include forms of nitrogen
4. Perform sensitivity analyses for soil classes and parameters and refine, if appropriate, using SSURGO mapping and parameters
5. Compare estimated fertilizer application with fertilizer sales/use data
6. Refine land use classes for Urban Commercial and Industrial related to imperviousness
7. Check land use class parameters against actual documented characteristics and practices
8. Compare modeled plant N uptake with harvest data and harvest N content data
9. Assess regional variations in gaseous N losses (volatilization, denitrification) in soils and aquifers

[80] It should be noted that, as the Draft and Local SNMPs are being developed, they will need to be developed within the context of and/or be coordinated with other related efforts within the region (e.g., regulation and siting of Managed Aquifer Recharge facilities/projects, acknowledgement and/or consistency with other goal such as those set for AB-599).

Other Model Data

Salt and nitrate loading are the primary drivers for the ICM computations, or any related type of analysis. Therefore, more accurate data regarding this loading will make the analysis more reliable. Specifically, in the future it is recommended that better data be developed on:

1. Actual applied water quality (surface and groundwater qualities applied to lands, and the proportions of each source employed for irrigation).
2. Actual (organic and inorganic) fertilizer and amendments applied to each land cover class. The amount of N is the most critical parameter, but as analyses become more refined, it would become helpful to know field-specific rates, forms, and timing of application.

Groundwater Data

1. Continue to expand and keep current the statewide databases (e.g., SWRCB Geotracker and other databases as described in Section 3). Recreate the database used for the ICM to fully address the Geotracker GAMA data issues described in Section 3.
2. Identify construction data for DPH and other monitored wells to improve utility of historical water quality records. This would be especially helpful for the work described for Phase II for the relatively higher priority areas that are recommended to be further evaluated.
3. Improve (or create for the relatively high priority areas) zone/aquifer-specific monitoring.

Scale of Analysis

1. Future SNMP areas of analysis should include horizontal and vertical delineation of upper and lower parts of the aquifer system, i.e., an upper part of the *aquifer system* that provides actual or probable beneficial uses. *Aquifer system* is italicized here to emphasize that for purposes of establishing ambient groundwater quality and preliminarily estimating assimilative capacity, the upper part of the aquifer system is not intended to be the uppermost part of the saturated zone.
2. Ambient groundwater quality should be characterized for the upper part of the aquifer system with a methodology that reflects recognition of spatial groundwater quality variability across the locally defined SNMP area. As shown in Phase I, averaging of median groundwater quality can greatly bias the representation of ambient groundwater quality which in turn can bias the representation of assimilative capacity.
3. Available groundwater quality data should be evaluated with respect to its suitability to adequately characterize present groundwater quality conditions
    a. Construction information for monitored wells such that the groundwater quality data can be appropriately used to represent appropriate parts of the aquifer system;
    b. Spatial distribution is adequate to establish ambient groundwater quality conditions and preliminarily assess assimilative capacity;

c. The historical period provides some indication of whether trends are stable, improving or degrading.

4. The existing monitoring network(s) should be assessed with respect to the above criteria to determine whether the network(s) will satisfy longer-term water quality monitoring interests and needs, for example:
    a. Can baseline conditions be established in the vicinity of a planned project that involves recycled water use?
    b. Are monitoring wells optimally located relative to key sources of community groundwater supplies in relation to significant recharge areas?

Groundwater Flow and Quality Modeling

1. For Local SNMPs, groundwater transport modeling could be refined to better account for local distribution of nitrogen, salt, and recharge inputs and flow field effects due to pumping and other water management scenarios.
2. For Local SNMPs, it is recommended that existing groundwater model platforms be evaluated for their utility for application to salt and nitrate planning and management. For areas where no model has yet been developed, CVHM could be considered for use, or local entities may choose to develop their own local model with another modeling approach.
3. Further improve WARMF mass loads estimated to reach groundwater, particularly as related to mass loads associated with groundwater recharge.
4. Consider performing sensitivity analyses and recalibrating available groundwater models as necessary.
5. California state agencies should cooperate to invest in the long-term development of a fully integrated surface water and groundwater flow and transport model that in the future could be used at the scale of the Central Valley. This is expected to be a long-term objective as such a model (which does not yet exist) would need to be able to perform complicated computations of "farm processes" involving solute uptake and transport (including atmospheric losses, denitrification, etc.), unsaturated zone processes, and saturated groundwater flow and solute transport processes. A first-step toward this objective would be to consider enhancements made by the USGS to the farm process to add solute transformation and transport which at the Central Valley scale would be coupled with CVHM-2. This would create a first order, fully-linked quality and quantity surface water/groundwater modeling tool.

Options for Delineating Future Areas of Analysis

The ICM Task 4 report described examples of the types of boundaries (including physical, geographical, political/institutional, regulatory, management, and model boundaries) that might be considered by local and regional entities for future delineation of Management Zones (MZs) that would be used in the development of Local SNMPs.

Although there are many options that local or regional entities may choose for areas of analysis for purposes of developing Local SNMPs, some of the options described in the Task 4 report include:

- DWR-defined groundwater basins and subbasins as defined in Bulletin 118,
- Groundwater Management Plan areas;
- Integrated Regional Water Management Regions;
- Local District and Water-Related Agency boundaries;
- City and County Ordinances and Urban Water Management Plans;
- Agricultural Water Quality Coalitions;
- Watershed Areas; and/or
- Smaller scaled zones and other user-defined MZs.

Future MZs can be delineated such that significant constraints are not placed on how the boundaries are determined. It is strongly recommended that new “basins” or “subbasins” are not delineated, or if they are, this is done in coordination with DWR. The Water Code makes reference to DWR basins in a very specific context; consequently, it would be confusing to create new basins or subbasins at the local level simply for the purpose of SNMPs. As needed, areas of analysis for SNMPs could alternatively be referred to as subareas. Within these areas, the local entity may choose to differentiate the unique attributes associated with various parts of the SNMP area, and these could be referred to as Management Zones.

Local and regional entities will benefit by selecting SNMP areas that align with other water resources related planning efforts. For example, Groundwater Management Plans and/or Integrated Regional Water Management Plans have typically involved monitoring programs and other data collection efforts that can inform the SNMP data needs. Similarly, other planning efforts that have resulted in knowledge about surface water and/or groundwater quality in a local/regional entity’s area can provide important foundational information for the development of an SNMP.

It is recommended that SNMP boundaries not be based on vertical or horizontal gradients. Such properties are dynamic and subject to change, pending such factors as available sources of supply, climate variability, and actions by adjacent entities.

Existing modeling platforms that have already been developed by local or regional entities could also be considered. The structure of such models should be evaluated to assess the appropriateness of their use for SNMP purposes. Local and regional entities will likely want to include more details on point sources of salt and nitrate loading that are not captured in the ICM ‘*concept level*’ analyses. Incorporation of point sources at the “field-scale”, or very site-specific scale, will necessarily occur as needed and as time and resources permit for local and regional entities to consider management scenarios that evaluate the potential effects or lack of significant effect of such sources.

10.4 RECOMMENDATIONS FOR PHASE II – DEVELOPMENT OF THE CENTRAL VALLEY SALT AND NITRATE MANAGEMENT PLAN (SNMP)

While the Phase I work completed the analyses at the IAZ scale for the Central Valley floor and tested prototype tools for two subareas with refined spatial analysis, additional work is necessary during Phase II in order to develop the background information, continue the refined analyses in prioritized and/or archetype areas, and/or to develop the approach/methods that are necessary for the various components of the SNMP. This is further detailed in recommended tasks below.

Develop the SNMP to Meet the Recycled Water Policy

Based on the discussion above and in order to meet the requirements for the SNMP (consistent with the Policy), the following technical tasks are recommended for Phase II:

- <u>Task 1 – Development of the SNMP</u>
  This task would include the development of the background and additional information necessary for the SNMP such as the basin characterization as well as the incorporation of the various elements described below in Tasks 2 – 7.

- <u>Task 2 – Water Recycling and Stormwater Recharge/Use Goals and Objectives</u>
  This task would include the identification of goals and objectives for water recycling and stormwater recharge/use for the Central Valley through interactions with the CV-SALTS Technical Advisory and Executive Committees. [This task would satisfy Section 6.b.(3)(c) of the Policy]

- <u>Task 3 – Salt and Nitrate Characterization - Source Identification and Loading Estimates</u>
  This task would include a presentation of major source categories and associated loading estimates either 1) at the IAZ level, and/or 2) in the Phase I Task 7 areas (Modesto and Kings), and/or 3) in additional areas selected by CV-SALTS for high resolution analysis.

  Results from the ICM have identified the following IAZs as having elevated levels of salt and nitrate:

  - Nitrate
    - IAZs 16 and 17 (Kings Subbasin)
    - IAZ 18 (Kaweah and Tule Basins)
  - TDS
    - IAZ 22 (Delta-Mendota Basin/Grassland area)
    - IAZ 14 (Westside and Northern Pleasant Valley Basins)
    - IAZ 19 (Western Kern County and Southern Pleasant Valley Basin)

  Additional subtasks that are recommended for Task 3 include:

  - Make corrections to the ICM database to address the SWRCB data transformation issue and update the database with more recent water quality data;
  - Obtain irrigation source and quality information, as available;
  - Refine the land cover for prototype areas and high priority basins to represent current land cover (i.e., modify as necessary for large areas of land cover that are different from that represented by DWR land cover data);
  - Identify methods necessary to evolve WARMF data to better represent the physical system, particularly groundwater recharge concentrations;

- Develop several future land use and water management scenarios;

The focus of Task 3 will be determined through additional discussions with CV-SALTS. [This task would satisfy Section 6.b.(3)(d) of the Policy]

- Task 4 – Salt and Nitrate Characterization - Assimilative Capacity
This task will include updating the salt and nitrate database to correct errors introduced by the SWRCB data transformation problem. Additionally, more recent well test data can be incorporated into the database. This task will also include a more detailed groundwater data characterization and a description of the methodology for the determination of potential refinements to the assimilative capacity at the IAZ level. It is recommended that higher spatial resolution of assimilative capacity be developed for all IAZs analyzed as part of the ICM, and particularly for each of the prototype/high priority areas. [This task would satisfy Section 6.b.(3)(d) of the Policy]

Additional IAZs were identified in Phase 1 as important due to apparent constraints on available assimilative capacity. The prototype/high priority areas include:

- Nitrate
  - IAZ 12 (Turlock Basin)
  - IAZs 16 and 17 (Kings Subbasin)
  - IAZ 18 (Kaweah and Tule Basins)
- TDS - Many IAZs exceed the assimilative capacity for the 500 mg/L threshold and five (5) IAZs exceed the 1,000 mg/L TDS threshold including:
  - IAZ 6 (Cache-Putah area)
  - IAZ 22 (Delta-Mendota Basin and Grasslands area)
  - IAZ 14 (Westside and Northern Pleasant Valley Basins)
  - IAZ 15 (Tulare Lake and Western Kings Basin)
  - IAZ 19 (Western Kern County and Southern Pleasant Valley Basin)

Additional subtasks that are recommended for Task 4 include:

- Assess which high priority areas have existing groundwater flow models with which groundwater transport simulations for salt and nitrate could be conducted with the application of MODPATH and MODPATH-OBS;
- Perform simulations for prototype areas and high priority basins using updated loading estimates and compare simulation results to measured results (includes use of MODPATH and MODPATH-OBS);
- Perform simulations for prototype areas and high priority basins using future land use/water management scenarios;
- Compare simulated results to available groundwater quality observations; identify major discrepancies and determine if related to land cover inputs or other factors; and

- Revisit assimilative capacity analyses as related to present ambient groundwater quality data and also the results of future land use and water management scenarios.

- Task 5 – Implementation Measures
This task would include the identification of candidate implementation measures to manage salt and nitrate loading on a sustainable basis based on the information developed in the CV-SALTS management measures committee, the measures identified and evaluated in the SSALTS effort, and the resulting recommendations from the CV-SALTS Technical and Executive Committees. The task would include a description of an implementation measures “package” as proposed by CV-SALTS and a qualitative analysis of the effectiveness of these measures in achieving water quality objectives in the Central Valley based on the relative importance of sources as identified in Tasks 3 and 4. [This task would satisfy Section 6.b.(3)(e) of the Policy]

- Task 6 – Monitoring Plan
This task would include a description of the approach to be taken for the development of local monitoring plans for SNMP management zones. The approach will include use of information collected in Phase I regarding well locations, well characteristics, surface water sampling locations, and water quality data. The approach will include a clear statement of the purpose and objectives of monitoring and the management questions to be addressed through the collection of new data to supplement available information. As further described for analyses relating to the additional prototype/high priority areas, and as recommended above, efforts would be made in Phase II to improve the linkage between measured data and the relationship of those data to the aquifer system. This effort will require cooperation from state agencies to provide the well attributes (e.g., well location and construction information) to make the measured data more meaningful. Due to the challenge of linking the well attributes to the measured data, this effort would focus on the prototype/high priority areas. [This task would satisfy Section 6.b.(3)(a) and 6.b.(3)(b) of the Policy]

- Task 7 – Antidegradation Analysis
This task would include a description of the methodology to be employed to perform the antidegradation analysis at the level needed for the SNMP Basin Plan amendment. Technical work to support this analysis would be performed, including an assessment of the incremental impacts/benefits of the proposed implementation measures “package” described in Task 5 as measured against a baseline condition as determined by CV-SALTS from the Phase I (ICM) work. The task will also include a description of the methodology for antidegradation analyses to be performed at the SNMP Management Zone level. Issues to be addressed, working with CV-SALTS Policy work group, include the determination of the baseline condition (best water quality since 1968, as modified by consideration of previously permitted activities) and best practicable treatment and control (BPTC) consistent with maximum benefit to the people of the state. [This task would satisfy Section 6.b.(3)(f) of the Policy]

- Task 8 Prepare SNMP Guidance with Details Applicable to Higher Spatial Resolution Level of Analysis

- Prepare guidance for higher resolution analysis of ambient groundwater quality;
- Detail land cover data options, including best use of available DWR land cover or acquiring contemporary land cover data by satellite image analysis;
- Benefits/limitations of existing model platforms; considerations associated with the development of an all new model platform;
- Water budget and mass budget components and important considerations; and
- Assimilative capacity analyses at higher spatial resolution with consideration of ambient groundwater quality conditions and future scenarios (i.e., overall land use and water management changes and/or planned projects; 20% of available assimilative capacity considerations).

Opportunities for Coordination with Other CV-SALTS Activities

It is also recommended that the Phase II work effort include the following tasks to support/complement other ongoing CV-SALTS work efforts. These tasks will provide essential information for the development and evaluation of proposed policy changes and policy language to be incorporated in the Central Valley Basin Plans.

- Task 9 – Strategic Salt Accumulation Land and Transport Study (SSALTS)
  This task would include coordination with the SSALTS effort to supply technical information as needed. Examples of these information needs have been previously identified for the TAC and include:
    - ICM information regarding sources of salt, salt accumulation capacity, and long term salt accumulation to support the study area analyses being performed under SSALTS Task 1.3 (Characterize Study Areas to Establish Baseline Information);
    - ICM information to characterize baseline conditions in study areas under SSALTS Task 1.3;
    - ICM 20-year output for surface water mass loadings and water quality for specific catchments overlying the SSALTS study areas to support SSALTS Task 1.4 (Screening Level Analysis of Long-Term Sustainability);
    - ICM modeling outputs to identify shallow groundwater impacts to support SSALTS Task 1.4.; and
    - Information to support Phases II and III of the SSALTS effort to develop and evaluate potential salt management and disposal alternatives.
- Task 10 – Crop Sensitivity Tools (GIS Task 5)
  This task would include the completion of work described under the previously approved Task 5.3 of the GIS work plan, with appropriate modification based on the results of future input from a group of independent salinity experts to establish parameters for that effort. Work on GIS Tasks 5.1 and 5.2 is ongoing and will be completed by mid to late 2013.
- Task 11 – CV-SALTS Policy Initiatives
  This task would include technical work to support various CV-SALTS policy initiatives, including the development and implementation of Management Zone archetypes to demonstrate the feasibility and policy issues associated with assimilative capacity and

antidegradation issues in the Central Valley groundwater basin. It is anticipated that these management zone archetypes would include the development of the following technical information:

- Guidelines for routine calculations of ambient conditions, mass balances, and assimilative capacity;
- Different scenarios for allocating assimilative capacity over space and time within a Management Zone;
- A trend analysis of the impact of legacy vadose zone conditions within a Management Zone;
- Evaluation of alternative approaches to the "point of compliance" question; and
- Information required for antidegradation policy consistency determinations.

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