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C V - S A L T S

Salt and Nitrate Sources Pilot Implementation Study Report

Submitted by:

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Executive Summary

STUDY OBJECTIVES, SCOPE, AND SUMMARY CONCLUSION

This pilot study is a key initial step in the effort by the CV-SALT initiative through the actions of the Central Valley Salinity Coalition (CVSC) to address the issue of salt and nutrient management in the Central Valley. The CVSC in coordination with the Regional Water Quality Control Board and State Water Resources Control Board seek guidance on approaches and tools that will facilitate the development of a Basin Plan amendment and accomplish better management of salts and nutrients. Correspondingly, methods are needed to evaluate the sources of salt and nitrate loads and the potential long-term effects of those loads on surface and groundwater resources throughout the Central Valley.

The objectives and outcomes of this pilot study are intended to provide the methodology and guidance that will be used by others in the development of salt and nutrient management plans throughout the Central Valley. The overall goals of the pilot study are to develop and document procedures and methodologies to fairly and equitably quantify the significant salt and nitrate sources in the Central Valley. Those procedures are to be pilot tested as part of the work in selected areas to evaluate their appropriateness for region-wide application. Specific objectives of the study include the following:

1. Define salt and nutrient sources of significance for purposes of the study
2. Provide the methods and manner of collection, characterization, and use of the salt and nutrient source data for the pilot areas
3. Outline data that are currently available and the quality of the data
4. Identify additional data that should be collected or developed
5. Indicate how the methodology will account for total salt loading balance and accumulation and identify critical concentration discharges
6. Ensure accurate accounting of all sources
7. Identify how historic, current, and future source quantities will be determined or estimated to provide trend information
8. Identify and quantify areas where nitrates are impacting beneficial uses of waters
9. Select analytical tools and methods that will work for the pilot areas as well as other parts of the Central Valley

This study report provides documentation of the following principal study tasks:

- Preparatory Tasks
  - Define constituents of concern
  - Identify significant salt and nitrate sources
  - Select tools for analysis
  - Identify data needs for tools
  - Identify data sources
- Primary Tasks
  - Select pilot study areas

    - Collect, assess, and input of data into analysis tools
    - Perform preliminary analyses and data validation
    - Final analyses and study results
    - Conclusions and recommendations

The report also provides detailed descriptions of the following:

- Methods used for data collection and analysis
- Tools used for data analysis
- Pilot areas selected for study

The study conclusions are listed at the end of this Executive Summary. The summary conclusion relative to CV-SALTS and project goals is as follows:

The principal goals of this work were to identify and assemble input data sets for available models, and then to use the selected models to quantitatively relate salt and nitrate sources and sinks within representative pilot study areas. Modeling of this kind is extremely sensitive to land cover (e.g., the distribution of impervious surfaces, irrigation and fertilization rates, salt loading, and plant community properties among analyzed catchments). Available data sources were combined to provide a level of land cover detail that was greater than previously employed with the widely used WARMF platform. The input data and modeling products achieved the principal project goal and advanced the CV-SALTS work. Recommendations for further refinements of the study approach and additional approaches are based on the study results.

OVERVIEW OF STUDY METHODS

Preparatory Tasks

Following are brief overviews of preparatory task activities.

Define Constituents of Concern

Total Dissolved Solids (TDS) (or Electrical Conductance (EC)) and nitrates and water quality related nitrogen species were identified as the first priority constituents of concern. Chloride was identified as a specific ion that could be used to demonstrate the methodology for determining the mass balance for a specific salinity ion.

Identify Significant Salt and Nitrate Sources

Salt and nitrate sources and sinks of potential significance are listed in Table ES-1. These sources are based on the standard input parameters for the WARMF model, which was developed to consider all potentially significant sources of chemical constituents to a watershed.

Table ES-1. Potentially Significant Salt and Nitrate Sources and Sinks

Sources	Sinks
Surface water upstream inflow	Surface water outflow
Imported surface water	Surface water diversions
Irrigation	Near-surface groundwater
Fertilizer	Deeper groundwater
Stormwater discharges	Plant uptake
Septic tank discharges	Reaction decay
Land application, including dairies	Gaseous loss, volatilization
Point Sources	
Municipal wastewater treatment plant discharges and facilities, including ponds	
Industrial discharges	
Livestock facilities	
Mineral weathering / reaction products	
Atmospheric deposition	
Groundwater extraction (dewatering) discharge	

Select Tools for Analysis

The Watershed Analysis Risk Management Framework (WARMF) was selected as the primary tool to account for surface water flows, deep percolation to groundwater, and salinity and nitrate sources and sinks. The WARMF model complemented by other data (including recharge, pumpage, and the quality of the pumped groundwater, which are input into the WARMF model) creates a means to account for salt and nitrate sources associated with deeper groundwater. As related to WARMF and the salt and nitrate accounting described in this report, "deeper" groundwater refers to the portion of the aquifer system that underlies groundwater near the water table where there is still the potential for interaction with surface water. The groundwater data were developed from previous groundwater models developed for the pilot study areas and/or collected from well-organized groundwater databases. Groundwater models that were used in this study to provide input data to WARMF include the United States Geological Survey (USGS) MODFLOW model revised for the Modesto area, the Harter MODFLOW model developed for the Tule River area, and the USGS Central Valley Hydrologic Model (CVHM) for the portion overlying the Yolo County area.

Identify Data Needs for Tools

Data types and parameters that are required to run the WARMF model and supporting groundwater models for this study are listed in Table ES-2. Some types of data are site-specific and essential to running the WARMF model or other models or methods used to characterize salt and nitrate status in an area of interest. These essential data types are indicated with the label (N) for "necessary". Fortunately, all of these data types are typically readily available for all regions of the Central Valley. While it is desirable to have complete sets of site-specific data for all parameters, some data types can typically be extrapolated or estimated from limited available data. These data types are labeled (N/E) for "necessary but can be estimated from other site-specific data". Other data types can be estimated based on knowledge of standard or typical practices, if site-specific data are not available. These data types are labeled (E), for "typically estimated, with or without site-specific data". Other process parameter rates listed typically have default values within models or values that can be adjusted by the model operator. These parameters are labeled "M", for "model default provides estimate unless changed by model operator". However, it is important to note that these data and parameter needs are not specific to the WARMF model, but are necessary to the understanding of any regional area for planning purposes and will apply to any conceptual model or tool to be used in the development of salt and nutrient management plan.

Table ES-2. Summary of Data Needs

Hydrologic Data	Salt and Nitrate Data	Process Parameters
Surface water flows (N)	Surface water quality (N)	Plant uptake rates (E)
Imported water flows (N)	Groundwater quality (N/E)	Atmospheric deposition (M)
Water diversions (N)	Point source quality (N/E)	Soil properties (N/E)
Point source flows (N/E)	Land cover class loadings (of salt; E)	Nitrification rate (M)
Irrigation return flows (E)	Fertilizer rates (E)	Denitrification rate (M)
Meteorology/effective rainfall (N)	Land application rates (E)	Mineralization rate (M)
Land cover classes (N)		Volatilization rate (M)
ET rates (N)		Sorption rates (M)
Irrigation rates (E)		Phytoplankton processes (M)
Irrigation efficiency (E)		
Groundwater pumpage (N/E)		
Groundwater recharge (N/E)		
Topography (N)		

Identify Data Sources

Data needed to run the WARMF Model and supporting groundwater models are available from a variety of federal, state, local, and private sources. A summary of data sources and the status of the data provided in terms of type and availability are presented in Table E-3.

Table ES-3. Data Source Status Summary

Reference / Contact	Data Type	Requested[1]	Provided/ Obtained[2]	Data Format
Central Valley RWQCB	Dairy location and size	●	●	Digital
CA Department of Water Resources (DWR)	Land cover database		●	Web / GIS Files
US Geological Survey (USGS)	National land cover database		●	Web / GIS Files
Dairy CARES	Dairy production and practices	●	◒	Verbal
UC Cooperative Extension	Dairy production and practices	●	◒	Verbal
Western United Dairymen	Dairy production and practices	●	◒	Verbal

Table ES-3. Data Source Status Summary

Reference / Contact	Data Type	Requested[1]	Provided/ Obtained[2]	Data Format
County Agricultural Commissioners.	Annual crop reports	●	●	Web / PDF
CA Dept. of Food and Agriculture	Fertilizer sales reports	●	◒	UCD Library; PDF or printed
Central Valley RWQCB	POTW/Industry WDR discharge data	●	◒	Digital
SWRCB – California Integrated Water Quality System (CIWQS)	POTW/Industry WDR Discharge data		◒	Web / PDF
Hilmar SEP Report	Land Discharge data	●	◒	Web/ PDF
Web H_2O	Hilmar SEP discharge data for POTW/Industry land dischargers	●	◒	PDF
National Atmospheric Deposition Program (NADP)	Rain concentrations		●	Web/digital
Clean Air Status and Trend Network (CASTNET)	Air concentrations		●	Web/digital
DWR Hydrologic data	Reservoir information		●	Web/digital
DWR Water Quality Data	Groundwater and Surface Water Quality data (WDL)	●	●	Web/digital
EPA-STORET	Surface water quality data		●	Web/digital
California Data Exchange Center (CDEC)	Surface flow and water quality data		◒	Web/digital
Bay Delta and Tributary Project	Surface water quality data		●	Web/digital
U.S. Bureau of Reclamation	Diversion flow data		●	Web/digital
California Irrigation Management Information System (CIMIS)	Meteorology, Irrigation requirements		●	Web/digital
Surface Water Ambient Monitoring Program (SWAMP)	Surface water quality data		●	Web/digital
USGS Hydrologic Data	Surface flow data		●	Web/digital
Local Irrigation and Water Districts	Point source flow and discharge data		●	Web/digital
U.S. EPA NPDES Database	Rain concentrations		●	Web/digital
SWRCB – (GAMA domestic and LLNL)	Groundwater Quality Data	●	◒	Web/digital
NAWQA	Surface water quality data		●	Web/digital
CA Department of Public Health (CDPH)	Groundwater quality data	●	◒	Digital
Integrated Groundwater Surface Water Model (IGSM) – Yolo County Area	YCIGSM model documentation from Yolo County Flood Control	●	●	Digital
USGS Central Valley Hydrologic Model (CVHM)	CVHM model documentation, input/output files	●	●	Web/Digital/GIS Files
USGS Water Quality Data	Groundwater and Surface Water Quality data (NWIS)	●	◒	Web/Digital

Table ES-3. Data Source Status Summary

Reference / Contact	Data Type	Requested[1]	Provided/ Obtained[2]	Data Format
Water Resources Information Database (WRID) – Yolo County	Well construction, location, groundwater quality data	●	●	Database
CA SWRCB – Geotracker	Groundwater quality data	●	●	Web/Digital
USGS Digital Elevation Models (DEM)	Topographic data		●	Web/Digital
Modesto Local MODFLOW Model	Model documentation, input/output files	●	●	Web/Digital/GIS Files
Harter Tule River Basin MODFLOW Model	Model documentation, input/output files	●	●	Web/Digital/GIS Files
Yolo County Flood Control District	Surface Water Quality Data	●	●	Digital

1. Data requested by personal contact. Other data sources accessed by web search
2. ● = Complete data provided or obtained; ◒ = Partial data provided or obtained; ○ = No data provided or obtained

Primary Tasks

Following are brief overviews of primary task activities.

Select Pilot Study Areas

Following extensive discussions with the CV-SALTS Technical Advisory Committee, the Committee recommended and approved three pilot areas for study: the Yolo, Modesto, and Tule River areas. The locations of these pilot areas are shown in Figure ES-1. The key criteria considered in selecting the pilot areas included:

1. The major Central Valley hydrologic basins are represented (Sacramento River, San Joaquin River, and Tulare Lake)
2. Advanced application status of the WARMF model for the area (previously applied, partially applied, or not currently applied but with relatively good input data availability)
3. Range of land use classes (including various urban, industrial, commercial, and agricultural) represented
4. Relatively advanced status of groundwater flow models applied
5. Available groundwater quality data

The three pilot areas selected represent a broad range of conditions meeting these criteria:

The Yolo study area represents the Sacramento River hydrologic basin; had previous application of the WARMF model to part of the area; contains a mix of urban and agricultural land uses; was included in the Central Valley Hydrologic Model (CVHM) which became available for use during the study; and had an extensive and well organized set of groundwater data.

The Modesto study area represents the San Joaquin River hydrologic basin; had previous application of the WARMF model to the full area; contains a major urban area and a high concentration of dairy land use; had a complete groundwater flow model applied to the area; and had less extensive groundwater quality data compared to the Yolo area, which required some estimation and extrapolation of data to provide inputs to WARMF for the full study area domain.

The Tule River area represents the Tulare Lake hydrologic basin; had no previous application of the WARMF model to the area; contains primarily agricultural land uses with a significant number of dairies; had a complete groundwater flow model applied to the area; and had limited groundwater quality data, which required extensive estimation and extrapolation of data to provide inputs to WARMF for the full study area domain.

Collect, Assess, and Input Data

Much of the data needed to run the WARMF model were previously collected and input into the WARMF database for the pilot areas where the model had been previously applied (Yolo and Modesto). Data not already in the WARMF database were collected from the identified sources and input into the WARMF database. Land cover data were updated based on the most current data available from the DWR and NLCD land cover databases. The land cover classifications provided from these sources were augmented and refined extensively for purposes of this study to more accurately account for inputs from dairy operations and variations in irrigation and fertilization practices. Groundwater pumpage, recharge, and quality data needed for WARMF were developed from the groundwater models and other sources of quality data.

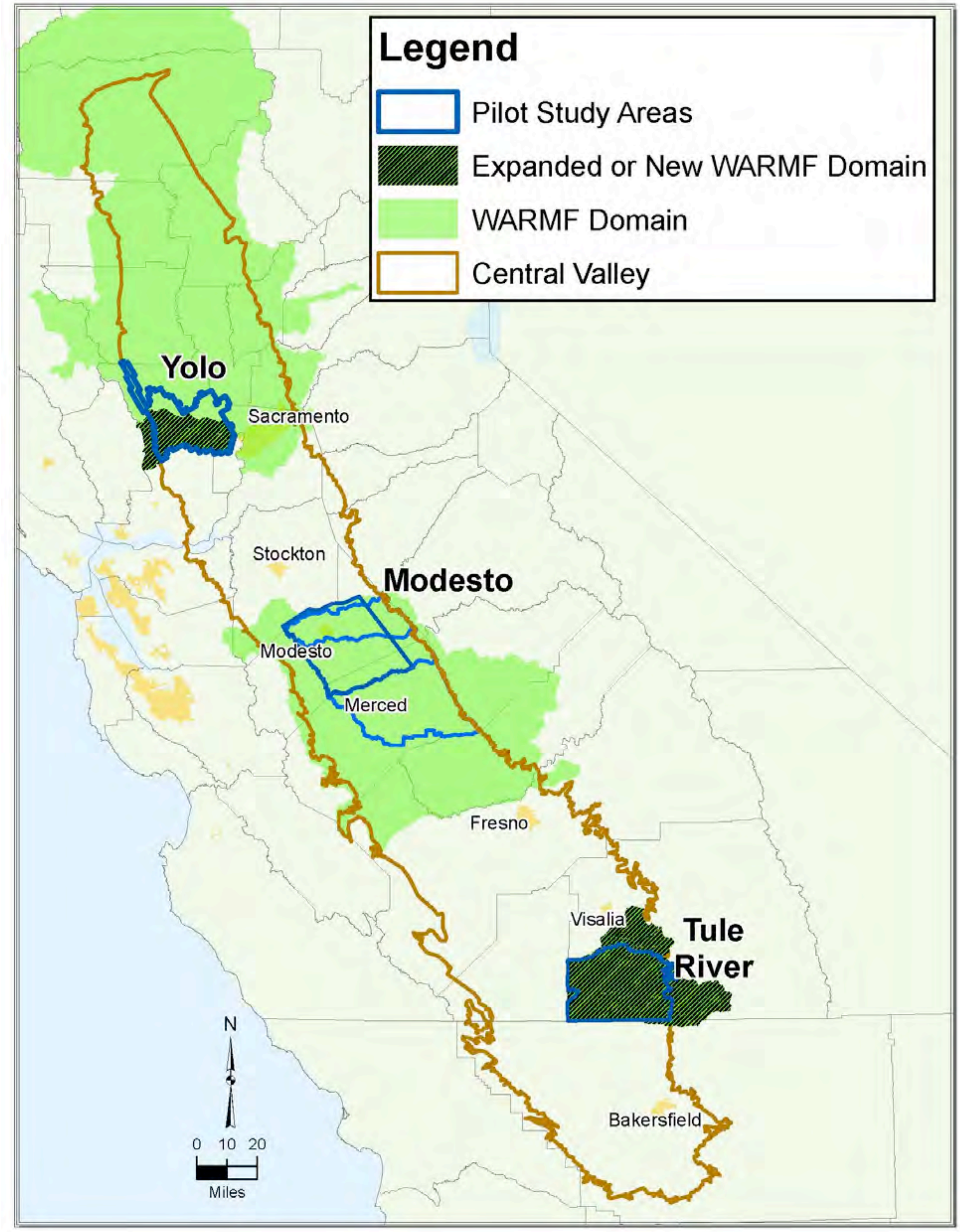

Figure ES-1. Pilot Areas General Location Map

Perform Preliminary Analyses and Data Validation

The procedure for quality assurance / quality control (QA/QC) was adapted to each data source. To avoid discarding data that would improve the salt and nitrate budgets, it was assumed that data received from outside sources were generally valid. Results of preliminary salt and nitrate budget analyses were used to critically evaluate inputs, providing an additional measure of data QA/QC.

As data were compiled from various sources, sources were cross checked against one another where appropriate. Consistency among sources provided another indication of data accuracy. The mass balance analyses for salt and nitrate are another mechanism to ensure data quality. The various sources and sinks need to balance so that the mass and its movement can be tracked. A serious imbalance in the mass balance is an indication of error in model assumptions or in the data. Imbalances were investigated to determine whether there were inaccuracies associated with the data.

Estimation techniques were used as necessary to fill data gaps. Sensitivity analyses were run to determine the amount of uncertainty introduced by the lack of data. Recommendations are provided regarding the filling of data gaps.

Where specialized expertise was available, the team consulted with resource persons and incorporated recommendations regarding the correct characterization of conditions or land and water use.

Refined Analysis and Pilot Study Output

The WARMF model was run with the final validated data set to perform mass balance analyses, trend analyses, and sensitivity analyses. Groundwater models with particle tracking were run to show water quality effects due to salt and nitrate loading, groundwater recharge, and pumping.

STUDY RESULTS

Mass balance results for all three pilot areas are reported in Table ES-4 for TDS and in Table ES-5 for nitrate. Table ES-5 also contains results for chloride mass balance for the Yolo area. Major source and sinks (greater than 10 percent) are indicated in italics. Results are also shown in graphical form in Figures ES-2 through ES-13 to provide a visual indication of the relative significance of sources and to allow comparison among pilot areas. Key conclusions regarding study results for mass balances of sources (inputs) and sinks (outputs) are presented in the Conclusions subsection.

Table ES- 4. Summary of Mass Balance Results for Pilot Areas – Total Dissolved Solids (lb/d)

Process	Yolo[1]	Modesto[1]	Tule River[1]
SURFACE WATER			
Total Inputs	**4,050,000**	**5,580,000**	**496,000**
Inflows from Upstream	*1,710,000*	4,510,000	*259,000*
Imported Water	*1,970,000*	*408,000*	*194,000*
Inflows from Near-surface Groundwater	241,000	486,000	41,200
Point Sources	127,000	174,000	0
Reaction Product	765	1,700	1,380
Total Outputs	**3,890,000**	**5,810,000**	**519,000**
Biological Uptake / Reaction Decay / Settling	165,000	2,350	4,250
Diversion	*668,000*	*1,310,000*	*319,000*
Outflow to Downstream	*3,060,000*	*4,500,000*	*196,000*
NEAR-SURFACE GROUNDWATER[2]			
Total Inputs	**1,720,000**	**2,330,000**	**2,450,000**
Atmospheric Deposition	*197,000*	*423,000*	119,000
Irrigation	*1,230,000*	*1,030,000*	*785,000*
Fertilizer / Land Application	*221,000*	*807,000*	*1,160,000*
Point Sources	7,680	22,500	44,000
Septic Systems	998	1,120	10,300
Mineral Weathering / Reaction Product	61,700	49,200	*333,000*
Total Outputs	**1,670,000**	**2,050,000**	**1,890,000**
Net Plant Uptake / Reaction Decay	130,000	*406,000*	*959,000*
Outflow to Surface Water	*241,000*	*499,000*	41,200
Recharge to Deeper Groundwater	*1,300,000*	*1,150,000*	*889,000*
Change in Storage	**48,000**	**280,000**	**565,000**
DEEPER GROUNDWATER[3]			
Total Inputs	**1,300,000**	**1,150,000**	**889,000**
Recharge from Near-surface Groundwater	*1,300,000*	*1,150,000*	*889,000*
Stormwater Recharge Wells or "Rock Wells"	0	0	0
Total Outputs	**919,000**	**1,060,000**	**713,000**
Pumping for Irrigation	*873,000*	*203,000*	*713,000*
Pumping for Municipal / Industrial Use	46,000	*860,000*	0
Pumping for Groundwater Control	0	0	0
Change in Storage	**381,000**	**87,000**	**176,000**

1. Major sources and sinks (greater than 10 percent) are indicated in italics.
2. Near-surface groundwater – defined as water down to the depth where it still interacts with surface water via lateral flow.
3. Deeper groundwater (as related to WARMF mass balance results) -- defined as the portion of the aquifer system underlying the "near-surface groundwater." "Deeper groundwater", as used here, does not distinguish between different units of the aquifer system.

Table ES-5. Summary of Pilot Area Mass Balance Results – Nitrate and Chloride (Yolo only), lb/d

Process	Yolo[1]		Modesto[1]	Tule River[1]
	Nitrate-N	Chloride	Nitrate-N	Nitrate-N
SURFACE WATER				
Total Inputs	**14,500**	**173,000**	**30,100**	**6,100**
Inflows from Upstream	*3,720*	*90,300*	*19,100*	*3,130*
Imported Water	*6,670*	*44,700*	415	52
Inflows from Near-surface Groundwater	*2,730*	9,920	*8,600*	*2,760*
Point Sources	1,310	*27,600*	1,800	0
Reaction Product	39	0	191	161
Total Outputs	**14,700**	**175,000**	**30,700**	**6,170**
Biological Uptake / Reaction Decay / Settling	30	0	429	0
Diversion	2,510	39,500	5,950	2,710
Outflow to Downstream	12,200	135,000	24,300	3,460
NEAR-SURFACE GROUNDWATER[2]				
Total Inputs	**45,700**	**94,100**	**85,300**	**205,000**
Atmospheric Deposition	1,290	3,960	584	2,550
Irrigation	*7,890*	*77,500*	*9,070*	*33,400*
Fertilizer / Land Application	*28,800*	*9,960*	*71,900*	*109,000*
Point Sources	43	2,280	495	184
Septic Systems[4]	0*	245	0*	0*
Mineral Weathering / Reaction Product	*7,650*	200	3,320	*60,200*
Total Outputs	**40,300**	**89,400**	**71,000**	**133,000**
Net Plant Uptake / Reaction Decay	*14,500*	22	*40,000*	*111,000*
Outflow to Surface Water	2,730	*13,300*	*8,610*	2,760
Recharge to Deeper Groundwater	*23,000*	*76,100*	*22,400*	*19,000*
Change in Storage	**5,460**	**4,700**	**14,300**	**71,900**
DEEPER GROUNDWATER[3]				
Total Inputs	**23,000**	**76,100**	**22,400**	**19,000**
Recharge from Near-surface Groundwater	*23,000*	*76,100*	*22,400*	*19,000*
Stormwater Recharge Wells or "Rock Wells"	0	0	0,	0
Total Outputs	**9,920**	**89,100**	**19,800**	**34,600**
Pumping for Irrigation	*9,440*	*84,000*	3,100	*34,600*
Pumping for Municipal / Industrial Use	481	5,100	*16,700*	0
Pumping for Groundwater Control	0	0	0	0
Change in Storage	**13,100**	**-13,000**	**2,600**	**-15,600**

1. Major sources and sinks (greater than 10 percent) are indicated in italics.
2. Near-surface groundwater – defined as water down to the depth where it still interacts with surface water via lateral flow.
3. Deeper groundwater (as related to WARMF mass balance results) -- defined as the portion of the aquifer system underlying the "near-surface groundwater." "Deeper groundwater", as used here, does not distinguish between different units of the aquifer system.
4. Septic Systems load nitrogen as ammonia-N: Yolo = 180 lbs/d; Modesto = 363 lbs/d; Tule River = 766 lbs/d

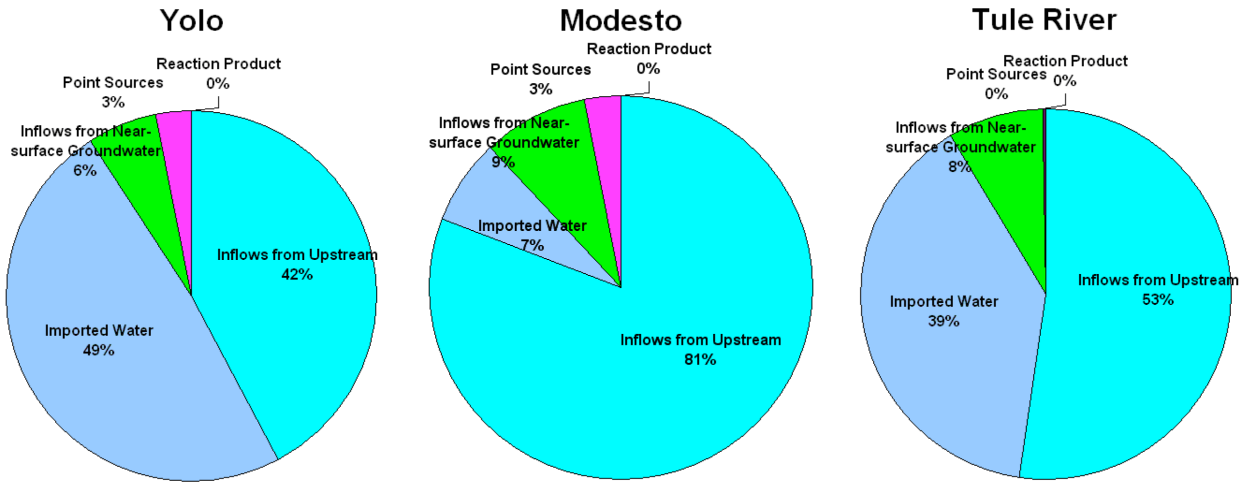

Figure ES - 2. Surface Water TDS Inputs for the Three Study Areas

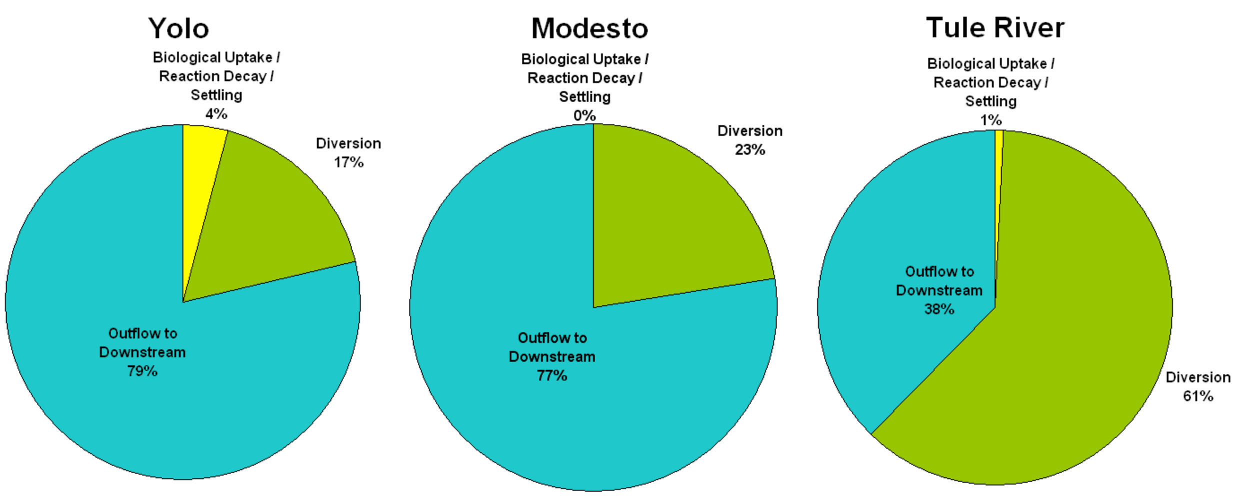

Figure ES - 3. Surface Water TDS Outputs for the Three Study Areas

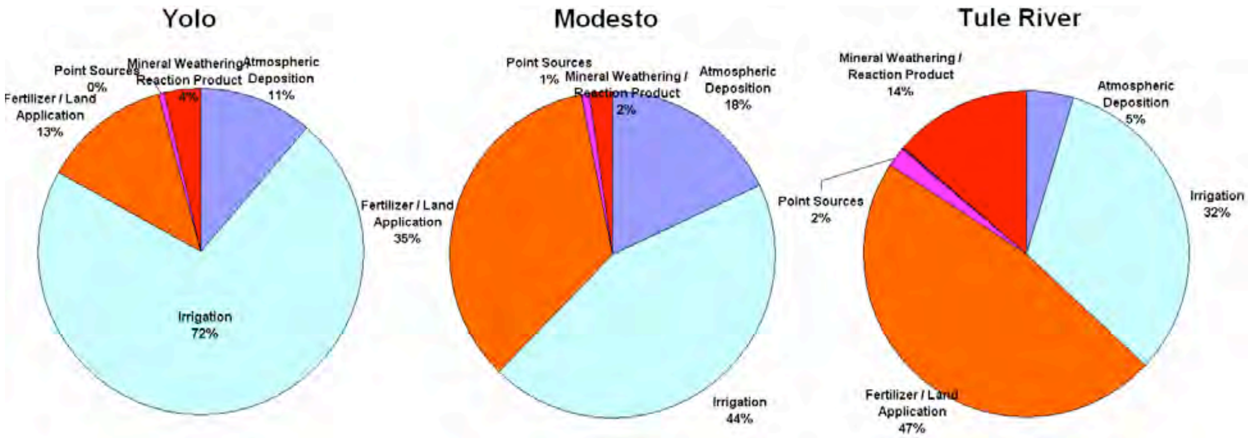

Figure ES - 4. Near-surface Groundwater TDS Inputs for the Three Study Areas

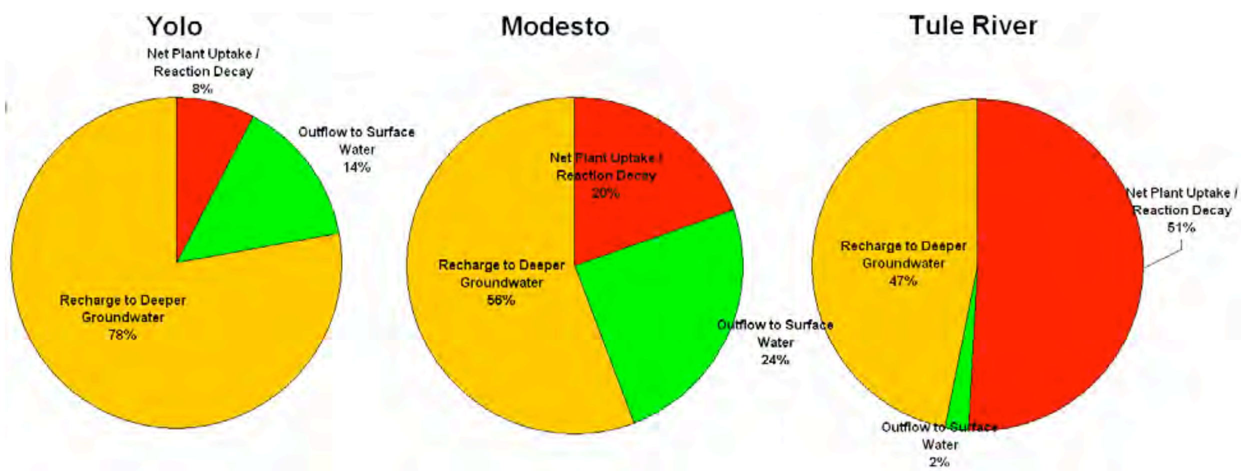

Figure ES - 5. Near-surface Groundwater TDS Outputs for the Three Study Areas

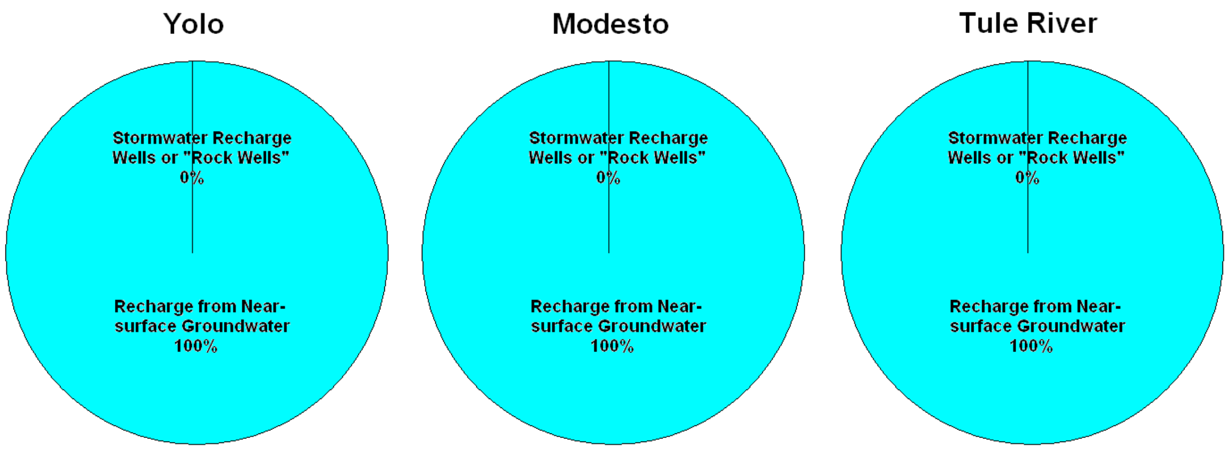

Figure ES - 6. Deeper Groundwater TDS Inputs for the Three Study Areas

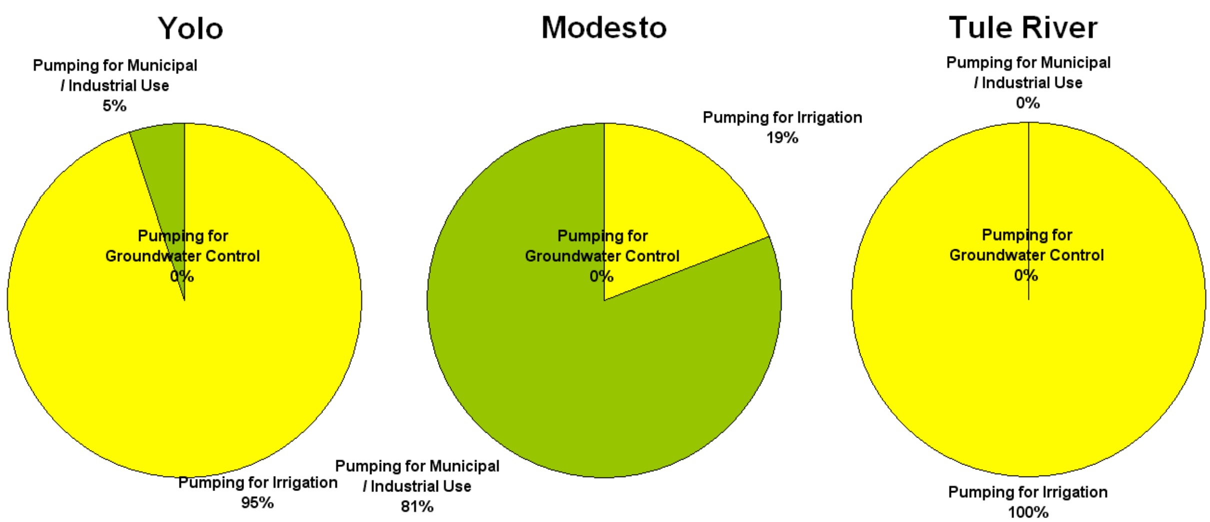

Figure ES - 7. Deeper Groundwater TDS Outputs for the Three Study Areas

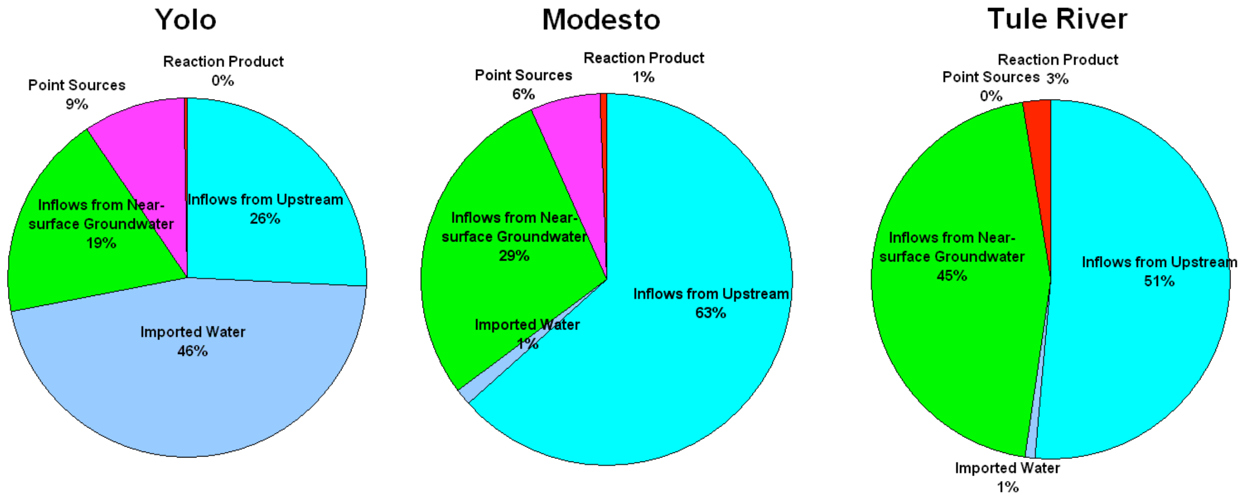

Figure ES - 8. Surface Water Nitrate Inputs for the Three Study Areas

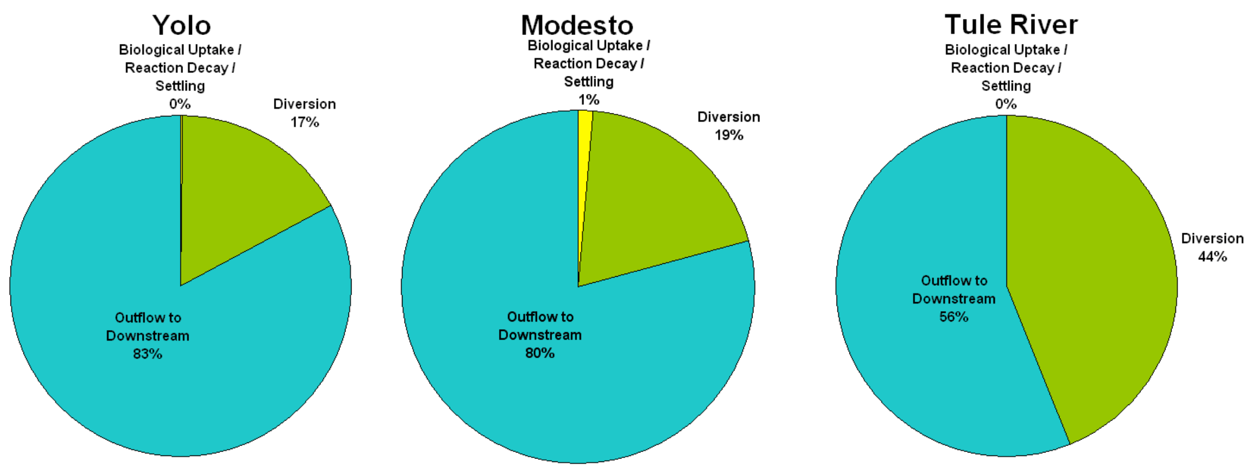

Figure ES - 9. Surface Water Nitrate Outputs for the Three Study Areas

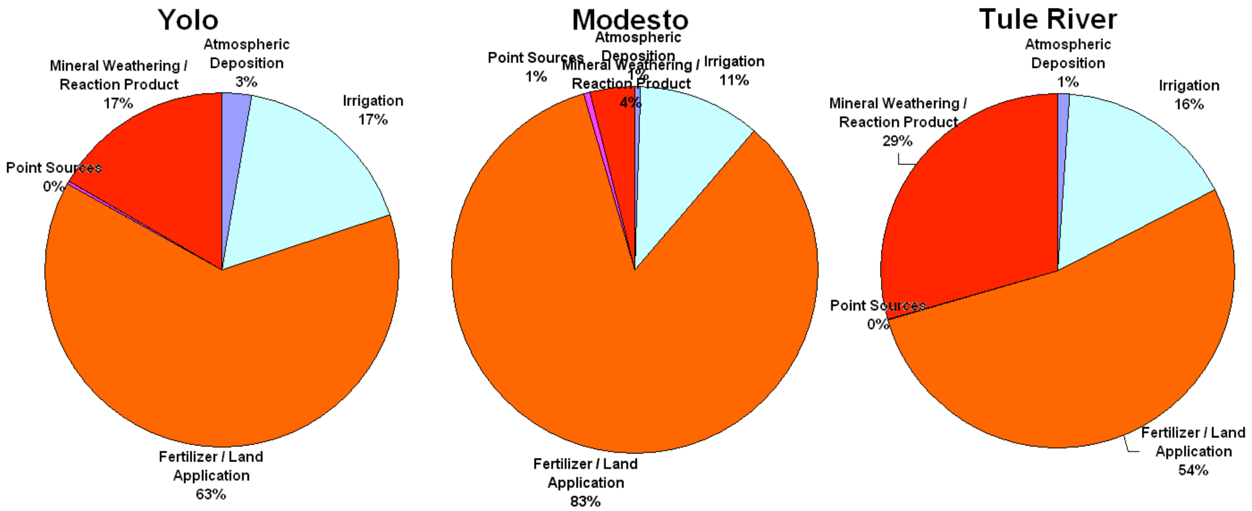

Figure ES - 10. Near-surface Groundwater Nitrate Inputs for the Three Study Areas

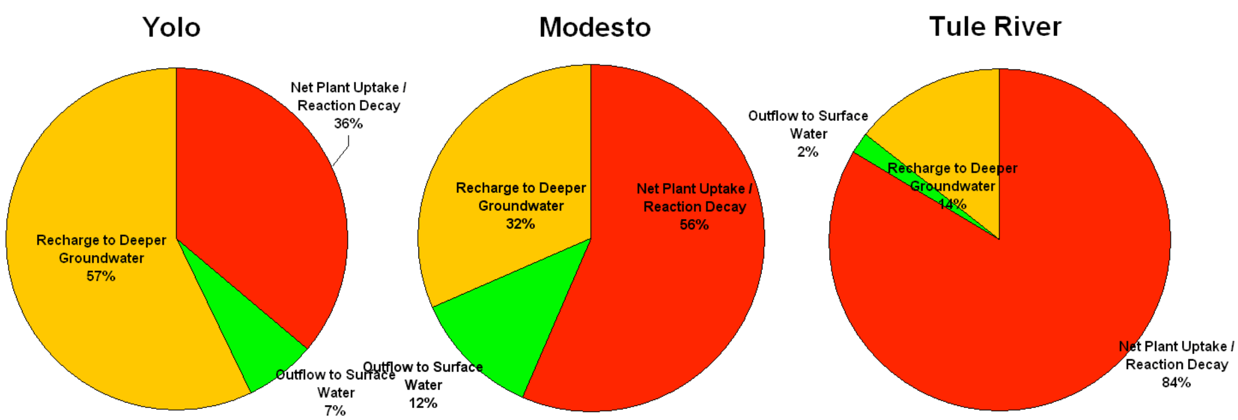

Figure ES - 11. Near-surface Groundwater Nitrate Outputs for the Three Study Areas

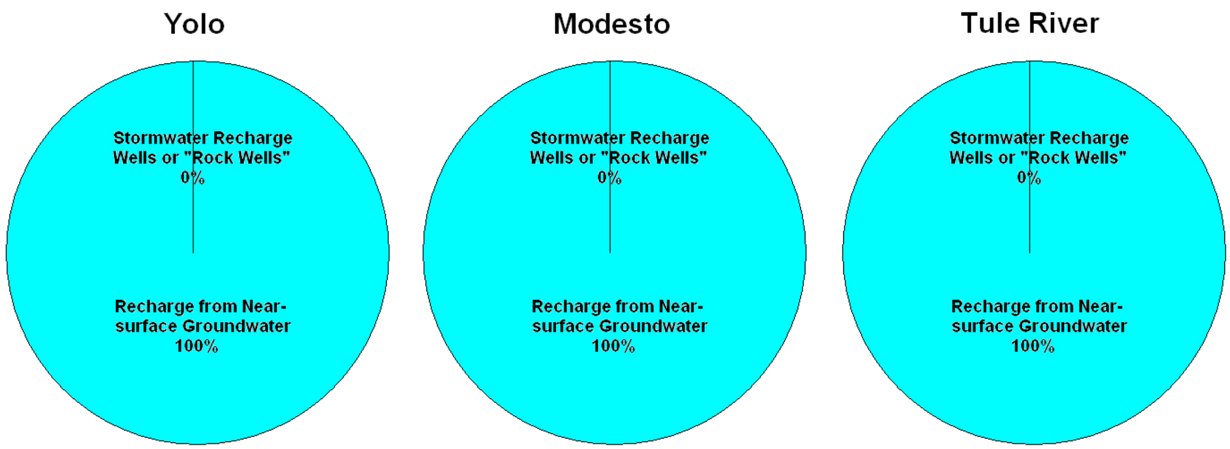

Figure ES - 12. Deeper Groundwater Nitrate Inputs for the Three Study Areas

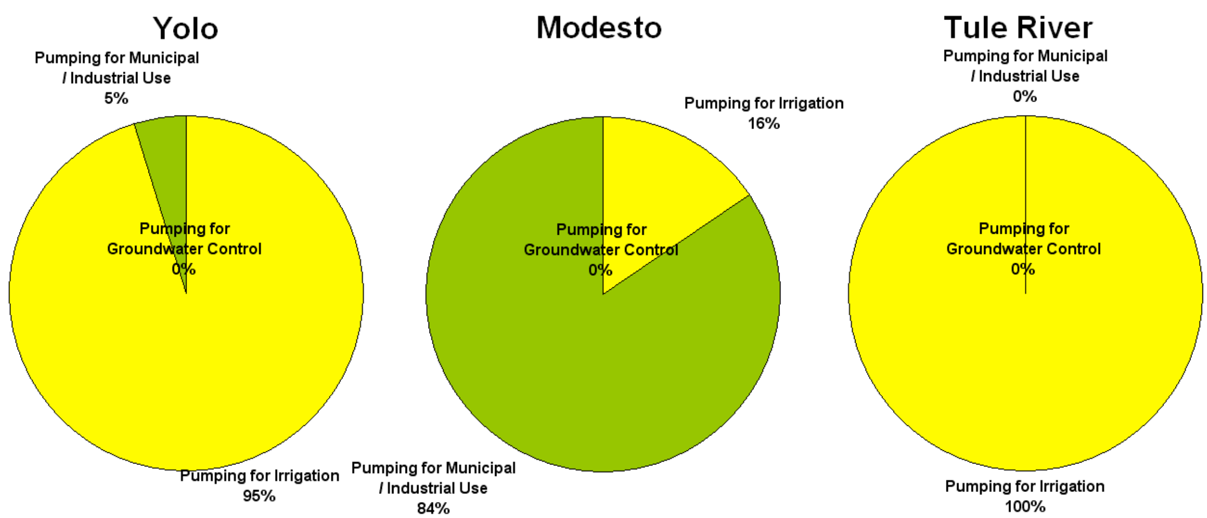

Figure ES - 13. Deeper Groundwater Nitrate Outputs for the Three Study Areas

CONCLUSIONS

Study Results

Key conclusions derived from study results for mass balances of sources and sinks of TDS and nitrate are stated below.

TDS

1. The principal inputs of TDS to near-surface groundwater, and therefore likely to deeper groundwater, in all three pilots areas are irrigation and fertilizer/land application.
2. Other sources contributing more than 10 percent TDS to near-surface groundwater include atmospheric deposition in the Yolo and Modesto areas and mineral weathering and reaction products in the Tule River area.
3. TDS is accumulating in the near-surface and deeper groundwater in all three pilot areas.

Nitrate

1. Principal inputs of nitrate to near-surface groundwater in all three pilot areas are irrigation, fertilizer/land application.
2. Other sources contributing more than 10 percent nitrate to near-surface groundwater include mineral weathering and reaction products in the Yolo and Tule River areas.
3. Nitrate is accumulating in the near-surface groundwater in all three pilot areas and in the deeper groundwater in the Yolo and Modesto areas, but is depleting in the Tule River area as a whole.

Project Objectives

Study conclusions regarding achievement of project objectives are summarized in Table ES-6.

Table ES- 6 . Conclusions Regarding Achievement of Project Objectives

Project Objective	Conclusion
Objective 2: Provide the methods and manner of collection, characterization, and use of the salt and nutrient source data for the pilot areas.	The study report identifies the types and sources of data that are needed to run the models employed to calculate TDS and nitrate (and chloride in one study) sources and sinks and an overall mass balance. The report further describes the methods used to collect and analyze the data and how the data are used in the models.
Objective 3: Outline data that are currently available and the quality of the data	The study report identifies the data sources used in the study and indicates limitations, including accessibility to data in useful formats and the general availability of the desired data. The report also indicates if site-specific data are necessary and essential to perform mass balance determinations or if the data can be estimated or extrapolated based on limited data or knowledge of typical practices.
Objective 4: Identify additional data that should be collected or developed.	The data collected during the study were adequate to run the models and perform the mass balance calculations. Additional data could improve the certainty and accuracy of the results.

Table ES- 6 . Conclusions Regarding Achievement of Project Objectives

Project Objective	Conclusion
Objective 5: Indicate how the methodology will account for total salt loading balance and accumulation and identify critical concentration discharges.	The methodology employed considers the input from all potentially significant sources of all constituents related to TDS and nitrate to water and land and accounts for changes in constituent concentrations as a result of physical, chemical, and biological processes that occur in the surface water and in the soil profile.
Objective 6: Ensure accurate accounting of all sources	The WARMF model tracks all constituents from all sources and creates input and output mass balances.
Objective 7: Identify how historic, current, and future source quantities will be determined or estimated to provide trend information	Specific trend analyses were not performed as part of this study, but the report describes how trend analyses can be performed and the type of information that these analyses can provide.
Objective 8: Identify and quantify areas where nitrates are impacting beneficial uses of waters.	Results from this study did not provide all data needed to make determinations of impacts to beneficial uses. This will be an area of scope development for future CV-Salts studies.
Objective 9: Select analytical tools and methods that will work for the pilot areas as well as other parts of the Central Valley.	The analytical tools and methods developed for this study would be applicable to all parts of the Central Valley. The primary data needed to run the mass balance calculation model 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.
Summary	The principal goals of this work were to identify and assemble input data sets for available models, and then to use the models to quantitatively relate salt and nitrate sources and sinks within representative pilot study areas. Modeling of this kind is extremely sensitive to land cover (e.g., the distribution of impervious surfaces, irrigation and fertilization rates, salt loading, and plant communities among analyzed catchments). Available data sources were combined to provide a level of land cover detail greater than previously employed with the widely used WARMF platform. The input data and modeling products achieved the principal project goal and advance the CV-SALTS work. The recommendations discussed below for further refinements are based on the study results.

General Conclusion

The physical, chemical, and biological data needed as input to the tools used to quantitatively relate salt and nitrate sources and sinks were gathered and evaluated for each of the pilot study areas. Data quality and quantity advantages and limitations were identified. The WARMF output demonstrates its utility as an accounting method for tracking salts and nitrates on and beneath the land surface. The groundwater models in each of the study areas demonstrated how these tools provide complementary data to the WARMF model application and also provide insights regarding the subsurface distribution of salts and nitrates in groundwater. Based on the pilot study results, recommendations are provided for further refinements and additional approaches that could be useful during the development and/or implementation of salt and nitrate management plans, pending regional plan objectives.

RECOMMENDATIONS

Key recommendations regarding the topics of land cover and soils, surface water modeling, groundwater data, groundwater flow and quality modeling, and analysis tools are summarized below in order of priority. All recommendations are focused on refinements that could be made 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 this study.

Land Cover And Soils

First Priority

1. Refine handling of non-Dairy CAFO's
2. Refine land use classes for mixed or blended classes of crops (e.g. other row crops)
3. Aggregate land use class with small percentages of total land use and loading where possible
4. Refine nitrogen loading parameters for dairy solids to include forms of nitrogen
5. Perform sensitivity analyses for soil classes and parameters and refine, if appropriate, using SSURGO mapping and parameters
6. Compare estimated fertilizer application with fertilizer sales/use data

Second Priority

1. Refine land use classes for Urban Commercial and Industrial related to imperviousness
2. Check land use class parameters against actual documented characteristics and practices
3. Compare modeled plant N uptake with harvest data and harvest N content data
4. Assess regional variations in gaseous N losses (volatilization, denitrification) in soils and aquifers

Surface Water Modeling

First Priority

1. Perform post-WARMF analyses to quantify salt and nitrate loadings to near-surface groundwater by land use class to better identify land use classes with the highest potential to impact groundwaters.
2. Perform a more extensive set of sensitivity analyses to better define the relative importance of major input and process parameters
3. Establish a single point of contact on the Regional Water Quality Control Board staff who is responsible for processing requests for discharger data related to salt and nutrient planning efforts
4. Expand CIWQS public access database to include basic discharge data: flow, effluent quality, location, land discharge area, if feasible

Second Priority

1. Collect data on soil pore water in and immediately below the root zone
2. Refine soil process parameters based on field study data
3. Monitor flow and quality in drainage-dominated waterways

Groundwater Data

First Priority

1. Identify construction data for CDPH wells to improve utility of historical water quality records
2. Add monitoring locations (existing wells with known construction and/or new dedicated monitoring wells) as needed, particularly in under-sampled areas (including water level measurements)

Second Priority

1. Continue to expand and keep current the Yolo countywide database
2. Develop central organized data repositories for the Modesto and Tule River areas (water levels, salt, nitrate, depth of screen)
3. Improve (or create for Modesto and Tule River areas) zone/aquifer-specific monitoring.
4. Develop refined estimates of separate pumpage volumes for agriculture and for Municipal/Industrial.

Groundwater Flow and Quality Modeling

First Priority

1. 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
2. WARMF output to groundwater should be disaggregated to the individual land unit scale, then used as input to groundwater model for more realistic simulation of the source distribution
3. Consider performing sensitivity analyses and recalibrating the groundwater models as necessary. Consider use of both head and groundwater age data
4. Further validate WARMF mass loads estimated to reach groundwater

Second Priority

1. Consider whether a higher vertical resolution model may improve groundwater age estimates
2. Collect depth-specific groundwater ages across a region for further validation
3. The 95 percent confidence intervals for predictions should be analyzed and provided to indicate the range of uncertainty of the model results.

Analysis Tools

Recommendations regarding the use of other tools to model salt and nitrates on a regional basis are listed below:

1. Evaluate water, salt, and nitrate balances with whole-systems approach (current and future scenarios)
2. Identify insights provided by and limitations of tools used to estimate future implications of mass loading
3. Evaluate sensitivity of tools to inputs and assumptions