RECLAMATION
Managing Water in the West

Technical Memorandum

Salt and Nitrate Budget

Westside Salt Assessment, California
Mid-Pacific Region

FINAL

U.S. Department of the Interior
Bureau of Reclamation

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Abbreviations and Acronyms

Ag	agriculture
APSIDE	Agricultural Production Salinity Irrigation Drainage Economics Model
Basin Plan	*Water Quality Control Plan for the Sacramento and San Joaquin River Basins*
BDAT	Bay-Delta and Tributary
BMP	best management practice
BOD	biological oxygen demand
Br	bromide
Ca	calcium
$CaCO_3$	calcium carbonate
CAFO	concentrated animal feeding operations
CALFED	CALFED Bay-Delta Program
CCID	Central California Irrigation District
CDEC	California Data Exchange Center
CDFA	California Department of Food and Agriculture
cfs	cubic foot per second
Cl	chloride
CVO	Central Valley Operations
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
CV Water Board	Central Valley Regional Water Quality Control Board
D-1641	State Water Resources Control Board Water Right Decision 1641
Delta	Sacramento-San Joaquin Delta
DFG	California Department of Fish and Game
DMC	Delta-Mendota Canal
DO	dissolved oxygen
DOC	dissolved organic carbon
DPH	California Department of Public Heath
DPR	California Department of Pesticide Regulation
DSM2–SJR	Delta Simulation Model II–San Joaquin River
DSM2	Delta Simulation Model II

DSS	Decision Support System
DWR	California Department of Water Resources
DWSC	Deep Water Ship Channel
Ea	absolute error
EC	electrical conductivity
EPA	U.S. Environmental Protection Agency
Er	relative error
ESA	Federal Endangered Species Act
ET	evapotranspiration
ETo	reference crop evapotranspiration
F	fluoride
GAMA	Groundwater Ambient Monitoring and Assessment
GBD	Grassland Basin Drainers
GBP	Grassland Bypass Project
GEA	Grassland Ecological Area
GIS	geographic information system
GRCD	Grassland Resource Conservation District
ILRP	Irrigated Lands Regulatory Program
IRDROP	Irrigation Drainage Operations Model
IWFM	Integrated Water Flow Model
IWRP	Integrated Water Resources Plan
K	potassium
MAA	Management Agency Agreement
Mg	magnesium
MP	milepost
MWC	Mutual Water Company
N	nitrogen
N_2	nitrogen gas
Na	sodium
NADP	National Atmospheric Deposition Program
NAWQA	National Water Quality Assessment
NEPA	National Environmental Policy Act
NH_4	ammonia
N_2O	nitrous oxide
NO_3	nitrate
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
NWA	National Wildlife Area

P	Potassium
POTW	publicly owned treatment works
Program	Program to Meet Standards
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RTMP	Real Time Management Program
SJR	San Joaquin River
SJRECWA	San Joaquin River Exchange Contractors Water Authority
SJRIO	San Joaquin River Input Output (model)
SJRRIODAY	San Joaquin River Input Output (daily model)
SJRMP	San Joaquin River Management Program
SLDMWA	San Luis and Delta-Mendota Water Authority
SNSPIS	Salt and Nitrate Sources Pilot Implementation Study
SO_4	sulfate
SOP	Standard Operating Procedure
State	State of California
Study Area	Westside Salt Assessment Study Area
SW	surface water
SWAMP	Surface Water Ambient Monitoring Program
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
TM	technical memorandum
TMDL	total maximum daily load
TIC	total inorganic carbon
TOC	total organic carbon
TKN	total Kjehldahl nitrogen
TSS	total suspended sediment
UCD	University of California, Davis
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
Vernalis	Airport Way Bridge near Vernalis
WA	wildlife management area
WADE	Westside Agricultural Drainage Economics model
WAP	Water Acquisition Program
WARMF	Watershed Analysis Risk Management Framework
Water Board	Regional Water Quality Control Board

WetManSim	Wetland Management Simulation Model
WestSim	Westside Simulation Model
WQS	Water Quality Subcommittee
WWTP	wastewater treatment plant

Abbreviations Units of Measure

µS/cm	microSiemens per centimeter
˚C =	degrees Celsius
gm	gram
L/kg	liters per kilogram adsorption isotherm coefficients
mg/L	milligrams per liter

Chapter 1 Introduction

U.S. Department of the Interior, Bureau of Reclamation (Reclamation) seeks to identify salt sources and understand the fate and transport within the Westside region of the San Joaquin River Valley. This study is referred to as the Westside Salt Assessment and includes two technical memorandums (TM). The TM for the Water Budget (Reclamation 2012a) and this TM for the Salt and Nitrate Budget complement each other and should be reviewed together.

This technical memorandum evaluates the methodology used to develop the salt and nitrate budget for the Westside Salt Assessment for Water Years 2000 to 2007. Specific areas of evaluation include general sources and sinks of salt and nitrate, the magnitude and importance of these sources, data availability, data quality and completeness, and relevance and completeness of salt and nitrogen transformation processes used in the modeling approach.

Through this work, Reclamation hopes to understand the effects on water quality and demonstrate the hydrologic processes to meet the actions identified in the Management Agency Agreement (MAA) with the Central Valley Regional Water Quality Control Board (CV Water Board). Reclamation must understand the costs and benefits of management actions on both human and environmental systems in order to plan effectively. Reclamation plans to develop a Decision Support System (DSS) that would allow water managers to simulate future conditions in order to identify, monitor, and evaluate management approaches and measures that would achieve desired results.

The DSS would integrate physical systems such as watershed processes, water quality and flow, and variables for ecosystems at various spatial levels ranging from subbasins to the main stem of the San Joaquin River (SJR). Reclamation's goals include identifying the most efficient ways to achieve water quality objectives while also sustaining agriculture. To achieve this, the DSS would likely include: process-based simulation models within defined watersheds, SJR forecast models, CALSIM II tributary temperature models, geographic information systems (GIS), topographic data, alternatives analysis, agricultural and ecological economics valuation models, plan formulation, and National Environmental Policy Act (NEPA) compliance documentation.

Reclamation conducted this study pursuant to two laws. The CALFED Bay-Delta Program (CALFED) Bay-Delta Authorization Act of 2004 directed the Reclamation, to develop and implement a Program to Meet Standards (Program). The purpose of the program is to "provide greater flexibility in meeting existing water quality standards and objectives for which the Central

Valley Project (CVP) has responsibility to reduce reliance on releases from New Melones Reservoir for those purposes" (Reclamation, 2006). Implementation of this program is consistent with direction given by Congress in the Water Supply, Reliability, and Environmental Improvement Act, Public Law 108-361.

The Central Valley Project Improvement Act (CVPIA) of 1992 (Public Law 102-575 Section 3406(g)) authorizes Reclamation to develop water quality data and models for the Sacramento, San Joaquin, and Trinity River watersheds. One of the purposes of these tasks and models is to improve the scientific understanding of the "water budget of surface and groundwater supplies, considering all sources of inflow and outflow available over extended periods" and to better evaluate existing and alternative operations of private and public water facilities. The Act emphasized water management related to water quality conditions including salinity, and improved temperature prediction capabilities as they relate to storage and flows. The demand for water in the dry or critical years within the San Joaquin River Valley exceeds the water availability. Reclamation is evaluating alternatives for managing salinity by best management practices and timing the salt discharges when there is adequate assimilative capacity in the SJR.

Studies suggest that importation of salt to the San Joaquin and Tulare basins through water supply and irrigation practices could jeopardize agriculture (Schoups et al., 2005). This has led to increased efforts to understand the salt sources and sinks. These efforts have in turn led to formation of the Central Valley Salinity Coalition and the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS). Under the auspices of CV-SALTS, a modeling exercise was undertaken to develop salt and nitrate budgets for three locations in the Central Valley: the Yolo area, located in Yolo County; Modesto area, located in Stanislaus and Merced counties; and Tulare area, located in Kern County. The modeling project had several objectives, but the overall goal was to determine if the modeling approach was adequate to develop salt and nitrate mass balance budgets. Results of those analyses were recently released as part of the Salt and Nitrate Sources Pilot Implementation Study Report (SNSPIS) (CV-SALTS, 2010). Reclamation designed the salt and nitrate budget modeling approach based on the methodology used for the SNSPIS.

Limitations of Analysis

This Technical Memorandum presents the framework for the salinity and nitrate modeling, Reclamation's study approach, and the limitations of the modeling effort. The results may not accurately simulate the actual salt loadings, and therefore should be used only for conceptual planning purposes, and to provide the lessons learned for future studies within the basin.

The salt and nitrate budget development was constrained by limitations related to data, the period of record, and model capabilities. Some of the limitations of analysis identified during the assessment include the following:

- Only publicly available data were used in the study for transparency. Irrigation water delivery data in particular came from Reclamation's Central Valley Operations (CVO) Office, rather than the Water Acquisition Program (WAP) or district data, due to concerns about data quality and consistency.

- Salinity budgets could only be as good as the previously developed water budgets, reported in the *Westside Salt Assessment, Technical Memorandum: Water Budget* (Reclamation, 2012a). The water budget had limitations in the availability of groundwater data and representation of groundwater management practices, applied water use, and application of CVO data. Additionally, exchanges between irrigators and water districts are not accounted for in the water budget analysis because the water quantities are not publicly available. These limitations carried over into the salt and nitrate budget analysis.

- The salt and nitrate budgets are also limited by the scarcity of groundwater hydrology data, including groundwater pumping and groundwater quality data. Due to the scarcity of data, significant assumptions were made regarding model inputs for groundwater quantity and quality, and are particularly important to the nitrate budget results.

- The simulation period used for the analysis described in this TM is Water Years 2000 to 2007. Several water management actions/projects affecting salinity in the San Joaquin River Basin have been implemented since 2007 and are not represented in the analysis.

- Groundwater model analysis suggests that Westside areas have significant deficit irrigation, which is not observed in the water delivery and use data and thus not simulated.

- Finally, although the model used to develop the water, salt, and nitrate budgets, Watershed Analysis Risk Management Framework (WARMF), is valuable tool for simulating hydrologic and water quality conditions in the San Joaquin River Basin, its capability to represent groundwater conditions and groundwater management, as well as wetland conditions and wetland management, is limited.

Study Area

The San Joaquin River Basin covers 15,880 square miles and encompasses the entire area drained by the San Joaquin River. The basin includes all watersheds tributary to the San Joaquin River and Sacramento-San Joaquin Delta (Delta), south of the Sacramento and American river watersheds (Central Valley Water Board, 2009). The lower San Joaquin River watershed covers the portion of the watershed downstream from Friant Dam.

The Central Valley Water Board has defined seven subareas within the lower San Joaquin River watershed (See Figure 1-1). These seven subareas are Lower San Joaquin River upstream of Salt Slough, Grassland, East Valley Floor, Northwest Side, Merced River, Tuolumne River, and Stanislaus River. The subareas on the west side of the San Joaquin River are detailed below (Central Valley Water Board, 2009):

- The **Grassland Subarea** drains approximately 1,370 square miles on the west side of the San Joaquin River in portions of Merced, Stanislaus, and Fresno counties. This subarea includes the Mud Slough, Salt Slough, and Los Banos Creek watersheds. The eastern boundary of this subarea is generally formed by the lower San Joaquin River between the Merced River confluence and Mendota Dam.

- The **Northwest Side Subarea** drains approximately 574 square miles and generally includes lands on the west side of the San Joaquin River between the Airport Way Bridge near Vernalis and the Newman Wasteway confluence. This subarea includes the entire drainage area of Orestimba, Del Puerto, and Hospital/Ingram creeks. The subarea is primarily located in western Stanislaus County, except a small area that extends into Merced County near the town of Newman and the Central California Irrigation District (CCID) Main Canal. The Northwest Subarea comprises three minor subareas, as follows:

  – The **Greater Orestimba Minor Subarea** is a 285-square-mile subset of the Northwest Side Subarea, located in southwestern Stanislaus County and a small portion of western Merced County. It contains the entire Orestimba Creek watershed and the remaining area that drains into the lower San Joaquin River from the west between the Crows Landing Road Bridge and the confluence of the Merced River, including Little Salad and Crow creeks.

- The **Westside Creeks Minor Subarea** comprises 277 square miles of the Northwest Side Subarea in western Stanislaus County. It consists of the areas that drain into the west side of the San Joaquin River between Maze Boulevard and Crows Landing Road, including the drainages of Del Puerto, Hospital, and Ingram creeks.

- The **Vernalis North Minor Subarea** is a 12-square-mile subset of land within the most northern portion of the Northwest Side Subarea. It contains the land draining to the San Joaquin River from the west between the Maze Boulevard Bridge and the Airport Way Bridge near Vernalis.

The Westside Salt Assessment Study Area (Study Area) is shown in Figure 1-1. It encompasses areas that receive water from the Central Valley Project (CVP), and that drain all or a portion of that water to the lower San Joaquin River. The Study Area comprises the Grassland Subarea and Northwest Subarea, but also includes a small area west of the Grassland Subarea to cover the entire eastward-draining watersheds of the coastal hills, and the Panoche Creek watershed south of the Grassland Subarea that drains to the Mendota Pool/Fresno Slough. The Grassland Subarea's southern boundary excludes areas within Westlands Water District that have no hydraulic connection to the San Joaquin River. Note that the Study Area includes lands served by the Columbia Canal Company that lie east of the San Joaquin River.

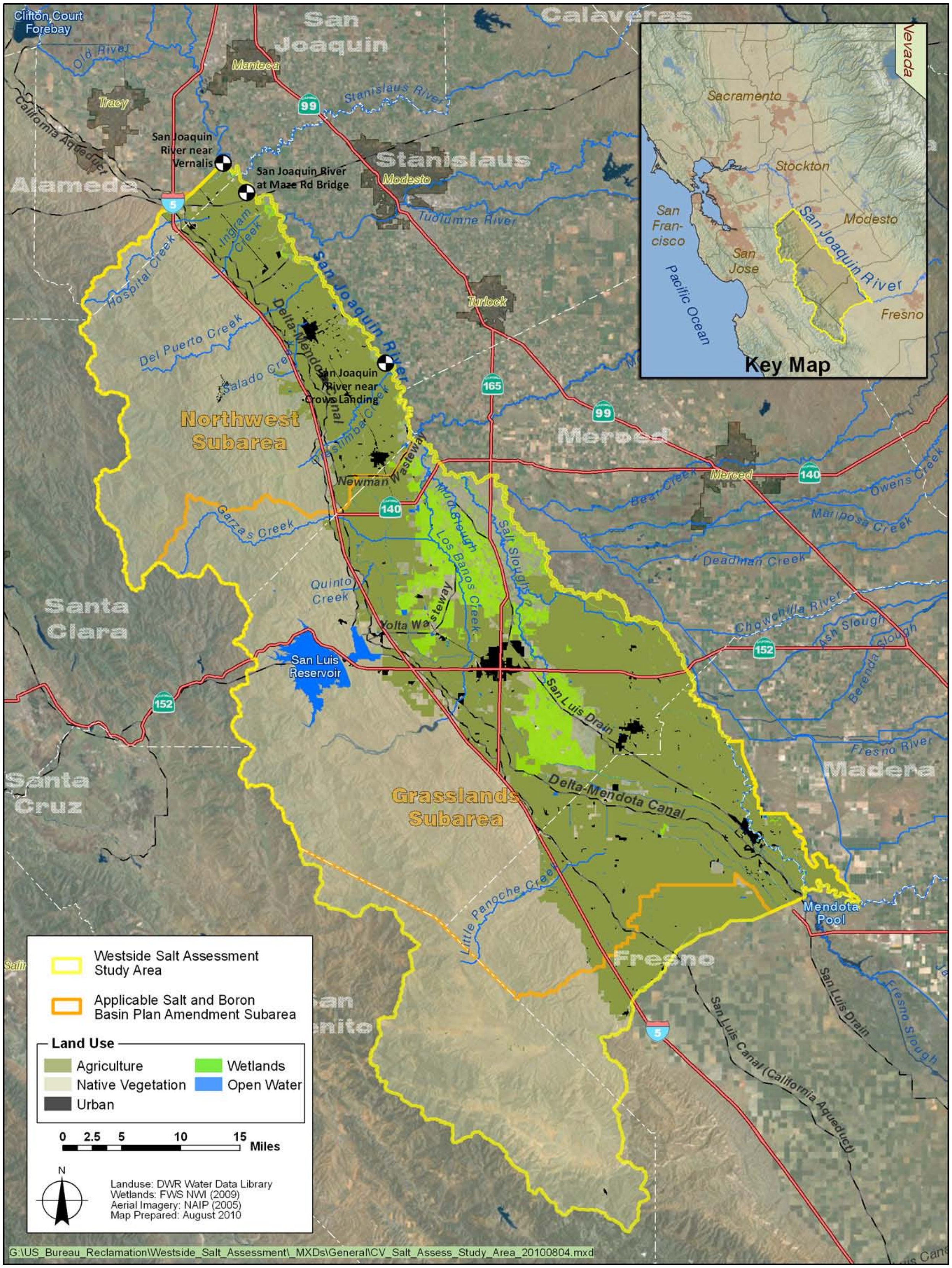


Figure 1-1. Westside Salt Assessment Study Area

For this analysis, the Study Area was subdivided into eight contributing areas, or subwatersheds, as identified in Table 1-1 and shown in Figure 1-2.

Table 1-1. Westside Salt Assessment Study Area Subwatersheds

Subwatershed No.	Subwatershed Name	Area (acres)
1	Salt Slough	246,228
2	San Luis Drain (Grassland Bypass)	101,164
3	Mud Slough	142,175
4	Los Banos Creek	125,621
5	Orestimba Creek	106,477
6	Del Puerto Creek	51,428
7	San Joaquin River, Stevinson to Crows Landing	147,235
8	San Joaquin River, Crows Landing to Vernalis	386,781

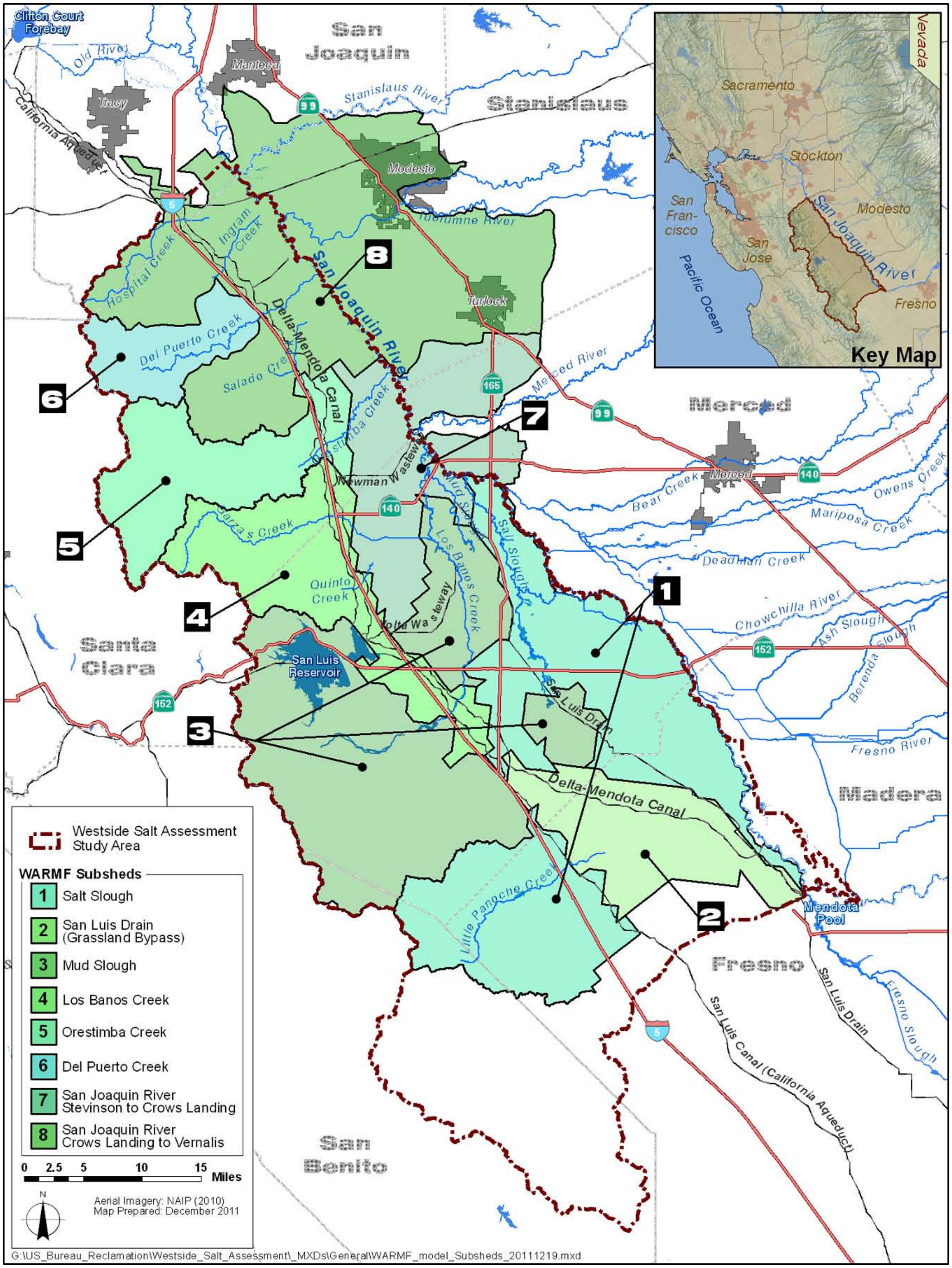


Figure 1-2. Westside Salt Assessment Study Area Subwatersheds

Previous Studies

The following sections briefly describe previous studies of the water resources of the Study Area and relevant regions along the west side of the San Joaquin Valley.

No recent water resources studies have focused specifically on the Northwest Subarea. Rather, this subarea has been addressed in the context of water demands and water supplies of CVP contractors, and in the CVP contract renewal process. An example study includes application of the Agricultural Production Salinity Irrigation Drainage Economics (APSIDE) model by Reclamation in collaboration with Lawrence Berkeley National Laboratory and the National Weather Service River Forecast Center to estimate long-term land-use changes in drainage-affected areas in the San Joaquin River Basin, and guide land retirement planning (Brekke et al., 2004; Quinn et al., 2004). Previous studies estimated agricultural yield and productivity response in the San Joaquin River Basin to reductions in water supply, irrigation water quality, root zone, and groundwater salinity, and predicted future agricultural drainage flows and water quality using the Westside Agricultural Drainage Economics (WADE) model (Hatchett et al., 1989; Quinn et al., 1989), the Irrigation Drainage Operations (IRDROP) model (Quinn, 1993), and the Statewide Agricultural Production Model (Howitt et al., 2001; Howitt et al., 2008).

In contrast, numerous studies have addressed the Grassland Subarea after the discovery of environmental problems related to selenium in agricultural drainage water in the 1980s. Studies conducted in this area include those of Burt and Katen (1988), Ayars and Schrale (1989), Fio and Leighton (1994), and the Irrigation Training and Research Center (1994). More recent studies by the San Luis and Delta-Mendota Water Authority (SLDMWA) (2006), and the U.S. Geological Survey (USGS), in partnership with Reclamation (Brush et al., 2004), have investigated changes in water use within the Grassland Subarea since the beginning of the Grassland Bypass Project (GBP) in 1996.

Numerous studies have been completed to review total salt and nitrate loading in the San Joaquin River watershed, and the interrelationships between water supply and drainage issues and their effect on river water quality. Many of these studies are related to CVP water contracting along the Delta-Mendota Canal (DMC) and water diverted from the Mendota Pool. Several studies were initiated in response to significant impacts on soil, groundwater, and surface water quality from naturally occurring selenium in small upstream watersheds, and salinity from water diverted from the DMC and Mendota Pool.

Grassland Subarea Projects and Programs

Reclamation's *Salinity Management Plan* (2010a) states the following:

> *A number of names have been given to salinity reduction actions in the agricultural areas of the Grassland Subarea (as*

> *defined in the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (Basin Plan)). There is also a substantial body of literature describing the regulatory, legal, and planning history of drainage management in this area that is not repeated here.*

For the purposes of this study, the salinity reductions achieved by actions described as the GBP, the *Westside Regional Drainage Plan* (SJRECWA et al., 2003), and/or the San Luis Unit Drainage Feature Reevaluation (Reclamation, 2008) are monitored and evaluated as Grassland Drainage Area Salinity Reduction actions for purposes of the MAA between Reclamation and the Central Valley Water Board. The Grassland Basin Drainers (GBD) manage drainage from 97,000 acres of agriculture, called the Grassland Drainage Area. Before 1996, agricultural drainage water was discharged into the San Joaquin River through Salt Slough and other channels used to deliver water to wetland areas. Since then, GBD has implemented the GBP to isolate drainage from wetland supplies, to reduce drainage through improved efficiency, blending, and reuse on increasingly salt-tolerant crops; and to use part of the San Luis Drain to convey remaining drainage to Mud Slough and the San Joaquin River.

Although drainage is managed primarily to control and reduce selenium discharges to Mud Slough, drainage management also reduces all contaminants associated with the drainage, including salinity.

The goal of these activities is to have zero discharge into the San Joaquin River by the end of 2019, which will require physical treatment of the concentrated drainage. Based on available funds, GBD has a goal to completely end discharges to the San Luis Drain by 2015.

While Reclamation lacks control of many of the resources needed to be an active participant in these drainage activities, Reclamation provides annual funding to support the activities. To date, Reclamation has provided more than $21 million in Federal funding to support this effort.

GBD activities rely on the following to reduce and then eliminate high-salinity irrigation drainage from these lands:

- Land retirement
- Reduction of drainage volumes to be managed through source control and efficient water management techniques
- Recirculation and blending of tile water for use on primary irrigation lands
- Installation of groundwater wells to lower groundwater in strategic locations to eliminate groundwater infiltration into tile drains

- Treatment of remaining drainage water for irrigation reuse and production of marketable salt product

Since implementation of GBD drainage management activities, discharges of most agricultural drainage water from the Grassland Drainage Area into wetlands and refuges have been eliminated. With about 4,000 acres of marginal land currently acting as a drainage water reuse area, total discharge volume from the drainage area was reduced by 75 percent. Selenium and salt loads discharged from the Grassland Drainage Area were reduced by 85 percent and 75 percent, respectively.

The GBP improves water quality in wildlife refuges and wetlands; sustains the productivity of approximately 90,000 acres of farmland; and fosters cooperation between area farmers and regulatory agencies in drainage management reduction, which reduces selenium and salt loading.

San Joaquin River Dissolved Oxygen Total Maximum Daily Load Studies

Under CALFED funding, the WARMF model was applied to the San Joaquin River hydrologic basin as part of the dissolved oxygen (DO) total maximum daily loads (TMDL) study of the Stockton Deep Water Ship Channel (DWSC). Reclamation provided funding to extend the San Joaquin River model upstream from Lander Avenue to Friant Dam.

Central Valley Salinity Alternatives for Long-Term Sustainability

Reclamation’s Salinity Management Plan (2010a) states the following:

> *In 2006, the Central Valley Water Board, the State Water Resources Control Board (SWRCB), and stakeholders began a joint effort to address salinity and nitrate problems in California’s Central Valley and adopt long-term solutions that will lead to enhanced water quality and economic sustainability. Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) is a collaborative basin planning effort aimed at developing and implementing a comprehensive salinity and nitrate management program. Reclamation participates in the CV-SALTS committees, provides technical support, and plans to continue with that participation. Information on CV-SALTS can be found at www.cvsalinity.org.*

CV-SALTS contracted for technical studies to support development of a regional salinity and nitrate management plan. Part of their effort includes evaluating beneficial use designations for the Basin Plan. CV-SALTS plans to recommend Basin Plan amendments (BPA) that may include language for the management of salts and nitrates.

The goal of CV-SALTS is to develop an implementation framework for sustainable salinity management in the Central Valley. Effectiveness is determined by how well critical stakeholders are engaged and by the quality of the plan.

Real Time Management Program

The San Joaquin River Management Program (SJRMP) was established through the California Legislature in 1990 to evaluate water management and water quality problems in the San Joaquin River. A Water Quality Subcommittee (WQS) was formed to implement solutions identified by the program (Quinn et al., 1997). The Real Time Management Program (RTMP) began in 1999 through a coordinated effort with the Central Valley Water Board, Reclamation, and DWR.

Reclamation's *Salinity Management Plan* (2010a) states the following:

> *A "Real Time Salinity Management" Program was proposed by the Central Valley Water Board in the salt and boron TMDL. Such a program would function through a cooperative effort in which dischargers would coordinate their discharges into the San Joaquin River. By monitoring the assimilative capacity of the river, dischargers can take advantage of increasing assimilative capacity and release their discharges in a coordinated fashion without violating salinity objectives in the river. This effort will require development of three major components: an integrated real time water quality monitoring network, potential physical infrastructure(s) to manage flows to the river, and an organizational institution to manage river activities and assure compliance with standards.*

The responsible parties identified in the TMDL are all potential stakeholders, and their involvement is crucial to the success of an RTMP. This program is developing stakeholder interest, support, and participation in RTMP through the following:

- Working with stakeholders to develop an integrated water quality monitoring network and common data platform
- Working with stakeholders to develop a forecast/decision support tool
- Working with stakeholders to develop an organizational structure to manage river activities and assure regulatory compliance
- Partnering with other programs to leverage resources to conduct salinity management pilot projects that will benefit, and provide new opportunities to further support, real-time management

Wetlands Best Management Practices

Reclamation's Salinity Management Plan (2010a) states the following:

> *The U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Game (DFG), and the Grassland Resource Conservation District (GRCD) in coordination with Reclamation are developing best management practices (BMP) plans to reduce the impact of discharges from managed wetlands into the San Joaquin River.*

Currently, a draft Wetland BMP plan has been developed and is awaiting USFWS approval. Initial funding is in place to begin implementing the BMP plan and to carry out the data collection effort. A small pilot study is underway for six paired sites to evaluate how the BMP measures would impact wetlands production, and impacts to the San Joaquin River.

Plan elements include the following:

- **Wetlands Recirculation –** This practice involves recycling water used on managed wetlands within the Grassland Ecological Area (GEA).
- **Early Drawdown –** Use early drawdown in February, where feasible, as a management tool for wetland areas with grazing programs and alkali bush scrub type habitat.

University of California, Davis, Monitoring Program

In 2002, the Central Valley Water Board executed an interagency agreement with the University of California, Davis (UCD), to evaluate the water quality of agricultural drains throughout the Central Valley. Several sites are located within or adjacent to the Study Area.

Westside Integrated Water Resources Plan

The 2006 Westside Integrated Water Resources Plan (IWRP) was developed by the SLDMWA in cooperation with Reclamation and local stakeholders. Its purpose is to guide future water management programs affecting the Westside region.

The Westside IWRP contains a water supply (and water demand) gap analysis for CVP water service contractors within the Delta Division, San Luis Unit, and San Felipe Division of the CVP. San Joaquin River Exchange Contractors are not included in the analysis because water supplies to these contractors have not been adversely affected by requirements of the Federal Endangered Species Act (ESA), CVPIA, or SWRCB Water Right Decision 1641 (D-1641). Similarly, the water supply gap analysis does not consider managed wetlands. The gap analysis identifies water supply, water use, and water shortages at 1999 and 2025 development levels, and is based on the 2000 *Water Needs Analysis* conducted by Reclamation (unpublished).

The Westside IWRP identifies a series of water management strategies to address water supply and drainage issues. One of the major strategies is elimination of subsurface agricultural drainage as part of the *Westside Regional Drainage Plan* (SJRECWA et al., 2003). Key elements of the drainage plan include land retirement, groundwater management, source control, reuse, treatment, and salt disposal.

San Joaquin River Input Output Model

In 1987, the SWRCB and UCD jointly developed the San Joaquin River Input Output Model (SJRIO) to predict San Joaquin River water quality for regulatory purposes. SJRIO uses mass balance accounting to calculate monthly flow and salt loads of the San Joaquin River from Lander Avenue to Vernalis. SJRIO inputs and outputs include flow and salt loading for tile drainage; groundwater flow; accretions/depletions; Westside region surface/subsurface agricultural discharges; and riparian, pre-1914, and post-1914 appropriative diversions.

SJRIO-2, the next generation of SJRIO, was developed as a physics-based model that calculates groundwater contributions to streamflow within the model, and includes a stochastic simulator of streamflow that allows for greater variability in monthly flows that can be analyzed in the model.

As described in the Real Time Management section above, a San Joaquin River Management Program – Water Quality Subcommittee (SJRMP-WQS) was formed to implement solutions identified by the SJRMP. Members of the SJRMP-WQS revised SJRIO to improve the timing, coordination, and management of agricultural drainage and reservoir releases into the San Joaquin River (Quinn et al., 1997). The SJRIO-2 model was revised to use a daily time-step to enable use of daily-averaged flow and water quality data. This subsequent model was renamed SJRIODAY and was used to make weekly forecasts of salinity in the San Joaquin River for 4 years by SWRCB, Lawrence Berkley National Laboratory, and California Department of Water Resources (DWR). A subsequent hydrodynamic version of SJRIODAY was developed in 2001 by DWR in partnership with the SJRMP WQS.

Similar to the hydrodynamic version of SJRIODAY, the Delta Simulation Model II (DSM2) is a hydrodynamic model developed by DWR to estimate diversions and drainage flows between Vernalis on the San Joaquin River and the DWSC. DSM2-San Joaquin River (SJR) is a one-dimensional model that uses the DSM2 HYDRO and QUAL engines to model the hydrodynamics and salinity of the San Joaquin River. DSM2-SJR uses the same input data as SJRIODAY, but is capable of running simulations with 15-minute data, which could provide more realistic estimates of San Joaquin River hydraulics and water quality dynamics. In addition, DSM2-SJR has the functionality to perform temperature modeling, and considers algal growth and cycling of nutrients (Quinn, 2003).

Groundwater Ambient Monitoring and Assessment Program, Western San Joaquin Valley Priority Basin Project

The SWRCB's Groundwater Ambient Monitoring and Assessment (GAMA) Priority Basin Project was implemented as the result of the Groundwater Quality Monitoring Act of 2001 (Assembly Bill 599) and is a product of collaboration with USGS and Lawrence Livermore National Laboratory. The main goals of GAMA are to improve comprehensive statewide groundwater monitoring and to increase the availability of groundwater quality information to the public. With the voluntary cooperation of local water agencies and well owners, USGS is testing water in California groundwater basins over a 10-year period.

The Western San Joaquin Valley study unit is one of 35 GAMA study units across the State of California (State). It includes the State DWR-defined groundwater subbasins, Delta-Mendota and Westside, which are located within portions of Stanislaus, Merced, Madera, Fresno, and Kings counties.

Starting March 1, 2009, and continuing for about 6 weeks, USGS scientists collected water quality samples from 60 wells. Between March 1, 2010 and July 8, 2010, 58 wells were sampled within the Western San Joaquin Valley study unit. A report providing results of groundwater quality analysis is expected to be available in early 2012.

Groundwater Nitrate and Organic Carbon Inputs to Lower San Joaquin River and Their Sources

USGS and UCD are conducting a study to quantify the amount of groundwater nitrate and organic carbon accretions to the lower San Joaquin River, from just upstream from the confluence of the San Joaquin River with Salt Slough to Vernalis. The study also aims to identify sources of nitrate in the groundwater accretions. The study includes a boat reconnaissance approach to identify groundwater "hot spots" or locations where accretions occur, using temperature, electrical conductivity (EC), and other tracers (Kratzer and Dahlgren, 2006; USGS, 2010). The USGS Web site indicates that results from this study were expected to be published in late in 2009 but, currently, no document has been publicly released.

Salt and Nitrate Budget Approach

The following sections summarize the salt and nitrate budget approach applied for the Westside Salt Assessment. Salt and nitrate budgets for the Westside Salt Assessment were developed for Water Years 2000 to 2007 (October 1999 to September 2007) using the WARMF model, described below. Selection of WARMF provides consistency with the approach adopted for the CV-SALTS pilot studies (2010). The associated water budgets were developed using the WARMF and IWFM models and described in the *Westside Salt Assessment, Technical Memorandum: Water Budget* (Reclamation, 2012a).

WARMF is an enhanced decision support system designed to facilitate a watershed approach to TMDL calculations and is capable of simulating flow and salt and nitrate transport for the entire San Joaquin River Hydrologic Region (Reclamation, 2011c). The purpose of the watershed approach is to develop a water quality management plan that improves water quality in a simulated river basin.

The engineering module within the WARMF model simulates hydrology and water quality for a river basin. WARMF simulates hydrology based on water balance and physics of flow. It begins with precipitation on the land surface; precipitation and irrigation water can percolate into the soil. WARMF simulates up to five layers of soil, with reaction products and infiltration of irrigation water through the soil layers. Within the soil, water first increases the moisture in each soil layer up to field capacity. Above field capacity, water percolates down to the water table, where it recharges deeper unconfined aquifers or flows laterally out of the land catchment according to Darcy's Law. A catchment is defined as …….Water on the soil or within the soil is subject to evapotranspiration (ET), 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 table rises. If the water table reaches the surface, the soil is saturated and overland flow occurs. Overland flow is calculated by Manning's equation.

Rivers accept subsurface and overland flow from catchments to which they are linked. They also receive point source discharges and flow from upstream river segments. Diversion flows are removed from river segments. The remaining water in a river is routed downstream using the kinematic wave algorithm. Channel geometry, Manning's roughness coefficient, and bed slope are used to calculate depth, velocity, and flow. Velocity is a measure of travel time down a river, which in turn affects water quality simulation.

Hydrology inputs to the WARMF model are described in the *Westside Salt Assessment, Technical Memorandum: Water Budget* (Reclamation, 2012a), including topography, soils, land use/cover, meteorology, surface water flow, groundwater pumping, and irrigation rates.

Simulations of water quality and salt and nitrate transformation processes with the WARMF model are described in Chapter 3. Water quality data are input to the WARMF model from both real-time and discrete monitoring data collected by several monitoring agencies. Water quality data input to the WARMF model include the following:

- **Surface water –** Temperature, pH, salt ions (calcium, magnesium, potassium, sodium, sulfate, and chloride), alkalinity, nitrate, inorganic carbon, biological oxygen demand, DO, total phosphorous, total Kjeldahl nitrogen, total organic carbon, total dissolved solids (TDS), total suspended sediment (TSS), and specific conductance (or EC).

- **Groundwater –** Temperature, ammonia, salt ions (calcium, magnesium, sodium, potassium, sulfate, and chloride), inorganic carbon, phosphate, and nitrate.

- **Air quality –** Ammonia, calcium, magnesium, potassium, sodium, sulfate, nitrate, chloride, and specific conductance (or EC).

Data sources for simulations of water quality and salt and nitrate transformation processes, along with data quality and completeness, are described in Chapter 3.

Report Organization

This TM includes the following topics:

- Background, Study Area, description of previous studies, and overview of the salt and nitrate budget approach (Chapter 1)

- Evaluation of the sources and sinks identified in the SNSPIS report, and identification of additional sources and sinks within the Study Area (Chapter 2).

- Review and discussion of salt and nitrate transformation processes (Chapter 3).

- Review of model coefficients and calibration procedures for the salt and nitrate budget analysis (Chapter 4).

- Review of results from the salt and nitrate budget analysis (Chapter 5).

- Recommendations for further analysis to improve the results and applicability of the Westside Salt Assessment (Chapter 6).

- A list of sources used in preparing this TM (Chapter 7).

Chapter 2
Westside Region Salt and Nitrate Sources and Sinks

Developing salt and nitrate budgets requires three elements: (1) identifying the water budget components that are sources and sinks of salt and nitrate; (2) identifying the sources, sinks, and processes that determine the mass in all identified compartments; and (3) obtaining sufficient data for the sources, sinks, and processes to parameterize models used to calculate the budgets. This chapter evaluates salt and nitrate sources and sinks identified in the SNSPIS report, and their applicability to the Westside region; a list of region-specific salts and nitrates is described, and data quality and completeness are summarized.

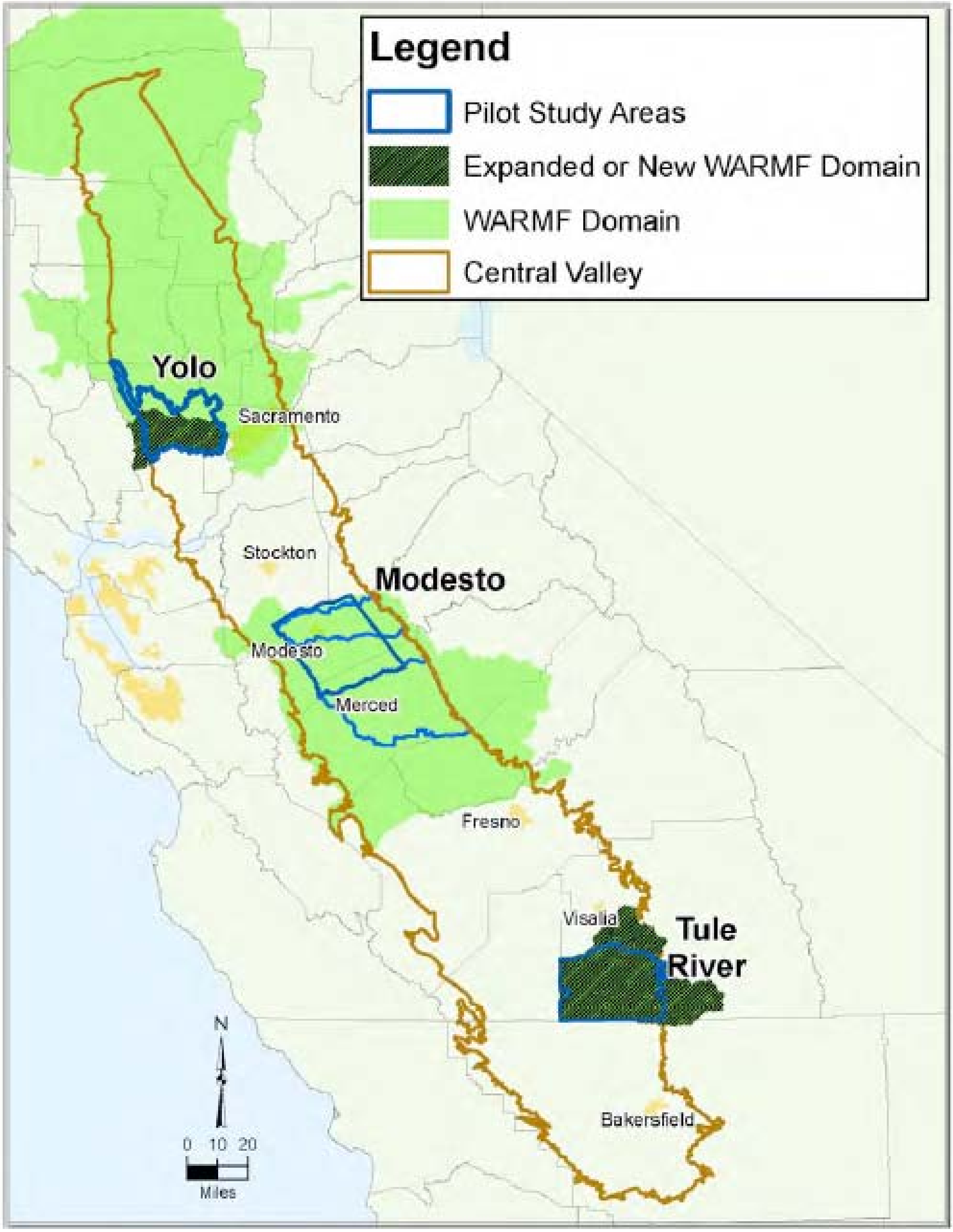
Pilot areas for analysis were selected for the SNSPIS to represent a broad range of conditions meeting key criteria (CV-SALTS, 2010):

- Representation of the major Central Valley hydrologic basins (Sacramento River, San Joaquin River, and Tulare Lake).
- Advanced application status of the WARMF model for the areas previously applied or partially applied, or sufficient data to adequately parameterize the model.
- Broad range of land cover classes.
- Relatively advanced status and availability of groundwater models for each area.
- Availability of groundwater quality data.

Three pilot areas in California's Central Valley region, shown in Figure 2-1, were selected for the SNSPIS and represent a broad range of conditions meeting the above criteria: Yolo area, Modesto area, and Tule River area (CV-SALTS, 2010).

Sources and sinks of salts and nitrate, and relevant processes for the three pilot areas in the Central Valley were identified in the SNSPIS report and simulated using the WARMF model to develop salt and nitrate budgets.

The following section describes sources of salt and nitrate identified in the SNSPIS and their applicability to the Westside region.



Source: CV-SALTS, 2010

Figure 2-1. Pilot Areas Evaluated in Salt and Nitrate Sources Pilot Implementation Study

Sources of Salt and Nitrate

The SNSPIS report listed salt and nitrate sources developed in collaboration with stakeholders in the three pilot areas (Yolo, Modesto, and Tule River). Table 2-1 identifies sources of salt and nitrate in the SNSPIS pilot areas and sources identified for the Westside region. Each of these sources and their applicability to the Westside Salt Assessment are discussed briefly below.

Table 2-1. Salt and Nitrate Sources Identified for Salt and Nitrate Sources Pilot Implementation Study Pilot Areas and Westside Region

Identified Sources	SNSPIS	Westside Salt Assessment
Surface water upstream inflow	✓	✓
Imported surface water	✓	✓
Irrigation	✓	✓
Managed wetlands	--	✓
Fertilizer	✓	✓
Stormwater discharges	✓	O
Septic tank discharges	✓	✓
Land applications, including dairies	✓	✓
Municipal wastewater treatment plant discharges and facilities, including ponds	✓	✓
Industrial discharges	✓	✓
Livestock facilities	✓	✓
Mineral weathering/reaction products	✓	✓
Atmospheric deposition	✓	✓
Groundwater extraction (dewatering) discharge	✓	✓

Key:
-- = Not identified or considered
✓ = Identified and considered
O = Identified, not considered
SNSPIS = Salt and Nitrate Sources Pilot Implementation Study

Surface Water Upstream Inflow

Surface water inflow refers to water that originates in, or would naturally drain into, the Study Area from upslope surface water bodies. Compared to the three pilot areas in the SNSPIS analysis, there are relatively fewer natural surface water inflows to the Study Area. Several major river and stream tributaries to the San Joaquin River originate in the Sierra Nevada and are developed for irrigation water supply, hydropower generation, and drinking water supply on the east side of the San Joaquin River.

Tributaries from the Coastal Ranges that enter the Study Area tend to be ephemeral, and only a small amount of the flow that originates in the Coastal Ranges reaches the San Joaquin River. Water that does enter the San Joaquin

River tends to be attributed to runoff during major storm events in the winter. Summer discharge through these tributaries consists almost entirely of irrigation return flows. These tributaries are Hospital Creek, Ingram, Del Puerto, Orestimba, Garzas, Quinto, Los Banos, Panoche, and Silver creeks. Hospital and Ingram creeks combine and discharge to the San Joaquin River at River Mile 75. In addition, Mud Slough and Salt Slough are major tributaries to the San Joaquin River. Los Banos Creek is dammed at the Los Banos Detention Dam to detain floodwater from Los Banos Creek to protect the San Luis Canal (Reclamation-owned portion of the California Aqueduct), the city of Los Banos, and surrounding farmlands. Flows from the Los Banos Detention Reservoir are released to Los Banos Creek, which flows into Mud Slough.

No water quality data are available for any of the tributaries upstream from where they enter the Westside region. These streams discharge stormwater, and the episodic nature of the storm events does not lend itself to monitoring.

Imported Surface Water

Imported surface water refers to water brought into the Westside region that would not naturally reach the Westside region. The primary source of imported surface water to the Westside region is the Delta via the DMC. Additional water is imported to the region from the Delta via the San Luis Canal (Reclamation-owned portion of the California Aqueduct), California Aqueduct (also referred to as the San Luis Canal downstream from the O'Neill Forebay) and from the San Joaquin River.

Both real-time and grab/autosampler water quality data are available from the DMC (Reclamation, 2010c). Four real-time monitoring stations along the DMC have water quality data for EC and TDS for 2000 to 2010: DMC Headworks Milepost (MP) 3.5, DMC Check 13 O'Neill, DMC Check 20, and DMC Check 21. Data are available as minimum, maximum, and mean. Continuous data are used without correction and have not been reviewed for statistical outliers. Since real-time monitoring stations record in situ information, there is little to no risk of contamination or poor sampling procedures. However, there is the possibility of inaccuracies of reported data if meters have malfunctioned or have not been properly maintained. It is assumed that meter malfunctions are detected and corrected early and that meters are maintained regularly by the managing agencies such that the use of continuous salt data on a daily time-step accurately portrays a daily average of water quality conditions during that day. Additional water quality data are available for daily or monthly time-steps for seven locations. These are DMC MPs 3.46, 68, 70 (Check 13), 97.7, 110.1, 116.5 (Check 21), and Mendota Pool (CCID Main Canal at Bass Avenue). Various constituents are monitored at these locations, including EC.

SLDMWA monitors EC weekly at eight locations: DMC MPs 16.2 (Check 2), 20.6 (Check 3), 34.4 (Check 6), 38.7 (Check 7), 48.6 (Check 9), 64.0 (Check 12), 85.1 (Check 16), and 100.9 (Telles Bridge). These eight sites are located near clusters of groundwater wells that sometimes pump water into the DMC.

Water quality of groundwater pumped into the DMC is subject to maximum allowable concentrations of numerous constituents; groundwater can only be pumped into the DMC if the groundwater quality is adequate based upon Reclamation's water quality standards of acceptance of groundwater into the DMC. Of concern for the salt and nitrate budgets are the allowable concentrations of EC and nitrate shown in Table 2-2.

Table 2-2. Allowable Concentrations of Constituents in Delta-Mendota Canal

DMC Segment	Constituent	Max Concentration
Upper DMC (at Check 13)	Electrical conductivity (EC)	1,200 µS/cm
Upper DMC (at McCabe Road, Milepost 68.0)	Nitrate as N	45 mg/L
Lower DMC (Headworks to Check 13)	Nitrate as NO_3	45 mg/L
Lower DMC (Headworks to Check 13)	Nitrate + Nitrite (as N)	10 mg/L
Lower DMC (Headworks to Check 13)	Nitrite (as N)	1 mg/L
Lower DMC (Headworks to Check 13)	TDS	1,500 mg/L

Source: Reclamation, 2011a

Key:
µS/cm = microSiemens per centimeter
DMC = Delta-Mendota Canal
mg/L = milligrams per liter
TDS = total dissolved solids

Water quality data are available for three locations along the San Luis Canal (Reclamation-owned portion of the California Aqueduct) within the Study Area: California Aqueduct Check 13, California Aqueduct Check 12 (between October 2000 and August 2002), and the Harvey O. Banks Pumping Plant stations HBP and HRO.

There are 25 diversions of water from the San Joaquin River to the Westside region between River Miles 75 and 203. Water containing salts is pumped from the river to irrigate crops near the San Joaquin River. These flows generally supplement water from other sources. Water quality data are available for locations along the San Joaquin River.

Irrigation

Depending on location, irrigation flows in the Westside region are from imported surface water deliveries, predominantly from the DMC; diversions from the San Joaquin River; groundwater; or a combination of these sources. Data from several groundwater wells are available for the Westside region (see below). Consequently, water quality of this category of sources can be estimated using information from water budget simulations and water quality monitoring data obtained for the DMC, San Luis Canal (Reclamation-owned portion of the California Aqueduct), San Joaquin River, and groundwater.

Salt is imported to the Westside region with irrigation source water, but another source of salt to the region is the dissolution of ions bound to soils in the Westside region as irrigation water moves from the surface to shallow and deeper groundwater. Dissolution rates are based on several parameters, including ions present in soils, soil pH, and infiltration rates. As a result, rates of dissolution are site specific. WARMF estimates the sorption/desorption kinetics of six major cations as well as many other chemical reactions in the soil to account for the movement of various ions through the soil profile.

Managed Wetlands

An important difference between the Westside region and the SNSPIS pilot areas is the Westside region's extensive series of managed wetlands (Table 2-3). Wetlands were not specifically addressed as part of the SNSPIS analysis, but the transport and transformation processes that occur in wetlands are possible to model within WARMF. Water quality data are available from Grassland Water District for the wetland areas for part of 2009 and 2010. These data are available for seven sites: Fremont Canal at Gun Club Road, Hollow Tree, Los Banos Creek, Los Banos Creek 1, Mud Slough at Gun Club Road, S-Lake, and Volta Wasteway. Currently water entering managed wetlands originates from the DMC and the California Aqueduct, but new management options include the use of groundwater and recaptured and recirculated flows. The primary issue to address with the wetlands is the transformation of nitrogen from organic to inorganic forms [NO_3].

Fertilizer

The following sections describe sources of salts and nitrate in the Westside region attributed to fertilizer applications. This study evaluates the importance of fertilizers to salt and nitrate loads using agronomic applications rates and California Department of Food and Agriculture (CDFA) sales records.

Nitrate

Fertilizer may be a significant source of nitrate in the Study Area, and was one of the major sources identified in the SNSPIS report. The SNSPIS analysis used agronomic rates of nitrogen fertilization derived from several sources as the default for application of fertilizer. In the SNSPIS report, a recommendation was made to find more appropriate values for fertilization rates given the large contribution of fertilizer to nitrate loadings in the pilot areas.

Fertilizer sales records are available for all counties from CDFA and were obtained for the period of analysis for this study. Sales records in tons are provided for 16 different fertilizers and a seventeenth category, "Other N."

The WARMF model used the SNSPIS rates to model nitrogen applications in the Westside region, allowing an estimation of the loading of fertilizer to the various sinks in the region.

Table 2-3. Managed Wetlands Within Study Area

Refuge/Wildlife Management Area	Area (acres)	Managed by	Water Source		Point of Diversion
			GW	SW	
Volta WA	2,889	DFG[1]		√	DMC via Volta Wasteway, CCID Main Canal
Kesterson Unit of San Luis NWR	5,900	USFWS	√	√	Grassland Water District via San Luis Canal, Santa Fe Canal, and Fremont Canal
Freitas Unit of San Luis NWR	5,600	USFWS	√[2]	√	Grassland Water District via San Luis Canal, Santa Fe Canal, and Fremont Canal
China Island Unit of North Grassland WA	3,315	DFG	√	√	CCID via J Lateral
Blue Goose Unit of San Luis NWR	N/A	USFWS		√	Grassland Water District via San Luis Canal, Santa Fe Canal, and Fremont Canal
San Luis Unit of San Luis NWR	7,430	USFWS		√	San Luis Canal Company via island C Canal, Salt Slough
West Bear Creek Unit of San Luis NWR	3,892	USFWS	√	√	San Luis Canal Company via island C Canal
Los Banos WA	5,586	DFG	√	√	San Luis Canal Company via San Pedro Canal, West Delta Canal, Grassland Water District Boundary Drain, and Salt Slough upstream from the Mud Slough (South) confluence Grassland Water District via San Luis Canal
Gadwall Unit of North Grassland WA	305	DFG		√	N/A
Salt Slough Unit of North WA	2,241	DFG	√	√	Grassland Water District via San Luis Canal
Grassland Water District – North	30,000	Private		√	DMC via Volta Wasteway, CCID Main Canal
Grassland Water District – South	20,500	Private		√	CCID via Main Canal, Arroyo Canal, and San Pedro Canal
Mendota WA	12,425	DFG		√	Mendota Pool via Fresno Slough

Notes:

[1] Although owned by Reclamation, the Wildlife Management Area has been leased to and managed by DFG since its creation in 1952.

[2] Drought period supply.

Key:

CCID = Central California Irrigation District
DFG = California Department of Fish and Game
DMC = Delta-Mendota Canal
GW = groundwater
N/A = not available
NWR = National Wildlife Refuge
SW = surface water
USFWS = U.S. Fish and Wildlife Service
WA = Wildlife Management Area

Salt

In some studies, nitrate fertilizers are considered a source of salt, although other studies assume that fertilizer does not contribute salts to the region (Steiger et al., 2010). The SNSPIS analysis found fertilizers to be an insignificant source of salt and they were omitted from calculations of salt budgets.

Soil amendments such as gypsum do have potential to add salts to the landscape. The amount of gypsum was extracted from CDFA fertilizer sales records, and the salt load applied to the landscape as a uniform application.

Stormwater Discharges

There are very few stormwater dischargers in the Westside region, and precipitation runoff is not considered a significant source of water in the region (Reclamation, 2010a). Stormwater was not considered a significant source of salt or nitrate in this study and was disregarded in the modeling.

Septic Discharges

Discharges from septic systems are a consistent issue in rural landscapes. However, in the Westside region, relatively few septic systems discharge to shallow groundwater, and their contribution is generally negligent from the perspective of salt and nitrate loading. In addition, many rural septic systems use water pumped from shallow wells, resulting in a rapid recharge of groundwater in the vicinity of a dwelling. While nitrates (generated through conversion from ammonium) and salts are added to the water discharged through septic systems, this contribution can be considered negligible compared to sources such as land application from publicly owned treatment works (POTW). An inventory of septic systems within the Westside region was included in the WARMF model, and septic discharges were considered a source of salt and nitrate in this study.

Land Applications – Concentrated Animal Feeding Operations

Dairies are present in the Westside region but are much less numerous than in the Modesto pilot area of the SNSPIS analysis. An analysis of Central Valley Water Board data indicates that there are less than 30,000 acres of dairy facility/land application area in the Westside region. Other concentrated animal feeding operations include swine, horses, goats, poultry, and beef cattle, but the acreages of these operations are very low.

Recent research by UCD indicates that dairy cows produce an average of 464 grams (gm) of nitrogen per head per day. Dairy cows produce an average of 3,420 gm of inorganic salts (excluding nitrogen) per head per year. Between 44 and 64 percent of the nitrogen excreted by dairy cows in the Central Valley is lost to volatilization (Central Valley Water Board, 2003).

Point Source/Industrial Discharges

There are very few permitted point source dischargers across the entire Westside region, and many of those identified discharge very little wastewater. Major dischargers include wastewater treatment plants (WWTP) (e.g., Los Banos, Patterson), and the remaining dischargers are considered minor. The majority are land applications (e.g., Patterson WWTP).

Livestock Facilities

Very few livestock facilities exist in the Westside region. The Central Valley Water Board lists several operations, including swine, poultry, goats, horses, and beef cattle. As indicated above, these facilities are small and should not contribute substantially to salt or nitrate loading in the Westside region.

Mineral Weathering/Reaction Products

Mineral weathering/reaction products were included in the WARMF model and are based on soils. They are incorporated into the analysis for the Westside region. Reaction product rate constants are used as calibration parameters in WARMF.

Atmospheric Deposition

Atmospheric deposition was also incorporated into the WARMF model and data from air quality stations were available to parameterize the model.

Groundwater Extraction (Dewatering) Discharge

Very little dewatering discharge occurs in the Westside region. One small permitted quarry operation is present in the northwest portion of the region. Drain tile is present throughout the region and discharges subsurface drainage water to surface waters. These discharges were incorporated into WARMF.

Magnitude and Importance of Sources

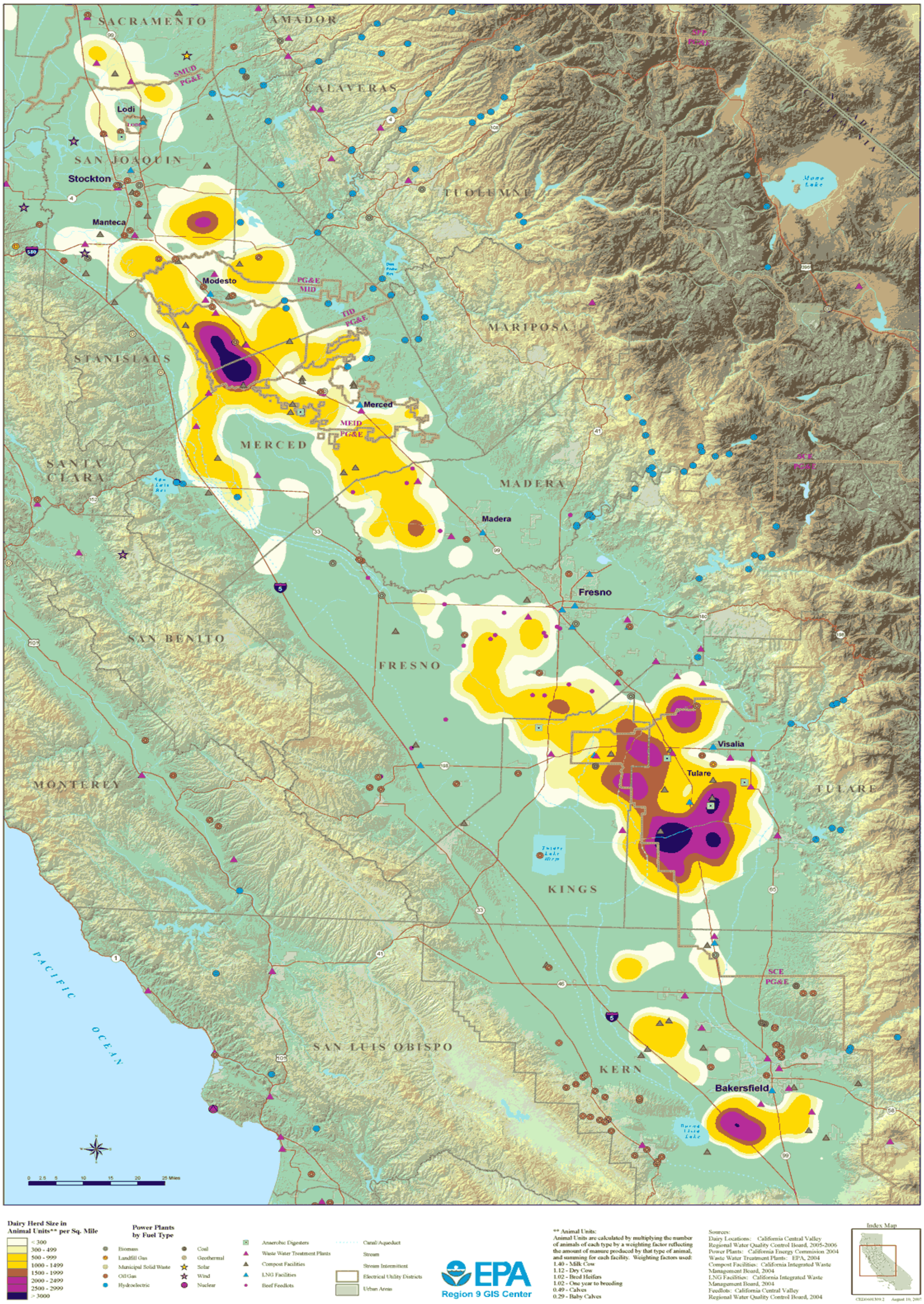
Results of the SNSPIS analyses suggest that the two major sources of salt and nitrate in the pilot areas are irrigation and fertilizer applications, with smaller contributions from mineral weathering and reaction processes, depending on the location. Other sources, such as point source discharges (e.g., food processors, POTWs), septic systems, and stormwater discharges, were minor contributors to salt and nitrate mass loadings.

Given the acreages for the different land-use categories in the pilot areas modeled in the SNSPIS, these results are not unexpected. Irrigated agriculture and dairy operations involving land applications of liquid dairy waste constitute a majority of the acreage in the Modesto and Tulare pilot areas. In the Yolo pilot area, irrigated agriculture has the largest acreage.

Within the Study Area, irrigated agriculture has the most acreage of any land cover category, suggesting that it is the largest contributor to salt and nitrate mass loadings in the Westside region. There are fewer point source dischargers (dairies, food processors, POTWs) on the west side, relative to the SNSPIS pilot areas, suggesting that these features are not major contributors in the Westside region. Figure2 2 depicts the concentration of dairy cattle in the San Joaquin Valley mapped by the U.S. Environmental Protection Agency (EPA) (2010). There are fewer dairies within the Study Area, with some in western Merced County, including within the GEA. In addition, private duck clubs are present that are also land and cattle clubs. However, the size of the dairies is less than 500 to 999 cow units per square mile, compared to the SNSPIS Modesto pilot area, which is a large portion that has more than 3,000 animal units per square mile.

Fertilizer application rates are critical for understanding the mass balance of nitrate but less important for the mass balance of salt. The SNSPIS analysis used agronomic application rates based on UCD Extension recommendations for specific crops. As mentioned, CDFA maintains fertilizer sales records by county and fertilizer type; this records the validity of the agronomic rates to be checked. Conversations with local growers suggest that their fertilizer application rates are lower than agronomic rates because of fertilizer costs and reduced need because of elevated nitrogen content in the soils. If fertilizer application rates were adjusted downward by calibrating WARMF to in-stream monitoring data, it would provide an alternate estimate of the application rates.

The anticipated importance of both irrigation flows and fertilizer application rates suggests that these parameters should be developed carefully. One of the primary sources of salts in groundwater is the dissolution of ions in soils as irrigation water moves downward to shallow and deeper groundwater. Dissolution is a complex process that depends on numerous factors, including cation exchange capacity, initial concentration of the ions, oxygen concentration, soil pH, alkalinity, and soil organic carbon content. These different factors that contribute to the dissolution process are site specific. However, the WARMF model simulates dissolution using default values of the components described above that can be adjusted to calibrate the model's simulation of drainage against measured surface drainage.



Source: EPA, 2010

Figure 2-2. Dairy Cow Concentration in San Joaquin Valley and Tulare Basin

Sinks for Salt and Nitrate

Sinks for salt and nitrate refer to flux of material out of the system. For purposes of this analysis, the system is the Study Area. Table 2-4 shows the salt and nitrate sinks evaluated in the SNSPIS and considered for the Westside Salt Assessment.

***Sinks** for salt and nitrate refer to flux of material out of the system.*

Table 2-4. Salt and Nitrate Sinks Identified By SNSPIS and Westside Study

Identified Sinks	SNSPIS	Westside Salt Assessment
Surface water outflow	✓	✓
Surface water diversions	✓	O
Near-surface groundwater	✓	✓
Deeper groundwater	✓	✓
Plant uptake	✓	✓
Reaction decay	✓	✓
Gaseous loss, volatilization	✓	✓
Managed wetlands	--	✓

Key:
-- = Not identified or considered
✓ = Identified and considered
O = Identified, not considered
SNSPIS = Salt and Nitrate Sources Pilot Implementation Study

Surface Water Outflow

There are 56 surface water discharges from the Westside region to the San Joaquin River. Contributions to flow of these discharges include irrigation return flows, direct flows from tributaries, and, in the case of Mud Slough, subsurface drainage from tile drain systems associated with the GBP. While Westside region tributaries to the San Joaquin River convey little natural flow, they serve as a conduit for irrigation return flows to the San Joaquin River. Los Gatos Creek, one of the streams draining the Westside region, is not a tributary to the San Joaquin River. During storm events, Los Gatos Creek conveys stormwater runoff outside the Study Area toward the Fresno Slough/James Bypass. A number of relic drainage systems throughout the Westside region also convey water to the San Joaquin River. For example, the New Jerusalem Drainage District, located within the Banta-Carbona Irrigation District, discharges directly to the San Joaquin River below Vernalis.

Additionally, water quality and flow data from monitoring stations along the San Joaquin River supported analysis of salt and nitrate outflow from the Westside region.

Surface Water Diversions

No surface water diversions to areas outside the Study Area were considered sinks for salt or nitrate. All surface water diversions within the Westside region are applied within the Study Area.

Near-Surface Groundwater

Groundwater flow in the Study Area occurs in two primary aquifers, which are separated by the Corcoran Clay layer, located approximately 300 feet below ground surface. Above the Corcoran Clay is a semiconfined aquifer that is fully saturated in much of the Study Area and consists of water tables within 5 feet of the ground surface. In general, the depth to groundwater in the semiconfined aquifer increases with distance away from the San Joaquin River.

"Near-surface" groundwater is defined as water down to the depth where the groundwater still interacts with surface water via lateral flow. In areas with shallow soils, this is the depth to bedrock. Where bedrock does not occur at a shallow depth, as in the floor of the Study Area, the underlying unconfined aquifer is referred to as "deeper groundwater." WARMF simulated the percolation of water from the surface into the near-surface groundwater. By default, WARMF assumed that the recharge from near-surface groundwater to deeper groundwater was negligible compared to ET and lateral flow. This default could be overridden to simulate deeper groundwater recharge.

Groundwater in the Study Area generally flows north and east in the aquifer above the Corcoran Clay. Near-surface groundwater may be conveyed to the San Joaquin River via direct discharge of tile drainage to the river, indirectly via discharge to tributaries of the San Joaquin River, lateral subsurface flows toward the San Joaquin River, and tributaries. Additional outflow occurs as a result of capillary rise to the root zone and resultant ET, and lateral groundwater flow eastward under the San Joaquin River.

Shallow groundwater quality data were available for numerous locations across the Study Area. However, sampling depth, and the aquifer from which the groundwater quality data were collected were unknown in most instances.

Deeper Groundwater

Deeper groundwater is defined in the WARMF model as groundwater within the underlying unconfined aquifer. WARMF does not simulate vertical movement of water to the deeper, confined aquifer. Recharge of the lower confined aquifer is primarily from subsurface inflow from the valley floor, and foothill areas beyond the eastern boundary of the Corcoran Clay layer. The Corcoran Clay layer is not continuous in some areas, and seepage from the semiconfined aquifer above does occur through the confining layer.

Scarce water quality data were available for the unconfined aquifer and the confined aquifer.

Plant Uptake

The WARMF model simulates plant uptake of nutrients that can then leave the Westside region as part of the biomass offtake of harvested crops. Because there are few food processors in the Westside region, harvested crops were assumed to be completely removed from the region. Plant uptake and biomass offtake were set to default parameter values in WARMF.

Reaction Decay

Reaction decay rates were simulated in the WARMF model using default values, and data were not needed to run the model. The primary reaction decay processes anticipated within the Westside region are denitrification and sulfate reduction.

Gaseous Loss, Volatilization

Gaseous loss, or volatilization, is another sink for salt and nitrate. The WARMF model simulates the volatilization of ammonia after application as fertilizer, both from dairy waste and ammonium-based synthetic fertilizers. The volatilization rate depends on soil pH and atmospheric conditions, which were simulated in the WARMF model.

Managed Wetlands

Managed wetlands represent areas with the potential for nitrogen transformation and sulfate reduction (reaction decay and/or volatilization), and can serve as sinks for salts, and nitrate within the vegetation (plant uptake) and sediments.

Nitrogen cycling in wetlands is a very complex process, and the flux of various forms of nitrogen depends on the age of the wetland. Young wetlands generally accumulate nitrogen while older wetlands are assumed to be in balance. Managed wetlands are harvested and tilled every 5 to 7 years, allowing new growth and recycling of nutrients. A more complete discussion of nitrogen transformations is included in Chapter 3.

Salt and nitrate transformation processes within wetlands were simulated in the WARMF model, with the exception of nitrogen fixation, although there are no known wetland-specific rate constants for salt or nitrate transformation reactions in the Study Area.

Magnitude and Importance of Sinks

Of all sinks discussed above, the largest outflows of salt and nitrate are expected to be to the San Joaquin River and shallow groundwater. Previous studies found that salt is accumulating in shallow groundwater in the San Joaquin Valley (e.g., Shoups et al., 2005). Exported food and animal products and POTWs are expected to account for a much smaller amount of salt and nitrate.

The magnitude and importance of the sinks described above were determined through development of a salt and nitrate budget for the Study Area.

Salt and Nitrate Budget Components

The salt and nitrate budget components included all major sources and sinks of constituents in the Study Area, shown Figure 2-3, and are defined in Table 2-5. For a given subwatershed land area, influx components to the overland flow and near-surface groundwater include atmospheric deposition, irrigation, fertilizer/land application, point sources, septic systems, and reaction products. Outflux components (sinks) included reaction losses (e.g., uptake/decay), outflow to streams, and deep groundwater recharge. Lateral and horizontal groundwater flow, referred to as “deeper groundwater” in WARMF model documentation, is not simulated in the WARMF-SJR model. However, deep groundwater recharge and deep groundwater pumping for applied irrigation were input to or simulated in the WARMF-SJR model. These components were presented as an estimate of the salt/nitrate budget for deeper groundwater; however, it should be noted that some potentially important components of the deeper groundwater budget, such as urban pumping and lateral flow, were ignored because they are not included in the WARMF-SJR model.

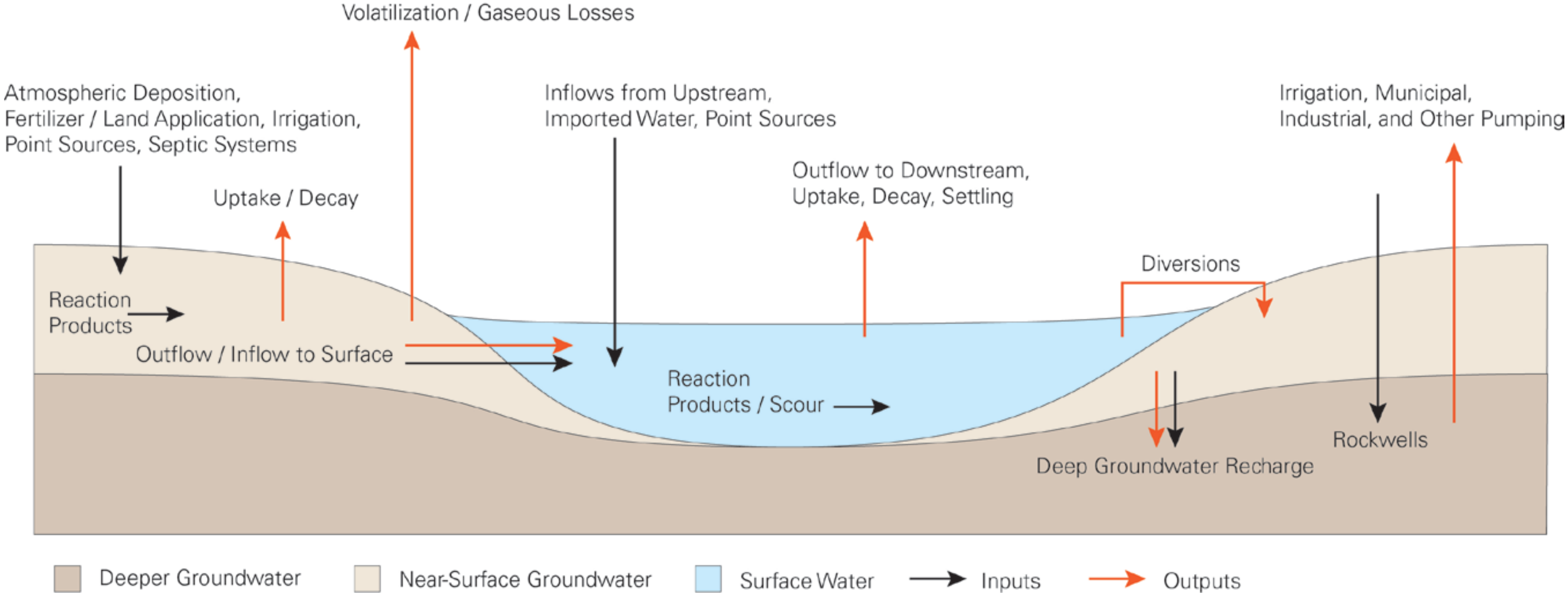


Figure 2-3. Conceptual Salt and Nitrate Budget Inputs and Outputs for Study Area

Table 2-5. Salt and Nitrate Budget Components Evaluated

Budget Component	Description
Surface Water – Inputs	
Inflows from Upstream	Inflow to surface water reach from upstream reach.
Imported Water	Water imported to the region and contributing to flows in surface waters.
Inflows from Near-Surface Groundwater	Lateral flow contributions from near-surface groundwater.
Point Sources	Permitted point source discharges, including wastewater treatment plants.
Reaction Product/Scour	Salt and nitrate developed from chemical reaction, mineral weathering, or stream scour.
Surface Water – Outputs	
Uptake/Decay/Settling	Plant uptake of nutrients; reaction decay (i.e., denitrification and sulfate reduction); sedimentation.
Diversions	Riparian and irrigation diversions from surface water.
Outflow to Downstream	Outflow from surface water reach to downstream reach.
Near-Surface Groundwater – Inputs	
Atmospheric Deposition	Wet and dry deposition of salts from the atmosphere.
Irrigation	Applied water to crops, either by diversions or irrigation pumping.
Fertilizer/Land Application	Salts and nitrate attributed to fertilizer applications and/or land applications associated with concentrated animal feeding operations.
Point Sources	Permitted point source discharges, including wastewater treatment plants.
Septic Systems	Discharges from septic systems.
Reaction Product	Salt and nitrate developed from chemical reactions and/or mineral weathering.
Near-Surface Groundwater – Outputs	
Uptake/Decay	Plant uptake of nutrients; reaction decay.
Volatilization/Gaseous Losses	Gaseous losses to the atmosphere.
Outflow to Surface	Lateral flow contributions to surface water.
Deep Groundwater Recharge	Vertical percolation and recharge to deeper groundwater.
Deeper Groundwater – Inputs	
Recharge from Near-Surface Groundwater	Vertical recharge from near-surface groundwater.
Deeper Groundwater – Outputs	
Irrigation Pumping	Water pumped from deeper groundwater for irrigation.
Municipal and Industrial Pumping	Water pumped from deeper groundwater for municipal or industrial use.
Other Pumping	Water pumped from deeper groundwater for use other than irrigation, municipal or industrial.

Data Quality and Completeness

The SNSPIS report lists 34 sources of data or information needed to parameterize the WARMF model for the three pilot areas (CV-SALTS, 2010). Of the 34 sources, only five are unique to the SNSPIS pilot areas. None of the data required to run WARMF rely uniquely on any of these five data sources.

The types of data and parameter values needed to create a salt and nitrate budget were characterized in the SNSPIS report under three types of data: hydrologic data, salt and nitrate data, and process parameters. As discussed above, the data and parameter values used in the SNSPIS evaluation and those needed for WARMF are almost identical, with the addition of managed wetlands data within the Study Area.

The sections below summarize data availability, data quality, and data completeness for developing salt and nitrate budgets for the Study Area under each of the following data types:

- Land use
- Hydrology
- Surface water quality
- Groundwater quality
- Air quality

Quality of discrete data was assumed based on the documentation of quality assurance (QA) procedures (i.e., Quality Assurance Program Plan (QAPP), standard operating procedures (SOP)) and adequate procedures to ensure accuracy and precision and avoid contamination. Quality of continuous data was assumed based on active maintenance of monitoring locations.

Land Use

The SNSPIS used land-use data from the DWR land-use cover class database. As described in the *Westside Salt Assessment, Technical Memorandum: Water Budget Methodology* (Reclamation, 2010b), land uses for various counties are updated periodically but relatively infrequently, meaning that the land cover classes could be significantly out of date. The methodology used to update the Westside Simulation (WestSim) Model and WARMF Model land-use classes is provided in the *Westside Salt Assessment, Technical Memorandum: Water Budget Methodology* (Reclamation 2010b). The water demand for land use acreages and crop types was e assigned to surface water and groundwater deliveries as in WestSim results.

Hydrology

Hydrologic data for the Study Area developed to support the Westside Salt Assessment are described in detail in the *Westside Salt Assessment, Technical Memorandum: Water Budget Methodology* (Reclamation, 2010b). The resulting water budget is used to identify the magnitude and importance of salt and nitrate sources, transport, and fate within the Study Area. Quality and completeness of hydrologic data available for developing the water budget were appropriate for this application. Limitations of the hydrologic data, particularly water delivery data, are described in Chapter 1.

Surface Water Quality

The following sections describe the data used to develop the salt and nitrate budget: available monitoring data, point source data, fertilizer application rates, and data quality and completeness.

Monitoring Data

There are several surface water quality monitoring programs in the Study Area. Sources of surface water quality data include the Surface Water Ambient Monitoring Program (SWAMP), Irrigated Lands Regulatory Program (ILRP), GBP, San Joaquin River DO TMDL, DWR, USGS, and water/irrigation districts. Surface water quality monitoring programs and data sources used for this study are listed in Table 2-6. Locations of existing surface water quality monitoring stations identified for this study are shown in Figures 2-4 and 2-5, from south to north. Water quality data in the immediate vicinity of the San Joaquin River were not available for all of the 56 discharges, but a significant amount of data were available. Monitoring programs such as the ILRP generate data from the lowest point in the watershed containing irrigated agriculture. As a result, a large number of monitoring sites are located in the immediate vicinity of the confluence of surface water outflows and the San Joaquin River. *Water Quality Data Source Information* (Attachment A to this TM) provides additional information on discrete and instantaneous water quality data compiled for this study.

Table 2-6. Water Quality Monitoring Programs and Data Sources in Study Area

Agency	Project Name	Start Date	End Date	Frequency	Parameters
Central Valley Water Board	Central Valley Trends	May 2009	October 2009	Twice (two dates, multiple times)	EC, DO, Temperature, pH
Central Valley Water Board	Grassland Bypass[1]	October 1995	Present	Daily/Weekly	EC, DO, Temperature, pH, Boron, K, Na, Hardness, Ammonia, Nitrate, Total Nitrogen, TKN, Orthophosphate, Phosphate, Sulfate, BOD, TDS, TSS
Central Valley Water Board	San Joaquin River Trends	October 2000	Present	Monthly	EC, DO, Temperature, pH, Boron, Ca, Cl, Mg, K, Na, Hardness, Ammonia, Nitrate, Total Nitrogen, TKN, Orthophosphate, Phosphate, Alkalinity, Sulfate, BOD, TDS, TSS
Central Valley Water Board	SWAMP	May 2008	January 2009	Three sample dates	EC, DO, Temperature, pH
Central Valley Water Board	Ag Waiver Phase I Monitoring	March 2003	September 2003	Monthly (irrigation/ storm)	Cl, Hardness, Alkalinity, Ammonia, Suspended Sediment Concentration
Central Valley Water Board	Ag Waiver Phase II Monitoring	July 2004	March 2006	Monthly (irrigation/ storm)	EC, DO, Temperature, pH, Hardness, Ammonia, Nitrite, Nitrate, Total Nitrogen, Orthophosphate, Phosphate, TDS, TOC
Central Valley Water Board	Organo-phosphate TMDL	January 2006	July 2007	Monthly (irrigation/ storm)	EC, DO, Temperature, pH
SWRCB	SWAMP SWRCB Statewide Perennial Streams	June 2008	July 2008	Twice (two dates)	EC, DO, Temperature, pH, Boron, Cl, Hardness, Ammonia, Nitrate, Nitrite, Orthophosphate, Phosphate, TDS, TSS
Reclamation	Grassland Bypass Project	October 1996	December 2007	Daily/ Monthly	EC, pH, Boron, TSS
Westside San Joaquin River Watershed Coalition	Irrigated Lands Regulatory Program Monitoring	July 2004	Present	Monthly	EC, DO, Temperature, pH, Boron, Hardness, Ammonia, Nitrite, Nitrate, TKN, Orthophosphate, Phosphate, TOC, TDS, TSS
Westside San Joaquin River Watershed Coalition	Special Study – Bacteria Sourcing	September 2006	September 2006	One-day special study	EC, DO, Temperature
DWR	DWR Operations and Maintenance – State Water Project Water Quality Monitoring	December 1997	Present	Monthly	EC, DO, Temperature, Boron, Ca, Cl, Br, Mg, Sodium, Hardness, Nitrate, Alkalinity, DOC, TOC, TDS

Table 2-6. Water Quality Monitoring Programs and Data Sources in Study Area (contd.)

Agency	Project Name	Start Date	End Date	Frequency	Parameters
DWR	DWR Operations and Maintenance – State Water Project Water Quality Monitoring	January 1986	Present	Hourly	EC, Temperature, pH, DOC, Br, Cl, F, Nitrate, Phosphate, Sulfate, Fluoresces
Reclamation	Delta-Mendota Canal Monitoring Program	August 1999	Present	Hourly	EC, Temperature
Multiple	San Joaquin River Water Quality Data Atlas	December 1983	December 2003	Variable	EC, DO, Temperature, pH, Ammonia, Nitrate, Total Nitrogen, TKN, Orthophosphate, Phosphate, Alkalinity, TOC, BOD, Total Phytoplankton, TDS, TSS
USGS	National Water Quality Assessment	July 1992	August 2001	Monthly/ Quarterly	EC, DO, Temperature, pH, Ammonia, Nitrate, TKN, Orthophosphate, Phosphate, Inorganic carbon, TSS
USGS	Surface Water Monitoring Sites	January 1991	Present	Continuously/ Monthly	EC, DO, Temperature, pH, Ammonia, Nitrate, Nitrate, Total Nitrogen, Orthophosphate, Phosphate, Inorganic Carbon, DOC,
Multiple	San Joaquin River DO TMDL	March 2005	September 2007	Variable	EC, DO, Temperature, pH, Ammonia, Nitrate, Phosphate, Alkalinity, TOC, BOD, TKN, Total Nitrogen, Total Phytoplankton, TDS, TSS
DWR	San Joaquin District – Surface Water Monitoring Sites	November 2004	Present	Continuously	EC, Temperature
DWR	Interagency Ecological Program, Environmental Monitoring Program	January 1982	Present	Continuously/ Monthly	EC, DO, Temperature, pH, Cl, Br, Hardness, Ammonia, Orthophosphate, TOC, DOC, TDS
Central Valley Water Board	NPDES Self-Monitoring Program	January 2007	Present	Quarterly/ Yearly	EC, DO, Temperature, pH, Cl, Hardness, TDS

Table 2-6. Water Quality Monitoring Programs and Data Sources in Study Area (contd.)

Note:
[1] Central Valley Water Board no longer collects GBP samples as of July 2011. Those stations are now monitored by Reclamation

Key:
Ag = agricultural
BOD = biological oxygen demand
Br = bromide
Ca = calcium
Cl = chloride
DO = dissolved oxygen
DOC = dissolved organic carbon
DWR = California Department of Water Resources
EC = electrical conductivity
F = fluoride
K = potassium
Mg = magnesium
Na = sodium
NPDES = National Pollutant Discharge Elimination System
Reclamation = U.S. Department of the Interior, Bureau of Reclamation
SWAMP = Surface Water Ambient Monitoring Program
SWRCB = State Water Resources Control Board
TDS = total dissolved solids
TKN = total Kjehldahl nitrogen
TMDL = total maximum daily load
TOC = total organic carbon
TSS = total suspended solids
USGS = U.S. Geological Survey
Water Board = Regional Water Quality Control Board

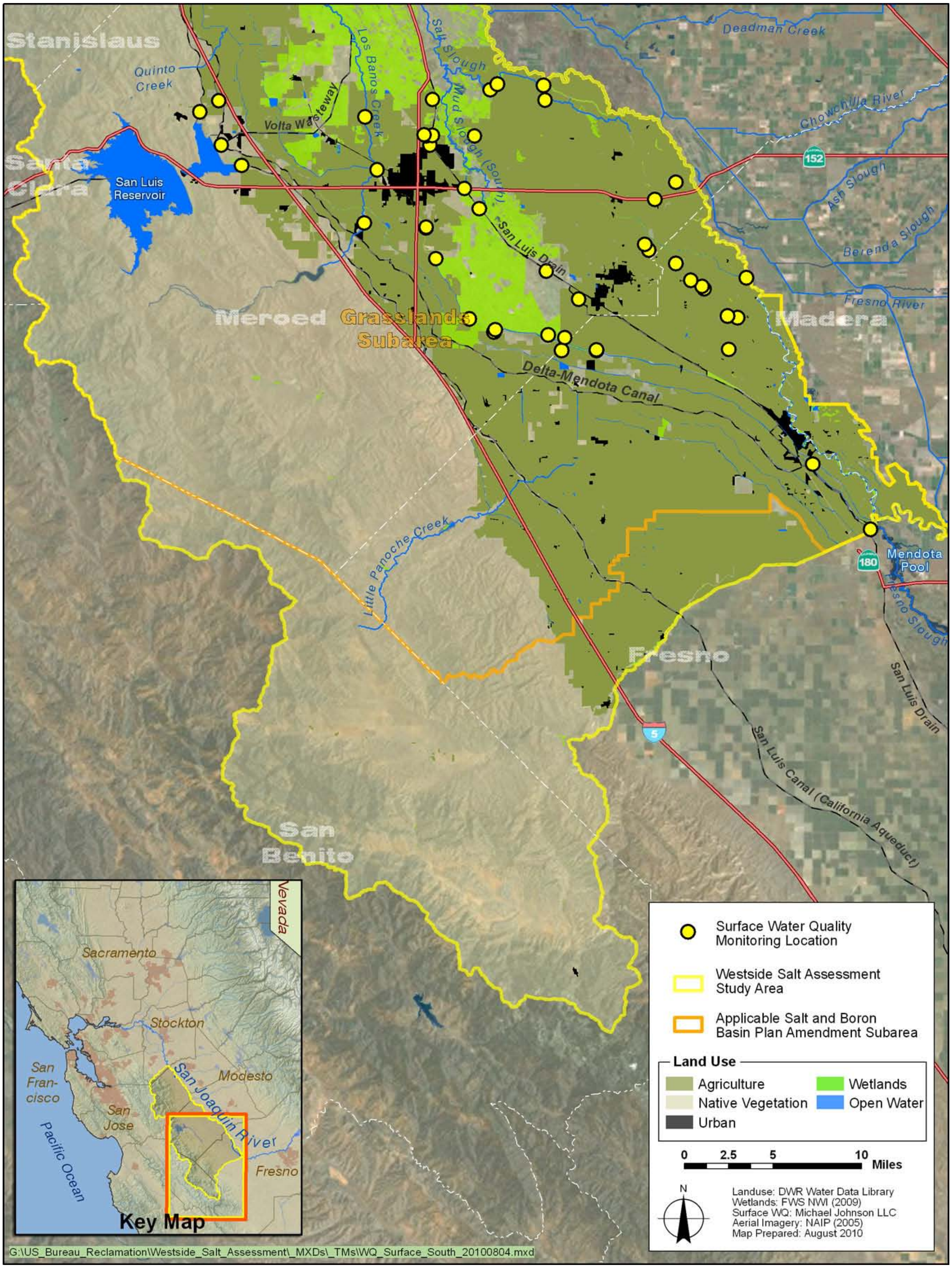


Figure 2-4. Study Area Surface Water Quality Monitoring Stations – South

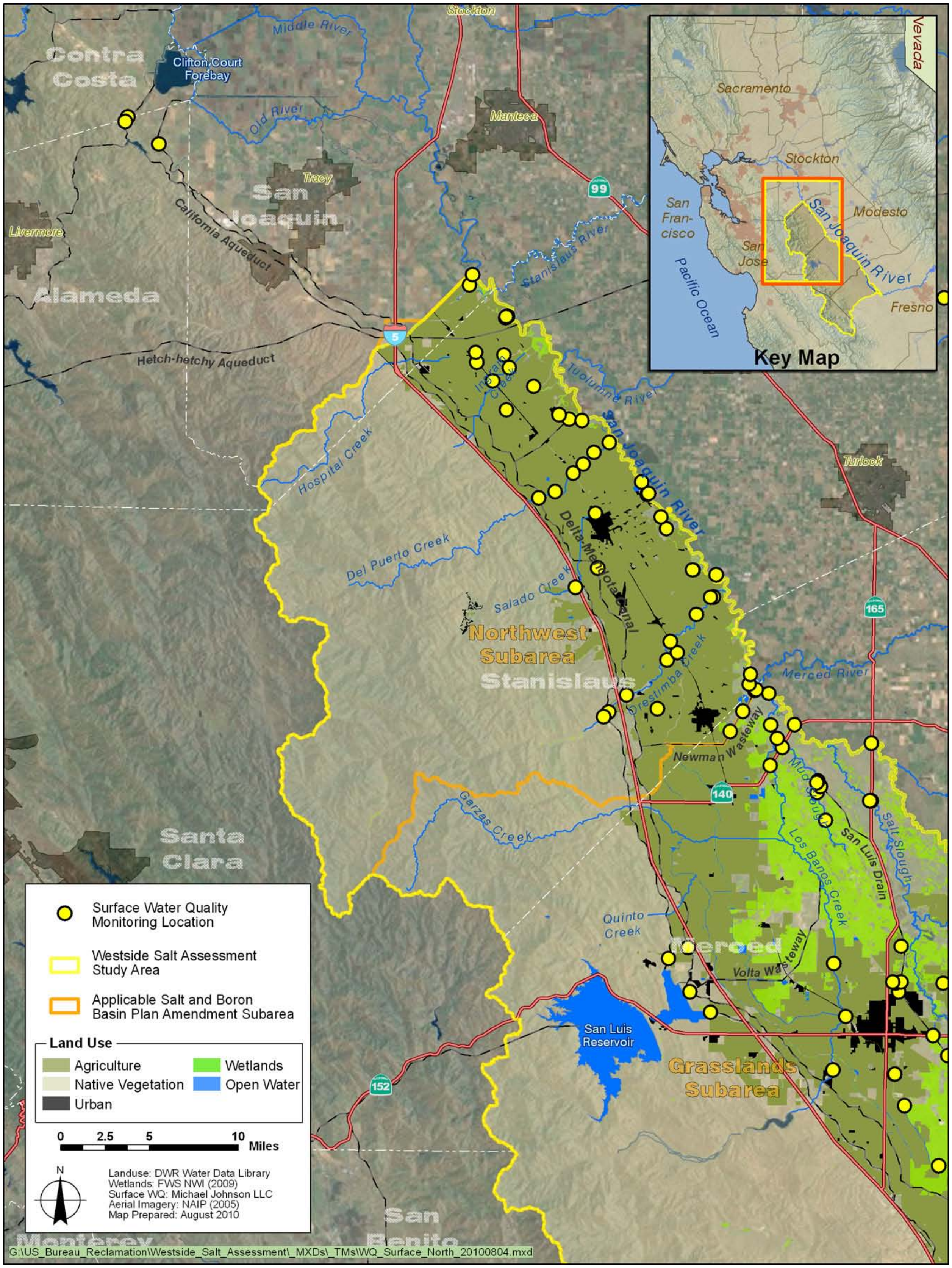


Figure 2-5. Study Area Surface Water Quality Monitoring Stations – North

A majority of the surface water quality data was previously compiled for a separate application of the WARMF model, and includes data from the San Joaquin River Atlas, the San Joaquin River DO TMDL studies, the California Data Exchange Center (CDEC), Central Valley Water Board, Bay Delta and Tributary (BDAT) projects, and ILRP.

WARMF water quality data were updated directly from the Westside San Joaquin River Watershed Coalition and SWAMP database. These sources contain up-to-date verified and validated data. Data qualifiers were reviewed and any rejected or questionable data were not used. All data were stored in a Microsoft Access database, which contains project name and description, data source, monitoring agency, monitoring location (latitude and longitude), reporting limits, data values, data qualifiers, and reference to the associated WestSim and WARMF subwatershed/subregion areas.

Water quality database analyte names and associated units used to develop the salt and nitrate budgets are listed in Table 2-7. The WARMF and spreadsheet models used the same water quality data; occasionally, the data were converted within the models to fit existing model parameters.

Inflow boundary conditions were defined by the water quality in the DMC, San Luis Canal (Reclamation-owned portion of the California Aqueduct), and tributaries to the San Joaquin River.

Point Sources

Water quality data for point sources were obtained from compliance reports provided to the Central Valley Water Board. These data are available at the Central Valley Water Board offices in Rancho Cordova and Fresno.

Fertilizer Rates

Fertilizer rates were incorporated into the models using either the agronomic application rates established in the SNSPIS analysis or the rates calculated using fertilizer sales records. Fertilizer sales were available by county and year and were obtained from CDFA. The application rates were calculated as the total number of pounds of nitrogen fertilizer sold, divided by the application area of the county in the Westside region.

Table 2-7. Salt and Nitrate Budget Water Quality Database Analytes and Associated Units

Analyte	Unit
Alkalinity as $CaCO_3$	mg/L
Ammonia as N, Total	mg/L
Biological Oxygen Demand	mg/L
Boron, Dissolved	mg/L
Boron, Total	mg/L
Calcium	mg/L
Chloride	mg/L
Dissolved Organic Carbon	mg/L
Hardness as $CaCO_3$	mg/L
Magnesium, Total	mg/L
Nitrate + Nitrite as N	mg/L
Nitrate as N	mg/L
Nitrite as N	mg/L
Nitrogen, Total Kjeldahl	mg/L
Nitrogen, Total	mg/L
OrthoPhosphate as P, Dissolved	mg/L
Oxygen, Dissolved	mg/L
pH	none
Phosphorus as P, Total	mg/L
Potassium, Total	mg/L
Sodium, Total	mg/L
Specific Conductivity	µS/cm
Sulfate	mg/L
Suspended Sediment Concentration	mg/L
Suspended Solids, Total	mg/L
Suspended Solids, Volatile	mg/L
Total Dissolved Solids	mg/L
Total Organic Carbon	mg/L
Turbidity	NTU
Water Temperature	˚C

Key:
µS/cm = microSiemens per centimeter
˚C = degrees Celsius
$CaCO_3$ = calcium carbonate
mg/L = milligrams per liter
N = nitrogen
NTU = nephelometric turbidity unit
P = phosphorus

Data Quality

Data quality was considered to be high if the data were collected through an established program by a federal or State agency following SOPs. Data collected by agricultural coalitions as part of the ILRP was also considered to be high quality, as data were collected under an approved Monitoring and Reporting Plan (San Joaquin Valley Drainage Authority, 2008) including a QAPP that is SWAMP-comparable and submitted to the Central Valley Water Board for review and approval. To be SWAMP-comparable, the data would meet the requirements of the SWAMP Data Management Plan and the SWAMP QAPP available through SWRCB. Continuous data were not qualified because precision and accuracy are not assessed for continuous, as for individual event-related sampling. The precision and accuracy involved in continuous monitoring were determined by the individual agency's maintenance schedule; no attempt was made as part of this study to review meter/agency maintenance records or evaluate data for statistical outliers.

The agencies generating surface water quality data include Reclamation, USGS, DWR, Central Valley Water Board, Westside San Joaquin River Watershed Coalition, and the SWRCB. All agencies generating surface water quality data maintain rigorous QA/quality control (QC) programs. The USGS National Water Quality Assessment (NAWQA) program includes 12 documents outlining protocols for sample collection and analysis of surface water, groundwater, and sediment (USGS, 2009). The SWRCB has developed and maintained an extremely rigorous QA program within the last several years. Reclamation, DWR, Central Valley Water Board, and Westside San Joaquin River Watershed Coalition maintain SWAMP-comparable monitoring programs for the period of interest for this study. Consequently, all discrete surface water quality data used by WARMF were of high quality. Continuous data were used on a daily time-step and were considered to be accurate portrayals of daily salt concentrations. Data were reviewed for duplicates, quality flags, and data gaps.

Data Completeness

Surface water quality data were available for locations on the DMC (Table 2-8), the San Luis Canal (Reclamation-owned portion of the California Aqueduct) (Table 2-9), and 70 locations within the Westside region and San Joaquin River (Table 2-10). The only constituent for which data were available at all sites is EC. Data for individual ions were available for a smaller number of those sites but are spread geographically across the region, providing reasonable coverage of the Study Area. Many programs generated data for the entire period (Water Years 2000 to 2007), while some provided data only for a portion of the period.

Table 2-8. Delta-Mendota Canal Water Quality Monitoring Locations

Station Code	Station Name	Constituents
DMC	Delta-Mendota Canal Headworks	EC, Temperature
DM2	Check 20	EC, Temperature
DM3	Check 21	EC, Temperature
ONI	Check 13	EC, Temperature
DMC 06716	DMC at McCabe Road near Check 12 (mile 67.15)	EC, Temperature, Boron, Ca, Cl, Hardness, Mg, Nitrate, DOC, Se, Na, SO_4, DO, pH, Turbidity, Alkalinity

Key:
Ca = calcium
Cl = chloride
DMC = Delta-Mendota Canal
DO = dissolved oxygen
DOC = dissolved organic carbon
EC = electrical conductivity
Mg = magnesium
Na = sodium
Se = selenium
SO_4 = sulfate

Table 2-9. California Aqueduct Water Quality Monitoring Locations

Station Code	Station Name	Constituents
C13	California Aqueduct Check 13, O'Neill Forebay Outlet	EC, Temperature, pH, Turbidity,
HBP	Harvey O. Banks Pumping Plant	EC, Temperature, pH, Turbidity, Fluoresces
HRO	Harvey O. Banks Pumping Plant	Cl, NO_3, SO_4

Notes:
California Aqueduct Check 12 water quality sensor has not been operational since August 18, 2002.

Key:
Cl = chloride
EC = electrical conductivity
NO_3 = nitrate
SO_4 = sulfate

Table 2-10. Surface Water Quality Locations By Subregion Within Study Area

Subregion Code	Subregion Name	Station Name
7	El Solyo Water District	Blewitt MWC Drain at State Route 132
7	El Solyo Water District	Hospital Creek at River Road
8	SJ/Stanislaus Unincorporated	Ingram Creek at River Road
8	SJ/Stanislaus Unincorporated	San Joaquin River at Vernalis
8	SJ/Stanislaus Unincorporated	San Joaquin River at Westside Irrigation District Pumps
8	SJ/Stanislaus Unincorporated	San Joaquin River at Airport Way
8	SJ/Stanislaus Unincorporated	San Joaquin River at Maze
9	West Stanislaus Irrigation District	Del Puerto Creek at Rogers
9	West Stanislaus Irrigation District	Del Puerto Creek at State Route 33
9	West Stanislaus Irrigation District	Grayson Road Drain at Grayson
9	West Stanislaus Irrigation District	Hospital Creek at State Route 33
9	West Stanislaus Irrigation District	Ingram Creek at State Route 33
9	West Stanislaus Irrigation District	West Stanislaus Main Canal at Hamilton
9	West Stanislaus Irrigation District	Westley Wasteway near Cox Road
11	Del Puerto Water District	Del Puerto Creek at Zacharins Road
12	Patterson Irrigation District	Del Puerto Creek at Frank Cox Road
12	Patterson Irrigation District	Del Puerto Creek at Intersection State Route 33 and Mulberry Road
12	Patterson Irrigation District	Del Puerto Creek at Vineyard Avenue
12	Patterson Irrigation District	Del Puerto Creek near Cox Road
12	Patterson Irrigation District	Marshall Road Drain near River Road
12	Patterson Irrigation District	Moran Drain
12	Patterson Irrigation District	Ramona Lake near Fig Avenue
12	Patterson Irrigation District	Salado Creek at State Route 33
12	Patterson Irrigation District	Salado Creek near Olive Avenue
12	Patterson Irrigation District	San Joaquin River at Patterson Irrigation District Pumps
12	Patterson Irrigation District	San Joaquin River at Patterson
12	Patterson Irrigation District	Spanish Grant Drain
12	Patterson Irrigation District	Unnamed Drain at Pomelo Avenue near Paradise Avenue
13	Oak Flat Water District	DMC at Del Puerto Water District
13	Oak Flat Water District	Salado Creek at Oak Flat Road
14	Sunflower Water District	Orestimba Creek at Bell Road.
14	Sunflower Water District	Orestimba Creek at Orestimba Road

Table 2-10. Surface Water Quality Locations by Subregion Within Study Area (contd.)

Subregion Code	Subregion Name	Station Name
16	CCID (North)	CCID Main Canal at JT Crow Road
16	CCID (North)	Orestimba Creek at Anderson Road
16	CCID (North)	Orestimba Creek at State Route 33
16	CCID (North)	Orestimba Creek at River Road
16	CCID (North)	Orestimba Creek at Kilburn Road
16	CCID (North)	San Joaquin River at Crows Landing
17	Stanislaus/Merced Unincorporated	San Joaquin River at Newman
17	Stanislaus/Merced Unincorporated	San Joaquin River at Hills Ferry
20	China Island Unit – North Grasslands Wildlife Area	Los Banos Creek
20	China Island Unit – North Grasslands Wildlife Area	Mud Slough (North) at State Route 140
20	China Island Unit – North Grasslands Wildlife Area	Mud Slough at Newman Gun Club
20	China Island Unit – North Grasslands Wildlife Area	Newman Wasteway above San Joaquin River
20	China Island Unit – North Grasslands Wildlife Area	Newman Wasteway near Hills Ferry Road
20	China Island Unit – North Grasslands Wildlife Area	San Joaquin River Upstream from the Newman Wasteway
22	San Luis/Kesterson NWA	Los Banos Creek at State Route 140
22	San Luis/Kesterson NWA	Mud Slough at San Luis Drain
22	San Luis/Kesterson NWA	San Luis Drain at Terminus
23	Freitas Unit – San Luis National Wildlife Refuge	Salt Slough at Lander Avenue
26	CCID (North-Central)	Newman Wasteway at Brazo Road
27	Grasslands Water District (North)	Mud Slough at Gun Club Road
27	Grasslands Water District (North)	Mud Slough Upstream from San Luis Drain Terminus
27	Grasslands Water District (North)	Porter-Blake Bypass
27	Grasslands Water District (North)	San Luis Canal at Henry Miller Road
27	Grasslands Water District (North)	Santa Fe Canal at Henry Miller Road
27	Grasslands Water District (North)	Santa Fe Canal at Weir
36	CCID (South-Central)	Los Banos Creek at China Camp Road

Table 2-10. Surface Water Quality Locations by Subregion Within Study Area (contd.)

Subregion Code	Subregion Name	Station Name
37	San Luis Canal Company	Boundary Drain at Henry Miller Avenue
37	San Luis Canal Company	Juncture of Poso Drain and Pick Anderson Bypass
37	San Luis Canal Company	Poso Drain at Northeast Corner of Turner Island and Palazzo Road
37	San Luis Canal Company	Salt Slough at Hereford Road
37	San Luis Canal Company	Salt Slough at Sand Dam
39	San Luis Water District (DMC)	Los Banos Creek at Sunset Avenue
40	CCID (South)	Almond Drive Drain
40	CCID (South)	Camp 13 Drain
40	CCID (South)	CCID Old Main Drain at Pipe – North of Cotton Road
40	CCID (South)	Charleston Drain at CCID Main
40	CCID (South)	Hamburg Drain
40	CCID (South)	San Luis Canal Upstream from Splits
40	CCID (South)	San Luis Drain Site A
41	Gadwell Unit	Gadwall Ditch at San Luis Drain Discharge
42	Grasslands Water District (South)	Rice Drain at Mallard Road
44	CCID	Agatha Canal at Mallard Road
44	CCID	CCID Main at Russell Boulevard
44	CCID	Holland Drain at Hudson
44	CCID	Inflow to San Luis Drain
44	CCID	Island Field Drain at Catrina Road
44	CCID	Main (Firebaugh) Drain at Russell Boulevard
44	CCID	Poso Slough at Hudson
44	CCID	Poso Slough at Eucalyptus
44	CCID	Poso Slough at Evans
44	CCID	Poso Slough at Indiana Avenue
44	CCID	Poso Slough at Merrill
44	CCID	Poso Slough at Newcomb
44	CCID	Poso Slough at Shain
44	CCID	Poso Slough at Valeria

Table 2-10. Surface Water Quality Locations by Subregion Within Study Area (contd.)

Subregion Code	Subregion Name	Station Name
44	Central California Irrigation District	San Joaquin River at Sack Dam
44	Central California Irrigation District	Santa Rita Slough at State Route 152
48	San Joaquin River Improvement Project	Helm Canal
48	San Joaquin River Improvement Project	Panoche Drain at O'Banion Gauging Station

Key:
CCID = Central California Irrigation District
DMC = Delta-Mendota Canal
MWC = Mutual Water Company
NWA = National Wildlife Area
SJ = San Joaquin

Groundwater Quality

The following sections describe groundwater quality monitoring data, data quality, and data completeness.

Monitoring Data

Fewer groundwater quality data were available for the Study Area compared to the SNSPIS Yolo and Modesto pilot areas. Groundwater quality data were available for the major groundwater basins within the Study Area for the WARMF model simulation period. *Water Quality Data Source Information* (Attachment A to this TM), provides additional information on groundwater quality data compiled for this study.

Table 2-11 summarizes groundwater quality monitoring programs with data applicable to this study. Groundwater quality monitoring locations within the Study Area are shown in Figures 2-6 and 2-7, south to north. Although the well data were not homogeneously distributed across the Westside region, sufficient data were available to adequately characterize the groundwater quality of the region. Water quality data from these wells include nitrate, sulfate, and chloride.

Table 2-11. Groundwater Quality Monitoring Programs Within Study Area

Agency	Project Name	Start Date	End Date	Frequency	Applicable Parameters
SWRCB	Site Cleanup Program	Various	Present	Quarterly, Semiannually, Annually	Nutrients, Major and Minor Ions
U.S. Geological Survey	GAMA	December 2004	February 2005	One-day Sample with Duplicate	Nutrients, DOC, Major and Minor Ions, TDS, Trace Elements,
California Department of Public Health	Chemicals and Contaminants in Drinking Water	1997	Present	Various	Major and Minor Ions, TDS, Trace Elements

Key:
DOC = dissolved organic carbon
GAMA = Groundwater Ambient Monitoring and Assessment Program
SWRCB = State Water Resources Control Board
TDS = total dissolved solids

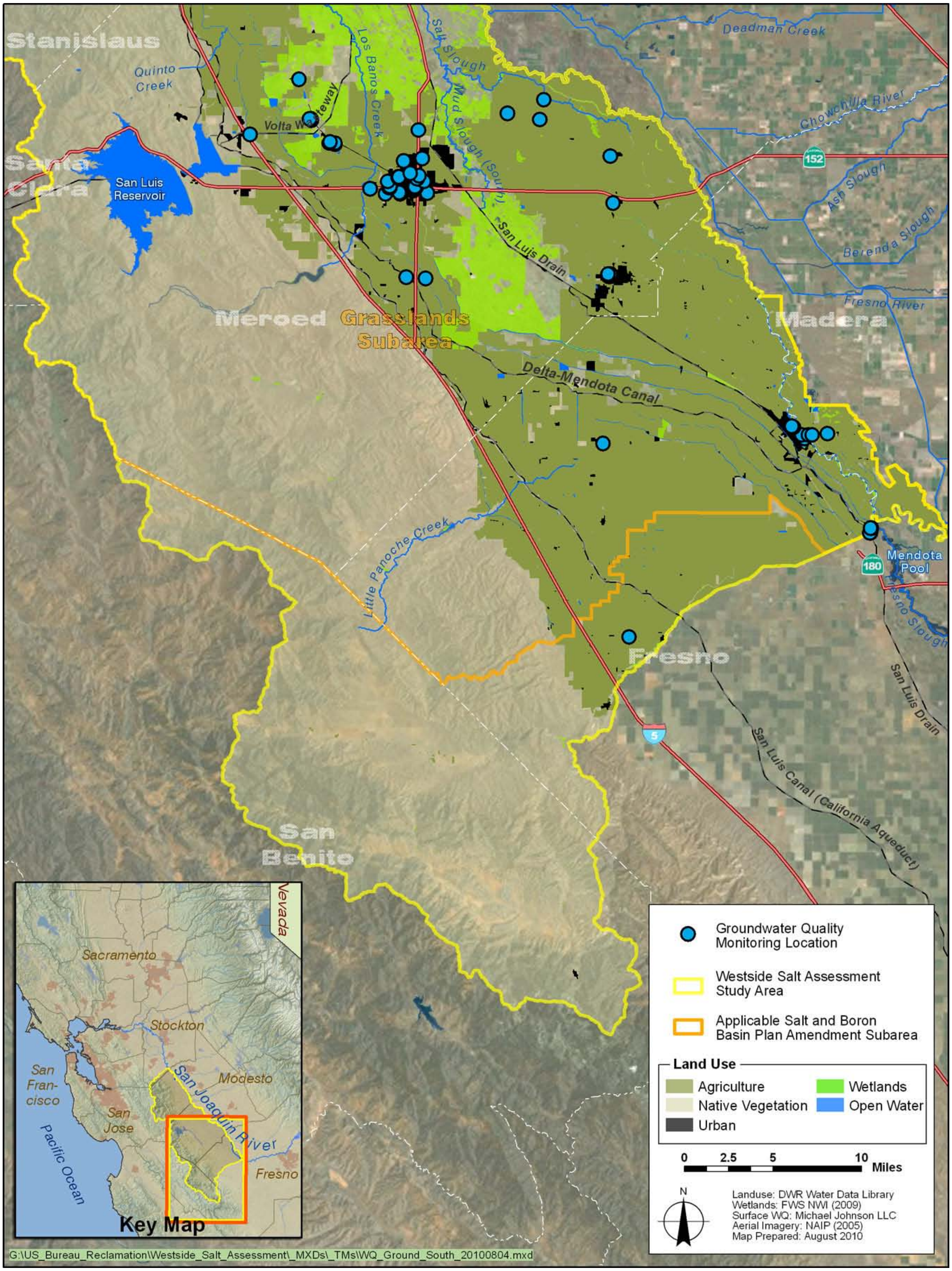


Figure 2-6. Study Area Groundwater Quality Monitoring Locations – South

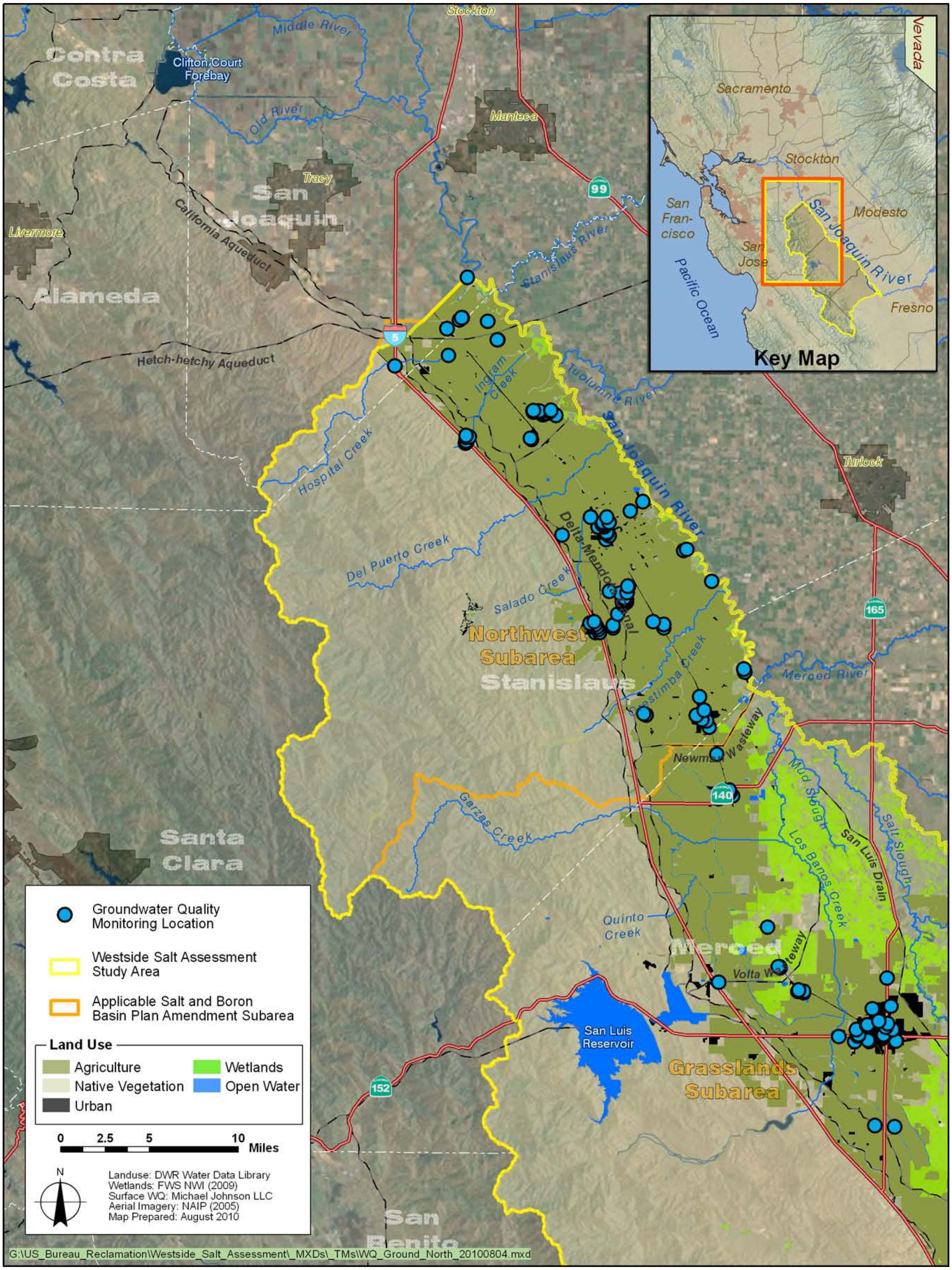


Figure 2-7. Study Area Groundwater Quality Monitoring Locations – North

Data Quality

Agencies generating groundwater quality data within the Study Area include USGS, DWR, the California Department of Public Health (DPH), Central Valley Water Board, and various agencies and organizations that report data to SWRCB. Data available through the GAMA program GeoTracker follow EPA protocols for analyzing constituents from groundwater with their specific QA requirements. The USGS NAWQA program includes 12 documents outlining protocols for sample collection and analysis of surface water, groundwater, and sediment (USGS, 2009). Overall, data used for modeling with WARMF were assumed to be of high quality for groundwater, based upon the data sources.

Data Completeness

Groundwater data were available for almost 600 locations within the Westside region, covering the major groundwater basins. Groundwater quality data available from GAMA are summarized in Table 2-12, and include data from wells categorized as either environmental monitoring or water supply wells. Water depths for these wells were not documented in GeoTracker, and would require additional review of well logs.

TDS was a commonly, although not universally, collected constituent. As with surface water quality data, groundwater quality data for individual ions were available for a smaller number of sites but were spread geographically across the Study Area.

As discussed in Chapter 1, groundwater quality data were relatively scarce for the Study Area. Due to the scarcity of data, significant assumptions were required for WARMF model input parameter related to groundwater quantity and quality. Additional groundwater quality data may be available through irrigation and water districts for private wells, but were not obtained for this study.

Table 2-12. Number of Groundwater Wells by Public Agency with Water Quality Information from Groundwater Ambient Monitoring Assessment Program's GeoTracker

Subregion Code	Subregion Name	DPH	Cleanup Sites	USGS
1	Westside Water District (West)	3	--	--
2	City of Tracy	26	--	3
3	Westside Water District (East)	7	21	--
4	Byron Bethany Irrigation District	7	--	2
5	Banta-Carbona Irrigation District	10	14	--
6	Hospital Water District	7	8	--
7	El Solyo Water District	2	--	--
8	San Joaquin/Stanislaus Unincorporated	5	9	--
9	West Stanislaus Irrigation District	11	31	--
11	Del Puerto Water District	1	1	--
12	Patterson Irrigation District	18	12	--
13	Oak Flat Water District	--	6	--
14	Sunflower Water District	2	93	--
15	Orestimba Water District	3	--	--
16	Central California Irrigation District (North)	1	--	--
17	Stanislaus\Merced Unincorporated	2	--	--
18	Foothill Water District	2	--	--
19	City of Newman Service Area	6	9	--
26	Central California Irrigation District (North-Central)	7	--	--
34	Volta Wildlife Management Area	3	--	--
36	Central California Irrigation District (South-Central)	6	--	--
37	San Luis Canal Company	5	--	--
38	City of Los Banos	16	56	--
39	San Luis Water District (Delta-Mendota Canal)	1	--	--
40	Central California Irrigation District (South)	2	--	--
43	City of Dos Palos	--	37	--
44	Central California Irrigation District	7	--	--
54	Columbia Canal Company	4	5	--
55	Panoche Water District (Delta-Mendota Canal/ San Luis Canal)	1	--	--
58	Mendota Pool Unincorporated	5	--	--
60	Farmers Water District	5	--	--

Notes:

*Additional private wells are present in the region. Data from some wells are available through Reclamation or individual water districts.

* *Monitored by various agencies and organizations and reported to SWRCB

Key:
-- = None
DPH = California Department of Public Health
Reclamation = U.S. Department of the Interior, Bureau of Reclamation
USGS = U.S. Geological Survey

Air Quality

Air quality data available for study include both wet and dry deposition data (Table 2-13). These data were available from a national array of monitoring stations whose results were reported on two Web sites. There were a limited number of monitoring stations in and around the Central Valley. In contrast to the SNSPIS, wet deposition data from a monitoring location in Davis, California, were used for this study. Air quality data quality and completeness were consistent and appropriate for this study.

Table 2-13. Air Quality (Wet and Dry Deposition) Data Sources

Data Category	Location	Data Source	Start Date	Constituents
Wet Deposition	Davis, California (Monitoring Location CA88)	National Atmospheric Deposition Program	September 1978 to December 2009	NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl, EC
Wet Deposition	Hodgon Meadow, Yosemite National Park, California (Monitoring Location CA99)	National Atmospheric Deposition Program	December 1995 to September 2007	NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl, EC
Dry Deposition	Turtleback Dome, Yosemite National Park, California (Monitoring Station YOS404)	Clean Air Status and Trends Network	October 1995 to September 2007	NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl, EC, SO_x, NO_x

Key:
Ca = calcium
Cl = chloride
EC = electrical conductivity
K = potassium
Mg = magnesium
Na = sodium
NH_4 = ammonium
NO_3 = nitrate
NO_x = nitrous oxide
SO_4 = sulfate
SO_x = sulfur oxide

Data Quality

The Clean Air Status and Trends Network provides its QAPP online (EPA, 2007). The procedures outlined in the QAPP provide confidence in the quality of the atmospheric deposition data collected for this network. The National Atmospheric Deposition Program (NADP) also provides its QAPP online (2009). The NADP QAPP identified QA measures that provide confidence in the quality of the wet deposition data for use by the WARMF.

Data Completeness

A limited number of monitoring stations were present in and around the Central Valley, and data from those stations were used in the SNSPIS modeling efforts. These same stations located within the Central Valley were selected and used in this study.

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Chapter 3
Westside Region Salt and Nitrate Transformation Process Information

This chapter describes information on site-specific salt and nitrate transformation processes in the Study Area that make up components of the salt and nitrate budget. The sections below summarize salt and nitrate transformation processes simulated by the WARMF model in the SNSPIS and San Joaquin River DO TMDL studies, and evaluate salt and nitrate transformation processes as they may relate to implementation activities of the Westside Regional Drainage Plan (SJRECWA et al., 2003).

Simulation of Transformation Processes During Previous Studies

Previous studies of pollutant transport and transformations of salt and nitrate simulated using the WARMF model include the SNSPIS report (CV-SALTS, 2010) and the San Joaquin River DO TMDL (Herr et al., 2008). Transformation processes for salt and nitrate identified in those studies and found to be significant in the San Joaquin River watershed are shown in Table 3-1.

Table 3-1. Transformation Processes in Surface Water and Near-Surface Groundwater

Surface Water	Near-Surface Groundwater
Adsorption to suspended sediment	Adsorption to soil particles
Settling of adsorbed constituents	
Resuspension of adsorbed constituents	
Uptake by phytoplankton	Uptake by plants
Production by organic matter decay	Production by organic matter decay
Formation by chemical reaction	Formation by chemical reaction
Decay by chemical reaction	Decay by chemical reaction

The fundamental principles that guide WARMF simulation of water quality are heat and mass balances. Heat enters the soil in water from precipitation and irrigation. Heat is exchanged between catchments and the atmosphere, based on thermal conductivity of the soil. Heat in water leaving the catchments enters river segments, which combine heat from multiple sources. As in catchments, thermal exchange with the atmosphere occurs, based on the difference in temperature between the water and the air. Temperature is then calculated by heat balance throughout the model.

Chemical constituents enter the model domain from atmospheric deposition and from point source discharges. Chemical constituents can also enter the land surface in irrigation water and fertilizer application. Chemical species move with water by percolation between soil layers, groundwater lateral flow to rivers, and surface runoff overland. Each soil layer is considered to be a mixed reactor, as is the land surface within each land use. 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 dissolved chemical constituents within the soil. The DO concentration is tracked and, as DO goes to zero, anoxic reactions take place. When overland flow occurs, sediment is eroded from the catchment surface according to the modified universal soil loss equation. The sediment carries adsorbed ions (e.g., phosphate) with it to the river.

Rivers receive water quality that comes with each source of flow. Each river segment is considered a completely mixed reactor. Ions reach an equilibrium between dissolved and adsorbed to suspended sediment. Sediment can settle to the riverbed and can also be scoured from a riverbed when velocity is high enough. Chemical reactions are based on first order kinetics, with their rate adjusted through a temperature correction.

Algae are represented by three types: greens, blue-greens, and diatoms. Each has its own optimum growth rate, nutrient half-saturation concentration, light saturation, optimum temperature, and temperature range for growth. At each time-step, algal growth is a function of nutrient limitation, light limitation, and temperature limitation. Light penetration is a function of the algae, detritus, and TSS concentrations. Light intensity is integrated over the depth of a river segment.

In wetlands, the primary conversion/transformation processes include fixation, ammonia volatilization, ammonification, nitrification, denitrification, anaerobic ammonium oxidation, dissimulatory reduction, plant and microbial assimilation (production of organic nitrogen (N)), and remineralization during decomposition. Previous mass balance calculations have demonstrated that bacterial denitrification, rather than plant uptake, is the main mechanism for nitrate removal from nontidal wetlands (Huang and Pant, 2009). Research in the upper Midwest on constructed wetlands also demonstrated that denitrification was the primary means of nitrogen removal from wetlands (Crumpton et al., 2008). These denitrification reactions take place in the sediments and result in an outflow to the atmosphere in the form of nitrous oxide (N_2O) or nitrogen gas (N_2) and are herein considered permanent removal. Plant uptake eventually becomes balanced with release by decomposition and remineralization.

Figure 3-1 shows the general nitrogen transformation process. WARMF incorporates the nitrification and denitrification processes as the two main nitrogen transformations that take place in soils (see below for water column transformations). Nitrification involves the conversion of ammonia or ammonium, in the presence of oxygen, to nitrate, with hydrogen and water as additional end products. Denitrification occurs in the absence of oxygen and converts nitrate to nitrogen gas, oxygen, and water. Ammonium in the soil is generated by the transformation of organic nitrogen in coarse leaf litter, fine leaf litter, or humus, with sulfate, carbon dioxide, and hydrogen ions as additional end products. Ammonium can also enter the soil by direct application of ammonium as fertilizer. All of the processes shown in Figure 3-1 except nitrogen fixation are included in the WARMF model. In surface water, WARMF incorporates the breakdown of dissolved organic carbon (DOC) to ammonium and the nitrification of ammonium to nitrate, as well as the uptake of nitrate by various algal groups as they convert inorganic nitrogen to organic nitrogen. As with reactions in the soil profile, any actions that would change the amount of organic carbon, ammonium, or nitrate would change the yield of algal species, but would not alter the stoichiometry.

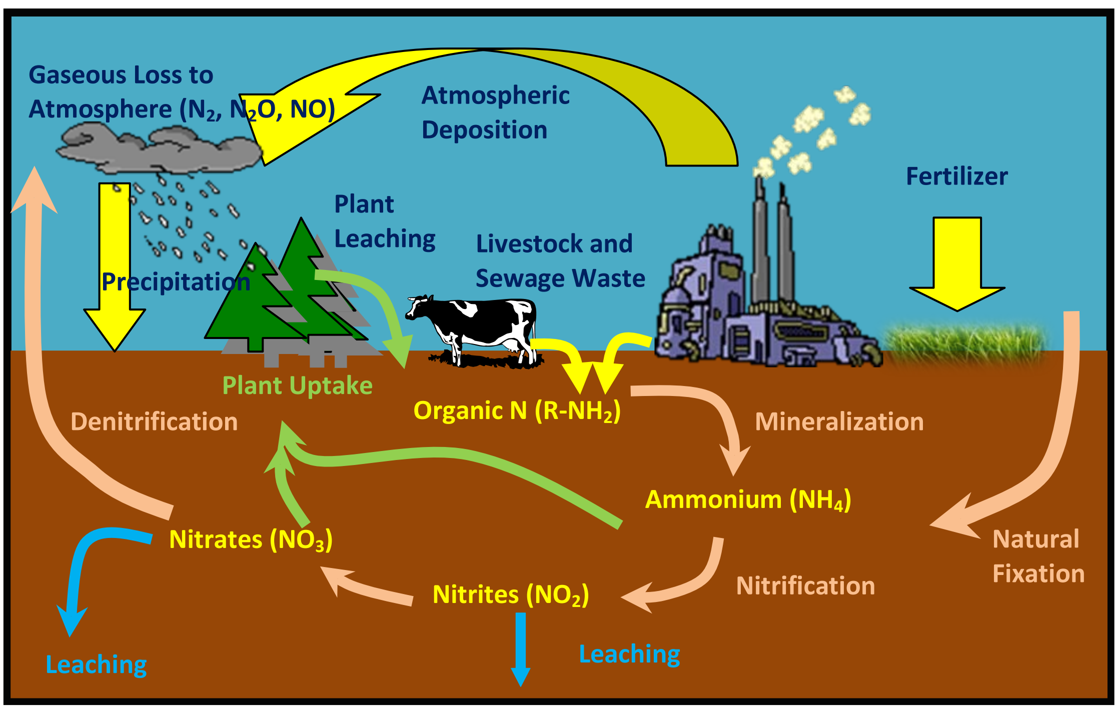

Figure 3-1. General Nitrogen Transformation Processes

WARMF incorporates all of the major transformation processes for nitrogen into the model except nitrogen fixation. Nitrogen fixation is expected to be a minor portion of the nitrogen budget for the Westside region.

Transformation Processes Associated with Westside Regional Drainage Plan Activities

The *Westside Regional Drainage Plan* (SJRECWA et al., 2003) integrates several interdependent strategies to reduce and eliminate high-salinity subsurface irrigation drainage from approximately 90,000 acres. The project began as the GBP, initiated to reduce the discharge of selenium to the San Joaquin River. Its success led to expansion of the project to eliminate selenium, boron, and salt discharges to the San Joaquin River. Five general approaches to eliminate saline subsurface irrigation drainage are being implemented:

1. Reduction of subsurface drainage volumes to be managed through source control and efficient water management techniques.

2. Recirculation and blending of tile drainage water for use on primary irrigation lands.

3. Collection and reuse of tile drainage water on halophytic croplands to concentrate drainage.

4. Installation of groundwater wells to lower groundwater in strategic locations, to reduce groundwater infiltration into tile drains.

5. Treatment of remaining drainage water for irrigation reuse and production of marketable salt product.

The project area in the drainage plan includes Panoche Drainage District, Broadview Water District, Firebaugh Canal Water District, Camp 13 Drainage District, Pacheco Water District, and Charleston Drainage District. Individual projects included in the drainage plan are as follows:

- **Reuse land purchase** – Purchase of 2,000 acres of land outside existing water or drainage district boundaries used for collection of subsurface drainage and reuse of that water.

- **Reuse area development** – Construction of subsurface drainage systems and planting of salt-tolerant crops (Jose tall wheatgrass, alfalfa) on the area purchased for reuse of subsurface drainage. All farming is performed using standard practices, including disking, development of field borders, preirrigation, and seeding. Initial irrigation is done with fresh water and, after a healthy stand has established, subsurface drainage is used to irrigate.

- **Irrigation improvement** – Installation of high-efficiency irrigation systems on as many as 30,000 acres within the drainage plan area. The high-efficiency irrigation systems will reduce subsurface drainage production through greater uniformity in irrigation application, which reduces deep percolation.

- **Infrastructure improvements –** Elimination of deep percolation of water from unlined irrigation canals by installing concrete linings or pipelines. These infrastructure improvements can reduce drainage production by 12,100 acre-feet per year.

- **Groundwater pumping –** Installation of up to 20 groundwater wells to pump between 10,000 and 20,000 acre-feet per year of groundwater to be blended with surface water for use in irrigation.

- **Salt disposal development project –** Removal of salt from the accumulation areas by (1) treatment and salt marketing, or (2) power generation through solar cells.

None of these projects involve modifying the soil profile in any way that would be considered unique to the Westside region or the *Westside Regional Drainage Plan* (SJRECWA et al., 2003) area in particular. Also, the activities would not change the water quality of surface water bodies (e.g., Panoche Creek) in a way that would be unique to the Westside region.

No activities in the *Westside Regional Drainage Plan* area would change the sorption/desorption kinetics in WARMF for the Study Area.

Salt and Nitrate Transformation Process Simulations for Westside Salt Assessment

WARMF used parameter estimates for rates of transformations in soils and surface waters as calibration parameters and, therefore, did not need data for these values. Obtaining estimates of transformation rates would be possible, although difficult, expensive, and time-consuming because many rates vary substantially across seasons as soil and water temperature change. Many of the rate constants for the reactions are temperature- and pH-dependent, and are controlled by the presence of oxygen.

WARMF did not model wetlands specifically, although wetlands could be incorporated into the Study Area simulations by combining soil reactions and plant uptake of nutrients with the inflows and outflows of irrigation water. Again, transformation processes in wetlands would be calibration parameters and not require additional data. Nitrate concentrations entering and leaving wetlands could be used to focus the calibration exercise by allowing wetlands to be treated as catchments with their own mass balances. Some data were available to facilitate this process, although data were not sufficient to model each wetland individually.

Overall, nitrogen transformation processes were incorporated into Study Area simulations through their use as calibration parameters in WARMF. The primary data gap was in understanding the range of possible values these parameters can assume so that calibration can be done more efficiently.

Any specific management activities or land cover categories unique to the Study Area that could result in the loss of oxygen from the soil or increase the amount of ammonium in the soil could change the yield of the nitrification or denitrification reactions but would not alter the stoichiometry of those reactions. Therefore, the stoichiometry in the WARMF model would not need to be modified to model the nitrogen transformations in the Study Area.

The ions that comprise “salt” do not typically undergo transformations in the same manner as N/nitrate. Sorption/desorption kinetics are incorporated into WARMF as calibration parameters. Consequently, the sorption/desorption kinetic processes were incorporated into the WARMF modeling analysis in the same way as the SNSPIS analyses.

Chapter 4
Model Calibration

This chapter describes the calibration procedure and calibration results for the salt and nitrate simulations from the WARMF-SJR model.

Calibration Procedure

Using meteorological and operational data as inputs to the modeling analysis for Water Years 2000 through 2007, WARMF-SJR made predictions for salt and nitrate at various river segments. At locations where in-stream monitoring data of flow, EC, and nitrate were collected, the model predictions can be compared to observed water quality. Initial conditions of some model coefficients were known, such as catchment slopes, aspects, and areas. Coefficients that could not be informed by available data were assumed to be equivalent to default model or typical literature values. Initial predictions did not always match observed values. Model calibration was typically performed by adjusting model coefficients within reasonable ranges to improve the match between model predictions and observed data.

In highly managed agricultural watersheds, like the San Joaquin River watershed, simulations were largely constrained by assumed model inputs, such as applied irrigation rates, irrigation source water quality (including groundwater quality), and land application (i.e., fertilizer) rates. Calibration performed by adjusting model coefficients may not be effective in such watersheds because the model could be much more sensitive to uncertainty in model inputs than to model parameters subject to calibration. When predictions did not match observations well, revising the model input assumptions was sometimes necessary to improve model simulations.

Model predictions of flow and water quality were compared against measured data graphically. The time series of model predictions were plotted along with observed data. Model predictions were determined to be good or poor, based on visual inspection of the match between predicted versus observed data.

Model predictions and observed data were also compared statistically. Differences between predicted and observed values were identified as errors. The magnitudes of the errors were calculated in statistical terms of relative error, absolute error, root mean square error, and correlation coefficient. Relative (E_r) and absolute (E_a) errors were the primary statistics used in model calibration and are described as follows:

$$E_r = \frac{\sum(simulated - observed)}{n}$$

$$E_a = \frac{\sum| simulated - observed |}{n}$$

The error of each instance when there are both simulation results and observed data was the simulated minus the observed. The relative error canceled out positive and negative errors and was thus a measure of model accuracy or bias. The absolute error measures model precision. Both can be expressed as a percent by dividing by the average observed value.

Both graphical and statistical comparisons were made with WARMF-SJR. Multiple model scenarios can be plotted together, where each scenario was a set of model input coefficients, assumptions, and simulation results. By visual inspection, it was relatively easy to observe whether the changes to model coefficients and/or input assumptions improve the match. WARMF-SJR also calculated the values of various error terms for each scenario. Comparison of the numerical values of errors for two scenarios led the user to make model adjustments to reduce the errors.

Model Coefficients

Numerous model coefficients affect water quality calibration in the WARMF-SJR model, including chemical reaction rates, soil mineral compositions, and many others. Some applied to a given land-use class throughout the whole watershed and other coefficients may vary by individual catchments and river segments. Many of the coefficients did not have a significant effect on simulation results during testing and therefore can be safely left at default literature values unless location-specific information was available. WARMF-SJR contains default values of those parameters to which the model is most sensitive; these were used as initial values for the model. If deemed necessary, the initial values were then adjusted during the model calibration process to better match the simulations of salt and nitrate with observations.

Land-Use Coefficients

A number of model coefficients have specific values for each land use which apply everywhere a land use occurs. Examples of land-use coefficients include productivity, erosion factors, leaf area index, and fraction of land with impervious surface. These land-use coefficients define how the different land uses receive anthropogenic model inputs, such as irrigation, and respond to natural model inputs such as atmospheric deposition. These land-use coefficients were set based on literature values and regional agricultural practices.

Catchment Coefficients

Catchment coefficients are coefficients applied to individual catchments throughout the modeled watershed area. These coefficients were important for simulating near-surface groundwater flow and nonpoint source load. Examples of catchment coefficients include soil layer thickness, field capacity, and hydraulic conductivity. The coefficients can be set to different values for each catchment if the catchments have different properties, or multiple catchments with the same properties can be lumped together.

Catchment reaction rates were among the most important coefficients for water quality simulations. The reaction rates of most significance for nitrate simulation, and their ranges of calibrated values, are shown in Table 4-1. These rates vary by catchment and are adjusted during the simulation, based on changes in temperature. Reactions only occur under the proper DO concentration; for example, nitrification under anoxic conditions and denitrification when DO is near zero.

Table 4-1. Important Catchment Reaction Rate Coefficients

Reaction Rate	Range of Values (1/day)
Organic Carbon Decay	0.007 – 0.01
Nitrification	0 – 0.01
Denitrification	0.05 – 0.15

Other important parameters for calibrating salt and nitrate of the shallow groundwater were the initial concentrations of each contributing chemical constituent in each soil layer of each catchment (see Table 4 2). Initial concentrations of the constituents were not calibrated, but were set, based on a balance over the course of the simulation. Initial concentrations of the constituents were set individually for each catchment and soil layer to match the ending concentrations of the simulation under the assumption that actual soil chemistry in the San Joaquin Valley is in relative equilibrium rather than undergoing a trend of increasing or decreasing concentration.

Table 4-2. Catchment Initial Soil Pore Water Concentrations

Constituent	Units	Range of Values
Ammonia	mg/L as N	0.01 – 2
Calcium	mg/L	20 – 300
Magnesium	mg/L	4 – 200
Potassium	mg/L	1 – 13
Sodium	mg/L	1 – 800
Sulfate	mg/L	1 – 1600
Nitrate	mg/L as N	1 – 10
Chloride	mg/L	1 – 600
Phosphate	µg/L as P	0.01 – 500
Total Inorganic Carbon	mg/L	20 – 300

Key:
µg/L = micrograms per liter
mg/L = milligrams per liter
N = Nitrogen
P = Phosphorus

River Coefficients

River coefficients are those applied to an individual river segment. River coefficients with the greatest impact on water quality simulations include reaction rates and adsorption isotherms. The values of reaction rates for processes that are important for nitrate simulation are shown in Table 4-3. These rates were used for all river segments. Adsorption isotherms control the partitioning between the dissolved phase of each constituent and the portion adsorbed to suspended sediment. Default isotherms were used for all constituents (Table 4-4).

Table 4-3. Important River Reaction Rate Coefficients

Reaction Rate	Value (1/day)
Organic Carbon Decay	0.07
Nitrification	0.5
Denitrification	0

Table 4-4. Adsorption Isotherm Coefficients

Reaction Rate	Value (L/kg)
Ammonia	27,000
Calcium	473
Magnesium	405
Potassium	198
Sodium	21
Sulfate	16
Nitrate	0
Chloride	0
Phosphate	17,000

Key:
L/kg = liters per kilogram

Water Quality Inputs

In addition to model coefficients, model inputs that specify the load of chemical constituents to a catchment surface have a large impact on calibration results. Detailed data quantifying the loads to each specific catchment were not available, and some assumptions were necessary to develop inputs for the Westside region. The inputs of most significance for prediction of surface water nitrate and salinity in the Westside region included fertilizer application rates, concentrations of salt and nitrate in the irrigation source water, and relative proportions of the various irrigation sources applied to each catchment (i.e., the amount of groundwater versus surface water applied). The development of irrigation rates and associated assumptions are described in detail in the *Westside Salt Assessment*, *Technical Memorandum: Water Budget* (Reclamation, 2012a).

Land Application Rates

Information sources for the rates of land application (including both fertilizer and animal waste) used in this study were discussed in Chapter 2. Table 4-5 lists resulting land application rates of ammonia and nitrate used for catchments in the WARMF-SJR model.

Table 4-5. San Joaquin River WARMF Model Assumed Land Application Rates

Land Use	Months Applied	pound/acre/month NO_3	pound/acre/month NH_4
Pasture	5 – 9	0	6
Alfalfa	5 – 9	0	6
Grain	5 – 9	24	10
Safflower	10 – 6	21	0
Corn	5 – 9	31	13
Other Field	5 – 9	31	13
Other Deciduous	5 – 9	8	3
Almonds	5 – 9	8	3
Pistachios	5 – 9	8	3
Tomatoes	5 – 9	19	8
Beans	5 – 9	19	8
Sugar Beets	5 – 9	19	8
Onions and Garlic	5 – 9	19	8
Cucurbits	5 – 9	19	8
Other Truck	5 – 9	19	8
SubTropical	5 – 9	28	12
Vineyards	5 – 9	11	5
Cotton	5 – 9	29	0
Rice	5 – 9	0	50
Other CAFOs	1 – 12	5	5
Farmsteads	5 – 9	13	13
Urban Residential	5 – 9	13	13

Key:
CAFO = concentrated animal feeding operations
NO_3= nitrate
NH_4 = ammonia
pound/acre/month = pound per acre per month

Irrigation Source Water Quality

Sources of irrigation water in the Westside region include surface water diversions from the DMC, Mendota Pool, San Joaquin River, and California Aqueduct, along with groundwater pumped from wells. The calculation procedure and assumptions employed to determine the quantity of water applied to each subwatershed/subregion, and the sources from which that water came, are documented in the *Westside Salt Assessment, Technical Memorandum: Water Budget* (Reclamation, 2012a). The concentrations of nitrate and salt components contained within the different irrigation sources were determined within WARMF-SJR in one of two ways. For water diverted from river segments inside the WARMF-SJR model domain (DMC, Mendota Pool, and San Joaquin River), concentrations in the diverted water were equal to simulated concentrations in the source river segment. For water derived from sources outside the WARMF-SJR model domain (California Aqueduct and pumped groundwater), concentrations were specified in a WARMF input file.

The average concentrations of nitrate, TDS, EC, and dominant ions in surface water diversions used for irrigation for Water Years 2000 to 2007 are listed below in Table 4-6. These sources are all located within the WARMF-SJR model domain. Average concentrations of the same constituents in pumped groundwater used for irrigation for Water Years 2000 to 2007 are listed in Table 4-7. For each water management area, groundwater concentrations of chloride, sulfate, nitrate, and TDS were input to the model as the average from all wells located within the subwatershed (if well data were available) or the nearest subwatershed (if no data were available within the respective subwatershed). The remaining ions that compose TDS were calculated based on average ion fractions observed in groundwater data on the east side of the San Joaquin River watershed.

Table 4-6. Average Concentration of Select Constituents in Surface Water Diversions, Water Years 2000 to 2007

Diversion Source	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Cl (mg/L)	TIC (mg/L)	TDS (mg/L)	EC (µS/cm)
Mendota Pool	17.7	11.1	43.5	32.3	0.65	61.4	19.6	252	419
Upper DMC	22.9	13.1	52.8	49.0	0.87	69.6	21.7	259	432
Lower DMC	19.2	12.0	47.8	36.3	0.68	67.7	24.0	287	478
San Joaquin River @ Patterson Irrigation District	65.8	31.9	102.5	155.3	2.64	103.5	46.5	665	1109

Key:
µS/cm = microSiemens per centimeter
Ca = calcium
Cl = chloride
DMC = Delta-Mendota Canal
EC = electrical conductivity
Mg = magnesium
mg/L = milligram per liter
Na = sodium
NO_3 = nitrate
SO_4 = sulfate
TDS = total dissolved solids
TIC = total inorganic carbon

Table 4-7. Average Concentration of Select Constituents in Groundwater, Water Years 2000 to 2007

Water Management Area	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Cl (mg/L)	TIC (mg/L)	TDS (mg/L)	EC (µS/cm)
Broadview Water District	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Firebaugh Canal Company (North)	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Firebaugh Canal Company (South)	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Firebaugh Canal Company (West)	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Widren Water District	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
San Joaquin River Improvement Project	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Camp 13	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Oro Loma Water District	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Eagle Field Water District	66.9	22.9	63.9	92.5	5.25	119.5	29.4	544	908
Panoche Water District	88.0	30.1	84.1	121.5	26.35	146.9	25.7	725	1,210
Pacheco Water District	109.3	37.4	104.4	150.6	45.81	175.3	23.2	906	1,513
San Luis Water District (North)	109.3	37.4	104.4	150.6	45.81	175.3	23.2	906	1,513
Grasslands Water District (North)	113.7	38.9	108.6	166.3	16.71	150.8	58.8	960	1,603
Grasslands Water District (South)	96.2	32.9	91.9	113.5	18.15	190.2	32.0	775	1,294
Patterson Irrigation District	114.1	39.0	109.0	286.8	21.98	139.7	28.6	940	1,569

Key:
µS/cm = microSiemens per centimeter
Ca = calcium
Cl = chloride
EC = electrical conductivity
Mg = magnesium
Mg/L = milligram per liter
Na = sodium
NO_3 = nitrate
SO_4 = sulfate
TDS = total dissolved solids
TIC = total inorganic carbon

Calibration Results

The following section describes calibration results for EC and nitrate for simulations performed with the WARMF model. Differences in simulated and observed data occur because of a combination of model error (i.e., because of model coefficients and model approximations of complex natural processes), data and input error (i.e., incorrect assumptions about irrigation or fertilizer application), and data measurement uncertainty (i.e., error in measured water quality data). Calibration results are shown below for the largest Westside tributaries (Salt Slough, San Luis Drain, and Mud Slough), San Joaquin River at Crows Landing, and San Joaquin River at Vernalis.

An alternate scenario of irrigation and return flow amounts (Scenario 2) was calculated for some agricultural subwatersheds to improve calibration results. This was done because the irrigation applied to crop demands under the original scenario, Scenario 1, which was based on water delivery data, was far greater than irrigation demand in those districts and resulted in an unrealistic quantity of unused water draining to Salt Slough. The large volume of return flow added to some river segments had a significant negative impact on hydrology and water quality calibration.

Therefore, Scenario 2 assumed that if significantly more surface water was available than was needed, based on crop demand estimates from WestSim, then the total amount of irrigation water applied to a subwatershed was underestimated potentially as a result of underestimates of the crop demand. The total amount of irrigation applied in such cases was increased by 30 percent for Central California Irrigation District and San Luis Canal Company lands to reach a more reasonable percentage of the diversion used versus returned directly to the river as return flow. Table 4-8 below describes the two irrigation scenarios. Although no direct information was obtained to verify the validity of this assumption, the modeling scenario was conducted to test the sensitivity of the calibration to these new assumptions.

For each water quality parameter, the simulated results for Scenario 1 (green lines), Scenario 2 (30 percent increased irrigation; blue lines) and observed data (black circles) were compared. The alternate scenario, Scenario 2, impacted irrigation and return flow amounts in seven subwatersheds.

Further refinement of input data obtained through stakeholder outreach could potentially improve understanding of crop demand, irrigation practices, and return flows in the region.

Table 4-8. Description and Name of Two WARMF Model Scenarios

Scenario	WARMF Scenario Name	Description
Scenario 1	San_Joaquin_2011Mar30_Returns	Total applied irrigation per subwatershed is based directly on WestSim estimates of crop demand; any remaining surplus of surface water is returned to the nearest river segment
Scenario 2	San_Joaquin_2011Mar30_30Irrig	Applied irrigation in subwatershed with a surplus in Scenario 1 is increased by 30 percent over WestSim crop demand estimates; remaining return flows, if any, are delivered to the nearest river segment

Key:
WARMF = Watershed Analysis Risk Management Framework

Electrical Conductivity

EC is used as a representation of salinity because it is inexpensive to measure in real time and is often well correlated to TDS. TDS and EC are largely conservative; thus, calibration of TDS and EC is a matter of accounting for the correct amount of salt at upstream boundary conditions and in the nonpoint source load to shallow groundwater. Because EC is easily measured on a continuous basis, generally ample data were available to characterize the upstream boundary conditions and, thus, less uncertainty associated with this salinity load. The load from shallow groundwater was calculated largely as a function of tracking the mass balance of inputs to determine the outputs. Irrigation water from various sources was applied to land in the WARMF-SJR model using water quality of the specific irrigation water sources for each subwatershed. Assumptions regarding total and relative amounts of the various irrigation sources applied to a catchment can have a significant effect on the simulated EC.

EC calibration is presented using the “Calculated EC” variable, which was calculated within WARMF-SJR as the sum of the individual ions of which it is composed. Calculated EC takes into account processes that can affect ions as they are transported throughout the watershed, including adsorption, settling, and equilibration of inorganic carbon with the atmosphere. Figures 4-1 through 4-5 illustrate the time series predicted (Scenario 1 and 2) and observed EC.

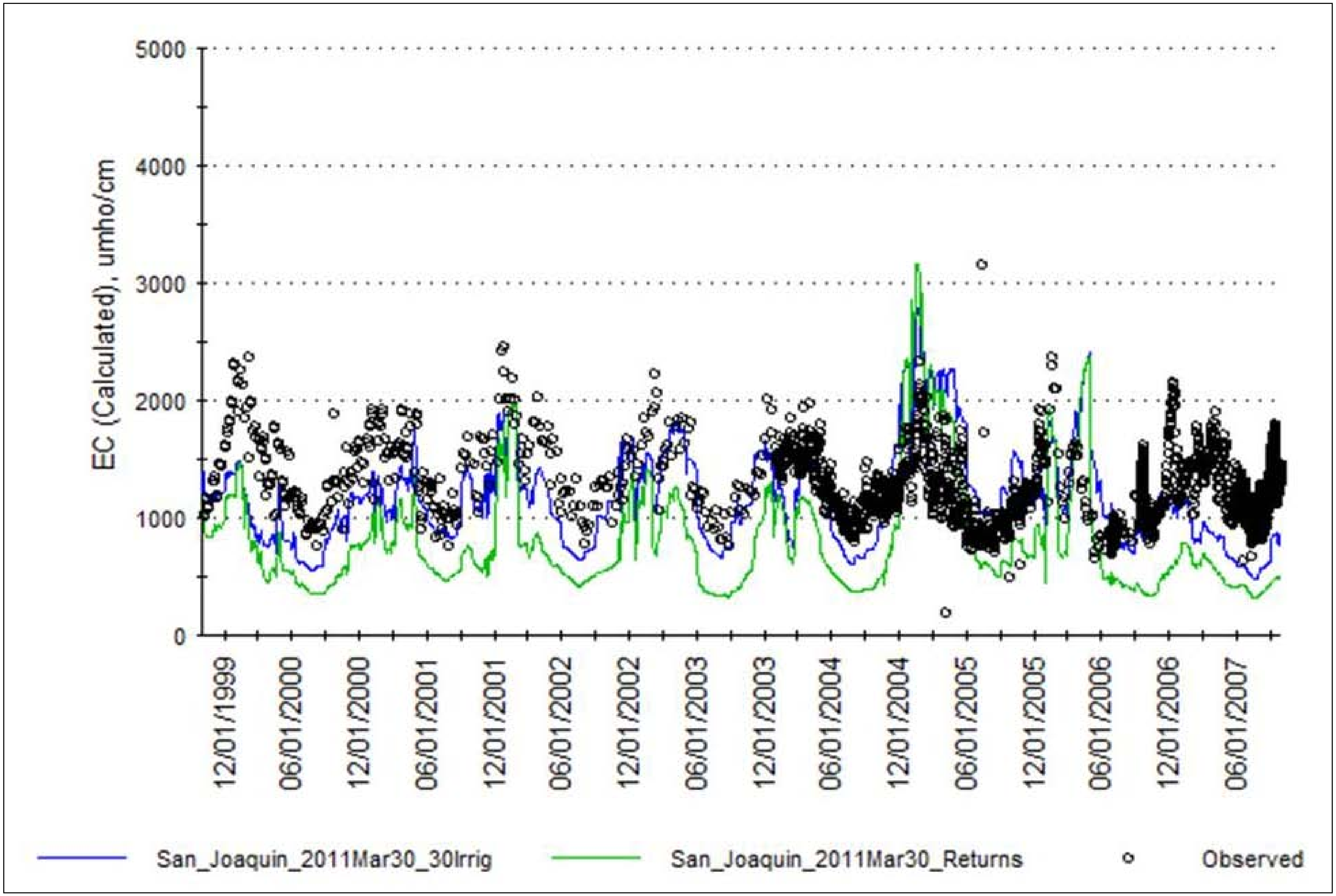

Figure 4-1. Salt Slough at Highway 165 Simulated EC for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed EC

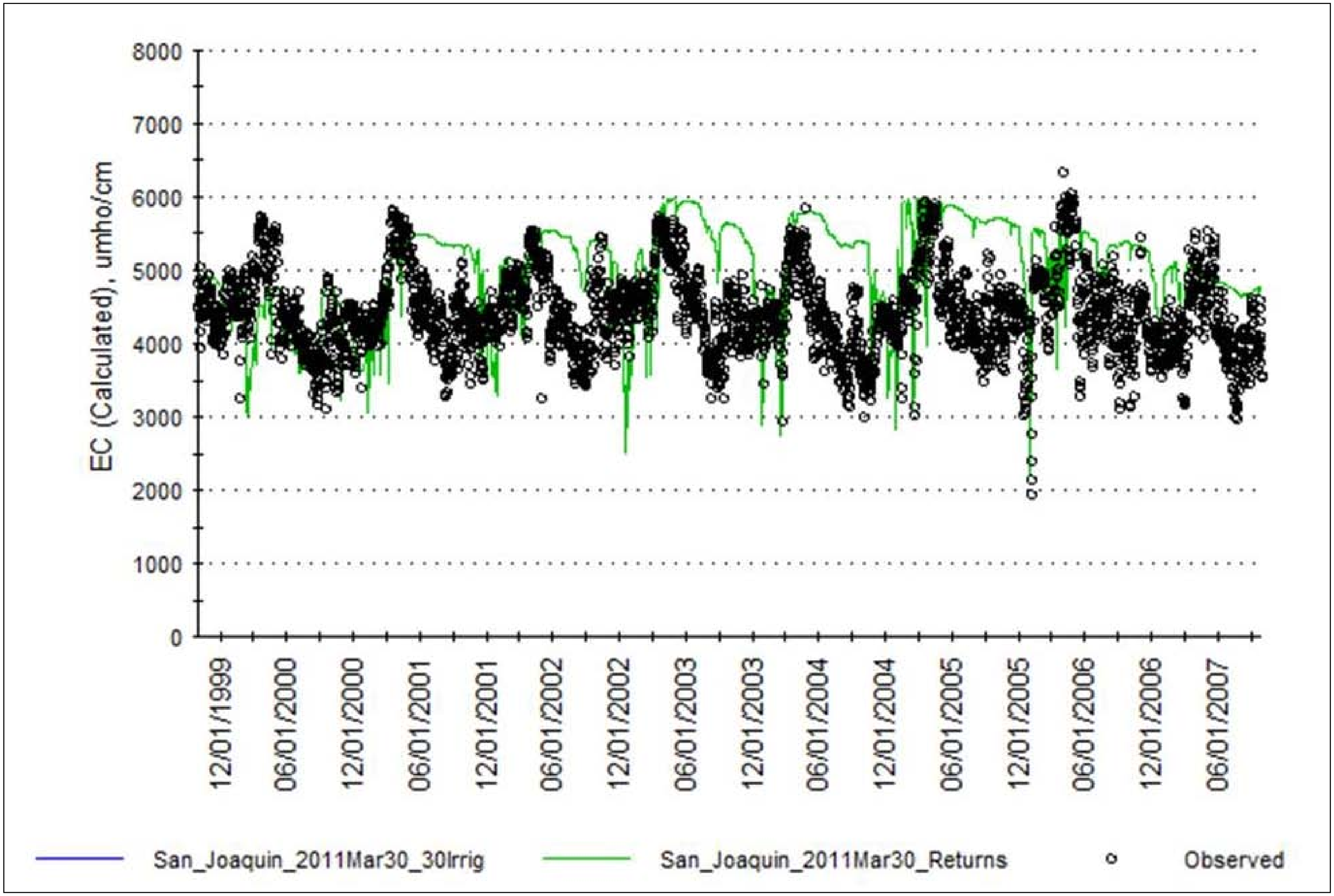

Figure 4-2. San Luis Drain Near Stevinson Simulated EC for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed EC

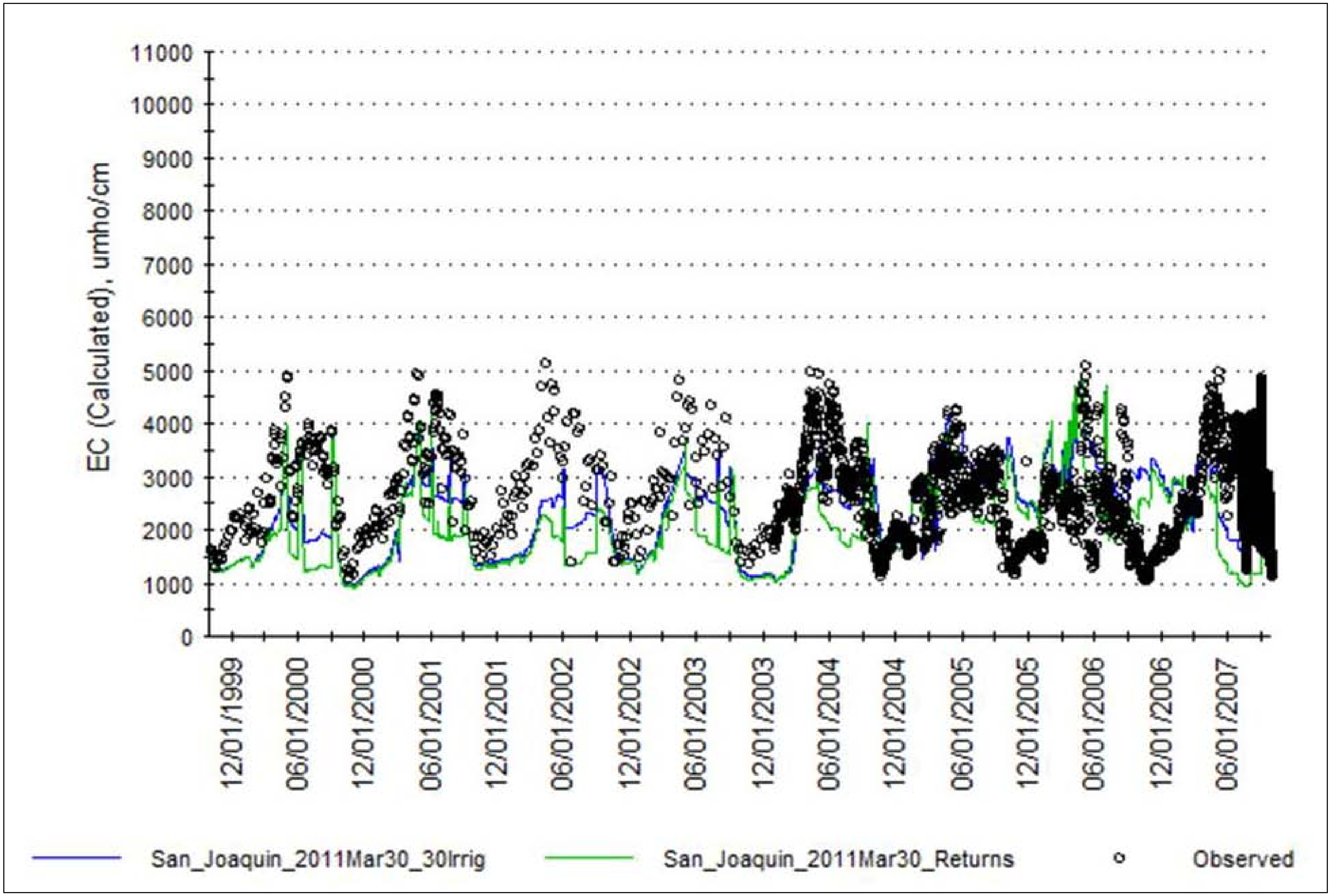

Figure 4-3. Mud Slough Near Gustine Simulated EC for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed EC

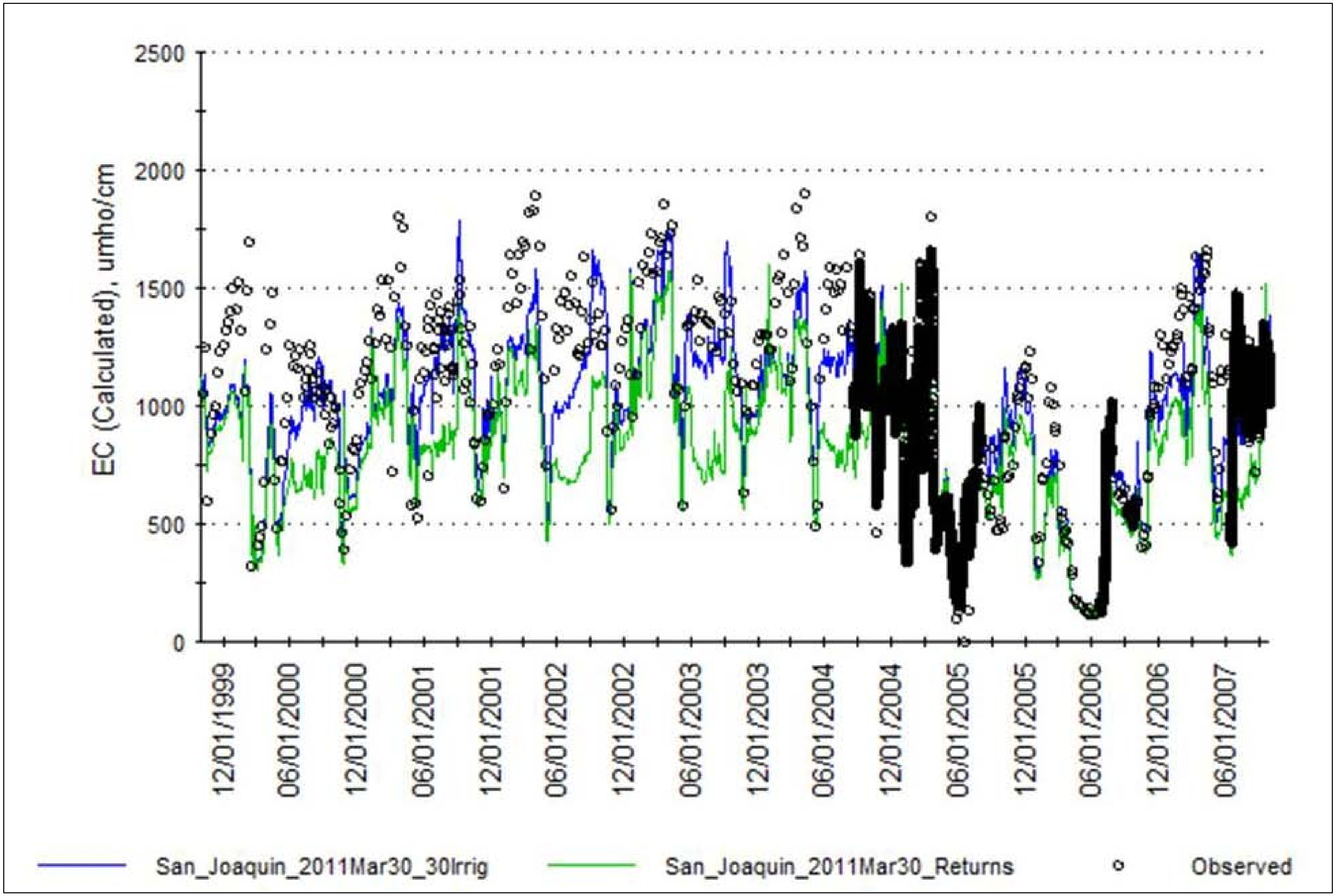

Figure 4-4. San Joaquin River at Crows Landing Simulated EC for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed EC

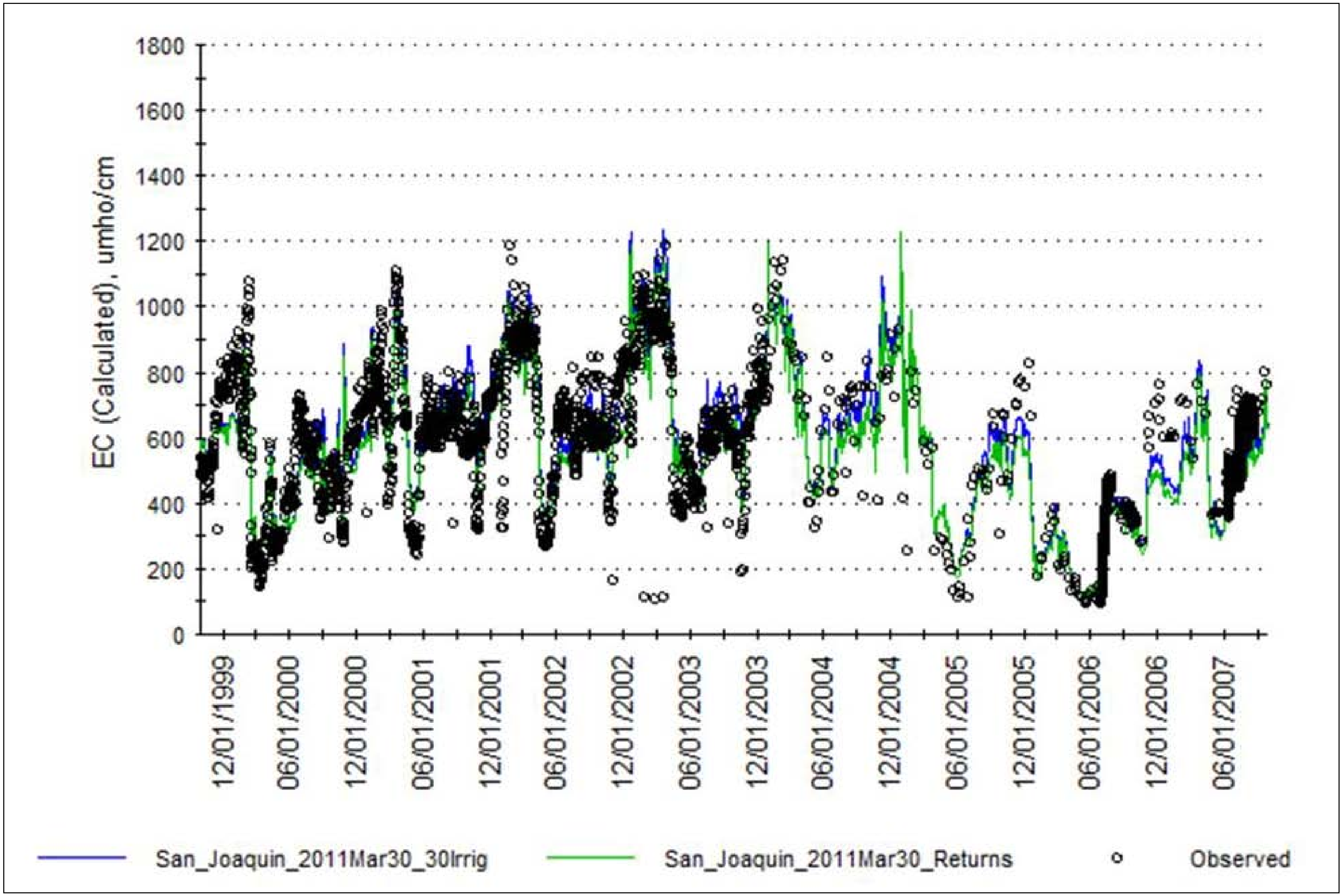

Figure 4-5. San Joaquin River at Vernalis Simulated EC for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed EC

Table 4-9 lists model errors in EC simulations for the five locations presented in the above figures. Both visual and statistical comparison demonstrates improvement in EC calibrations from Scenario 1 to Scenario 2. For Scenario 2, relative error of simulated EC met the typical calibration target of 10 percent or less for four out of five locations. Overall, the simulated seasonal minimum and maximum EC matched the observed seasonal patterns of EC. However, in the San Luis Drain subwatershed, EC was consistently too high during summer months. During the same months, flow (not shown, but presented in the *Westside Salt Assessment, Technical Memorandum: Water Budget* (Reclamation, 2012a)) was too low; therefore, the high EC concentrations were likely because of an underestimation of the amount of irrigation water applied (i.e., resulting in more concentrated salt content). Other causes of the summer over-prediction of EC could be attributed to an incorrect proportion of surface water versus groundwater applied as irrigation, or incorrect estimates of groundwater quality. None of the catchments located within the San Luis Drain subwatershed area had groundwater wells with data available to estimate EC concentrations in groundwater. Thus, EC concentrations of groundwater were estimated from data in nearby catchments, which may have introduced additional model error. Combined with the improvement of Scenario 2 versus Scenario 1, these issues suggest that revising assumptions regarding agricultural management practices in the region are necessary to further improve EC calibration.

Table 4-9. Electrical Conductivity Calibration Statistics

Location	Scenario 1		Scenario 2	
	Relative Error (%)	Absolute Error (%)	Relative Error (%)	Absolute Error (%)
Salt Slough at Highway 165	-57	78	-10	34
San Luis Drain near Stevinson	12	16	12	16
Mud Slough near Gustine	-18	46	-1	36
San Joaquin River at Crows Landing	-23	29	-4	15
San Joaquin River at Vernalis	-3	16	3	15

Nitrate

WARMF tracks nitrate loading to river segments and catchments from sources, including boundary inflows, atmospheric deposition, point sources, irrigation, and fertilizer application, through the watershed surface and soil layers to drainage and surface water. Nitrate is nonconservative and is subject to nitrification and denitrification. WARMF accounted for changes in the mass of nitrate due to nitrification and denitrification in situ processes. Like salinity, uncertainty in the load of nitrate applied to a catchment surface via irrigation and fertilization can have a significant impact on how well simulated nitrate matches measured in-stream data. Figures 4-6 through 4-10 compare the time series of predicted and observed nitrate concentration.

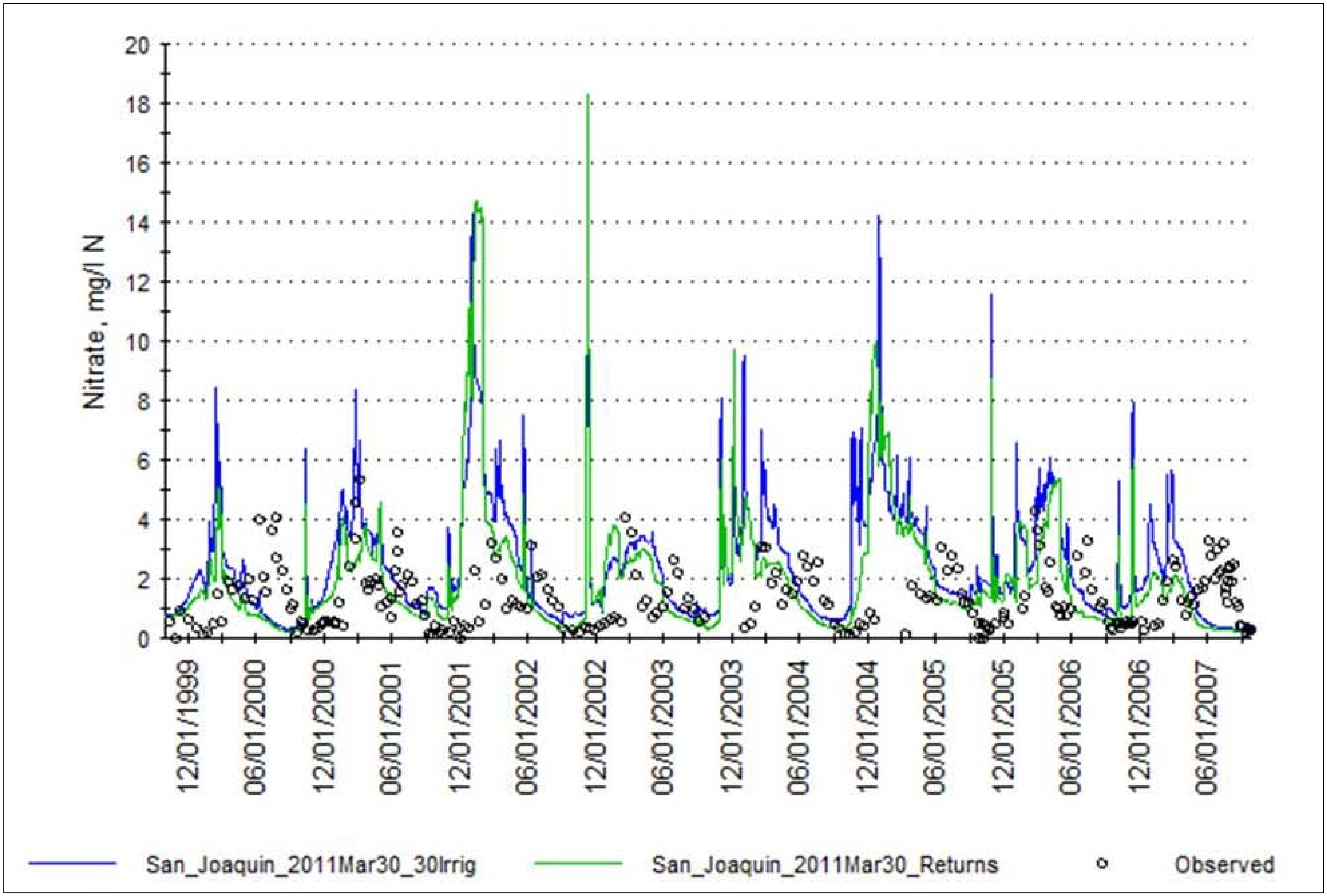

Figure 4-6. Salt Slough at Highway 165 Simulated Nitrate for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed Nitrate

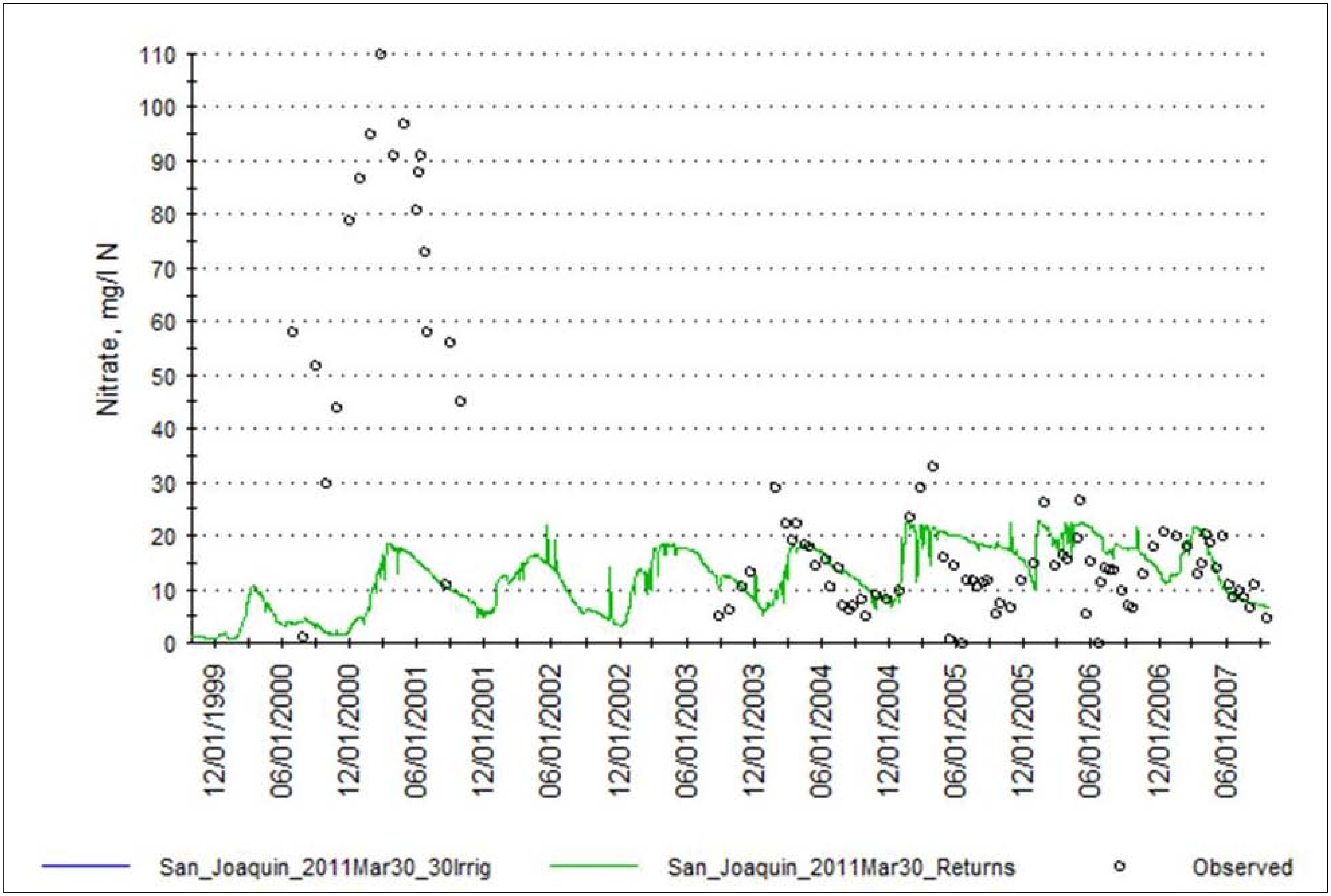

Figure 4-7. San Luis Drain near Stevinson Simulated Nitrate for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed Nitrate

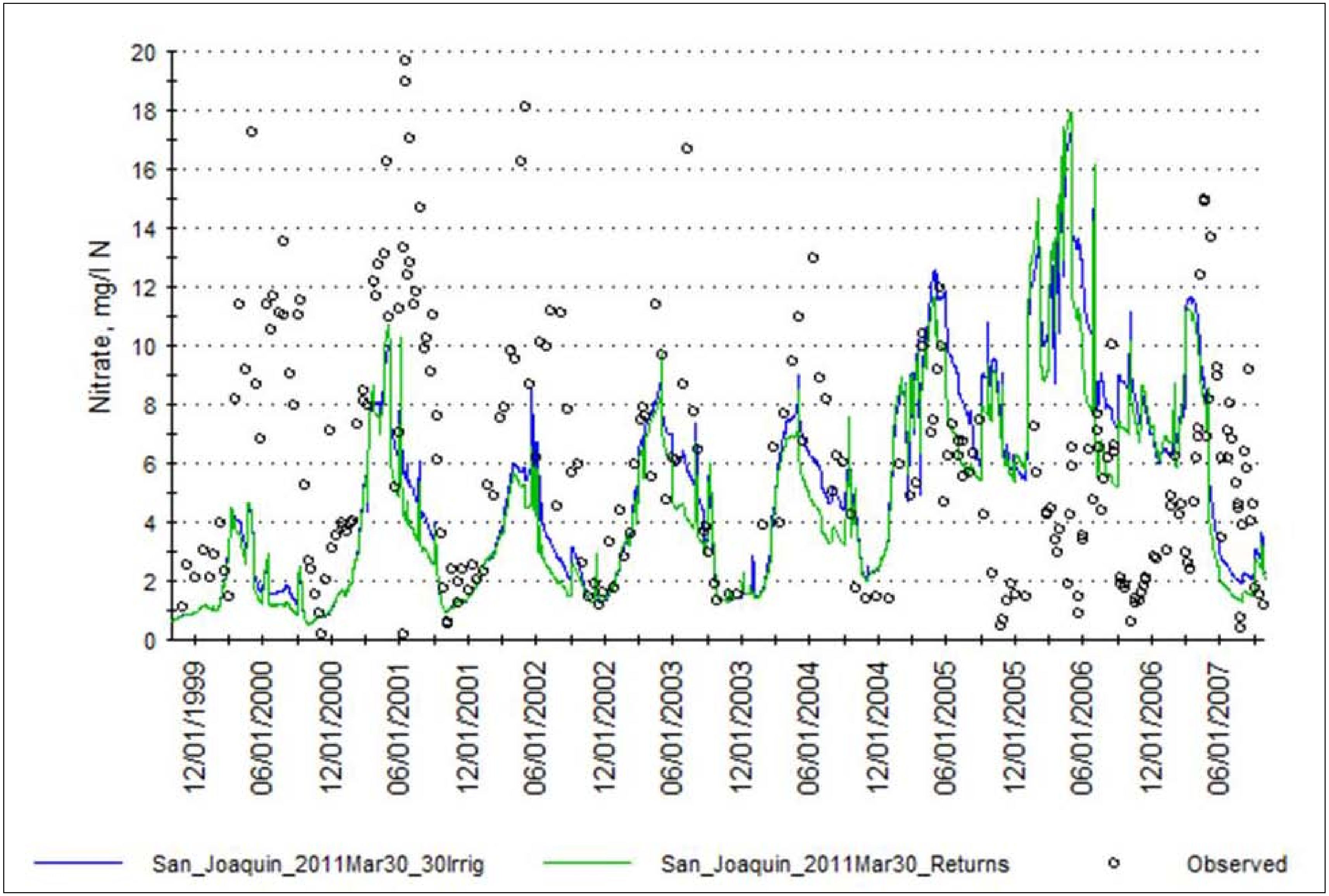

Figure 4-8. Mud Slough near Gustine Simulated Nitrate for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed Nitrate

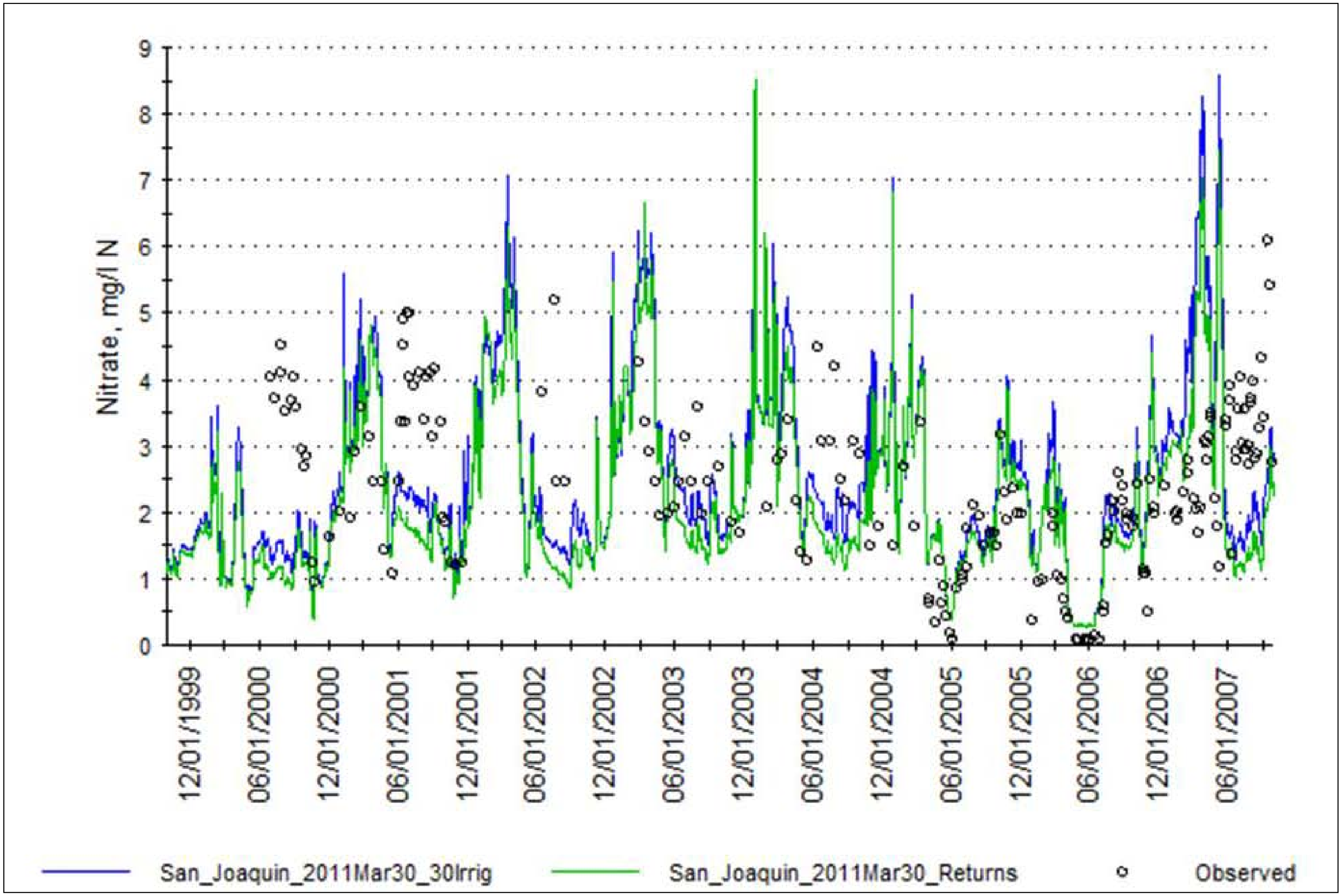

Figure 4-9. San Joaquin River at Crows Landing Simulated Nitrate for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed Nitrate

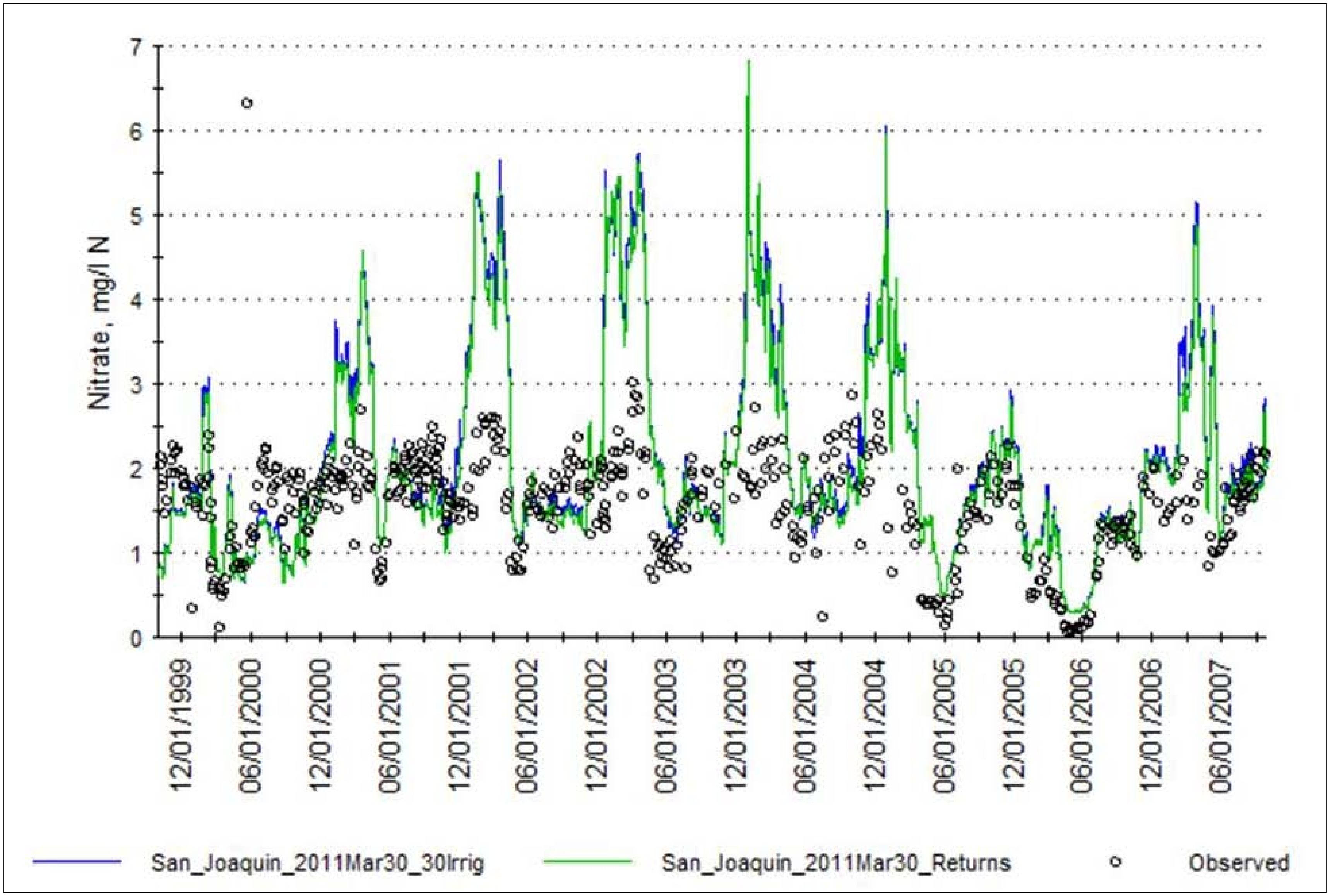

Figure 4-10. San Joaquin River at Vernalis Simulated Nitrate for Scenario 1 (green line) and Scenario 2 (blue line) Versus Observed Nitrate

Table 4-10 lists model errors in the nitrate simulations for the five locations presented in Figures 4-6 through 4-10. Greater model errors were observed for nitrate than for EC. This could be because of the greater complexity of processes (e.g., a nonconservative species) and assumptions (e.g., highly impacted by irrigation rates, irrigation water quality, and fertilizer application rates) that affect nitrate concentrations. At three calibration locations (San Luis Drain, Mud Slough, and Crows Landing) the model estimates generally fall within the range of observed data. Along with reaction rates such as nitrification and organic carbon decay rates, fertilizer application rates of ammonia and nitrate were found to significantly impact nitrate simulations. The reasonable nitrate simulations at Crows Landing but over prediction of nitrate at Vernalis could indicate that the source of over prediction is in the northern catchments' (both east and west sides of the river) near-surface groundwater contribution to the San Joaquin River. Irrigation application rates, irrigation water quality, and fertilization rates, particularly in the northern catchments, should be revisited to improve nitrate simulation for Vernalis.

Table 4-10. Nitrate Calibration Statistics

Location	Scenario 1		Scenario 2	
	Relative Error (%)	Absolute Error (%)	Relative Error (%)	Absolute Error (%)
Salt Slough at Highway 165	18	70	32	64
San Luis Drain near Stevinson	20	47	20	47
Mud Slough near Gustine	-26	86	-13	76
San Joaquin River at Crows Landing	-13	60	1	52
San Joaquin River at Vernalis	20	35	22	35

Chapter 5
Salt and Nitrate Budget Results

This chapter presents the results of salt and nitrate budget analyses for the San Joaquin River from Stevinson to Vernalis and the eight contributing areas, or subwatersheds, as identified in Table 1-1 and shown in Figure 1-2. Results are summarized for each of the salt and nitrate budget components identified for surface water, near-surface groundwater, and deeper groundwater, as described in Table 2-5.

San Joaquin River from Stevinson to Vernalis

Salt and nitrate budgets for the San Joaquin River watershed from Stevinson to Vernalis are presented in Tables 5-1 through 5-8. The largest sources of salt to near-surface groundwater for both scenarios simulated were irrigation, land application, and atmospheric deposition. The largest source of nitrate was land application, followed by irrigation. Results for the two irrigation scenarios were very similar in the sources' relative contributions to these total salt and nitrate loads; however, total loads were higher under Irrigation Scenario 2.

Overall, the salt and nitrate budget results presented provide good insight into the relative importance of salt and nitrate sources and sinks within the Westside region. Agricultural components, including irrigation, land application of fertilizer and animal waste, and groundwater pumping for irrigation, are consistently the largest fluxes in each subregion. Therefore, as discussed throughout this and the previous chapter, gathering additional information regarding agricultural management practices in the region could improve associated model inputs and thus lead to refined salt and nitrate budget results.

In general for both salt and nitrate, the minimum loads occur during late fall in conjunction with lower flows and higher concentrations, and maximum loads occur in late winter or early spring in conjunction with higher flows and lower concentrations. The Mud Slough and Salt Slough subwatersheds contribute most of the salts to the Study Area, accounting for about 65 percent of total salt load.

Tables 5-1 to 5-2 provide simulated salt budgets San Joaquin River from Stevinson to Vernalis under Irrigation Scenario 1, and Tables 5-3 to 5-4 provide simulated budgets under Irrigation Scenario 2. Simulated nitrate budgets under Irrigation Scenarios 1 and 2, respectively, are provided in Tables 5-5 to 5-6 and 5-7 to 5-8.

Table 5-1. Simulated Salt Budget for Surface Water in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2002**						**March 2005**		
Total Inputs	**1,299**	**NA**	**2,857,000**	**4,062**	**NA**	**5,853,000**	**8,246**	**NA**	**16,077,000**
Inflows from Upstream	953	258	1,326,000	3,019	67	1,093,300	7,177	256	9,907,000
Imported Water	52	339	95,000	362	313	611,000	0	NA	84,000
Inflows from Near-Surface Groundwater	294	906	1,436,000	664	1,130	4,048,700	1,029	967	5,367,000
Point Sources	0	NA	0	17	312	28,000	40	NA	72,000
Reaction Products / Scour	NA	NA	0	0	NA	72,000	0	NA	647,000
Total Outputs	**1,299**	**NA**	**2,857,000**	**4,062**	**NA**	**5,982,480**	**7,269**		**16,077,000**
Uptake / Decay / Settling	5	NA	69,000	92	NA	119,880	31	NA	0
Diversions	333	582	1,046,000	273	409	601,600	69	567	211,000
Outflow to Downstream	960	336	1,742,000	3,697	264	5,261,000	7,169	410	15,866,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-2. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**4,564**	**NA**	**8,274,600**
Atmospheric Deposition	1,508	NA	367,000
Irrigation	3,033	372	6,092,000
Fertilizer / Land Application	0	NA	1,502,300
Point Sources	23	419	52,000
Septic Systems	0	NA	2,000
Reaction Products	0	NA	259,300
Total Outputs	**4,568**	**NA**	**8,086,000**
Uptake / Decay	3,585	NA	752,300
Outflow to Surface	664	1,130	4,048,700
Deep Groundwater Recharge	319	1,910	3,285,000
Change in Storage	**NA**	**NA**	**188,600**
Deeper Groundwater			
Total Inputs	**319**	**NA**	**3,285,000**
Recharge from Near-Surface Groundwater	319	1,911	3,285,000
Total Outputs	**NA**	**NA**	**4,014,000**
Irrigation Pumping	NA	NA	4,014,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-729,000**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-3. Simulated Salt Budget for Surface Water in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 2), Water Years 2000 Through 2007

4Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2002**						**April 2006**		
Total Inputs	**1,179**	**NA**	**2,900,000**	**3,959**	**NA**	**5,791,000**	**32,076**	**NA**	**15,144,000**
Inflows from Upstream	851	280	1,287,000	3,019	67	1,093,300	31,208	70	11,739,000
Imported Water	22	353	41,000	232	312	391,000	5	164	4,000
Inflows from Near-Surface Groundwater	307	951	1,572,000	691	1,128	4,206,700	864	679	3,163,000
Point Sources	0	NA	0	17	312	28,000	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	72,000	NA	NA	238,000
Total Outputs	**1,179**	**NA**	**2,862,000**	**3,959**	**NA**	**5,706,480**	**32,076**		**15,314,000**
Uptake / Decay / Settling	33	NA	69,000	92	NA	119,880	299	NA	0
Diversions	335	762	1,377,000	273	409	601,600	416	96	216,000
Outflow to Downstream	811	324	1,416,000	3,594	257	4,985,000	31,361	89	15,098,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-4. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 2), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**4,693**	**NA**	**8,468,600**
Atmospheric Deposition	1,508	NA	403,000
Irrigation	3,162	366	6,250,000
Fertilizer / Land Application	0	NA	1,502,300
Point Sources	23	419	52,000
Septic Systems	0	NA	2,000
Reaction Products	0	NA	259,300
Total Outputs	**4,695**	**NA**	**8,425,000**
Uptake / Decay	3,659	NA	782,300
Outflow to Surface	691	1,128	4,206,700
Deep Groundwater Recharge	345	1,846	3,436,000
Change in Storage	**NA**	**NA**	**43,600**
Deeper Groundwater			
Total Inputs	**345**	**NA**	**3,436,000**
Recharge from Near-Surface Groundwater	345	1,846	3,436,000
Total Outputs	**NA**	**NA**	**4,014,000**
Irrigation Pumping	NA	NA	4,014,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-578,000**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-5. Simulated Nitrate Budget for Surface Water in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2002**						**February 2005**		
Total Inputs	**1,299**	**NA**	**11,210**	**4,062**	**NA**	**36,546**	**7,267**	**NA**	**114,840**
Inflows from Upstream	953	1.16	5,940	3,019	0.50	8,204	5,429	1.72	50,330
Imported Water	52	0.57	160	362	0.72	1,400	24	1.07	140
Inflows from Near-Surface Groundwater	294	3.22	5,110	664	7.01	25,136	1,751	6.51	61,500
Point Sources	0	NA	0	17	5.57	500	63	NA	1,600
Reaction Products / Scour	0	NA	0	0	NA	1,306	0	NA	1,270
Total Outputs	**1,299**		**11,210**	**4,062**	**NA**	**36,443**	**7,267**		**114,840**
Uptake / Decay / Settling	5	NA	1,310	92	NA	566	70	NA	0
Diversions	333	1.47	2,640	273	1.82	2,677	28	2.22	340
Outflow to Downstream	960	1.40	7,260	3,697	1.66	33,200	7,169	2.96	114,500

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-6. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**4,564**	**NA**	**209,036**
Atmospheric Deposition	1,508	NA	3,274
Irrigation	3,033	3.95	64,590
Fertilizer / Land Application	0	NA	127,072
Point Sources	23	NA	900
Septic Systems	0	NA	0
Reaction Products	0	NA	13,200
Total Outputs	**4,568**	**NA**	**201,961**
Uptake / Decay	3,585	NA	169,445
Outflow to Surface	664	7.01	25,136
Deep Groundwater Recharge	319	4.29	7,380
Change in Storage	**NA**	**NA**	**7,075**
Deeper Groundwater			
Total Inputs	**319**	**NA**	**7,380**
Recharge from Near-Surface Groundwater	319	4.29	7,380
Total Outputs	**NA**	**NA**	**62,000**
Irrigation Pumping	NA	NA	62,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-54,620**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-7. Simulated Nitrate Budget for Surface Water in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 2), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2002**						**February 2005**		
Total Inputs	**1,179**	**NA**	**10,390**	**3,959**	**NA**	**36,556**	**7,181**	**NA**	**104,810**
Inflows from Upstream	851	1.31	6,000	3,019	0.50	8,204	5,471	1.73	51,200
Imported Water	22	0.69	80	232	0.73	920	7	1.07	40
Inflows from Near-Surface Groundwater	307	2.61	4,310	691	6.87	25,606	1,641	5.83	51,600
Point Sources	0	NA	0	17	6	500	63	5	1,600
Reaction Products / Scour	NA	NA	0	NA	NA	1,326	NA	NA	370
Total Outputs	**1,179**		**10,390**	**3,959**	**NA**	**36,463**	**7,181**		**104,810**
Uptake / Decay / Settling	33	NA	1,090	92	NA	566	180	NA	0
Diversions	335	1.74	3,140	273	1.82	2,677	28	2.03	310
Outflow to Downstream	811	1.41	6,160	3,594	1.71	33,220	6,973	2.78	104,500

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-8. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Stevinson to Vernalis (Irrigation Scenario 2), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**4,693**	**NA**	**209,426**
Atmospheric Deposition	1,508	NA	3,284
Irrigation	3,162	3.81	64,990
Fertilizer / Land Application	0	NA	127,072
Point Sources	23	7.25	900
Septic Systems	0	NA	0
Reaction Products	0	NA	13,180
Total Outputs	**4,695**	**NA**	**202,731**
Uptake / Decay	3,659	NA	169,945
Outflow to Surface	691	6.87	25,616
Deep Groundwater Recharge	345	3.85	7,170
Change in Storage	**NA**	**NA**	**6,695**
Deeper Groundwater			
Total Inputs	**345**	**NA**	**7,170**
Recharge from Near-Surface Groundwater	345	3.85	7,170
Total Outputs	**NA**	**NA**	**62,000**
Irrigation Pumping	NA	NA	62,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-54,830**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Salt Slough Subwatershed

The salt and nitrate budgets for Salt Slough subwatershed (Figure 5-1) are presented in Tables 5-9 through 5-16. Tables 5-9 to 5-10 and Tables 5-11 to 5-12 provide simulated salt budgets for the Salt Slough subwatershed under Irrigation Scenarios 1 and 2, respectively. Tables 5-13 to 5-14 provide simulated nitrate budgets for the Salt Slough subwatershed under Irrigation Scenario 1, and Tables 5-15 to 5-16 provide simulated nitrate budgets under Irrigation Scenario 2.

In Scenario 1, imported water dominates the salt and nitrate budgets for the minimum loads and flows, while the local watershed runoff dominates the salt and nitrate budgets for maximum loads and flows. The difference between Scenario 1 and Scenario 2 is a 30 percent increase in applied irrigation water, which is assumed to come from groundwater pumping. The increase in salt storage in near-surface groundwater under Scenario 2 is greater than expected based on recent evaluations of water and salt budgets for wetlands in the region (Reclamation, 2011b). Because drainage is not restricted in this watershed, it is expected that salt inputs and outputs would be in balance. The results could be associated with general model assumptions or could be attributed to groundwater quality data. Improved groundwater quality and quantity data would also improve the model and could help resolve the amplified significance of groundwater due to the current assumption of increased groundwater use for irrigation.

There were no salt inputs associated with atmospheric deposition in the Salt Slough subwatershed. Due to the pH of soils in subwatershed reach, dissolved inorganic carbon flux is out of the soil/near-surface groundwater to maintain equilibrium with atmospheric carbon dioxide. This outflux of dissolved inorganic carbon is larger than deposition of other ions, creating losses of dissolved inorganic carbon to the atmosphere, shown as an output for TDS in the salt budget.

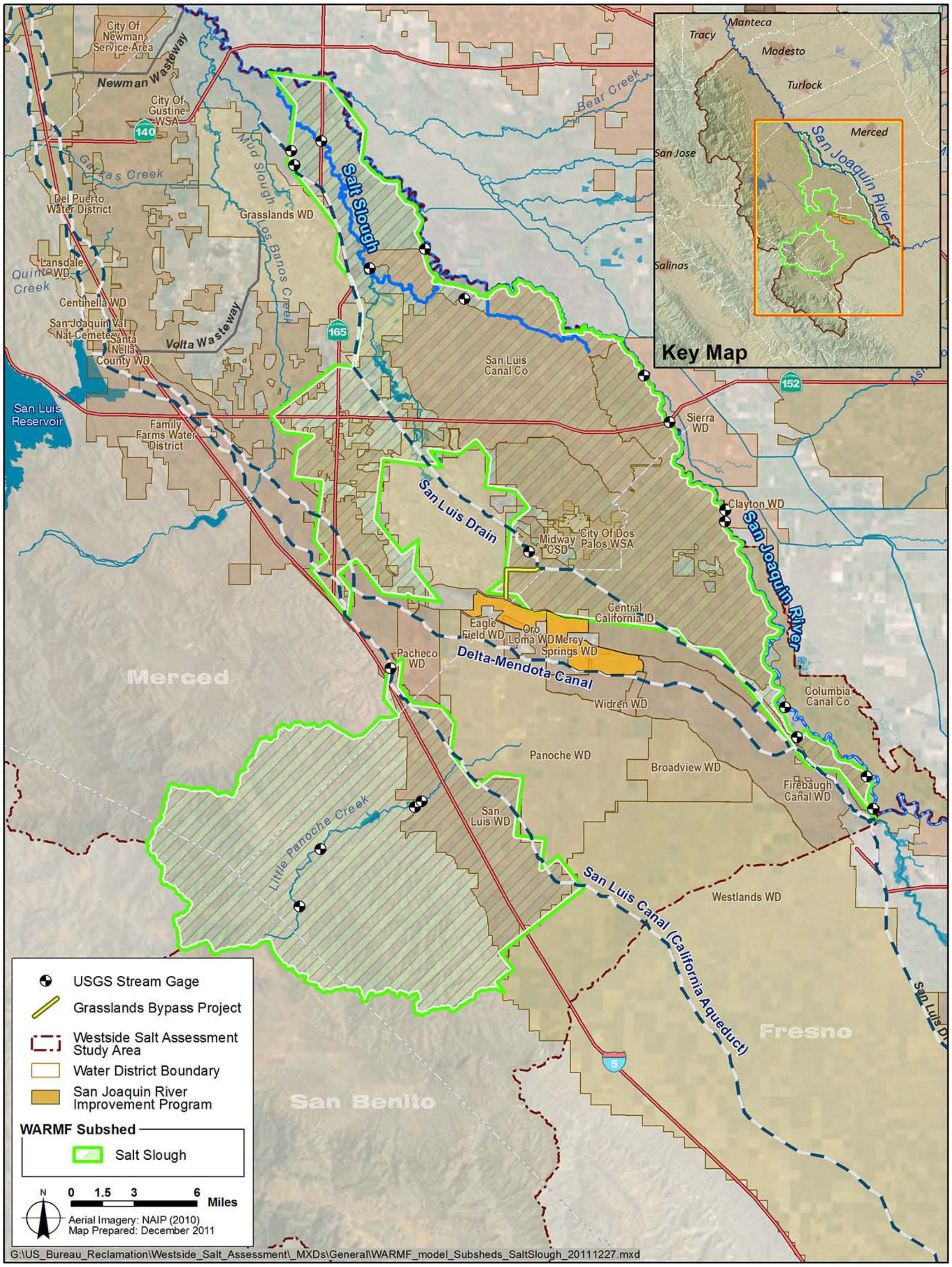

Figure 5-1. Salt Slough Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 5-9. Simulated Salt Budget for Surface Water in Salt Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**November 2002**						**March 2005**		
Total Inputs	**32**	**NA**	**54,600**	**249**	**NA**	**620,000**	**381**	**NA**	**2,601,000**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	24	329	41,900	207	281	314,000	129	369	257,000
Inflows from Near-Surface Groundwater	8	205	8,700	42	1,331	302,000	252	1,670	2,269,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	4,000	NA	NA	4,000	NA	NA	75,000
Total Outputs	**33**	**NA**	**54,600**	**249**	**NA**	**620,000**	**381**		**2,601,000**
Uptake / Decay / Settling	0	NA	0	0	NA	4,000	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	33	311	54,600	249	459	616,000	381	1,266	2,601,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-10. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in Salt Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**761**	**NA**	**1,651,000**
Atmospheric Deposition [1]	NA	NA	NA
Irrigation	555	448	1,340,000
Fertilizer / Land Application	0	NA	257,000
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	54,000
Total Outputs	**763**	**NA**	**1,283,000**
Uptake / Decay	654	NA	171,000
Volatilization / Gaseous Losses	206	NA	86,000
Outflow to Surface	42	1,333	302,000
Deep Groundwater Recharge	67	2,014	724,000
Change in Storage	**NA**	**NA**	**368,000**
Deeper Groundwater			
Total Inputs	**67**	**NA**	**724,000**
Recharge from Near-Surface Groundwater	67	2,014	724,000
Total Outputs	**NA**	**NA**	**557,000**
Irrigation Pumping	NA	NA	557,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**167,000**

Notes:
[1] No net atmospheric deposition due to volatilization of inorganic carbon in soils.
Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-11. Simulated Salt Budget for Surface Water in Salt Slough Subwatershed (Irrigation Scenario 2), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2007**						**March 2005**		
Total Inputs	**68**	**NA**	**187,000**	**146**	**NA**	**558,000**	**324**	**NA**	**2,430,000**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	44	289	69,000	78	225	94,000	48	370	96,000
Inflows from Near-Surface Groundwater	24	915	118,000	69	1,242	460,000	276	1,445	2,154,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	4,000	NA	NA	180,000
Total Outputs	**68**	**NA**	**187,000**	**146**	**NA**	**556,000**	**325**		**2,430,000**
Uptake / Decay / Settling	0	NA	1,000	0	NA	4,000	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	69	497	186,000	146	701	552,000	325	1,384	2,430,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-12. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in Salt Slough Subwatershed (Irrigation Scenario 2), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**890**	**NA**	**1,809,000**
Atmospheric Deposition [1]	NA	NA	NA
Irrigation	684	406	1,498,000
Fertilizer / Land Application	0	NA	257,000
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	54,000
Total Outputs	**890**	**NA**	**1,586,000**
Uptake / Decay	728	NA	201,000
Volatilization / Gaseous Losses	206	NA	50,000
Outflow to Surface	69	1,242	460,000
Deep Groundwater Recharge	93	1,744	875,000
Change in Storage	**NA**	**NA**	**223,000**
Deeper Groundwater			
Total Inputs	**93**	**NA**	**875,000**
Recharge from Near-Surface Groundwater	93	1,744	875,000
Total Outputs	**NA**	**NA**	**557,000**
Irrigation Pumping	NA	NA	557,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**318,000**

Notes:
[1] No net atmospheric deposition due to volatilization of inorganic carbon in soils.
Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-13. Simulated Nitrate Budget for Surface Water in Salt Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2007**						**March 2005**		
Total Inputs	**124**	**NA**	**161**	**249**	**NA**	**2,240**	**381**	**NA**	**8,160**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	117	0.22	139	207	0.69	770	129	1.02	710
Inflows from Near-Surface Groundwater	7	0.62	22	42	6.26	1,420	252	5.24	7,120
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA		NA	NA	60	NA	NA	330
Total Outputs	**126**		**161**	**249**	**NA**	**2,240**	**381**		**8,160**
Uptake / Decay / Settling	0	NA	29	0	NA	40	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	126	0.19	132	249	1.64	2,200	381	3.97	8,160

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-14. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in Salt Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**761**	**NA**	**48,360**
Atmospheric Deposition	206	NA	590
Irrigation	555	3.61	10,800
Fertilizer / Land Application	0	NA	36,400
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	570
Total Outputs	**763**	**NA**	**47,330**
Uptake / Decay	654	NA	44,300
Outflow to Surface	42	6.26	1,420
Deep Groundwater Recharge	67	4.48	1,610
Change in Storage	**NA**	**NA**	**1,030**
Deeper Groundwater			
Total Inputs	**67**	**NA**	**1,610**
Recharge from Near-Surface Groundwater	67	4.48	1,610
Total Outputs	**NA**	**NA**	**9,460**
Irrigation Pumping	NA	NA	9,460
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-7,850**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-15. Simulated Nitrate Budget for Surface Water in Salt Slough Subwatershed (Irrigation Scenario 2), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2007**						**March 2005**		
Total Inputs	**68**	**NA**	**134**	**146**	**NA**	**2,260**	**324**	**NA**	**8,530**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	44	0.22	52	78	0.69	290	48	1.00	260
Inflows from Near-Surface Groundwater	24	0.63	81	69	5.10	1,890	276	5.15	7,670
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	80	NA	NA	600
Total Outputs	**68**		**134**	**146**	**NA**	**2,260**	**325**		**8,530**
Uptake / Decay / Settling	0	NA	10	0	NA	40	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	69	0.33	124	146	2.82	2,220	325	4.86	8,530

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate
WARMF = Watershed Analysis Risk Management Framework

Table 5-16. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in Salt Slough Subwatershed (Irrigation Scenario 2), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**890**	**NA**	**48,700**
Atmospheric Deposition	206	NA	600
Irrigation	684	3.04	11,200
Fertilizer / Land Application	0	NA	36,400
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	550
Total Outputs	**890**	**NA**	**48,100**
Uptake / Decay	728	NA	44,800
Outflow to Surface	69	5.13	1,900
Deep Groundwater Recharge	93	2.79	1,400
Change in Storage	**NA**	**NA**	**600**
Deeper Groundwater			
Total Inputs	**93**	**NA**	**1,400**
Recharge from Near-Surface Groundwater	93	2.79	1,400
Total Outputs	**NA**	**NA**	**9,460**
Irrigation Pumping	NA	NA	9,460
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-8,060**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

San Luis Drain Subwatershed

The salt and nitrate budgets for the San Luis Drain subwatershed (Figure 5-2) are presented in Tables 5-17 through 5-20. The contributions of salt to surface water are from near-surface groundwater, or tile drainage in the watershed. Deeper groundwater is below the tile drains. Through implementation and expansion of SJRIP project, higher accumulation of salts was expected in the near surface groundwater within this subwatershed than simulated.

Reuse of agricultural return flows for water supply may not be appropriately captured in the water budget for this subwatershed, leading to overestimate of water demands met through groundwater pumping and underestimate of change in salt storage in deeper groundwater. Current practices suggest that a portion of lower quality tile drainage may be conveyed to upstream areas and reused through blending with higher quality water inflows before irrigating. Reuse would be part of irrigation in near-surface groundwater and would introduce more salt.

As described above, salt and nitrate budgets are also limited by the scarcity of groundwater hydrology data, including groundwater pumping, and groundwater quality data. Model simulations assumed groundwater pumped within the subwatershed is applied in the same subwatershed. Because the salt load associated with groundwater pumping is not being exported elsewhere, an artificially high salt load may be observed in the simulation. Additionally, due to the scarcity of data, significant assumptions were made regarding model inputs for groundwater quantity and quality, and are particularly important to the nitrate budget results.

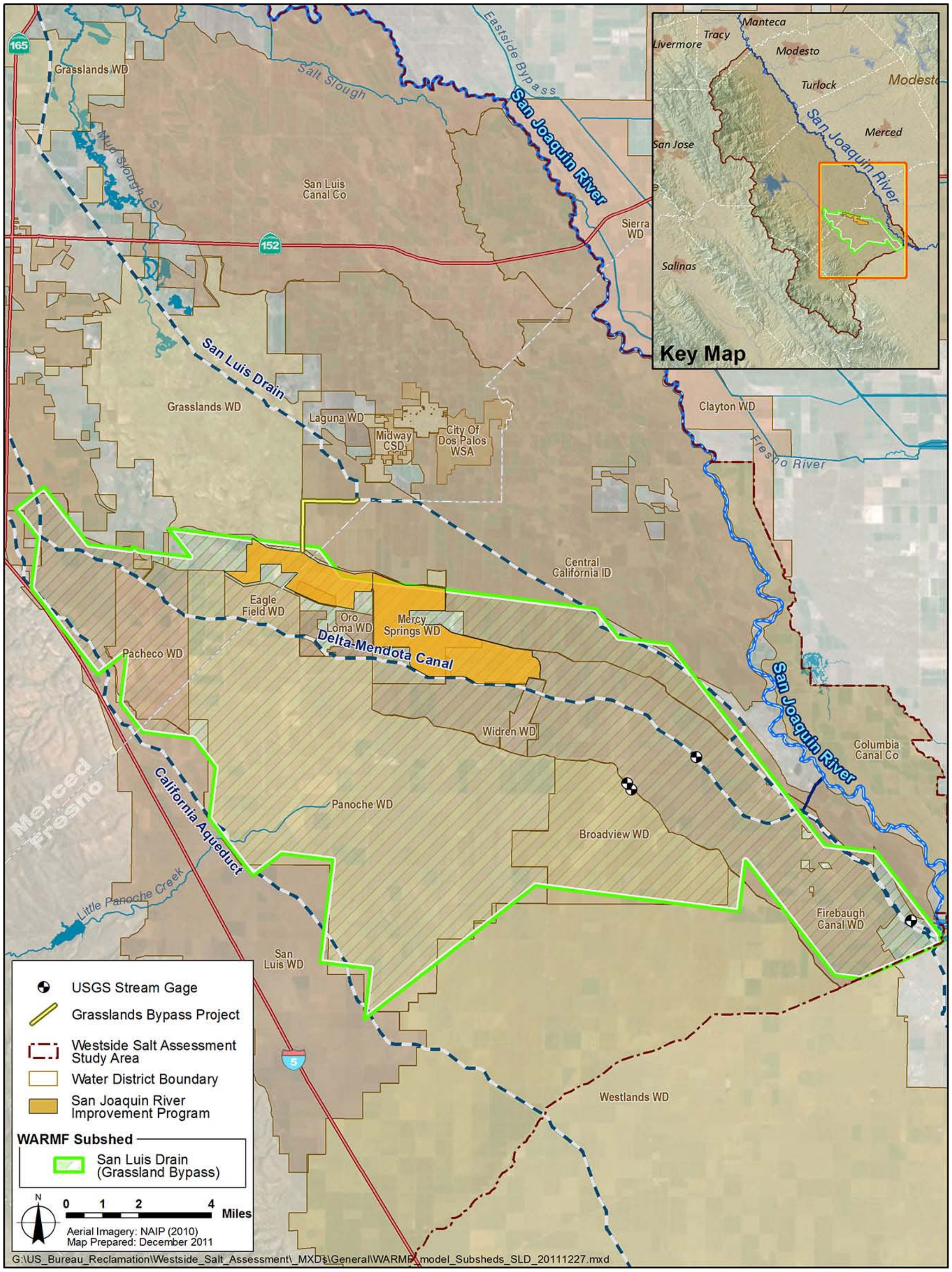

Figure 5-2. San Luis Drain Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 5-17. Simulated Salt Budget for Surface Water in San Luis Drain Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2007**						**April 2005**		
Total Inputs	**13**	**NA**	**199,000**	**41**	**NA**	**697,000**	**95**	**NA**	**1,803,000**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	13	2,837	199,000	41	3,021	675,000	95	3,518	1,803,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	22,000	NA	NA	0
Total Outputs	**13**	**NA**	**199,000**	**41**	**NA**	**697,000**	**95**	**NA**	**1,803,000**
Uptake / Decay / Settling	0	NA	0	0	NA	1,880	0	NA	0
Diversions	0	NA	0	0	NA	12,600	0	NA	0
Outflow to Downstream	13	2,837	199,000	41	3,053	682,000	95	3,514	1,803,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-18. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in San Luis Drain Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**409**	**NA**	**1,277,000**
Atmospheric Deposition	85	NA	108,000
Irrigation	324	558	976,000
Fertilizer / Land Application	0	NA	159,000
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	0
Total Outputs	**407**	**NA**	**1,247,000**
Uptake / Decay	344	NA	124,000
Outflow to Surface	41	3,021	675,000
Deep Groundwater Recharge	21	3,951	448,000
Change in Storage	**NA**	**NA**	**30,000**
Deeper Groundwater			
Total Inputs	**21**	**NA**	**448,000**
Recharge from Near-Surface Groundwater	21	3,951	448,000
Total Outputs	**NA**	**NA**	**464,000**
Irrigation Pumping	NA	NA	464,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-16,000**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-19. Simulated Nitrate Budget for Surface Water in San Luis Drain Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**January 2000**						**March 2005**		
Total Inputs	**25**	**NA**	**134**	**41**	**NA**	**3,240**	**100**	**NA**	**10,900**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	25	0.87	119	41	14.37	3,210	100	20.20	10,900
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	15	NA	NA	26	NA	NA	0
Total Outputs	**25**	**NA**	**134**	**41**	**NA**	**3,240**	**100**	**NA**	**10,900**
Uptake / Decay / Settling	0	NA	0	0	NA	6	0	NA	0
Diversions	0	NA	0	0	NA	77	0	NA	0
Outflow to Downstream	25	0.98	134	41	14.14	3,160	100	20.20	10,900

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-20. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in San Luis Drain Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**409**	**NA**	**34,900**
Atmospheric Deposition	85	NA	220
Irrigation	324	6.32	11,060
Fertilizer / Land Application	0	NA	23,170
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	490
Total Outputs	**407**	**NA**	**33,060**
Uptake / Decay	344	NA	27,880
Outflow to Surface	41	14.37	3,210
Deep Groundwater Recharge	21	17.11	1,940
Change in Storage	**NA**	**NA**	**1,840**
Deeper Groundwater			
Total Inputs	**21**	**NA**	**1,940**
Recharge from Near-Surface Groundwater	21	17.11	1,940
Total Outputs	**NA**	**NA**	**10,570**
Irrigation Pumping	NA	NA	10,570
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-8,630**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Mud Slough Subwatershed

The salt and nitrate budgets for Mud Slough subwatershed (Figure 5-3) are presented in Tables 5-21 through 5-24. The Mud Slough subwatershed includes areas upstream from the irrigated agricultural areas on the valley floor, in addition to wetlands and the Grasslands Ecological Area wildlife refuges, but excludes the Grasslands Bypass Project.

Maximum salt and nitrate loads within the subwatershed are attributed to maximum periods of runoff. Based on recent analyses of water and salt budgets within wetlands in the region (Reclamation, 2011b), output of salt from the Mud Slough subwatershed through recharge to deeper groundwater is higher than anticipated. Note, however, that model simulations were constrained by measured water quality and flow at monitoring stations along with calculated evapotranspiration demands based on land use and vegetation types within the subwatershed. Conceptual model improvements may also be necessary to improve the simulated results.

Though the gage data provides consistency for the Mud Slough budgets, other input data may account for unexpected imbalances. In particular, CVO data suggest much larger deliveries to wetlands in the Mud Slough subwatershed and wetland deliveries during periods when water is not actually delivered compared to delivery data from Reclamation's WAP. WAP tracks water deliveries, specifically to the wetlands and refuges in the region. Inflows greater than actual deliveries could account for a salt source within the budget that is greater than expected as well as higher concentrations of salt that is output as recharge to deeper groundwater. Because only publicly available data were used in the study for transparency, the application of WAP and/or other irrigation water delivery input data are likely to yield different salt output results for the subwatershed.

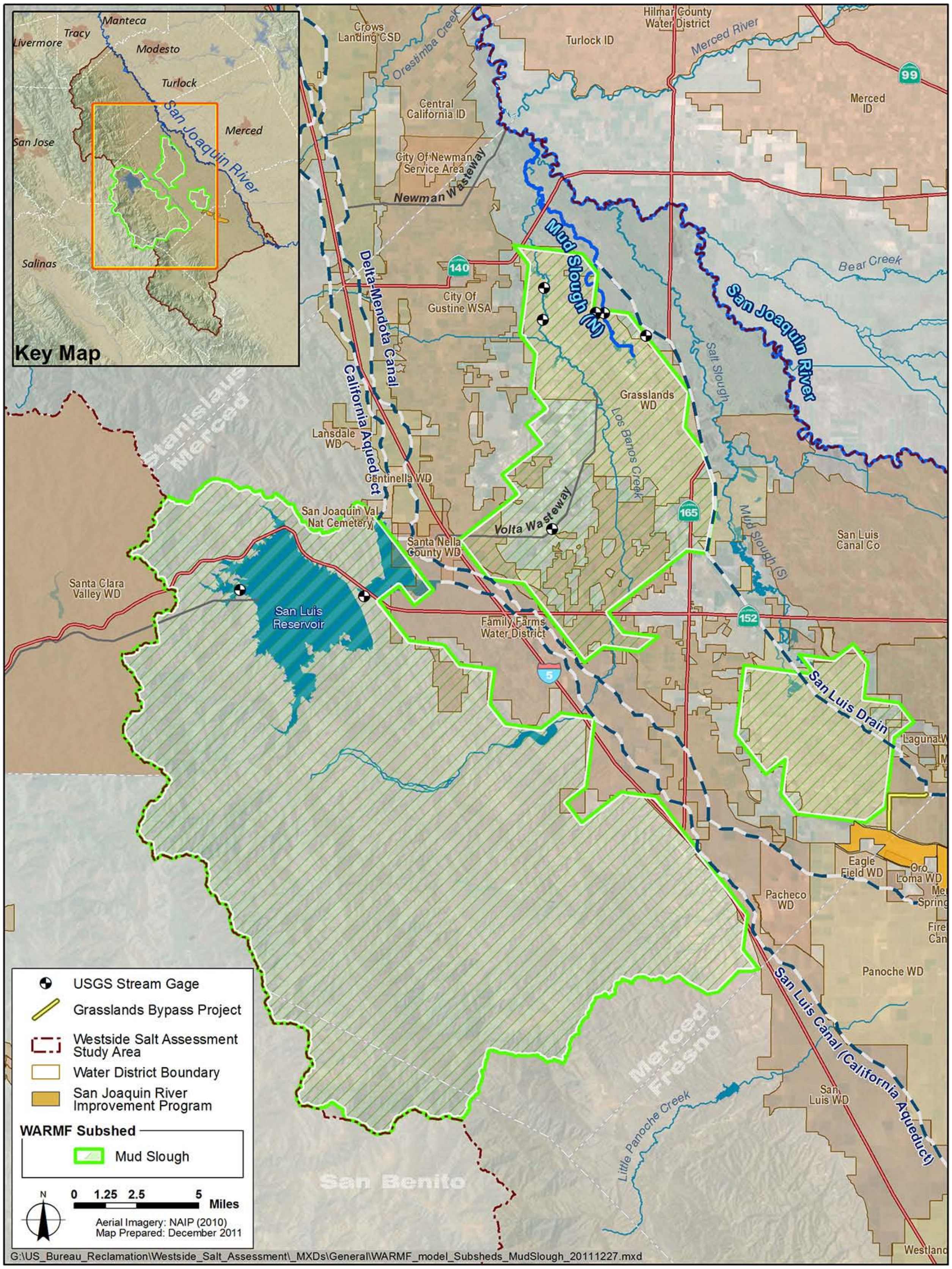

Figure 5-3. Mud Slough Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 5-21. Simulated Salt Budget for Surface Water in Mud Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2007**						**March 2005**		
Total Inputs	**38**	**NA**	**237,000**	**157**	**NA**	**971,000**	**259**	**NA**	**2,454,000**
Inflows from Upstream	13	2,837	199,000	41	3,020	697,000	100	3,306	1,782,000
Imported Water	23	289	36,000	43	629	146,000	33	372	66,000
Inflows from Near-Surface Groundwater	1	439	3,000	73	361	142,000	127	793	543,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	1,000	NA	NA	63,000
Total Outputs	**38**	**NA**	**237,000**	**157**	**NA**	**971,000**	**259**		**2,454,000**
Uptake / Decay / Settling	0	NA	0	0	NA	2,000	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	38	1,143	237,000	157	1,144	969,000	259	1,758	2,454,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-22. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in Mud Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**538**	**NA**	**1,000,000**
Atmospheric Deposition	130	NA	116,000
Irrigation	408	380	835,000
Fertilizer / Land Application	0	NA	34,000
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	15,000
Total Outputs	**538**	**NA**	**1,082,000**
Uptake / Decay	337	NA	39,000
Outflow to Surface	73	361	142,000
Deep Groundwater Recharge	125	1,337	901,000
Change in Storage	**NA**	**NA**	**-82,000**
Deeper Groundwater			
Total Inputs	**125**	**NA**	**901,000**
Recharge from Near-Surface Groundwater	125	1,337	901,000
Total Outputs	**NA**	**NA**	**258,000**
Irrigation Pumping	NA	NA	258,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**643,000**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-23. Simulated Nitrate Budget for Surface Water in Mud Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2000**						**March 2005**		
Total Inputs	**88**	**NA**	**646**	**157**	**NA**	**3,630**	**259**	**NA**	**11,900**
Inflows from Upstream	21	2.75	305	41	14.14	3,160	100	20.22	10,900
Imported Water	3	0.21	4	43	0.56	130	33	1.13	200
Inflows from Near-Surface Groundwater	66	0.95	337	73	0.83	330	127	1.17	800
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	10	NA	NA	0
Total Outputs	**88**		**646**	**157**	**NA**	**3,630**	**259**		**11,900**
Uptake / Decay / Settling	0	NA	217	0	NA	20	0	NA	100
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	88	0.90	429	157	4.26	3,610	259	8.45	11,800

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-24. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in Mud Slough Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**538**	**NA**	**8,810**
Atmospheric Deposition	130	NA	510
Irrigation	408	1.56	3,440
Fertilizer / Land Application	0	NA	4,530
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	330
Total Outputs	**538**	**NA**	**8,460**
Uptake / Decay	337	NA	7,880
Outflow to Surface	73	0.83	330
Deep Groundwater Recharge	125	0.37	250
Change in Storage	**NA**	**NA**	**350**
Deeper Groundwater			
Total Inputs	**125**	**NA**	**250**
Recharge from Near-Surface Groundwater	125	0.37	250
Total Outputs	**NA**	**NA**	**2,360**
Irrigation Pumping	NA	NA	2,360
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-2,110**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Los Banos Creek Subwatershed

Salt and nitrate budgets for Los Banos Creek subwatershed (Figure 5-4) are presented in Tables 5-25 through 5-28. The results show a change in salt storage higher than was anticipated. Delineation of the Los Banos Creek subwatershed presented a challenge and provides some uncertainty in simulated results. The delineation of the Los Banos Creek subwatershed was further complicated by agricultural drainage, dairy returns, municipal returns, crossing through wetlands as well as Mud Slough. The simulations salt and nitrate budgets for this subwatershed would likely be improved by refining the delineations for Los Banos Creek and Mud Slough subwatersheds.

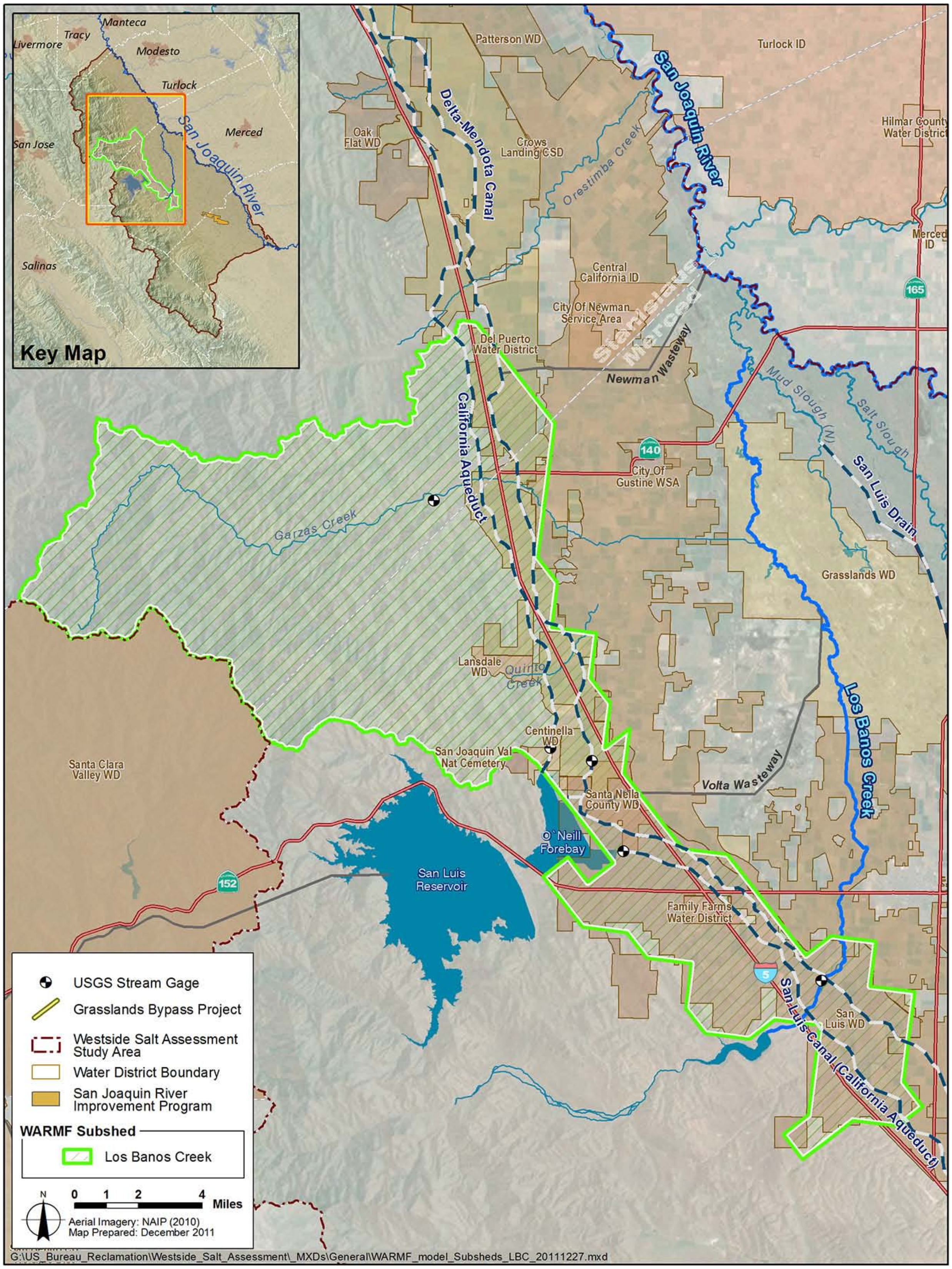

Figure 5-4. Los Banos Creek Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 5-25. Simulated Salt Budget for Surface Water in Los Banos Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2007**						**March 2005**		
Total Inputs	**5**	**NA**	**34,700**	**31**	**NA**	**287,000**	**161**	**NA**	**1,336,000**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	5	1,255	34,700	31	1,704	282,000	161	1,535	1,336,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	5,000	NA	NA	0
Total Outputs	**5**	**NA**	**34,700**	**31**	**NA**	**284,000**	**162**		**1,336,000**
Uptake / Decay / Settling	0	NA	1,700	0	NA	5,000	0	NA	16,000
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	5	1,216	33,000	31	1,686	279,000	162	1,510	1,320,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-26. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in Los Banos Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**227**	**NA**	**478,000**
Atmospheric Deposition	130	NA	136,000
Irrigation	96	498	259,000
Fertilizer / Land Application	0	NA	39,000
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	44,000
Total Outputs	**227**	**NA**	**346,000**
Uptake / Decay	194	NA	29,000
Outflow to Surface	31	1,704	282,000
Deep Groundwater Recharge	5	1,430	35,000
Change in Storage	**NA**	**NA**	**132,000**
Deeper Groundwater			
Total Inputs	**5**	**NA**	**35,000**
Recharge from Near-Surface Groundwater	5	1,430	35,000
Total Outputs	**NA**	**NA**	**226,000**
Irrigation Pumping	NA	NA	226,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-191,000**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-27. Simulated Nitrate Budget for Surface Water in Los Banos Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2000**						**March 2005**		
Total Inputs	**9**	**NA**	**97**	**31**	**NA**	**1,880**	**161**	**NA**	**8,110**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	9	2.02	96	31	10.69	1,770	161	9.26	8,060
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	1	NA	NA	110	NA	NA	50
Total Outputs	**9**		**97**	**31**	**NA**	**1,880**	**162**		**8,110**
Uptake / Decay / Settling	0	NA	0	0	NA	0	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	9	2.07	97	31	11.36	1,880	162	9.28	8,110

Key:
cfs = cubic feet per second
lb /day N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-28. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in the Los Banos Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**227**	**NA**	**8,570**
Atmospheric Deposition	130	NA	310
Irrigation	96	4.80	2,500
Fertilizer / Land Application	0	NA	5,760
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	0
Total Outputs	**227**	**NA**	**8,010**
Uptake / Decay	194	NA	6,200
Outflow to Surface	31	10.69	1,770
Deep Groundwater Recharge	5	1.63	40
Change in Storage	**NA**	**NA**	**560**
Deeper Groundwater			
Total Inputs	**5**	**NA**	**40**
Recharge from Near-Surface Groundwater	5	1.63	40
Total Outputs	**NA**	**NA**	**2,330**
Irrigation Pumping	NA	NA	2,330
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-2,290**

Key:
cfs = cubic feet per second
lb /day N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Orestimba Creek Subwatershed

Salt and nitrate budgets for Orestimba Creek subwatershed (Figure 5-5) are presented in Tables 5-29 through 5-32. Orestimba Creek subwatershed is a relatively large, natural upland watershed without significant irrigated agriculture. Atmospheric deposition dominates the inputs in the salt budget. Irrigation is the main contributor of nitrate to the subwatershed, but the load amount is relatively small. This subwatershed is not a major contributor to the overall salt and nitrate budget for the Study Area. Because its contributions are relatively insignificant, the Orestimba Creek subwatershed was not calibrated as closely in WARMF-SJR model in comparison to other subwatersheds in the Study Area. Futures studies are underway to improve WARMF-SJR model representation of Orestimba Creek.

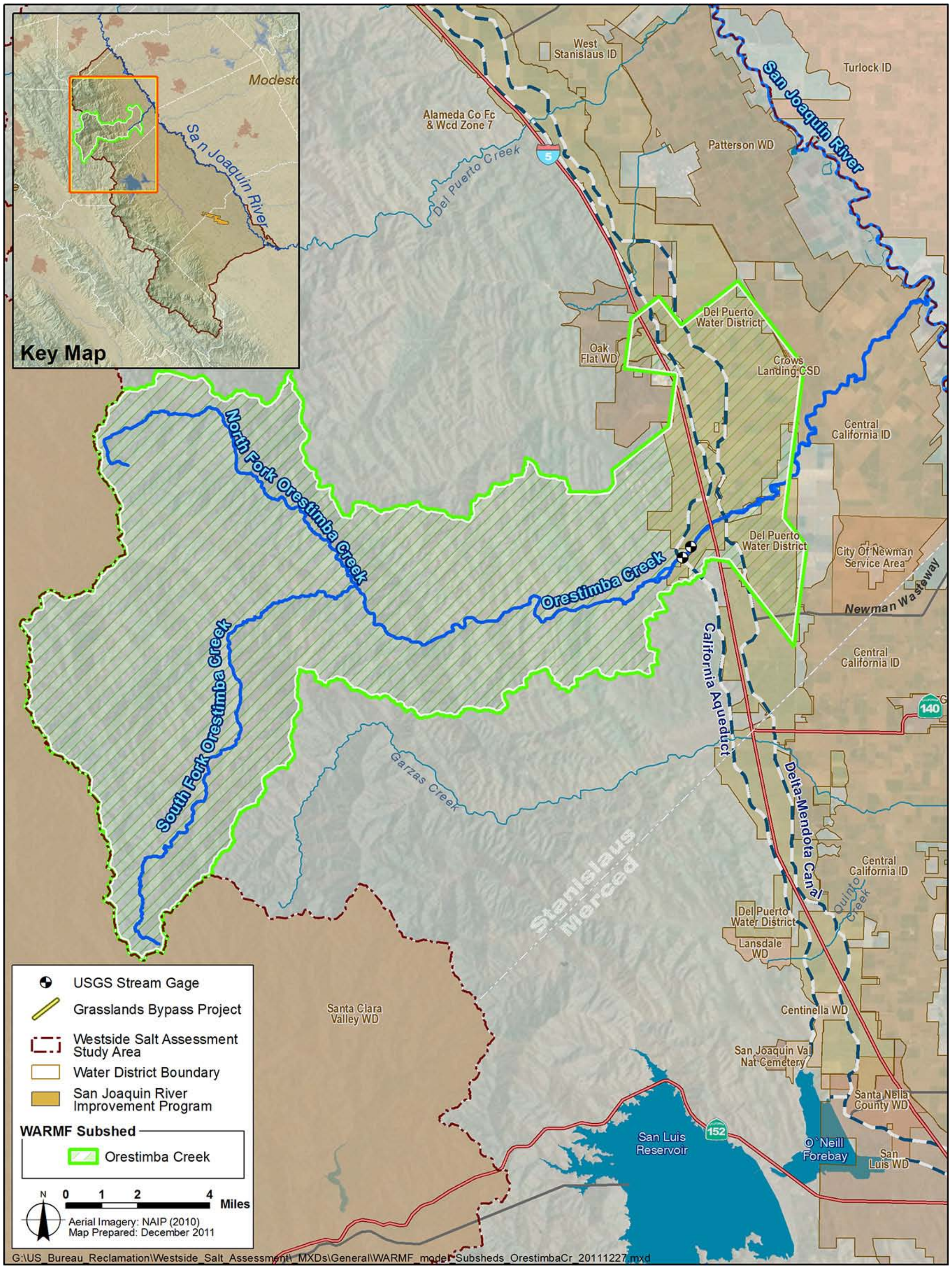

Figure 5-5. Orestimba Creek Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 5-29. Simulated Salt Budget for Surface Water in Orestimba Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2007**						**February 2004**		
Total Inputs	**2**	**NA**	**12,400**	**23**	**NA**	**143,000**	**288**	**NA**	**1,316,000**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	2	1,321	12,400	23	1,172	143,000	288	847	1,316,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	0	NA	NA	0
Total Outputs	**2**	**NA**	**12,400**	**23**	**NA**	**141,000**	**286**		**1,316,000**
Uptake / Decay / Settling	0	NA	500	0	NA	0	0	NA	13,000
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	2	1,275	11,900	23	1,157	141,000	286	843	1,303,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-30. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in the Orestimba Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**171**	**NA**	**243,000**
Atmospheric Deposition	123	NA	138,000
Irrigation	48	320	82,000
Fertilizer / Land Application	0	NA	16,000
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	7,000
Total Outputs	**171**	**NA**	**199,000**
Uptake / Decay	145	NA	17,000
Outflow to Surface	23	1,172	143,000
Deep Groundwater Recharge	4	1,895	39,000
Change in Storage	**NA**	**NA**	**44,000**
Deeper Groundwater			
Total Inputs	**4**	**NA**	**38,800**
Recharge from Near-Surface Groundwater	4	1,885	38,800
Total Outputs	**NA**	**NA**	**67,700**
Irrigation Pumping	NA	NA	67,700
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-28,900**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-31. Simulated Nitrate Budget for Surface Water in Orestimba Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**October 2000**						**February 2005**		
Total Inputs	**3**	**NA**	**131**	**23**	**NA**	**1,800**	**438**	**NA**	**9,370**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	3	9.44	131	23	14.76	1,800	438	3.97	9,370
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	0	NA	NA	0
Total Outputs	**3**		**131**	**23**	**NA**	**1,800**	**438**		**9,370**
Uptake/Decay/ Settling	0	NA	2	0	NA	0	0	NA	20
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	3	9.43	129	23	14.77	1,800	438	3.96	9,350

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-32. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in the Orestimba Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**171**	**NA**	**6,420**
Atmospheric Deposition	123	NA	290
Irrigation	48	14.01	3,590
Fertilizer / Land Application	0	NA	2,390
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	150
Total Outputs	**171**	**NA**	**5,900**
Uptake / Decay	145	NA	3,440
Outflow to Surface	23	14.76	1,800
Deep Groundwater Recharge	4	32.07	660
Change in Storage	**NA**	**NA**	**520**
Deeper Groundwater			
Total Inputs	**4**	**NA**	**660**
Recharge from Near-Surface Groundwater	4	32.07	660
Total Outputs	**NA**	**NA**	**3,500**
Irrigation Pumping	NA	NA	3,500
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-2,840**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Del Puerto Creek Subwatershed

Salt and nitrate budgets for the Del Puerto Creek subwatershed (Figure 5-6) are presented in Tables 5-33 through 5-36. Del Puerto Creek is one of the upper watersheds of the Study Area. There are no irrigation deliveries within the subwatershed above the Del Puerto Creek gage, and all flow within the subwatershed is associated watershed runoff. Compared to other subwatersheds in the Study Area, the Del Puerto Creek subwatershed salt and nitrate loads and storage are negligible.

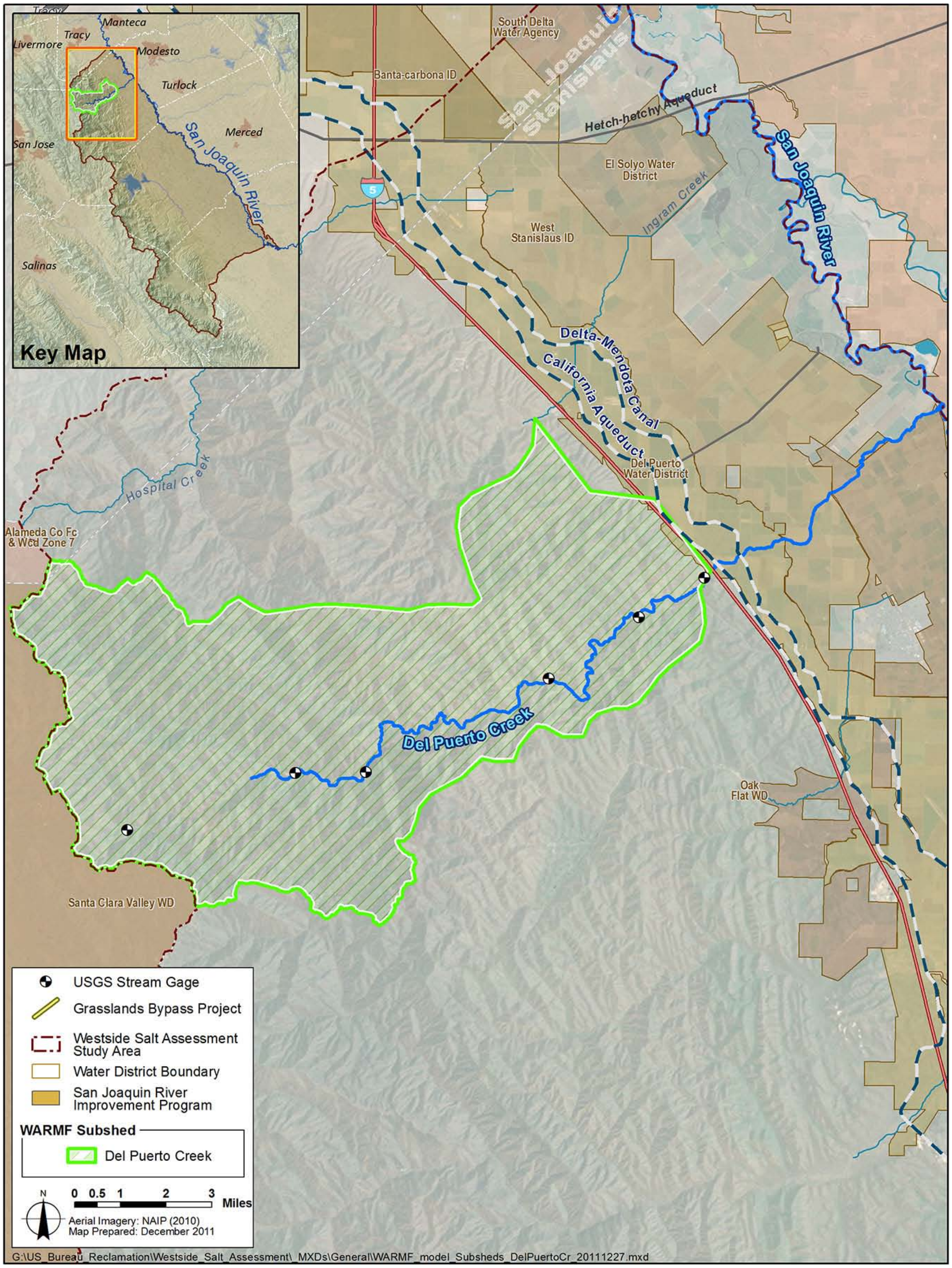

Figure 5-6. Del Puerto Creek Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 5-33. Simulated Salt Budget for Surface Water in Del Puerto Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**August 2007**						**February 2005**		
Total Inputs	**0**	**NA**	**0**	**5**	**NA**	**21,700**	**128**	**NA**	**522,000**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	0	NA	0	5	771	21,700	128	757	522,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	0	NA	NA	0
Total Outputs	**0**	**NA**	**0**	**5**	**NA**	**21,700**	**127**		**520,000**
Uptake / Decay / Settling	0	NA	0	0	NA	0	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	0	NA	0	5	771	21,700	127	756	520,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-34. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in the Del Puerto Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**57**	**NA**	**26,200**
Atmospheric Deposition	57	NA	25,000
Irrigation	0	NA	0
Fertilizer / Land Application	0	NA	300
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	900
Total Outputs	**57**	**NA**	**23,000**
Uptake / Decay	52	NA	1,300
Outflow to Surface	5	771	21,700
Deep Groundwater Recharge	0	NA	0
Change in Storage	**NA**	**NA**	**3,200**
Deeper Groundwater			
Total Inputs	**0**	**NA**	**0**
Recharge from Near-Surface Groundwater	0	NA	0
Total Outputs	**NA**	**NA**	**0**
Irrigation Pumping	NA	NA	0
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**0**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-35. Simulated Nitrate Budget for Surface Water in Del Puerto Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**August 2007**						**February 2005**		
Total Inputs	**0**	**NA**	**0**	**5**	**NA**	**6**	**128**	**NA**	**135**
Inflows from Upstream	0	NA	0	0	NA	0	0	NA	0
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	0	NA	0	5	0.21	6	128	0.20	135
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	0	NA	NA	0
Total Outputs	**0**		**0**	**5**	**NA**	**6**	**127**		**135**
Uptake / Decay / Settling	0	NA	0	0	NA	0	0	NA	0
Diversions	0	NA	0	0	NA	0	0	NA	0
Outflow to Downstream	0	NA	0	5	0.21	6	127	0.20	135

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-36. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in the Del Puerto Creek Subwatershed (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**57**	**NA**	**146**
Atmospheric Deposition	57	NA	124
Irrigation	0	NA	0
Fertilizer / Land Application	0	NA	22
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	0
Total Outputs	**57**	**NA**	**151**
Uptake / Decay	52	NA	145
Outflow to Surface	5	0.21	6
Deep Groundwater Recharge	0	NA	0
Change in Storage	**NA**	**NA**	**-5**
Deeper Groundwater			
Total Inputs	**0**	**NA**	**0**
Recharge from Near-Surface Groundwater	0	NA	0
Total Outputs	**NA**	**NA**	**0**
Irrigation Pumping	NA	NA	0
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**0**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

San Joaquin River from Stevinson to Crows Landing

Salt and nitrate budgets for the San Joaquin River from Stevinson to Crows Landing (Figure 5-7) are presented in Tables 5-37 through 5-40. The major salt and nitrate sources in this reach of the San Joaquin River are inflows from upstream. Although relatively small amounts of salt and nitrate are stored in near-surface groundwater, most of the salt and nitrate loads are output to the San Joaquin River downstream from Crows Landing.

A larger change in salt storage was anticipated for this reach due to observations of salt accumulation in the watershed. The simulated change in storage may not be representative, but would likely be improved with more/better groundwater quality data. Due to the scarcity of data, significant assumptions were made regarding model inputs for groundwater quantity and quality, and are particularly important to the nitrate budget results. The simulated budget for deeper groundwater also showed a large imbalance in nitrate, likely due to assumed nitrate concentrations in groundwater. Despite limited groundwater quality data, groundwater pumping/usage data and simulations compared favorably to previous WestSim estimates of groundwater recharge and usage. Again, simulations would likely be improved with more and better groundwater quality data.

There were no salt inputs associated with atmospheric deposition for the San Joaquin River from Stevinson to Crows Landing. Due to the pH of soils in this reach, dissolved inorganic carbon flux is out of the soil/near-surface groundwater to maintain equilibrium with atmospheric carbon dioxide. This outflux of dissolved inorganic carbon is larger than deposition of other ions, creating losses of dissolved inorganic carbon to the atmosphere, shown as an output for TDS in the salt budget

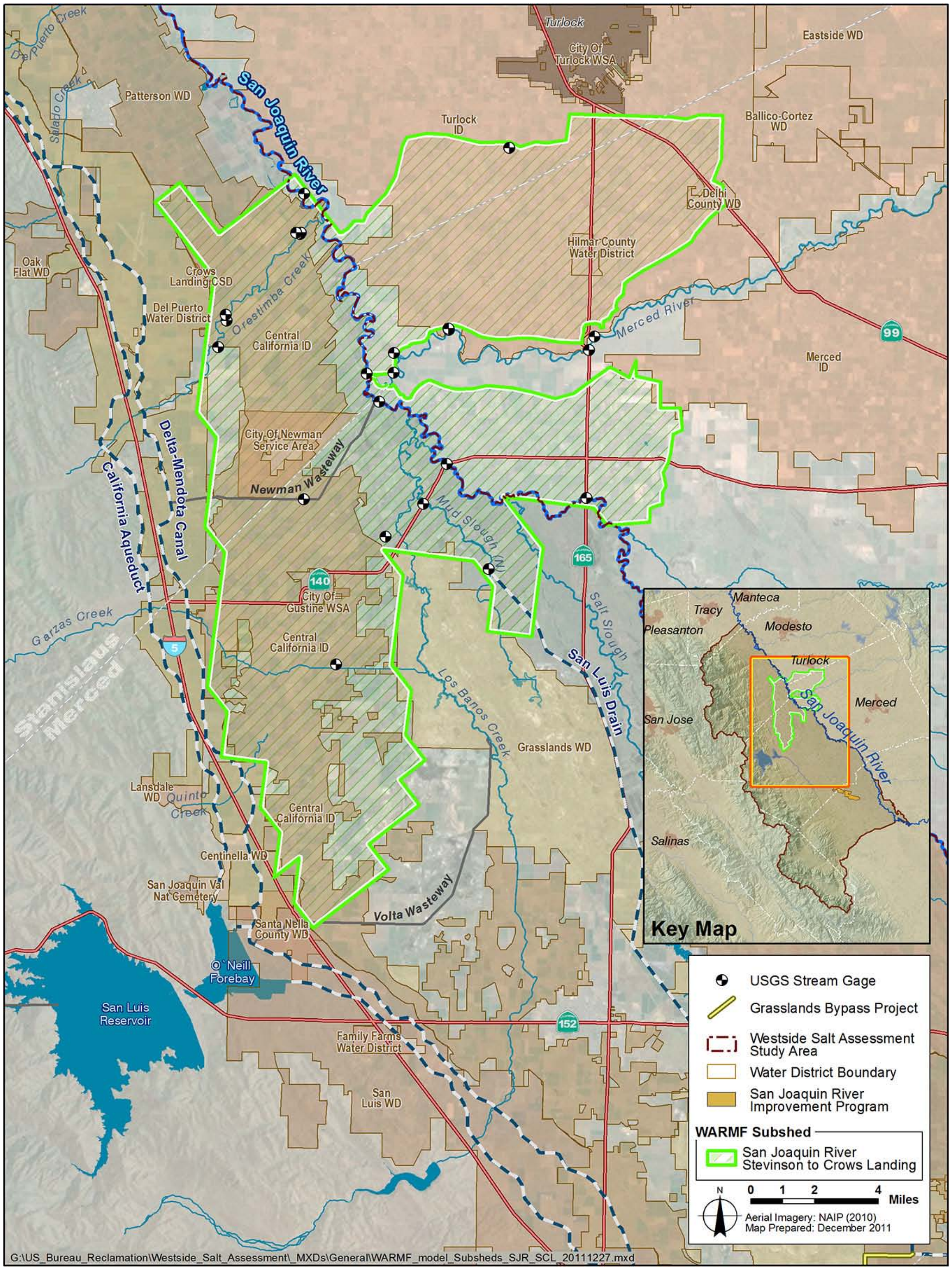

Figure 5-7. San Joaquin River from Stevinson to Crows Landing Area Applied for Salt and Nitrate Budget Analysis

Table 5-37. Simulated Salt Budget for Surface Water in the San Joaquin River from Stevinson to Crows Landing (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2002**						**March 2005**		
Total Inputs	**412**	**NA**	**1,529,000**	**1,796**	**NA**	**3,334,000**	**3,599**	**NA**	**9,737,000**
Inflows from Upstream	317	580	992,000	1,541	280	2,328,000	3,101	461	7,712,000
Imported Water	52	339	95,000	112	251	151,000	43	362	84,000
Inflows from Near-Surface Groundwater	43	1,890	442,000	143	1,085	840,000	455	694	1,703,000
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	15,000	NA	NA	238,000
Total Outputs	**412**	**NA**	**1,529,000**	**1,794**	**NA**	**3,408,000**	**3,599**		**9,737,000**
Uptake/Decay/ Settling	0	NA	21,000	0	NA	25,000	31	NA	0
Diversions	66	743	264,000	61	525	172,000	42	384	87,000
Outflow to Downstream	347	665	1,244,000	1,734	343	3,211,000	3,526	507	9,650,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-38. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Stevinson to Crows Landing (Irrigation Scenario1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**714**	**NA**	**1,485,000**
Atmospheric Deposition [1]	NA	NA	NA
Irrigation	541	356	1,040,000
Fertilizer / Land Application	0	NA	393,000
Point Sources	0	NA	1,000
Septic Systems	0	NA	0
Reaction Products	0	NA	51,000
Total Outputs	**711**	**NA**	**1,453,000**
Uptake / Decay	543	NA	132,000
Volatilization / Gaseous Losses	173	NA	99,000
Outflow to Surface	138	1,128	840,000
Deep Groundwater Recharge	30	2,329	382,000
Change in Storage	**NA**	**NA**	**32,000**
Deeper Groundwater			
Total Inputs	**30**	**NA**	**382,000**
Recharge from Near-Surface Groundwater	30	2,329	382,000
Total Outputs	**NA**	**NA**	**551,000**
Irrigation Pumping	NA	NA	551,000
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-169,000**

Notes:
[1] No net atmospheric deposition due to volatilization of inorganic carbon in soils.
Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-39. Simulated Nitrate Budget for Surface Water in the San Joaquin River from Stevinson to Crows Landing (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2002**						**February 2005**		
Total Inputs	**412**	**NA**	**3,310**	**1,796**	**NA**	**16,200**	**2,863**	**NA**	**53,340**
Inflows from Upstream	317	1.43	2,440	1,541	1.37	11,400	2,273	2.73	33,430
Imported Water	52	0.57	160	112	0.83	500	24	1.07	140
Inflows from Near-Surface Groundwater	43	3.04	710	143	5.17	4,000	565	6.43	19,600
Point Sources	0	NA	0	0	NA	0	0	NA	0
Reaction Products / Scour	NA	NA	0	NA	NA	300	NA	NA	170
Total Outputs	**412**		**3,310**	**1,796**	**NA**	**16,200**	**2,863**		**53,340**
Uptake / Decay / Settling	0	NA	290	2	NA	100	11	NA	0
Diversions	66	1.13	400	61	1.53	500	11	2.30	140
Outflow to Downstream	347	1.40	2,620	1,734	1.67	15,600	2,841	3.47	53,200

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

Table 5-40. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Stevinson to Crows Landing (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**714**	**NA**	**33,890**
Atmospheric Deposition	173	NA	330
Irrigation	541	4.08	11,900
Fertilizer / Land Application	0	NA	16,700
Point Sources	0	NA	0
Septic Systems	0	NA	0
Reaction Products	0	NA	4,960
Total Outputs	**711**	**NA**	**32,780**
Uptake / Decay	543	NA	28,100
Outflow to Surface	138	5.37	4,000
Deep Groundwater Recharge	30	4.15	680
Change in Storage	**NA**	**NA**	**1,110**
Deeper Groundwater			
Total Inputs	**30**	**NA**	**570**
Recharge from Near-Surface Groundwater	30	4.15	680
Total Outputs	**NA**	**NA**	**7,980**
Irrigation Pumping	NA	NA	7,980
Municipal and Industrial Pumping	NA	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-7,410**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

San Joaquin River from Crows Landing to Vernalis

Salt and nitrate budgets for the San Joaquin River from Crows Landing to Vernalis (Figure 5-8) are presented in Tables 5-41 through 5-45. The majority of salt and nitrate inputs into this reach of the San Joaquin River come from upstream flows, but a significant quantity also enters the river via near-surface groundwater in this reach. Groundwater recharge and a limited outflow to surface water created a net storage of salts in the deeper groundwater. This change in salt storage in deeper groundwater may be higher than anticipated because relative recharge on each side of the San Joaquin River is difficult to characterize. Uncertainty in these results is introduced in linking groundwater on both sides of the San Joaquin River because determining the relative amount of recharge on either side of the river is challenging. Salt and nitrate sources on the east and west sides of the river cannot be distinguished, so sources are assigned based on very limited groundwater quality data.

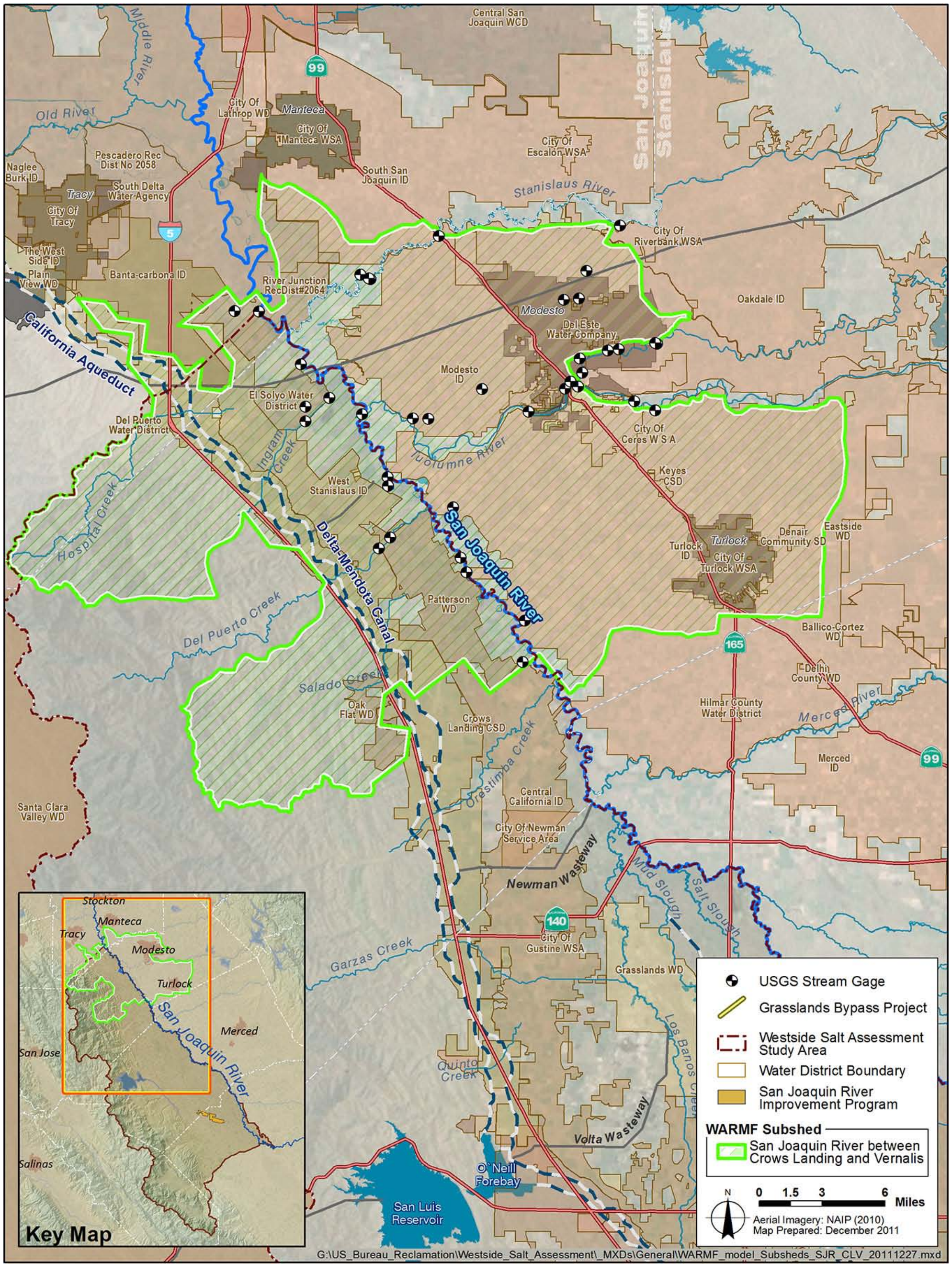

Figure 5-8. San Joaquin River from Crows Landing to Vernalis Area Applied for Salt and Nitrate Budget Analysis

Table 5-41. Simulated Salt Budget for Surface Water in the San Joaquin River from Crows Landing to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load TDS			Mean Load TDS			Maximum Load TDS		
	Flow at Min Load TDS (cfs)	[TDS] at Min Load TDS (mg/L)	Min Load TDS (lbs/d)	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)	Flow at Max Load TDS (cfs)	[TDS] at Max Load TDS (mg/L)	Max Load TDS (lbs/d)
Surface Water	**September 2002**						**February 2005**		
Total Inputs	**1,233**	**NA**	**2,572,000**	**4,001**	**NA**	**5,699,000**	**7,245**	**NA**	**15,896,000**
Inflows from Upstream	982	298	1,578,000	3,678	202	4,003,000	5,997	355	11,489,000
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	251	735	994,000	306	995	1,643,000	1,186	666	4,261,000
Point Sources	0	NA	0	17	312	28,000	63	305	103,000
Reaction Products / Scour	NA	NA	0	NA	NA	25,000	NA	NA	43,000
Total Outputs	**1,233**	**NA**	**2,572,000**	**4,001**	**NA**	**5,760,000**	**7,245**		**15,896,000**
Uptake / Decay / Settling	5	NA	48,000	92	NA	82,000	59	NA	0
Diversions	267	542	782,000	212	364	417,000	17	NA	30,000
Outflow to Downstream	960	336	1,742,000	3,697	264	5,261,000	7,169	410	15,866,000

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS
WARMF = Watershed Analysis Risk Management Framework

Table 5-42. Simulated Salt Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Crows Landing to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load TDS		
	Flow at Mean Load TDS (cfs)	[TDS] at Mean Load TDS (mg/L)	Mean Load TDS (lbs/d)
Near-Surface Groundwater			
Total Inputs	**1,688**	**NA**	**2,333,400**
Atmospheric Deposition	604	NA	29,000
Irrigation	1,061	273	1,560,000
Fertilizer / Land Application	0	NA	604,000
Point Sources	23	411	51,000
Septic Systems	0	NA	2,000
Reaction Products	0	NA	87,400
Total Outputs	**1,689**	**NA**	**2,638,000**
Uptake / Decay	1,316	NA	239,000
Outflow to Surface	306	995	1,643,000
Deep Groundwater Recharge	67	2,077	756,000
Change in Storage	**NA**	**NA**	**-304,600**
Deeper Groundwater			
Total Inputs	**67**	**NA**	**756,000**
Recharge from Near-Surface Groundwater	67	2,077	756,000
Total Outputs	**NA**	**NA**	**435,000**
Irrigation Pumping	NA	NA	435,000
Municipal and Industrial Pumping	0	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**321,000**

Key:
cfs = cubic feet per second
lbs/d = pounds per day
mg/L = milligrams per liter
NA = Not applicable / Not available
TDS = total dissolved solids
[TDS] = concentration of TDS

Table 5-43. Simulated Nitrate Budget for Surface Water in the San Joaquin River from Crows Landing to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Minimum Load Nitrate			Mean Load Nitrate			Maximum Load Nitrate		
	Flow at Min Load Nitrate (cfs)	[NO3] at Min Load Nitrate (mg/L)	Min Load Nitrate (lbs/d N)	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)	Flow at Max Load Nitrate (cfs)	[NO3] at Max Load Nitrate (mg/L)	Max Load Nitrate (lbs/d N)
Surface Water	**September 2002**						**February 2005**		
Total Inputs	**1,233**	**NA**	**10,520**	**4,001**	**NA**	**35,800**	**7,245**	**NA**	**114,700**
Inflows from Upstream	982	1.15	6,120	3,678	1.10	21,900	5,997	2.17	70,100
Imported Water	0	NA	0	0	NA	0	0	NA	0
Inflows from Near-Surface Groundwater	251	3.25	4,400	306	7.63	12,600	1,186	6.55	41,900
Point Sources	0	NA	0	17	6	500	63	5	1,600
Reaction Products / Scour	NA	NA	0	NA	NA	800	NA	NA	1,100
Total Outputs	**1,233**		**10,520**	**4,001**	**NA**	**35,700**	**7,245**		**114,700**
Uptake / Decay / Settling	5	NA	1,020	92	NA	400	59	NA	0
Diversions	267	1.55	2,240	212	1.83	2,100	17	2.17	200
Outflow to Downstream	960	1.40	7,260	3,697	1.66	33,200	7,169	2.96	114,500

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate
WARMF = Watershed Analysis Risk Management Framework

Table 5-44. Simulated Nitrate Budget for Near-Surface Groundwater and Deeper Groundwater in the San Joaquin River from Crows Landing to Vernalis (Irrigation Scenario 1), Water Years 2000 Through 2007

Process	Mean Load Nitrate		
	Flow at Mean Load Nitrate (cfs)	[NO3] at Mean Load Nitrate (mg/L)	Mean Load Nitrate (lbs/d N)
Near-Surface Groundwater			
Total Inputs	**1,688**	**NA**	**67,900**
Atmospheric Deposition	604	NA	900
Irrigation	1,061	3.72	21,300
Fertilizer / Land Application	0	NA	38,100
Point Sources	23	7.25	900
Septic Systems	0	NA	0
Reaction Products	0	NA	6,700
Total Outputs	**1,689**	**NA**	**66,300**
Uptake / Decay	1,316	NA	51,500
Outflow to Surface	306	7.63	12,600
Deep Groundwater Recharge	67	6.05	2,200
Change in Storage	**NA**	**NA**	**1,600**
Deeper Groundwater			
Total Inputs	**67**	**NA**	**2,160**
Recharge from Near-Surface Groundwater	67	5.94	2,160
Total Outputs	**NA**	**NA**	**12,100**
Irrigation Pumping	NA	NA	12,100
Municipal and Industrial Pumping	0	NA	0
Other Pumping	NA	NA	0
Change in Storage	**NA**	**NA**	**-9,940**

Key:
cfs = cubic feet per second
lbs/d N = pounds per day nitrate
mg/L = milligrams per liter
NA = Not applicable / Not available
[NO3] = concentration of nitrate

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Chapter 6
Recommendations for Further Analysis

As described above, this TM demonstrates the methodology used to develop the salt and nitrate budgets reported in the SNSPIS report, and presents results from the salt and nitrate budget analysis completed for the Westside Salt Assessment for Water Years 2000 to 2007. The specific areas evaluated for the Westside Salt Assessment include general sources and sinks of salt and nitrate, the magnitude and importance of these sources and sinks, data availability, data quality and completeness, and relevance and completeness of salt and nitrogen transformation processes used in the modeling approach. Additionally, analyses conducted as part of the Westside Salt Assessment identified limitations and constraints to salt and nitrate budget development related to data, the period of record, and model capabilities. The results may not accurately simulate the actual salt loadings, and therefore should be used only for conceptual planning purposes, and to provide the lessons learned for future studies within the basin.

A thorough review of available data and technical tools led to development of recommendations for further analysis to inform development of salt and nitrate management strategies for the San Joaquin River basin. These recommendations include:

- Updates to the simulation period for analysis to capture highly variable hydrological conditions and water management actions recently implemented and that affect existing conditions, including implementation of the San Joaquin River Restoration Program, Grasslands Bypass Project Phase III, and expansion of the San Joaquin River Improvement Project, and regulatory restrictions to CVP and State Water Project operations in the Delta.

- Comparative analysis of water delivery data and verification with Reclamation's CVP and WAP, water districts, and refuges for refinement of water budget analyses to improve representation of Westside region water operations.

    – CVO and WAP water delivery data were compared for watersheds within the study area, and no pattern or consistency could be determined between the data sets. Because CVO data is available for all the study area watersheds, CVO rather than WAP data is used for the water budgets for the entire Westside Salt Assessment.

  - Input should be solicited from Study Area stakeholders on improving WARMF-SJR inputs and assumptions beyond data that is currently publicly available, including:
    - Water delivery data
    - Water management strategies (groundwater management, deficit irrigation practices, unaccounted water transfer/exchanges)
    - Groundwater quality data

- Improved Graphical User Interface and visualization tools for combining data from all models scenario analysis and communication of results to stakeholders.
- Refinements to analytical tools to better capture operations of seasonally managed wetlands.
- Update WestSim model to IWFM to version 4.x to include IWFM – Demand Calculator for simulating DWR land-use based evapotranspiration.
- Integrated allocations of recharge to groundwater below root zone within WestSim and WARMF models.
- Peer review of analytical tools and Beta testing of analytical tools.

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