RECLAMATION
Managing Water in the West

Technical Memorandum

Water Budget

Westside Salt Assessment, California
Mid-Pacific Region

FINAL

U.S. Department of the Interior
Bureau of Reclamation

December 2012

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

Banks Pumping Plant	Harvey O. Banks Pumping Plant
Basin Plan	Water Quality Control Plan for the Sacramento and San Joaquin River Basins
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
C2VSim	California Central Valley Simulation (Model)
CIMIS	California Irrigation Management Information System
CVHM	Central Valley Hydrologic Model
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
DAU	Detailed Analysis Unit
Delta	Sacramento-San Joaquin Delta
DEM	digital elevation model
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
DST	data storage system
DWR	California Department of Water Resources
EC	electrical conductivity

EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
ETo	reference crop evapotranspiration
GIS	geographic information system
IWFM	Integrated Water Flow Model
IWRP	Integrated Water Resources Plan
Jones Pumping Plant	C.W. Bill Jones Pumping Plant
MAA	Management Agency Agreement
M&I	municipal and industrial
MP	milepost
NCDC	National Climate Data Center
NEPA	National Environmental Policy Act
NLCD	National Land Cover Data
NO_3	nitrate
NPDES	National Pollutant Discharge Elimination System
NWA	National Wildlife Area
Program	Program to Meet Standards
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RTMP	Real Time Management Program
SJR	San Joaquin River
SJRIO	San Joaquin River Input Output (model)
SJRRP	San Joaquin River Restoration Program
SLC	San Luis Canal
SLDMWA	San Luis and Delta-Mendota Water Authority
SNSPIS	Salt and Nitrate Sources Pilot Implementation Study
State	State of California
Study Area	Westside Salt Assessment Study Area
SW	surface water
SWP	State water project
SWAMP	Surface Water Ambient Monitoring Program
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
TM	technical memorandum
TMDL	total maximum daily load
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
WAP	Water Acquisition Program
WARMF	Watershed Analysis Risk Management Framework
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
cfs	cubic foot per second

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 Salt and Nitrate Budget (Reclamation 2012a) and this TM for the Water Budget complement each other and should be reviewed together.

This technical memorandum evaluates the methodology used to develop the water budget for the Westside Salt Assessment for Water Years 2000 to 2007. The purpose 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" to better evaluate existing and alternative operations of private and public water facilities.

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).

Limitations of Analysis

This Technical Memorandum presents the framework for the water budget modeling, Reclamation's study approach, and the limitations of the modeling effort. The results should be used only for conceptual planning purposes, and to provide the lessons learned for future studies within the basin.

The water 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.

- 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 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. The subareas on the west side of the San Joaquin River are as follows (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 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 Subarea, located in southwest 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 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 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 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 to the 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 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.

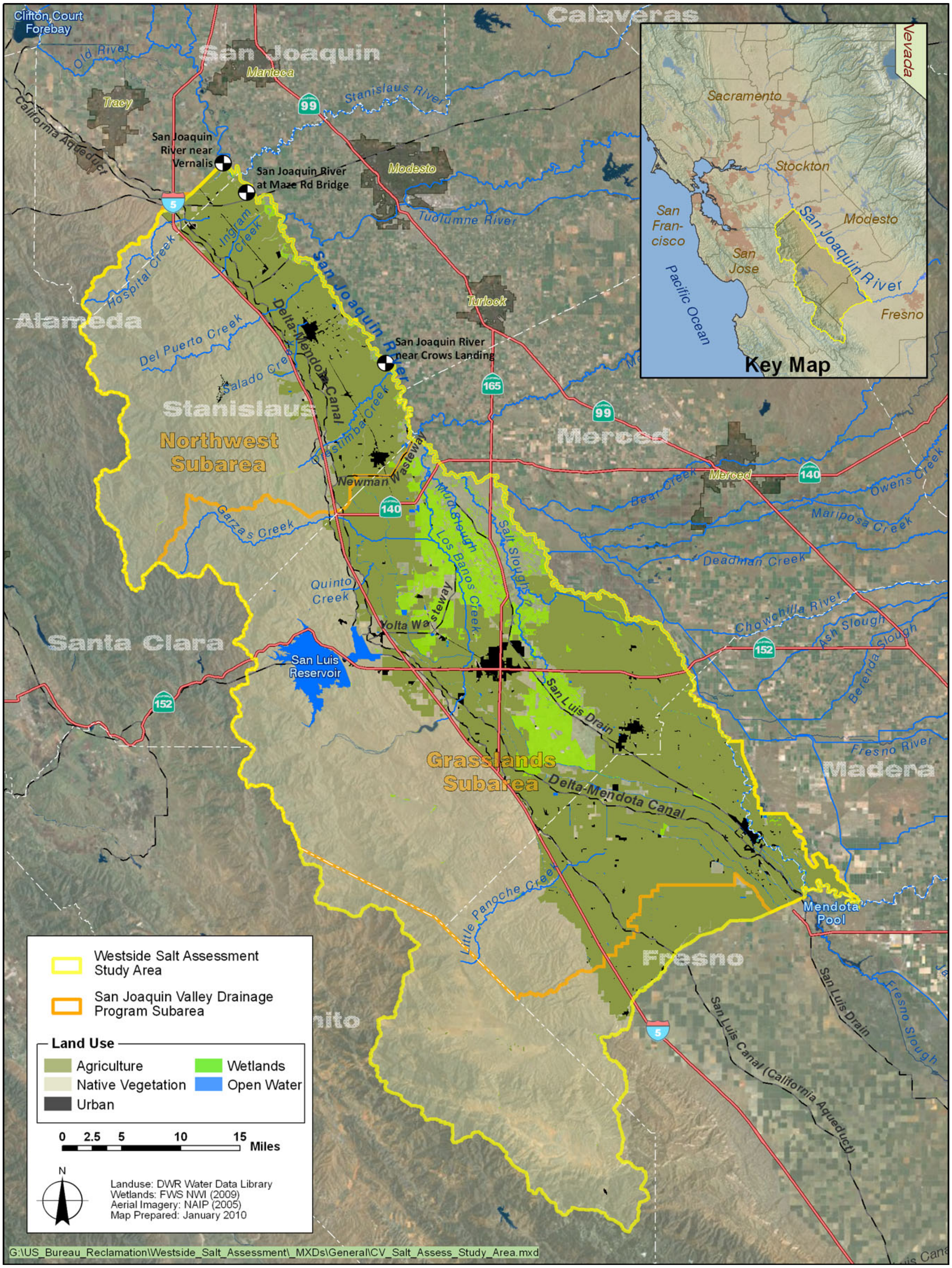

Figure 1-1. Westside Salt Assessment Study Area

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

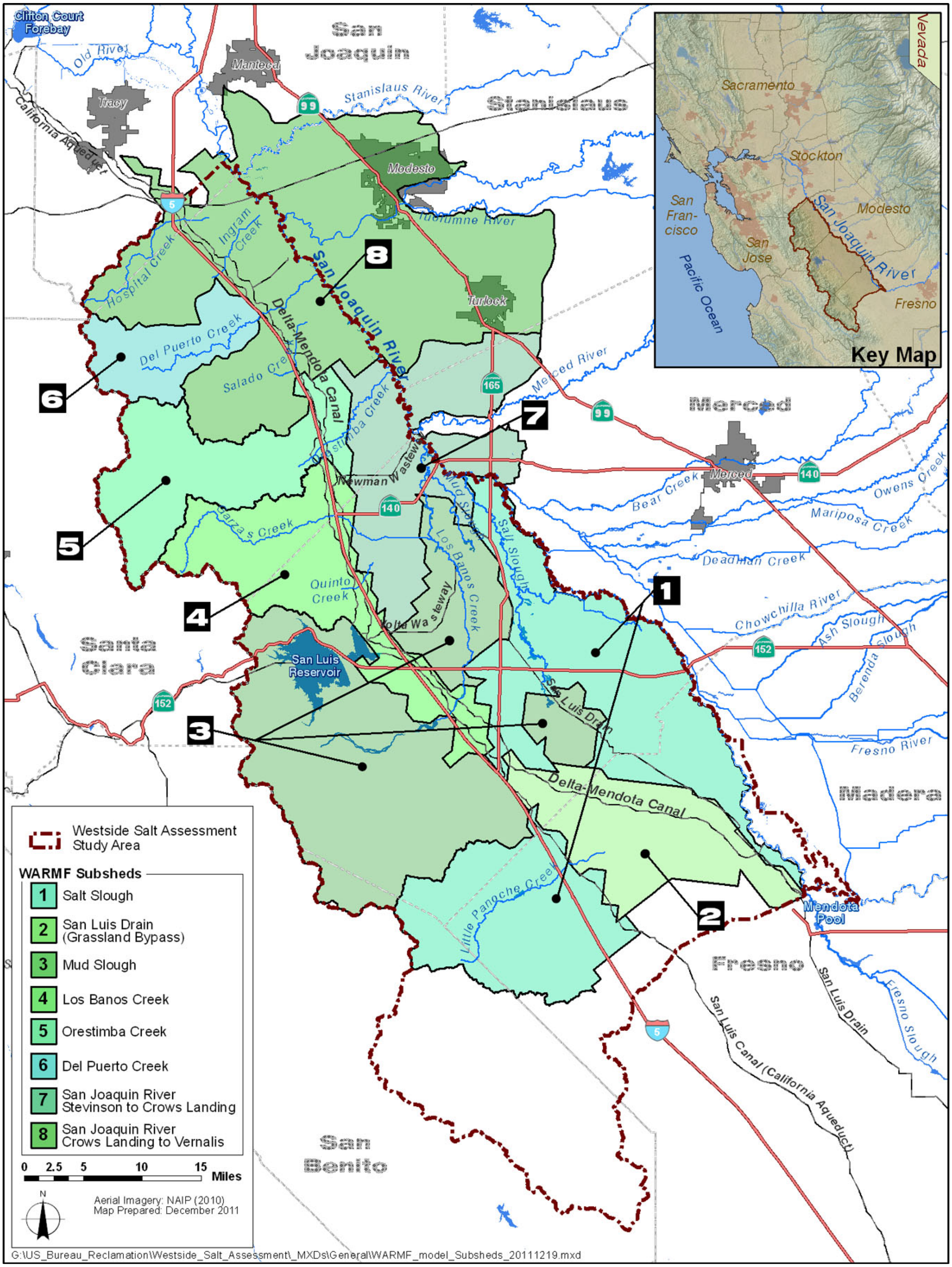

Figure 1-2. Westside Salt Assessment Study Area Subwatersheds

Previous Studies

The following sections briefly describe previous studies of the water resources of the study, area and relevant regions along west side of the San Joaquin Valley, and analytical tools that have been applied to this region to develop a water budget. 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. In contrast, numerous studies have addressed the Grassland Subarea after the discovery in the 1980s of environmental problems related to selenium in agricultural drainage water. Studies conducted in this area include those of Burt and Katen (Burt, 1988), Ayars and Schrale (Ayers, 1989), Gronberg and Belitz (1992), Belitz et al. (1993), Fio and Leighton (Fio, 1994), and the Irrigation Training and Research Center (Burt, 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 in 1996.

Groundwater Studies

Several studies have addressed groundwater conditions for the west side of the San Joaquin Valley. These studies have applied local and regional groundwater models to assess subsurface impacts and the influence of subsurface drainage to surface water drainage along the west side.

California Department of Water Resources Study of the Central Valley

The California Department of Water Resources (DWR) developed and maintains the Integrated Water Flow Model (IWFM), an integrated hydrologic model that couples a finite element groundwater model with a one-dimensional stream model, and includes a land surface root zone component to estimate stormwater runoff. The IWFM also includes agricultural irrigation and municipal water demands, groundwater pumping, and groundwater recharge (DWR, 2010). The current version of the model is Version 3.02, which was released in September 2010.

DWR has applied the IWFM code to create a water resources model of the Central Valley that simulates evolution of the groundwater system over the historical period of October 1921 to September 2003 using a monthly time-step. This application is known as the California Central Valley Simulation Model (C2VSim). C2VSim represents the groundwater system by three layers, each with 1,393 elements. Land surface processes are simulated using 21 subregions corresponding to DWR's water supply planning areas (DWR, 2010). An initial calibration of the model has been completed.

Westside Simulation Model

As a result of water redistribution under the CVPIA, numerous conjunctive use, land retirement, and water transfer proposals were generated by local, state, and federal agencies, each of which had potential to impact the basin groundwater resources and Reclamation's future operations. Agriculture on the west side of the San Joaquin Basin was also threatened by salinization, groundwater overdraft, and land subsidence; so understanding water movement, flow, and quality was paramount to the physical and economic survival of the area. Westside Simulation Model (WestSim) was the first application using the new IWFM model code, developed by DWR. The WestSim model was collaboratively developed by Reclamation and Lawrence Berkley National Laboratory for a number of applications that could not be addressed by existing regional groundwater models. These applications included (1) impact of reductions in contract water deliveries on aquifer subsidence, (2) increased competition for water – impacts to streamflow in the San Joaquin river, (3) climate change impacts on water supply reliability, and (4) technical assistance to water districts and refuges facing salt, boron, and dissolved oxygen (DO) total maximum daily loads (TMDL).

U.S. Geological Survey Study of Central Valley Aquifer System

The Groundwater Resources Program of the USGS has assessed in detail the Central Valley aquifer system. The principal product of the assessment is the Central Valley Hydrologic Model (CVHM), which simulates surface water and groundwater flows across the floor of the Central Valley for water years 1962 to 2003 using a monthly time-step.

Groundwater is simulated using the USGS numerical modeling code MODFLOW-2000, a square-mile grid cell, and 10 vertical layers. The Farm Process for MODFLOW is used to simulate surface water deliveries, flow, and groundwater pumping for 21 "water balance regions" (these correspond to the C2VSim regions). The Farm Process module dynamically determines groundwater recharge and groundwater pumping based on crop water demands, surface water deliveries, and depth to the water table.

CVHM represents the west side study area by a single water budget area, Region 10 ("Delta-Mendota Basin," which is equivalent to DWR Depletion Study Area 49A). The coarse spatial resolution of CVHM for representing the surface water system limits use of the model for the Westside Salt Assessment.

Surface Water Studies

Numerous surface water 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.

San Joaquin River Input Output Model

In 1987, the State Water Resources Control Board (SWRCB) and University of California, Davis (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, west side surface/subsurface agricultural discharges, and riparian and pre-1914 and post-1914 appropriative diversions. SJRIO was last updated in 2003 (SJRIO Version 3), and is capable of simulating the historical period of October 1977 through September 2000.

Grasslands Area

As part of a larger study, USGS, in cooperation with Reclamation, completed a study to estimate groundwater recharge and groundwater pumping in the “Grasslands Area,” an area that comprises both the Grassland Drainage Area and a portion of Westlands Water District, situated north of Cantua Creek (Brush et al., 2004). Crop water demands were estimated for each water year from 1972 through 2000 based on crop acreages, daily reference crop evapotranspiration (ETo), and daily crop coefficients. Recharge and irrigation pumping were subsequently estimated for 11water budget areas (i.e., unique catchment areas within the Grasslands/Westlands study area) using root-zone soil moisture accounting. Groundwater pumping for irrigation was assumed to be the difference between crop water demand and effective precipitation and surface water deliveries. Irrigation and infiltrated precipitation that exceeded crop water demand was assumed to recharge the underlying aquifer.

Central Valley Project Contract Renewal

Following completion of the Programmatic Environmental Impact Statement for the CVPIA, Reclamation prepared environmental documents for renewal of water service contracts with districts within the DMC Unit and San Luis Canal Unit of the CVP in 2005. Water needs assessments were completed for contractors who owned more than 2,000 acres of irrigable land, and whose contract total was greater than 2,000 acre-feet. Crop acreages, cropping patterns, crop water needs, effective precipitation, and conveyance loss information provided by each contractor were reviewed for agricultural water use. Residential, commercial, industrial, institutional, recreational, and environmental uses, along with landscape coefficients, system losses, and landscape acreage information provided by each contractor, were reviewed for municipal and industrial (M&I) water use.

Drainage Studies

Several studies have focused solely on drainage in the San Joaquin Valley in response to significant impacts to soil, groundwater, and surface water quality from naturally occurring selenium and small upstream watersheds and salinity from water diverted from the DMC and Mendota Pool.

San Joaquin Valley Drainage Program

The San Joaquin Valley Drainage Program was created by Reclamation and the State of California (State) in response to selenium-related issues at Kesterson Reservoir. The final report, published in 1990, recommended an in-valley drainage solution that included source reduction, drainage reuse, land retirement, evaporation basins, groundwater management, and San Joaquin River discharge.

San Joaquin Valley Drainage Authority

The San Joaquin Valley Drainage Authority, which includes districts in the Grassland Subarea, was formed to develop a long-term solution for drainage problems in the San Joaquin River basin, including out-of-valley disposal (e.g., piping water directly to the Pacific Ocean).

San Joaquin Drainage Monitoring Program

In partnership with other agencies and organizations, the San Joaquin District of DWR has monitored agricultural drainage water in the San Joaquin Valley since 1959. DWR currently collects samples and measures flows at 43 subsurface drainage sumps; 23 of these stations lie within the Westside Salt Assessment study area.

University of California, Davis, Monitoring Program

In 2002, the Central Valley Water Board executed an interagency agreement with 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 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 Endangered Species Act, 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 the elimination of subsurface agricultural drainage as part of the *Westside Regional Drainage Plan* (San Joaquin River Exchange Contractors Water Authority et al., 2003). Key elements of the drainage plan include land retirement, groundwater management, source control, reuse, treatment, and salt disposal (SLDMWA, 2006).

Report Organization

This TM includes the following topics:

- Background, study area, and description of previous studies (Chapter 1).
- Summary of study area characteristics (Chapter 2).
- Approach to establishing a set of volumetric water budgets for the study area (Chapter 3).
- Summary of the modeling tools that were used to develop the water budgets (Chapter 4).
- Summary of model inputs, data requirements, and data sources used for model update and refinement (Chapter 5).
- Overview of model workflow and data sharing for Westside Region water budget analyses and discussion of hydrologic calibration of models (Chapter 6).
- Overview of the results from the water budget analysis (Chapter 7).
- Recommendations for further analysis to improve the results and applicability of the Westside Salt Assessment (Chapter 8).
- A list of sources used in preparing this TM (Chapter 9).

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Chapter 2
Study Area Characteristics

This chapter discusses study area characteristics relating to water supply and water use. Quantifying and tracking of both applied irrigation water and precipitation are important elements in assessing water sources and their fate through surface and hydrogeologic features in each catchment area within the study area.

Climate

The San Joaquin Valley has an arid to semiarid climate characterized by hot summers and mild winters. The study area lies in the rain shadow of the Coast Range and is relatively dry compared to the eastern side of the San Joaquin Valley. Precipitation decreases from north to south and from east to west. Average annual precipitation within cultivated lands of the study area varies from 8.5 to 12.0 inches per year.[1] Potential ETo increases from north to south; average annual ETo is approximately 55 inches per year.

Geology and Soils

Soils within the study area are derived from erosion of the marine rocks that form the Coast Range. These soils contain salt and other trace elements, such as arsenic, boron, selenium, and molybdenum. Salts within the root zone are leached into the shallow groundwater by irrigation and precipitation.

Hydrology and Water Supply

The study area is a highly managed hydrologic system partially because of the diversion and storage of perennial flows from the San Joaquin River basin at Friant Dam. Water supplies for agricultural purposes are imported into the basin from the Delta through the Delta-Mendota and San Luis canals, and are supplemented by San Joaquin River diversions downstream from Lander Avenue, and by groundwater pumping. Figure 2-1 shows a schematic of CVP South-of-Delta water conveyance.

[1] Based on an analysis of Parameter-elevation Regressions on Independent Slopes Model (PRISM) data for 1970 through 2000.

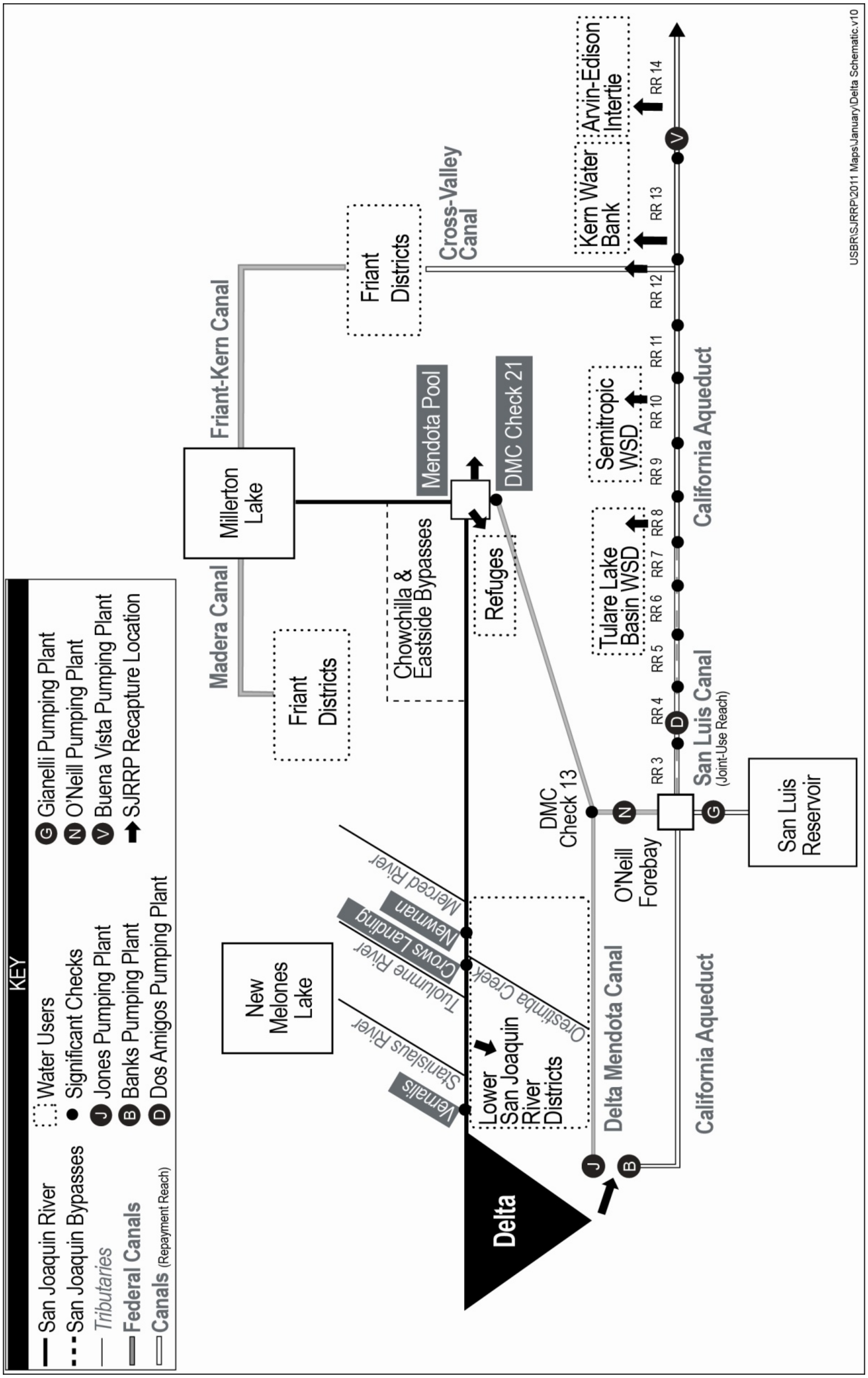


Figure 2-1. Schematic of Central Valley Project South-of-Delta Water Conveyance

California Aqueduct

The California Aqueduct approximately parallels the western boundary of the valley floor, conveying water from the Clifton Court Forebay in the Delta to Central and Southern California. The section of the California Aqueduct between Check 13 (Milepost (MP) 70.85) and Check 21 (MP 172.40) is a joint facility, shared by Reclamation and DWR, and is known as the San Luis Canal. CVP water from the “Joint Reach” is delivered to CVP contractors located in the San Joaquin River and Tulare Lake hydrologic regions. Other shared Federal-State facilities within the study area include the Gianelli Pumping-Generating Plant and San Luis Reservoir. Oak Flat Water District is the only State Water Project (SWP) contractor located within the study area. The district is located north of the O’Neill Forebay and receives deliveries directly from the California Aqueduct.

Delta-Mendota Canal

The DMC is located downslope from the California Aqueduct and is operated by Reclamation and SLDMWA. The canal stretches 117 miles from the C.W. “Bill” Jones Pumping Plant (Jones Pumping Plant) in the south Delta to the Mendota Pool on the San Joaquin River near the town of Mendota, 30 miles west of Fresno. The canal initially runs south along the western edge of the San Joaquin Valley, parallel to the California Aqueduct, but diverges from the aqueduct after passing San Luis Reservoir. Water may be pumped from the canal through the O'Neill Pumping-Generating Plant into the O'Neill Forebay, and then into San Luis Reservoir by the Gianelli Pumping-Generating Plant. Water from San Luis Reservoir may be released back into the canal, or diverted through the Pacheco Tunnel to the CVP San Felipe Division. The first 95 miles of the DMC have a concrete lining and the remaining distance is unlined to Mendota Pool.

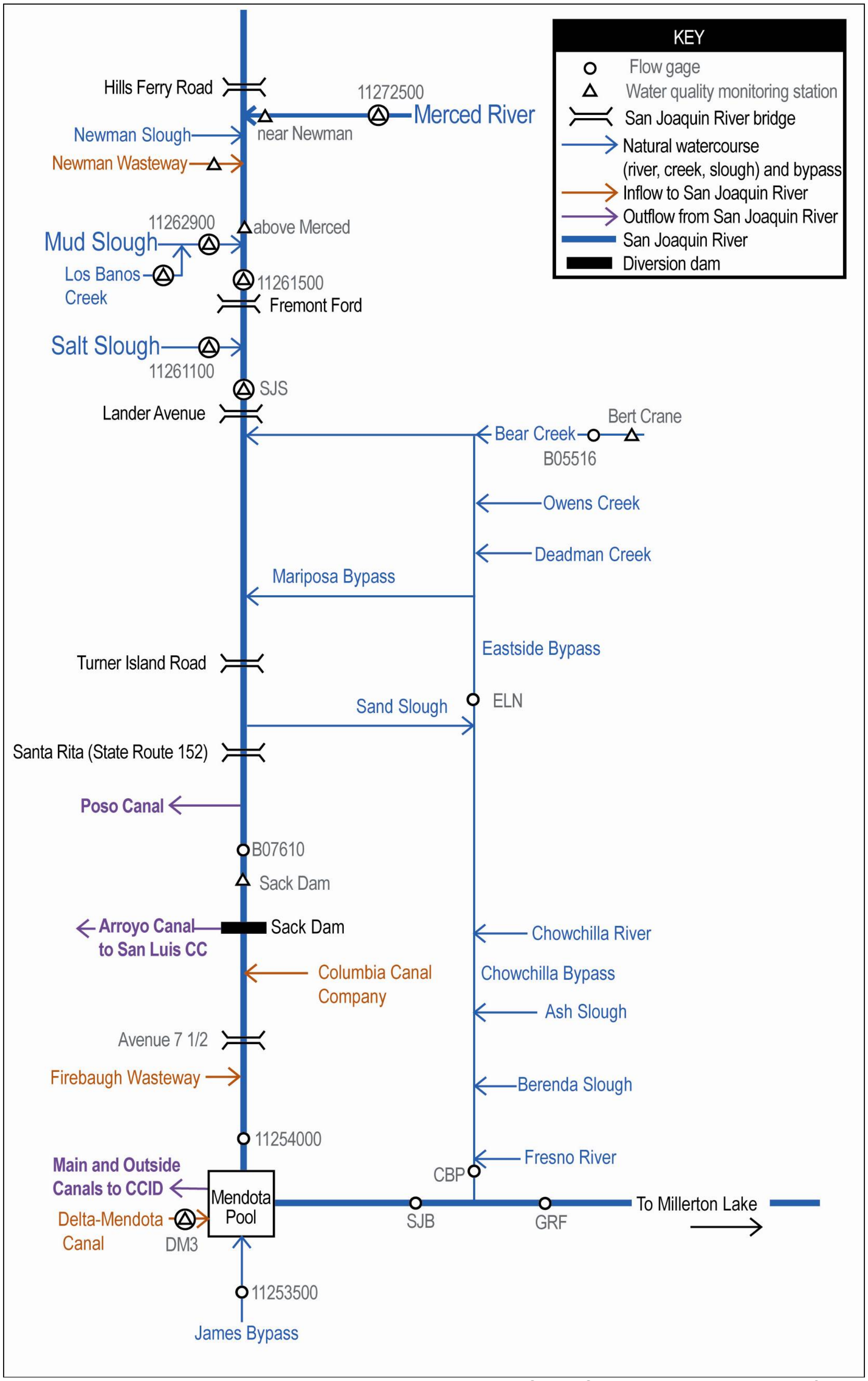
Stormwater runoff from upstream watersheds flows into both the California Aqueduct and DMC. There is seepage from these canals into the underlying groundwater and, during wet hydrologic periods, groundwater accretions to the lower reaches of the DMC. Seasonal groundwater extractions also occur by private well owners that are discharged directly into the DMC. Water from both the California Aqueduct and the DMC is temporarily stored in San Luis Reservoir during the fall and winter months and released in the spring and summer to supplement direct deliveries from the Delta. As a result, salinity can vary significantly along the length of both canal systems.

Lower San Joaquin River

The Vernalis gage on the San Joaquin River is regarded as the farthest downstream boundary that separates the San Joaquin Valley from the Delta; it is the most downstream flow measurement station on the river not subject to tidal influence. At the Vernalis gage, the San Joaquin River drains approximately 13,500 square miles of watershed area bounded by the Sierra Nevada mountains to the east, the Coastal Range to the west, and the Tulare Lake Basin to the south.

Downstream from Friant Dam, the San Joaquin River can be subdivided into six reaches: Friant Dam to Gravelly Ford; Gravelly Ford to Mendota Pool; Mendota Pool to Sack Dam; Sack Dam to Bear Creek; Bear Creek to the Merced River; and the Merced River to the Vernalis gage.

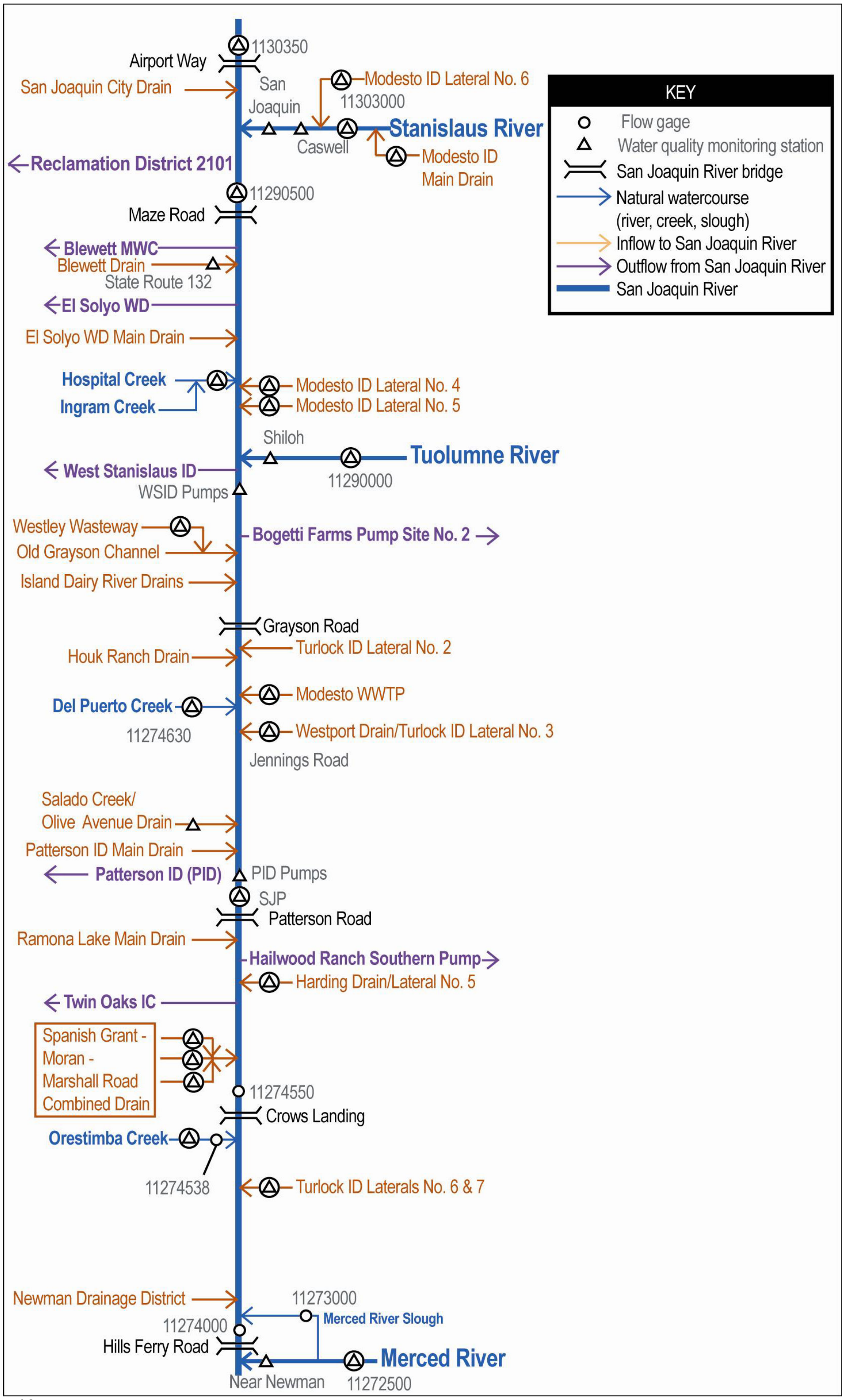
Continuous flow measurement along the San Joaquin River from the Chowchilla Bypass to the river gage at the Airport Way Bridge near Vernalis provides the best data for calibration and validation of the proposed water budget at a regional scale for the study area. The control volume for the San Joaquin River includes westside tributaries and the lower reaches of the eastside tributaries below the most downstream gage locations. Figures 2-2 and 2-3 illustrate components of the water budget along the San Joaquin River. Table 2-1 lists flow gages along the San Joaquin River, and gages on tributaries that define boundary conditions for the water budget. (Note that ungaged inflows from the eastside of the San Joaquin Valley are taken directly from the San Joaquin River (SJR) application of WARMF. No additional analysis or refinement of these flow components was conducted. The WARMF model is described in Chapter 4.)



Key:

CBP = Chowchilla Bypass at Head below Control Structure
ELN = Eastside Bypass near El Nido
GRF = San Joaquin River at Gravelly Ford
SJB = San Joaquin River below Bifurcation Structure
SJS = San Joaquin River near Stevinson
CCID = Central California Irrigation District
CC = Canal Company

Figure 2-2. Lower San Joaquin River, Mendota Pool to Merced River



Key:

Dist. = District	SJP = San Joaquin River at Patterson
IC = Irrigation Company	WWTP = Wastewater Treatment Plant
ID = Irrigation District	MWC = Mutual Water Company
No. = Number	WD = Water District

Figure 2-3. Lower San Joaquin River, Merced River to Airport Way

Table 2-1. Selected Flow Gages on San Joaquin River and Tributaries

River Reach	Gage Name	Gage Station ID			Period of Record
		USGS	DWR	CDEC	
San Joaquin River, Gravelly Ford to Mendota Pool	San Joaquin River at Gravelly Ford	-	B07770	GRF	10/1974 – present
	San Joaquin River below control structure	-	B07798	SJB	10/1974 – 09/1986 10/1988 – 09/1997 10/2005 – present
	James Bypass near San Joaquin	11253500	C00200	JBP	10/1974 – 09/1987 10/1995 – 09/1997
	Delta-Mendota Canal Check 21	-	B00770	DM3	
San Joaquin River, Mendota Pool to Sack Dam	San Joaquin River near Mendota	11254000	B07710	MEN	10/1950 – 09/1954 10/1974 – present
	Sack Dam gage	-	-	-	1/1/2010 – present
San Joaquin River, Sack Dam to Bear Creek	Sand Slough gage	-	-	-	Proposed
San Joaquin River, Bear Creek to Merced River	San Joaquin River near Stevinson		B07400	SJS	10/1981 – present
	Salt Slough at Highway 165 near Stevinson	11261100	B00470	SSH	10/1985 – present
	San Joaquin River at Fremont Ford Bridge	11261500	B07375	FFB	10/1936 – 09/1971 10/1985 – 09/1989 10/2001 – present
	Mud Slough near Gustine	11262900		MSG	10/1985 – present
	Merced River near Stevinson	11272500	B05125	MST	10/1940 – present
	Merced River Slough near Newman	11273000	B05110	-	10/1941 – 09/1972
San Joaquin River, Merced River to Vernalis	San Joaquin River near Newman	11274000	B07300	NEW	10/1911 – present
	Orestimba Creek at River Road near Crows Landing	11274538		OCL	10/1991 – present
	San Joaquin River near Crows Landing	11274550	B07250	SCL	10/1995 – present
	San Joaquin River near Patterson			SJP	01/1984 – present
	Del Puerto Creek (at Vineyard Road) near Patterson	11274630	B88004		07/1965 – present
	Tuolumne River at Modesto near Stevinson	11290000	B04120	MOD	10/1939 – present
	Ingram Creek	-	-	-	
	Hospital Creek	-	-	-	
	San Joaquin River at Maze Road Bridge near Modesto	11290500	B07040	MRB	01/2005 – present
	Stanislaus River at Ripon	11303000	B03125	RIP	10/1940 – present
	Airport Way Bridge near Vernalis	11303500	B07020	VNS	10/1923 – 09/1924 10/1929 – present
Chowchilla/Eastside Bypass	Chowchilla Bypass at head below control structure	-	B07802	CBP	10/1974 – 09/1986 10/1988 – 09/1997
	Eastside Bypass near El Nido	-	B00435	ELN	10/1980 – present
	Bear Creek below Eastside Canal	-	B05516	-	10/1980 – 09/2007

Key:
- = not applicable
CDEC = California Data Exchange Center
DWR = California Department of Water Resources
USGS = U.S. Geological Survey

Table 2-2 summarizes the number and location of surface water diversions along the San Joaquin River by river reach.

Table 2-2. Surface Water Diversions from San Joaquin River

Description	Upstream River Mile	No. of Westside Diversions	No. of Eastside Diversions
Mendota Dam to Avenue 71/2	203	0	1
Avenue 71/2 to Sack Dam[1]	192	1	0
Sack Dam to Santa Rita Bridge (State Route 152)	180	1	0
Santa Rita Bridge to Sand Slough Control Structure	173	1	2
Sand Slough Control Structure to Turner Island Road	166	0	2
Turner Island Road to Mariposa Bypass	157	1	1
Mariposa Bypass to Bear Creek	145	1	2
Bear Creek to Lander Avenue Bridge (State Route 165)	134	0	0
Lander Avenue Bridge to Salt Slough	131	0	1
Salt Slough to Fremont Ford Bridge (State Route 140)	127	0	0
Fremont Ford Bridge to Mud Slough	123	0	1
Mud Slough to Hills Ferry Road Bridge	119	0	0
Hills Ferry Road Bridge to Crows Landing Road Bridge	115	3	8
Crows Landing Bridge to Patterson Bridge	105	3	5
Patterson Bridge to Grayson Road Bridge[2]	96	5	3
Grayson Road Bridge to Maze Road Bridge (State Route 132)[3]	87	6	6
Maze Road Bridge to Airport Way near Vernalis	75	3	3

Friant Dam to Gravelly Ford

Friant Dam is located on the San Joaquin River, 25 miles northeast of Fresno. The dam controls San Joaquin River flows, provides downstream releases to meet requirements above the Mendota Pool, provides flood control and conservation storage, and delivers water to a million acres of agricultural land in Fresno, Kern, Madera, and Tulare counties in the San Joaquin Valley. This reach of the river is not considered in the water budget for the Westside Region.

Gravelly Ford to Mendota Pool

Reach 2 extends from the Gravelly Ford gage station to Mendota Dam. There are significant flow losses into the river bed downstream from Gravelly Ford, caused by a combination of low groundwater levels and sandy soils. Before the San Joaquin River Restoration Program (SJRRP)[2] Interim Flows, no flow occurred in Reach 2 except during periods of high flows and substantial releases from Friant Dam. For flood control purposes, flows greater than 2,500 cubic feet per second (cfs) are diverted from the San Joaquin River into the

[2] The SJRRP is a comprehensive long-term effort to restore flows to the San Joaquin River from Friant Dam to the confluence of the Merced River, and restore a self-sustaining Chinook salmon fishery in the river while reducing or avoiding adverse water supply impacts from Restoration Flows.

Chowchilla Bypass at the Chowchilla Bypass Bifurcation Structure.[3] Flow measurement at the San Joaquin River gage below the Chowchilla Bypass (DWR gage B07798) provides the upstream boundary condition for the water budget along the San Joaquin River.

Under historical conditions, winter and spring flood flows from the Kings River entered Fresno Slough, which discharges into the San Joaquin River at the Mendota Pool. Since 1954, flood flows on the Kings River have been regulated by Pine Flat Dam, reducing the frequency and magnitude of flood spills to Fresno Slough. The Kings River is now operated to convey the first 4,750 cfs of flow to the San Joaquin River (the published capacity of the channel downstream from Mendota Dam is 4,500 cfs).

Mendota Pool to Sack Dam

Reach 3 extends from Mendota Dam to Sack Dam. Landowners adjacent to this river reach rely on water supplies diverted from the Mendota Pool, tailwater reuse, and groundwater; there are no riparian diversions between the Mendota Pool and Sack Dam.

The first dam at Mendota was constructed by Miller & Lux holdings (a corporation formed to build the canal system) in 1871 to provide sufficient water depth to divert water into diversion canals upstream from the dam. As part of negotiations to allow the construction of Friant Dam, a group of water right holders (with Miller & Lux water rights dating back to the 1870s) exchanged San Joaquin River water for water considered surplus in the Sacramento River system. This group's legal water right diversion points are located at Lone Willow Slough, Mendota Pool, and Sack Dam.[4] This exchange allowed water pumped from the Delta to be delivered to the Exchange Contractors at the Mendota Pool through the DMC to satisfy irrigation demands. The agreement includes an accord that the Exchange Contractors would receive water from Friant Dam if Reclamation is unable to provide adequate Delta water supplies through the DMC. In addition, the Exchange Contractors retain the right to divert San Joaquin River water when excess flows are released into the river from Friant Dam. Although construction of Friant Dam was completed in 1942, current operations did not take effect until the 1950s when the DMC was completed and demands for Friant Division water increased.

Reclamation has contracts to deliver up to 936,631 acre-feet per year of water from the Mendota Pool (including diversions at Sack Dam). CVP exchange and water service contract water is diverted and distributed by four water districts:

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3 The Chowchilla Bypass Bifurcation Structure is a gated structure used to divert flood flows from the San Joaquin River into the Chowchilla Canal Bypass, and limit flows past Mendota Dam to 4,500 cfs. Operation of the structure depends on both Kings River inflows from the James Bypass and water elevations at the Mendota Pool. Mendota Dam can pass up to 1,500 cfs through sluice gates in the dam. The check boards in Mendota Dam must be removed to pass flows in excess of 1,500 cfs.

4 The structure was originally constructed annually using sand-filled sacks to divert water from the San Joaquin River into Temple Slough (now the Arroyo Canal) during periods of low flow.

Central California Irrigation District, Columbia Canal Company, Firebaugh Canal Water District, and San Luis Canal Company. Up to 700,000 acre-feet per year are used to replace San Joaquin River water diverted at Friant Dam. Reclamation also delivers CVP water to the Mendota Pool to satisfy the prior rights of James Irrigation District (45,000 acre-feet per year), Tranquility Irrigation District (34,000 acre-feet per year), and the Mendota Wildlife Area (30,000 acre-feet per year), as well as a portion of the water contract for Westlands Water District. The Westlands Water District contract with Reclamation is for 50,000 acre-feet per year from the Mendota Pool.

The current Mendota Dam is a non-Federal facility owned and operated by Central California Irrigation District. The dam is located just downstream from the confluence of the San Joaquin River and Fresno Slough, and forms the Mendota Pool. The pool is generally considered to extend to the south past the Mendota Wildlife Area to the terminus of the James Bypass. SLDMWA maintains the water level in the Mendota Pool so that its contractors and prior water right holders may redivert water imported via the DMC.

The Mendota Pool is generally less than 10 feet deep and averages about 400 feet wide. The total capacity of the pool is about 8,500 acre-feet. Water quality conditions in the Mendota Pool are the result of interaction between the quantity and quality of inflows from the Delta (via the DMC), and intermittent inflows from the San Joaquin River, Fresno Slough, James Bypass, Panoche Creek, and seasonal groundwater pumping to the pool.

Sack Dam is a low-head structure built to direct water released from Mendota Dam into the Arroyo Canal (previously known as Temple Slough). Flows released from Mendota Dam average up to 600 cfs during the irrigation season and about 200 cfs during the nonirrigation season; flows greater than 600 cfs spill over the top of the dam. The Arroyo Canal delivers water to the San Luis Canal Company, and National Wildlife Refuges and wetlands in Grassland Water District.

Sack Dam to Bear Creek

Reach 4 extends from Sack Dam to the San Joaquin River's confluence with Bear Creek. Reach 4 is generally dry throughout the year, except during high-flow events when water spills over Sack Dam. This spill water is subsequently diverted into the Eastside Bypass at the Sand Slough Control Structure. The Sand Slough Control Structure is designed to route up to 3,000 cfs into the Eastside Bypass and divert 1,500 cfs into the San Joaquin River. Flows have not been diverted into the downstream reach of the San Joaquin River (including during the 1997 flood) because of low conveyance capacity. The Mariposa Bypass Control Structure diverts the first 8,500 cfs of flow from the Eastside Bypass into the Mariposa Bypass and then to the San Joaquin River. Additional flow remaining in the Eastside Bypass travels to Bear Creek and then returns to the San Joaquin River. There are no riparian diversions in Reach 4.

Bear Creek to Merced River

Reach 5 extends from the Bear Creek confluence to the San Joaquin River's confluence with the Merced River. Levees along the river disconnect it from the historical floodplain and network of secondary channels. Tributaries to this stretch of the river include Bear Creek/Eastside Bypass, Salt Slough, and Mud Slough. During the summer months, groundwater inflows to this reach of the river are supplemented by agricultural and wetland return flows. During winter flood flow events, there is inflow from the Eastside Bypass via Mariposa Slough and Bear Creek. A considerable backwater area extends upstream from Salt Slough and Mud Slough to approximately 1 mile upstream from the Lander Avenue (State Route 165) crossing. There are minor river diversions along this reach.

Merced River to Vernalis Gage

Reach 6 is the lower San Joaquin River from its confluence with the Merced River to the Vernalis gage. Flow in this section of the river is characterized by inflow from tributary streams and rivers, groundwater accretions, and agricultural drainage water.

The Central Valley Water Board identified 75 pump diversions between the Merced River confluence and Vernalis (CV Water Board, 1989). Major diverters along this reach of the river are West Stanislaus Irrigation District, Patterson Irrigation District, and El Solyo Water District, all located on the westside. West Stanislaus Irrigation District is the largest diverter, and also diverts water for the White Lake Mutual Company. Patterson Irrigation District is the second largest diverter. El Solyo Water District, unlike the other two districts, has no contract with Reclamation for CVP water, and therefore relies on San Joaquin River water, supplemented by groundwater pumping.[5] All three districts report river diversions to SWRCB.

Kratzer (Kratzer, 1987) estimated the volume of surface water diversions along this reach of the river based on water rights and land-use data. Diversions by post-1914 appropriative water right holders were based on the maximum allowable diversion specified in the water right license. Diversions by pre-1914 and riparian water right holders were estimated based on land use and crop water requirements. Kratzer (Kratzer, 1987) estimated that the three largest diverters accounted for approximately 50 percent of the total diversion.

In 1991, the California Department of Fish and Game (DFG) initiated a study to inventory water diversions (Herren, 1991). The initial focus of the study was the Delta and Suisun Marsh, continuing to the Sacramento River and the San Joaquin River basin. The DFG survey documents 19 left-bank and 20 right-bank diversions along the San Joaquin River between the Merced River confluence and Vernalis.

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[5] In addition to these districts, Banta-Carbona Irrigation District diverts water from the San Joaquin River downstream from Vernalis, to irrigate lands located north of the study area within the Delta.

Westside Tributaries

The flow in the main stem of the San Joaquin River from Bear Creek to Vernalis is supplemented by a large number of ephemeral streams that convey stormwater runoff from the Coast Range in the winter, and contain mostly agricultural runoff and drainage during the summer months. Westside tributaries along the main stem of the San Joaquin River may represent 16 percent of the San Joaquin River flow at Vernalis (Quinn, 2002). From north to south, these creeks include Hospital and Ingram creeks, Del Puerto Creek, Orestimba Creek, Garzas Creek, Quinto Creek, Los Banos Creek, and Panoche and Silver creeks. Water in Garzas and Quinto creeks is diverted into the Central California Irrigation District Main Canal. Outflow from other westside watersheds mostly infiltrates into the ground before reaching the San Joaquin River.

Hospital and Ingram Creeks

Hospital and Ingram creeks combine to the east of Highway 33. The combined flow from the ungaged watersheds runs through West Stanislaus Irrigation District before discharging to the San Joaquin River at River Mile 75. The combined outfall discharges stormwater runoff originating from the Hospital and Ingram creek watersheds, agricultural drainage (including 2,300 acres of tile drain flows), and outflow from the White Lake Mutual – Hagemann Ranch Main Drain and Hagemann Ranch Southern Main Drain.

Del Puerto Creek

Del Puerto Creek drains from Del Puerto Canyon, and flows through West Stanislaus Irrigation District into the San Joaquin River just north of the City of Patterson, at River Mile (RM) 92. Flow in Del Puerto Creek is highly seasonal, with highly flashy flows during the storm season, and is dominated by agricultural return flows during the dry season.

Orestimba Creek

Orestimba Creek is the dominant Westside Region tributary and can produce substantial and sustained flows after prolonged precipitation. The creek flows into the San Joaquin River just south of the City of Patterson at RM 107. Similar to Del Puerto Creek, flows are highly flashy during the wet season. During the dry season, flows are dominated by agricultural drainage; the majority of inflow originates from the Central California Irrigation District Main canal, which spills into Orestimba Creek approximately 2 miles upstream from the creek's confluence with the San Joaquin River.

Garzas Creek

Garzas Creek is located roughly 2 miles south of the town of Gustine. The creek is used to distribute water from the Central California Irrigation District Main Canal to north Grassland Water District. The creek does not convey drain water.

Quinto Creek

The Quinto Creek watershed is relatively small and of minor significance.

Los Banos Creek

Los Banos Detention Dam and Reservoir provide flood protection for the California Aqueduct, DMC, and City of Los Banos. The reservoir has a maximum operational storage of 34,560 acre-feet. From September to May, 14,000 acre-feet of space are maintained for flood control. Los Banos Creek merges with Mud Slough (north) before discharging to the San Joaquin River at RM 127.

Mud Slough (North)

Mud Slough (North) is one of the major westside tributaries of the San Joaquin River, and also conveys drainage water from the Grassland Drainage Area to the San Joaquin River. Flows are highly variable throughout the year, ranging from high flow during the wet season and during periods of wetland releases to very low flow during the summer and early fall.

Agricultural drainage from the selenium-affected area of the Grassland Basin, conveyed through San Luis Drain, is discharged into Mud Slough at a point about 6 miles upstream from the slough's confluence with the San Joaquin River. Flow in Mud Slough upstream from this discharge point consists of wetland releases from Grassland Water District and Volta Wildlife Management Area, and operational spills from the DMC and the Central California Irrigation District Main Canal. Mud Slough downstream from the San Luis Drain discharge point receives stormwater runoff from Los Banos Creek but is often dominated by water originating from the Grassland Drainage Area. Flow from the San Luis Drain accounts for 20 to 40 percent of the annual flow in Mud Slough (North). The USGS maintains a flow gaging station (11262900 – CalSim 3.0 node MSN008) 0.6 miles downstream from the San Luis Drain discharge point (USGS, 2010a and 2010b).

Salt Slough

Salt Slough conveys a blend of agricultural drainage and wetland return flows. Mud Slough (South) flows into Salt Slough before discharging to the San Joaquin River at RM 127. Before initiation of the Grassland Bypass Project in 1996, selenium-contaminated subsurface drainage water was diverted into Salt Slough via the Blake-Porter Bypass. Subsurface drainage water from Panoche, Pacheco, Widren, Broadview, and Firebaugh water districts was combined in the Main Drain, (a conveyance facility that runs parallel to the Central California Irrigation District Main Canal), and conveyed through either Camp 13 and Agatha canals to Mud Slough (South) in a "flip-flop" system. From Mud Slough south, agricultural drainage flows were diverted through the Blake-Porter Bypass to Salt Slough. After the Grassland Bypass Project was implemented, Salt Slough has carried a blend of wetland discharges, operational spills, and agricultural return flows from areas outside the Grassland Drainage Area (Quinn and Tulloch, 2002). USGS maintains a flow gaging station on Salt Slough at State Highway 165 near Stevinson (USGS 11261100).

Panoche-Silver Creek

This 380-square-mile watershed lies on the southern boundary of the San Joaquin River basin. During and after sustained precipitation such as occurred in 1995 and 1997, considerable runoff is generated within the watershed. Flood flows move east along Belmont Avenue into the town of Mendota, discharging directly into the Mendota Pool and occasionally overtopping the Firebaugh Canal Water District Third lift canal.

Lower San Joaquin River Drainage Inflows

In addition to the westside tributaries, stormwater runoff and drainage from irrigated lands and managed wetlands are conveyed via a series of man-made channels to the San Joaquin River. Additionally, Firebaugh, Newman, and Westley wasteways discharge significant operational spills from the DMC and tailwater from irrigation. Table 2-3 summarizes the number and location of drainage discharges to the San Joaquin River by river reach. Major Westside Region drainage inflows and bridges are listed by river mile. Major westside and eastside tributaries are listed for reference. Kratzer (Kratzer, 1987) reported areas of subsurface tile drains that discharge to the San Joaquin River, as listed in Table 2-4.

Subsurface drainage from the Grassland Drainage Area is conveyed via the San Luis Drain to Mud Slough (North). The Grassland Drainage Area includes Firebaugh Canal Water District, Panoche Water District, Pacheco Water District, and parts of San Luis Water District and Central California Irrigation District. Panoche Drainage District provides drainage service to Panoche, Oro Loma, Eagle Field, and Mercy Springs Water Districts.[6] Broadview and Widren water districts lie within the Grassland Drainage Area but are no longer irrigated and do not contribute drainage to the Grassland Bypass Channel. Charlestown Drainage District consists of lands in San Luis Water District and Central California Irrigation District (4,275 acres and 500 acres, respectively). Camp 13 Drainage District is an association of landowners within Central California Irrigation District.

[6] Note that drainage areas are based on natural and manmade drainage pathways for each watershed or catchment area, whereas water service areas are jurisdictional boundaries for providing irrigation and municipal water supplies.

Table 2-3. Discharges to San Joaquin River

River Reach	Location and Description of Major Discharges	Upstream River Mile	Westside Inflows3	Eastside Inflows3
1	Mendota Dam to Avenue 71/2	203	2	1
	Firebaugh Wasteway			
2	Avenue 71/2 to Sack Dam	192	1	3
	Columbia Canal Company return flows			
3	Sack Dam to Santa Rita Bridge (State Route 152)	180	0	0
4	Santa Rita Bridge to Sand Slough Control Structure	173	1	1
5	Sand Slough Control Structure to Turner Island Road	166	1	0
6	Turner Island Road to Mariposa Bypass	157	0	2
7	Mariposa Bypass to Bear Creek	145	2*	11*
8	Bear Creek to Lander Avenue Bridge (State Route 165)	134	0*	4*
	Bear Creek[1]	**134**		
9	Lander Avenue Bridge to Salt Slough	131	0*	0*
10	Salt Slough to Fremont Ford Bridge (State Route 140)	127	1	3*
	Salt Slough	**127**		
11	Fremont Ford Bridge to Mud Slough	123	0	0*
12	Mud Slough to Hills Ferry Road Bridge	119	4	1*
	Mud Slough	**119**		
	Newman Wasteway			
	Newman Slough			
	Merced River	**116**		
13	Hills Ferry Road Bridge to Crows Landing Road Bridge	115	10	3
	Newman Drainage District			
	Orestimba Creek	**106**		
14	Crows Landing Bridge to Patterson Bridge	105	5	4
	Spanish Grant – Moran Road Combined Drain			
	Ramona Lake Main Drain			
15	Patterson Bridge to Grayson Road Bridge	96	14	3
	Patterson Irrigation Main Drain			
	Olive Avenue Drain			
	Del Puerto Creek	**91**		
	Houk Ranch Drain			
16	Grayson Road Bridge to Maze Road Bridge (State Route 132)	87	14	9
	Island Dairy River Drain			
	Old Grayson Channel			
	Tuolumne River	**81**		
	Ingram – Hospital Combined Outfall			
	El Solyo Water District Main Drain			
	Blewitt Drain			
17	Maze Road Bridge to Airport Way (Vernalis)	75	1	3
	Stanislaus River	**72**		
	San Joaquin City Drain			

Source: Central Valley Water Board, 1989

Notes:

[1] Major tributaries are shown in bold.

[2] "*" indicates that numerous flood gates are located along this section of the river.

[3] Based on Central Valley Water Board, 1989.

Table 2-4. Subsurface Agricultural Drainage

Tiled Area (acres)	Point of Discharge	River Mile
600	Newman Drainage District – Collector Line A	119.0
2,500	Newman Drainage District – Collector Line A	119.0
1,550	Spanish Grant – Moran Road Combined Drain	105.0
1,360	Ramona Lake Drain	100.0
1,650	Patterson Irrigation District Main Drain	101.5
350	Richie Slough Main Drain	91.5
1,350	Hospital Creek – Haggerman Ranch Drain	79.9
250	El Solyo Water District – Hetch Hetchy Drain	77.6
400	McCracken Road Drain	73.0

Source: Kratzer, 1987

Central Valley Project Agricultural Contractors

The CVP Agricultural Contractors comprise agricultural lands that hold CVP water contract entitlements, with diversion of waters directly from the DMC and Mendota Pool. The three primary CVP service areas include the Upper DMC, Lower DMC and Mendota Pool service areas. Additional CVP contractors share diversions with the SWP contractors along the Joint Reach of the California Aqueduct.

Upper Delta-Mendota Canal Service Area

Check 13 on the DMC, just upstream from the O'Neill Pumping-Generating Plant, marks the division between the upper and lower canal service areas. CVP contractors receiving deliveries from the DMC upstream from Check 13 include the following: (note that listed items are in order of delivery points along the DMC from north to south)

- Byron Bethany Irrigation District (only the former Plainview Irrigation District is located within the study area)
- City of Tracy (located outside the study area)
- Banta-Carbona Irrigation District (located outside the study area)
- Westside Irrigation District (almost entirely located outside the study area)
- West Stanislaus Irrigation District
- Patterson Irrigation District
- Del Puerto Water District

Del Puerto Water District was reorganized in 1995, through a formal consolidation with 10 other districts (Hospital, Kern Canon, Salado, Sunflower, Orestimba, Foothill, Davis, Mustang, Quinto, and Romero water districts). The reorganized Del Puerto Water District is located on both sides of the DMC and consists of a narrow strip of land averaging less than 2 miles in width and stretching 50 miles in length.

Lower Delta-Mendota Canal Service Area

CVP Contractors receiving water from the DMC downstream from Check 13 include the following:

- Laguna Water District
- Eagle Field Water District
- Mercy Springs Water District
- Oro Loma Water District
- Firebaugh Canal Company
- San Luis Water District
- Panoche Water District
- Pacheco Water District

Eagle Field, Mercy Springs, Oro Loma, Panoche, and Pacheco water districts and the Firebaugh Canal Company lie within the Grassland Drainage Area. Part of San Luis Water District is also located within the Grassland Drainage Area. Broadview and Widren water districts also lie within the Grassland Drainage Area but are no longer irrigated and do not contribute drainage to the Grassland Bypass Project.

Mendota Pool Service Area

Water from the Mendota Pool is delivered to the following CVP water service and exchange contractors:

- Laguna Water District
- Central California Irrigation District (partly located within the Grassland Drainage Area)
- San Luis Canal Company
- Firebaugh Canal Company (located within the Grassland Drainage Area)
- Columbia Canal Company
- Coelho Family Trust (located outside the study area)

- Fresno Slough Water District (located outside the study area)
- James Irrigation District (located outside the study area)
- Reclamation District 1606 (located outside the study area)
- Tranquility Irrigation District (located outside the study area)
- Tranquility Public Utility District (located outside the study area)
- Westlands Water District (located partly outside the study area)
- Mendota Wildlife Area (located outside the study area)

Laguna Water District has no distribution facilities of its own. Water released from the DMC into the Mendota Pool is subsequently transported from the pool through the distribution facilities of the Central California Irrigation District to the Laguna Water District.

California Aqueduct – Joint Reach Service Area

CVP contractors receiving water from the Joint Reach of the California Aqueduct include San Luis District, Pacheco Water District, Panoche Water District, and Westlands Water District. Westlands Water District is located partly outside the study area.

About 200,000 acres within the San Luis District, referred to as the Direct Service Area, receive water from 39 turnouts on the DMC and 23 turnouts on the San Luis Canal. In addition to the Direct Service Area, three improvement districts are also served through distribution systems branching off the Joint Reach of the California Aqueduct. Pacheco Water District is supplied from the San Luis Canal, with the DMC serving as a backup source. The Pacheco Water District also has a surface water supply from the Central California Irrigation District, under a Railroad Commission Order authorizing service to Pacheco Water district. Panoche Water District obtains CVP water through two diversion points on the DMC and five diversion points on the San Luis Canal.

Westlands Water District is located between the Coast range and the trough of the San Joaquin Valley in the Tulare Lake Hydrologic Region. When the district was originally organized, it included approximately 376,000 acres. In 1965, Westlands Water District merged with its western neighbor, Westplains Water Storage District, adding 210,000 acres. Additionally, lands comprising about 18,000 acres were annexed to the district after the merger to form the current 604,000-acre district. The district has three distinct water service areas. Priority Area I covers the original lands; the Westplains area is referred to as Priority Area II. Priority Area III is land added to the district after the merger and has no established water allocation. Most of Priority Area I is located east of the San Luis Canal and has gravity water service. Much of Priority Area II is west and upslope from the San Luis Canal, and is served by pumping from the San Luis Canal and gravity supply from the Coalinga Canal. Westlands Water District Distribution Districts No. 1 and 2 were formed from lands within the Westlands Water District for the purpose of entering into assignment contracts with Reclamation.

Managed Wetlands

Table 2-5 summarizes managed wetlands located within the study area. These include National Wildlife Refuges and Wildlife Management Areas managed by the U.S. Fish and Wildlife Service (USFWS), wildlife areas managed by DFG, and private wetlands and duck clubs within Grassland Water District. With the exception of the Mendota Wildlife Management Area,[7] these wetlands lie within the Grassland Ecological Area, which encompasses 160,000 acres, or nearly 300 square miles of wetlands that have been affected by water diversions, urban encroachment, and agricultural development.

Federal refuges include the Kesterson, Freitas, West Bear Creek, and San Luis units of the San Luis National Wildlife Refuge. State wildlife areas include Volta Wildlife Management Area, Los Banos Wildlife Management Area (which lies within Grassland Water District), and the North Grasslands Wildlife Management Area, which consists of the China Island, Salt Slough, and Gadwall units. Grassland Water District contains approximately 200 separate ownerships, most of which are hunting or duck clubs. Grassland Water District was established in 1953 as a legal entity for contracting with Reclamation to receive CVP water. It is composed of two separate geographical areas, commonly referred to as North Grassland and South Grassland.

[7] The Mendota Wildlife Management Area is located outside the study area, but is included here because it diverts from the Fresno Slough/Mendota Pool.

Table 2-5. 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]		√	Delta-Mendota Canal 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	√	√	Central California Irrigation District 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		√	Delta-Mendota Canal via Volta Wasteway, CCID Main Canal
Grassland Water District - South	20,500	Private		√	Central California Irrigation District 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
GW = groundwater
N/A = not available
NWR = National Wildlife Refuge
SW = surface water
USFWS = U.S. Fish and Wildlife Service
WA = Wildlife Management Area

The CVPIA altered management of the CVP to give fish and wildlife protection, restoration, and enhancement project purposes equal priority to agriculture, M&I, and power purposes. As part of Section 3406(d) of the CVPIA, "Central Valley Refuges and Wildlife Habitat Areas", Reclamation signed long-term water supply contracts, agreements, and memorandums of understanding to provide long-term water supplies (up to 25 years) to specified Federal National Wildlife Refuges, State Wildlife Management Areas, and private wetlands in the Grassland Resource Conservation District. The CVPIA adopted by reference dependable water supplies from the *Report on Refuge Water Supply Investigations, Central Valley Hydrologic Basin, California* (Reclamation, 1989) as specific quantities of water to be provided to the refuges. Historical average water supplies are defined as Level 2 supplies. Incremental Level 4 water supplies are the additional water required to achieve optimum waterfowl habitat management. Reclamation, in partnership with USFWS, has developed a Water Acquisition Program to provide Level 4 refuge water supplies. The Water Acquisition Program goal is to acquire up to 163,000 acre-feet annually (133,264 acre-feet of Level 4 water, and 26,007 acre-feet of replacement water).

Municipal Water Use

Urban development within the study area consists of small cities and towns that mostly rely on groundwater. The exception is the City of Dos Palos, which receives raw water deliveries from the California Aqueduct. The City of Tracy is the largest community in the Westside Region of the San Joaquin Valley, but lies north of the study area. Based on DWR's water use estimates for the *California 2009 Water Plan Update* (DWR, 2009a), per capita water use for the towns of Dos Palos, Gustine, Los Banos, and Newman range from 200 to 240 gallons per capita per day, with a total annual use of approximately 13,000 acre-feet. Urban water use is not a significant component of the Westside Region water budget.

Groundwater

Groundwater underlying the alluvial portion of the study area occurs within the Tracy and Delta-Mendota subbasins (DWR, 2003). The Corcoran Clay layer divides the groundwater system into two major aquifers: an upper semiconfined aquifer above the clay layer, and a confined aquifer below the clay layer (Williamson et al., 1989). The Corcoran Clay layer occurs throughout all but the eastern and western margins of the San Joaquin Valley at about 300 feet below sea level. Above the Corcoran Clay layer, three main hydrogeologic categories are defined: Coast Range alluvium (derived from marine deposits rich in salts), Sierran sand (medium- and coarse-grained fluvial deposits from the Sierra Nevada to the east), and flood-basin deposits (silt and clay deposits overlying the Sierran sand). Natural recharge of the upper aquifer occurs from stream seepage, deep percolation of precipitation, and subsurface inflow along basin boundaries. This natural recharge is augmented by deep percolation of irrigation water, seepage from permanent and semipermanent managed wetlands, and seepage from conveyance and distribution canal systems. 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 some seepage from the semiconfined aquifer above does occur through the confining layer.

Outflows from the groundwater aquifers include capillary rise into the root zone and associated evaporation/ETo, subsurface drainage, inflow to Westside Region tributaries and the San Joaquin River, and lateral groundwater flow eastward under the San Joaquin River.

The semiconfined aquifer above the Corcoran Clay is fully saturated in much of the study area, with water tables within 5 feet of the ground surface. The combination of imported salts from irrigation water and irrigation-induced leaching of the soil profile has degraded water quality in the upper portion of the semiconfined aquifer. Water quality generally improves with depth. Groundwater extractions for agricultural purposes are from private wells and district-owned groundwater wells. Within the Grassland Drainage Area, Firebaugh Canal Company and Central California Irrigation District both pump to offset surface water deliveries and allow for export of water out of the districts. Pumping may also occur within these districts from the shallow water table to reduce subsurface drainage. Groundwater pumping below the Corcoran Clay layer is limited because of concerns about land subsidence.

Chapter 3 Analytical Approach

This chapter discusses the approach to establishing a set of volumetric water budgets for the study area. Conceptually simple, these water budgets assess inflows and outflow across a three-dimensional control volume, and changes in storage within the control volume. Changes in storage include detention storage of precipitation, changes in soil moisture, changes in groundwater storage, and storage of surface water in permanent and seasonal wetlands. Many components of the water budgets must be determined indirectly because observed gage data are limited, particularly for the Northwest Subarea where the modes of water use, storage, and reuse are uncertain from year to year.

Control Volumes

Volumetric water budgets were developed for four control volumes, or water budget components, using a watershed model, and the IWFM model, WestSim. The hydrology of the four control volumes includes conveyance, land surface, and shallow root zone, San Joaquin River, and groundwater. Although the water budgets are described separately, overlap exists between the individual water budgets. Within WestSim, water budgets were created for each water or irrigation district for the purposes of managing the results for future stakeholder outreach.

California Aqueduct, Delta-Mendota Canal, and San Luis Reservoir

For the first control volume, water budgets were developed for the California Aqueduct and DMC to better understand how canal operations and filling and draining San Luis Reservoir influence salinity of water deliveries to CVP Contractors within the study area. The control volume for the DMC includes the entire length of the canal. The water budget accounts for water deliveries, groundwater pump-ins, inflow from stormwater runoff, and canal seepage losses.

For the California Aqueduct, the control volume stretches from Harvey O. Banks Pumping Plant (Banks Pumping Plant) in the Delta to Check 21, located at the end of the Joint Reach (San Luis Canal). The aqueduct water budget considers the interchange of water with San Luis Reservoir at the O’Neill Forebay through the Gianelli Pumping/Generating Plant, and the interchange of water with the DMC through the O’Neill Pumping/Generating Plant.

Land Surface Topology and Root Zone

The second control volume consists of the land surface within the study area and the underlying root zone. Inflows to this control volume consist of CVP and SWP deliveries, precipitation, groundwater inflow to drains (including subsurface drainage) and Westside Region tributaries, capillary rise, and groundwater pumping. Outflows consist of evaporation and ETo, tributary and surface drainage flows to the San Joaquin River, and deep percolation from the root zone to the underlying aquifer.

San Joaquin River

The control volume for the San Joaquin River includes the Mendota Pool and reach of the river between Mendota Dam and Vernalis. The control volume was subdivided into shorter river reaches based on flow gage stations. Inflows to the river include tributary inflows, stormwater runoff, agricultural surface and subsurface drainage, managed wetland releases, and groundwater accretion. Exports from the San Joaquin River are predominantly agricultural surface water diversions, but may also include seepage losses and evaporation to a lesser extent. Tributary inflows and diversions from the eastside of the San Joaquin River, as well as seepage and evaporation, were taken from previous modeling work that was conducted to determine the San Joaquin River dissolved oxygen TMDL, and to support the *Central Valley Salinity Alternatives for Long-Term Sustainability* (CV-SALTS) pilot studies (CV-SALTS, 2010).

Groundwater

The fourth control volume considers shallow groundwater below the root zone to below the Corcoran Clay underlying the study area. The groundwater budget validates groundwater recharge and groundwater pumping rates, determines the surface water budget, and estimates of groundwater inflow to the San Joaquin River from the Westside Region.

Temporal Scale

In general, all water budgets were developed and presented at a monthly timestep. However, various components of the water budget required a finer timescale. For example, estimates of stormwater runoff were developed from daily precipitation records to capture high intensity events. Similarly, baseflow separation of flow data was performed using a daily time step from hydrographs.

Spatial Scale

The spatial resolution of the analysis was determined to facilitate the use of available flow and water quality gage data for model calibration and validation. Spatial resolution of the analysis honored, as far as possible, resolution of available input data. Distributed land use, land cover, and soils data were available at field scale. Daily meteorological data are point data, although distributed grids of precipitation and evapotranspiration (ET) averaged over a longer timestep were available. CVP delivery data used were contractor-based. San Joaquin River diversion data were available for larger water districts.

In general, the geographic extent of the water budget analysis coincided with the study area, which is consistent with the subareas defined within the Sacramento and San Joaquin Water Quality Control Plan (Basin Plan) (Central Valley Water Board, 2009). However, the spatial extent of the selected groundwater model (discussed later) extends outside the limits of the study area.

For the valley floor, the spatial units considered for this analysis are defined by the intersection of water district boundaries with drainage area boundaries. Most surface drainage is captured within each district boundary and returned to head ditches. Subsurface drainage from the districts is collected separately and a portion is recirculated. Most districts were treated as a single unit. Water budgets presented at a district scale are expected to facilitate an understanding of water and salt transport at a local level, and options to manage salt loading to the San Joaquin River. Spatial units are presented in Table 3-1.[8] Within the Coast Range, water budget units were delineated by watershed.

Time Period

Water budgets were developed for October 1999 to September 2007. This period was defined to limit analysis to a time frame that coincided with current management and operations of the Grassland Bypass Project. Table 3-2 presents a range of parameters that characterize water years 2000 through 2007.

[8] The spatial units (or subregions) identified in the table were refined as part of the study effort and were updated in aerial extent and name as part of Task 2 (Westside Region Water Budget) and Task 7 (Model Refinement) deliverables. For this reason, subregion names may be inconsistent with subregions in Figure 4-1.

Table 3-1. Water Budget Subregions

Subregion	WestSim ID	WARMF Catchment ID	Surface Water Source	CVP Contract Amount (acre-feet/year)				
				Water Service	Water Right	Exchange	Refuge Level 2	Refuge Level 4
San Joaquin/Stanislaus Unincorporated	8	-	SJR	-	-	-	-	-
Hospital Water District	6	-	DMC	34,105	-	-	-	-
West Stanislaus Irrigation District	9	-	DMC/SJR	50,000	189,791	-	-	-
El Solyo Water District	7	-	SJR	-	22,806-	-	-	-
Kern Canyon Water District	10	-	DMC	7,700	-	-	-	-
Patterson Water District	12	-	DMC/SJR	16,500	6,000*	-	-	-
Del Puerto Water District	11	-	DMC	12,060	-	-	-	-
Salado Water District	11/14	-	DMC	9,130	-	-	-	-
Central California Irrigation District (North)	16/19/26	-	DMC	-	-	140,000	-	-
Sunflower Water District	14	-	DMC	16,625	-	-	-	-
Stanislaus/Merced Unincorporated	17	-	SJR	-	-	-	-	-
China Island Unit – North Grasslands Wildlife Area	20	819	DMC	-	-	-	6,967	3,483
Orestimba Water District	15	823	DMC	15,860	-	-	-	-
City of Los Banos	38	832	-	-	-	-	-	-
Foothill Water District	18	409	DMC	10,840	-	-	-	-
Davis Water District	21	828	DMC	5,400	-	-	-	-
Kesterson Unit – San Luis NWR	22	411	DMC	-	-	-	10,000	0
West Bear Creek – San Luis NWR	24/28	470	DMC	-	-	-	7,207	3,603
Freitas Unit – San Luis NWR	23	470	DMC	-	-	-	5,290	0
Grassland Water District (North)	27	844	DMC	-	-	-	125,000	55,000
Mustang Water District	25	564	DMC	14,680	-	-	-	-
San Luis Unit – San Luis NWR	29	817	DMC	-	-	-		19,000
San Luis Canal Company	37	961	DMC	-	-	163,600	-	-
Salt Slough Unit – North Grasslands Wildlife Area	28	780	DMC	-	-	-	6,680	3,340
Quinto Water District	31	795	DMC	8,620	-	-	-	-
Lansdale Water District	30	790	DMC	CVP contract not renewed				
Los Banos Wildlife Area	33	822	DMC	-	-	-	16,670	8,330
Volta Wildlife Area	34	854	DMC	-	-	-	13,000	3,000
Centinella Water District	32	776	DMC	CVP contract transferred to Westlands Water District				
Romero Water District	35	779	DMC	5,190	-	-	-	-

Table 3-1. Water Budget Subregions (contd.)

Subregion	WestSim ID	WARMF Catchment ID	Surface Water Source	CVP Contract Amount (acre-feet/year)				
				Water Service	Water Right	Exchange	Refuge Level 2	Refuge Level 4
Central California Irrigation District (South)	44	777	DMC/MP	-	-	392,400	-	-
CCID – Charlestown Drainage District				-	-		-	-
San Luis Water District (North)	39	852	DMC	65,000	-	-	-	-
Grassland Water District (South)	42/41	815	DMC/MP	-	-	-	-	-
Eagle Field Water District – CCID Contracts	48	778	DMC	-	-	-	-	-
San Luis Water District (South)	59	789	SLC	60,080	-	-	-	-
SLWD – Charleston Drainage District					-	-	-	-
Panoche Water District	55	962	DMC/SLC	94,000	-	-	-	-
Eagle Field Water District	46	801	DMC	4,550	-	-	-	-
Pacheco Water District	50	761	DMC/SLC	10,080	-	-	-	-
Mercy Springs Water District	48	853	DMC	2,840	-	-	-	-
Oro Loma Water District	47	836	DMC	4,600	-	-	-	-
Firebaugh Canal Company	53/57	818/800	DMC/MP	-	-	85,000	-	-
Widren Water District	52	963	-	CVP contract transferred to Westlands Water District				
Broadview Water District	56	762	-	CVP contract transferred to Westlands Water District				
Westlands Water District (Northeast)	64	959	SLC/MP	1,234,188	-	-	-	-
Westlands Water District (Northwest)	61	843	-		-	-	-	-
Columbia Canal Company	67	N/A	MP	-	-	59,000	-	-
Oak Flat Water District	14	N/A	CA	-	-	-	-	-

Notes:
[1] WestSim subregions 1 through 4 lie outside the study area and are not included in this table.
[2] WestSim subregions 47 through 63 lie outside the study area and are not included in this table.
[3] Contract amount for Westlands Water District and associated distribution districts comprises 1,200,000, 2,500 from Centinella Water District, 27,000 acre-feet from Broadview Water District, 4,198 acre-feet from Mercy Springs Water District, 2,990 acre-feet from Widren Water District.
[4] Subregions may include non-district lands adjacent to district lands.
[5] Widren Water District and Firebaugh Canal Company are represented by a single subregion.
[6] The San Joaquin River Improvement Project associated within the Grassland Drainage Area comprises Mercy Springs Water District and the part of Eagle Field Water District that has water supply contracts with Central California Irrigation District.
[7] Level 2 supplies include replacement water. Without replacement water, San Luis (13,350), Kesterson (3,500), Freitas (3,527), Volta (10,000).
* Replacement water to be provided by Reclamation

Key:
- = zero value or no source of supply
CA = California Aqueduct
CCID = Central California Irrigation District
CVP = Central Valley Project
DMC = Delta-Mendota Canal
MP = Mendota Pool
N/A = Not applicable
NWR = National Wildlife Refuge
SJR = San Joaquin River
SLC = San Luis Canal
SLWD = San Luis Water District
WARMF = Watershed Analysis Risk Management Framework
WestSim – Westside Simulation Model

Table 3-2. Water Year Parameter Data

Parameter/Water Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Runoff/Inflows									
Sacramento Valley Runoff[1] (MAF)	18.9	9.81	14.6	19.31	16.04	18.55	32.09	10.28	N/A
San Joaquin Valley Runoff[1] (MAF)	5.9	3.18	4.06	4.87	3.81	9.21	10.44	2.51	N/A
James Bypass[2] (TAF)	0.0	0.0	0.0	0.0	0.0	60.5	612.1	No data	0.0
San Joaquin River below Friant Dam[3] (TAF)	176.6	132.2	114.0	121.5	116.5	713.8	1,370.1	151.5	141.3
Climate									
Precipitation	8.4	8.8	5.8	9.1	8.7	15.8	10.6	3.9	6.2
Evapotranspiration, Los Banos (inches)		57.8	56.5	55.3	60.3	51.9	53.1	57.7	61.0
Water Year-Type									
Sacramento Valley Index[1]	Above-Normal	Dry	Dry	Above-Normal	Below-Normal	Above-Normal	Wet	Dry	Critical
San Joaquin Valley Index[1]	Above-Normal	Dry	Dry	Below-Normal	Dry	Wet	Wet	Critical	Critical
South-of-Delta Allocations[4]									
Agricultural Contractors (%)	65	49	70	75	70	85	100	50	40
M&I Contractors (%)	90	77	95	100	95	100	100	75	75
CVP Pumping									
Jones Pumping Plant (TAF)	2,487	2,332	2,505	2,685	2,722	2,679	2,628	2,679	2,018
Banks Pumping Plant (TAF)	3,692	2,635	2,900	3,458	3,251	3,625	3,527	2,954	1,527
South-of-Delta Deliveries[5]									
Agricultural Contractors (TAF)	1,397	1,181	1,327	1,404	1,332	1,507	1,563	1,138	843
M&I Contractors (TAF)	10	12	12	13	14	14	16	18	18
Exchange Contractors (TAF)	778	761	780	767	825	769	776	708	714
Refuges, duck clubs, and wildlife areas (TAF)	345	312	336	392	393	296	319	319	282
CVP San Luis Reservoir Storage									
High-point (TAF)	965	1,050	895	969	951	966	969	778	862
Low-point (TAF)	359	245	176	258	90	378	402	83	37
Irrigated Land Index (acres)	N/A	784	825	832	842	839	807	784	N/A

Sources:
1 DWR, 2009
2 USGS, 2010a
3 USGS, 2010b
4 Reclamation, 2004
5 Reclamation, 2010

General Notes:
[1] CVP south-of-Delta delivery allocation refers to the contract year beginning in March of the corresponding water year.
[2] CVP south-of-Delta deliveries are for CVP contract year, rather than water year.
[3] Irrigated land index is a partial measure of crop acreage; data are limited to CVP contractors who reported acreage for all water years, from 2000 to 2007.
[4] South-of-Delta deliveries include Westlands Water District, outside the project study area

Key:
CVP = Central Valley Project
M&I = municipal and industrial
MAF = million acre-feet
N/A = Not applicable
TAF = thousand acre-feet

Chapter 4
Modeling Tools

Modeling tools used to develop the water budgets include WestSim, WARMF, and the Wetland Management Simulation (WetManSim) models. The below sections describe the modeling tools applied for the Westside Salt Assessment in greater detail.

Westside Simulation Model

WestSim is an application of IWFM Version 3.02 (DWR, 2010) of the entire CVP service area on the westside of the San Joaquin Valley, including the northern portion of the Tulare Lake Hydrologic Region. This model was the accounting tool for the water budgets relating to the agricultural and urban water demands calculation and deep groundwater movement. The demand calculator embedded in IWFM was used to estimate agricultural demand based on the consumptive use of applied water, and estimated irrigation application efficiency for each crop, while accounting for reuse of irrigation return flows. The urban water demand is specified by the user using historical or projected total urban demand, and the fraction to be used as the indoor urban demand. Applying the output capabilities of IWFM, WestSim is configured to output detailed water budgets for each of the water districts and Federal and State wildlife refuges within the study area. WestSim's simulation of the water budget along the westside of the San Joaquin Valley provides a better understanding of groundwater fluxes into and out of subregions and the model domain and fluxes to WARMF-SJR (i.e., subsurface groundwater movement vertically).

WestSim was collaboratively developed by Reclamation and Lawrence Berkley National Laboratory. WestSim was one of the first applications of DWR's generic code Integrated Groundwater Surface Water Model 2, subsequently renamed IWFM. Initially, WestSim used a mesh developed for a previous MODFLOW model, which was then triangulated to better represent water district areas. WestSim's detailed finite element spatial resolution distinguishes it from other groundwater models covering the Westside Region. WestSim uses the water districts as subregions for analysis; this is a useful means of collaborating and interacting directly with water districts. Before the model was updated for the purposes of this study, WestSim consisted of 2,602 nodes, 2,176 elements, and 61 subregions. The new model mesh allows close conformity with water district boundaries, which illustrates to stakeholders direct correspondence with maps. Detailed surface water and groundwater budgets may be output for each subregion. Other unique features of the model include its detailed depiction of surface water deliveries, agricultural and wetland water use, and subsurface tile drainage.

The previous version of WestSim simulated historical conditions on the westside from October 1969 through September 2000. WestSim model boundaries extend beyond the study area both to the north and south. The western boundary follows the California Coast Range based on topography and the geologic extent of water-bearing soil materials. The eastern boundary follows the San Joaquin River and Fresno Slough. South of Fresno Slough, the eastern edge of the model domain follows water district boundaries. The new WestSim boundaries more accurately represent changes during the past decade because of water district consolidation and land acquisition (Figure 4-1).

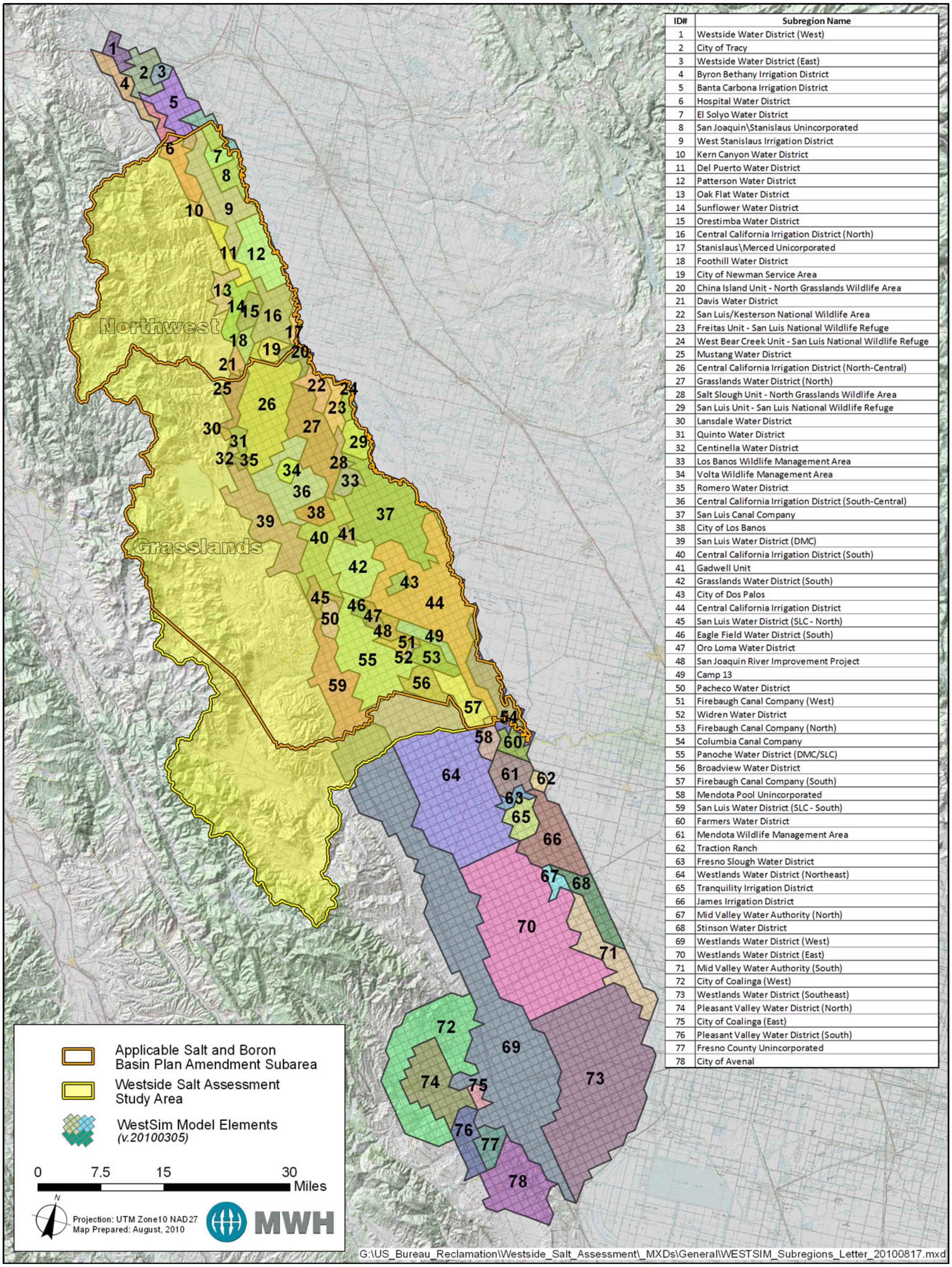


Figure 4-1. Updated WestSim Subregions

Boundary conditions used in the previous WestSim model include both fixed and variable groundwater heads, and use of the IWFM small watershed routines to determine surface and subsurface inflows from lands outside the finite element domain. The WestSim model eastern boundary used time series data obtained by running the Central Valley Groundwater Surface Water Model to obtain groundwater hydrographs at points located some distance east of the San Joaquin River and Fresno Slough. This variable head boundary condition permitted WestSim to simulate flows and diversions along the San Joaquin River. Additional subsurface time series boundary conditions for each of WestSim's seven model layers were included in the model input files. This study effort used the latest update to IWFM (Version 3.02) and more recent statewide models (C2VSim, Central Valley application of IWFM) to establish and update relevant boundary conditions of the WestSim model.

Model refinement activities completed as part of Task 7 (Model Refinement) were performed to complete the following:

- **Model Grid Expansion** – The WestSim model finite element grid was expanded to include Oakflat Water District (a state water project (SWP) contractor) and Columbia Canal Company (a major diverter from the Mendota Pool and San Joaquin River).

- **Subregion Definitions** – With attention given to the study area, WestSim subregion delineations were refined to reflect the current water catchments and political boundaries of managed wetlands, reuse areas, water districts, and city boundaries. Changes to model subregions and naming conventions reflect current ownership, as of 2006/2007.

- **Model Element Definitions** – With the addition of groundwater model nodes and subregions, model elements and geometry were redefined using the current version of WestSim and data from a geographic information system (GIS) after the above refinements.

- **Model Input Files** – Model input data were reconfigured from the previous version of WestSim to reflect the model refinements above. This included changes to land use, surface water delivery, groundwater pumping, and water demand data.

The current version of the WestSim model domain consists of 2,663 nodes, 2,810 elements, and 78 subregions. The detailed model domain, which includes both water districts and managed wetlands, is illustrated in Figures 4-1 and 4-2.

Model Extension

A sequence of steps was followed to refine WestSim for application to the Westside Salt Assessment, as follows:

1. Migration of WestSim input files from IWFM Version 2.4 to Version 3.02, including translation of time series input data to the data storage system (DST) database format.

2. Extension of the model domain to include the Columbia Canal Company (located east of the San Joaquin River), Oak Flat Water District (which is an SWP contractor located adjacent to the California Aqueduct), and disaggregation of wetland regions to represent individual units of the Federal San Luis National Wildlife Refuge and units of the State North Grasslands Wildlife Management Area.

3. Extension of WestSim input data to include water years 2001 through 2007.

Simulated groundwater use for each model subregion was developed as inputs to application of WARMF-SJR.

Model Linkage

WestSim simulated output used in the WARMF-SJR analysis includes the following:

- Agricultural and urban water demands calculated from the IWFM demand calculator

- Subregion definitions and associated land use within the subregions

To maintain consistency between WestSim and WARMF-SJR, the refined WARMF-SJR follows WestSim's subregion definitions. The associated land use, urban water, and agricultural demand in WestSim were used as inputs in WARMF-SJR.

Additionally, WestSim simulated outputs informed WARMF-SJR water budget analysis of the following:

- Deep percolation of irrigation water and precipitation from the root zone to the shallow (semiconfined) aquifer

- Groundwater pumping from the semiconfined and confined aquifers

WestSim's deep groundwater model outputs cannot be directly applied within WARMF-SJR because WARMF-SJR does not simulate vertical recharge to the groundwater aquifer. To address this inconsistency between the two models, WestSim deep percolation (or recharge) outputs were adjusted to account for calculated recharge estimates for the region from WARMF (further described in

Chapter 5). This enabled the models to maintain consistent relative spatial and temporal distribution of fluxes, while correcting the deep groundwater volume.

To provide a common dataset for all models, WestSim input and output data are maintained in a DST format.[9] The resulting DST file is maintained and updated in, and released from, a single location for data integrity.

Watershed Analysis Risk Management Framework

The WARMF model 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. The purpose of the watershed approach is to develop regional water quality management strategies that improves water quality in a simulated river basin.

The WARMF model is publicly available; the model and model documentation can be downloaded from the U.S. Environmental Protection Agency (EPA) Web site.[10] Detailed descriptions of the model are available from several sources, including Chen et al. (2001), and Herr et al. (2000). The model has undergone peer review (Keller, 2001; Driscoll et al., 2004). Selection of WARMF provides consistency with the approach adopted for the CV-SALTS pilot studies (CV-Salts, 2010).

Flow Balance

WARMF divides a river basin into interconnected compartments of land catchments, river segments, and lakes.[11] Catchments are further subdivided into land surfaces (canopy) and soil layers, with a fluctuating groundwater table. The catchment model, driven by meteorological data, calculates soil infiltration, ET, groundwater exfiltration, surface runoff, and nonpoint source loading. River segments receive the inflows from catchments, upstream river segments, and point sources. Flow is routed using the kinematic wave approximation. Diverted flow is removed from rivers, and the portion used for irrigation is added to precipitation on irrigated land uses.

Within the catchment model, precipitation infiltrates into the ground, is held in detention storage, or contributes to overland flow. Flow through the soil profile is simulated by volumetric mass balance. With each timestep, the water table rises or falls based on the amount of water entering the soil and the amount leaving. Precipitation that percolates into the soil adds to its moisture content. If the moisture content is greater than field capacity, there is lateral flow to the

[9] U.S. Army Corps of Engineers Hydrologic Engineering Center Data Storage System

[10] www.epa.gov/athens/wwqtsc/html/warmf.html

[11] River basins are typically delineated into watersheds based on a digital elevation model (DWM). However, for the Westside Salt Assessment, water districts have significantly affected drainage patterns within the valley floor. Water district boundaries better define flow routing than the use of watersheds. In this TM, WARMF watershed objects refer to drainage areas, whether defined by natural topography or man-made drainage channels.

stream network, which is calculated using Darcy's Law. Once the soil profile becomes saturated, precipitation contributes to overland flow (sheet flow), which is simulated and routed using Manning's equation. Potential ET is calculated from meteorological data using the Hargreaves equation. Actual ET is also a function of moisture content in the root zone.

Irrigation efficiencies are not specified in WARMF. Rather, WARMF calculates soil water budgets, accounting for surface water deliveries, groundwater pumping, precipitation, and ET. Runoff and drainage are calculated by volume balance; irrigation efficiencies can subsequently be estimated based on the amount of applied water and simulated ET.

"Near-surface" groundwater is defined as water down to the depth where it still interacts with surface water via lateral flow. 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." By default, WARMF assumes that the recharge to deeper groundwater is negligible compared to ET and lateral flow.

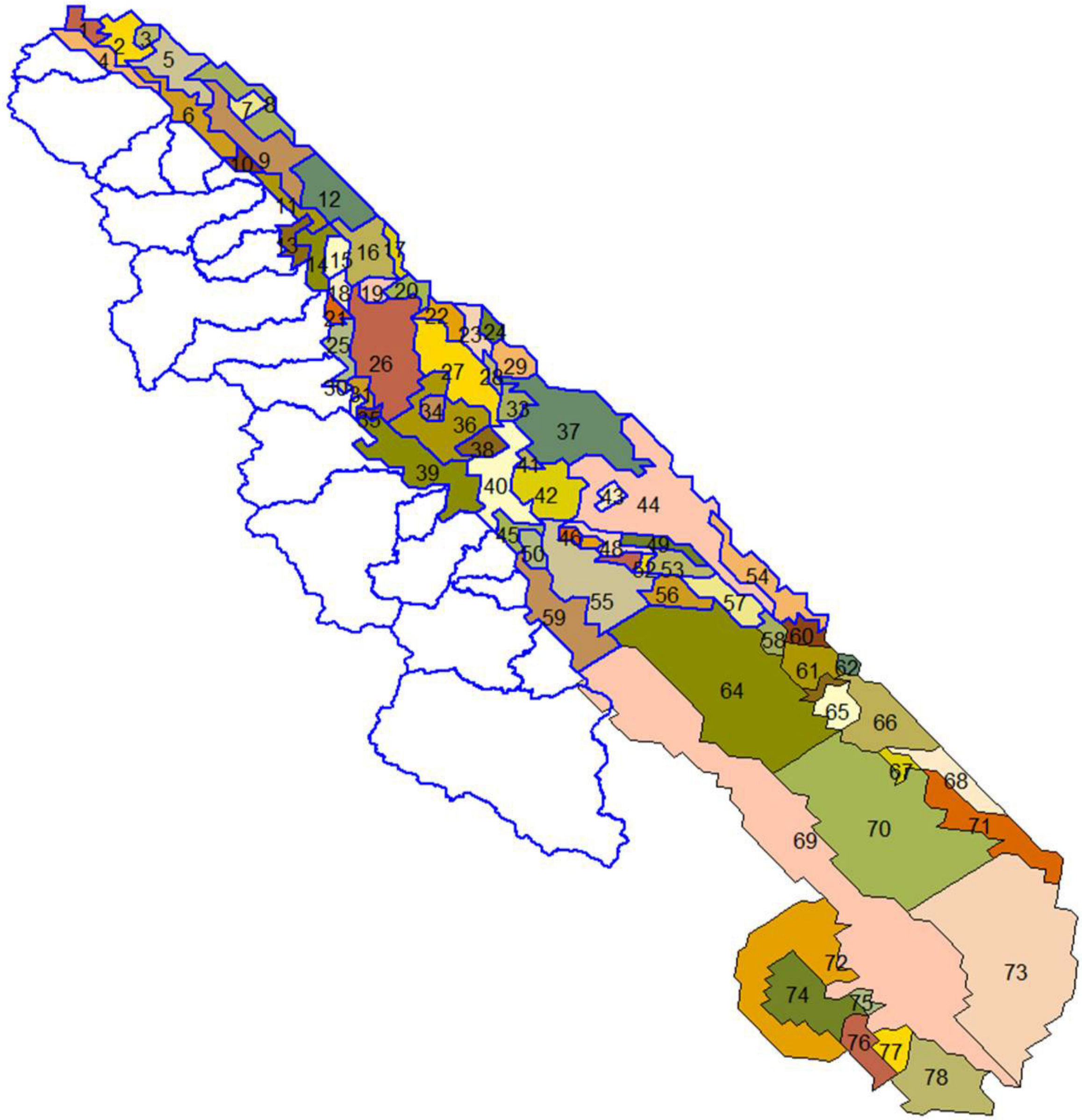
For the Westside Salt Assessment, time-varying recharge rates were specified based on WestSim output. Pumping from deeper groundwater is represented as a point source, with an associated time series of flow and water quality.

Existing Model

The domain of the San Joaquin River model (WARMF-SJR) before this study was initiated included the majority of lands tributary to the San Joaquin River, from Friant Dam to the Old River junction near Mossdale. Additionally, a link-node model was developed to simulate tidal flows in the San Joaquin River reach between Mossdale and the Stockton Deep Water Ship Canal at Venice Island. Neither the previous nor the revised model simulates watersheds of the Stanislaus River above Tulloch Dam, the Tuolumne River above New Don Pedro Dam, or the Merced River above New Exchequer Dam. Inflow from these mountain watersheds is represented by the historical time series of reservoir releases. On the Westside of the San Joaquin Valley, the previous and revised model excludes modeling of the Mud Slough/Salt Slough/Los Banos Creek watersheds, and the Orestimba Creek, Del Puerto Creek, Ingram Creek, and Hospital Creek watersheds using a daily time step as a function of quantity and quality of water. South of the Mendota Pool, the model excludes lands draining to Fresno Slough.

Model Extension

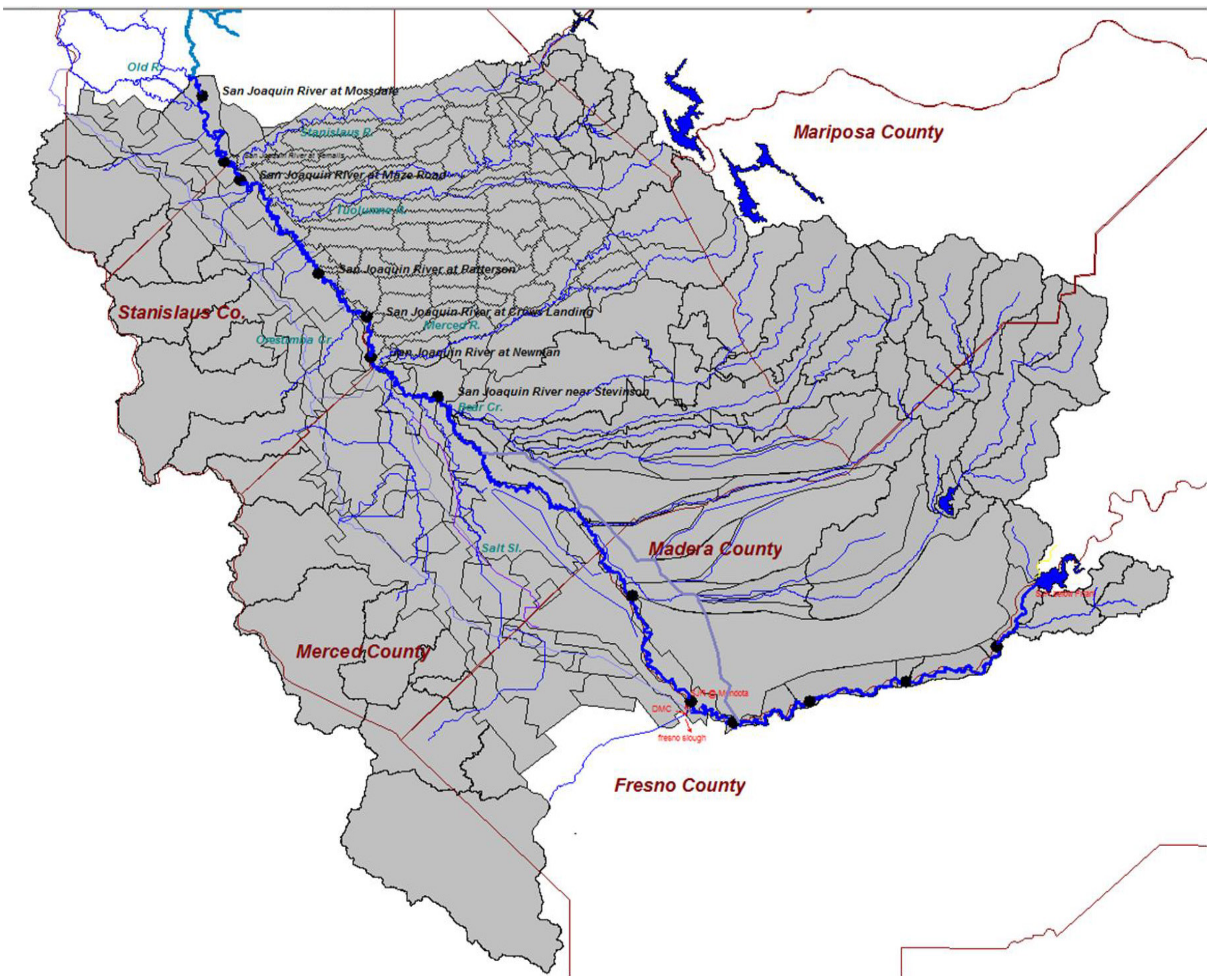
WARMF-SJR was refined to reflect the management units of the study area consistent with WestSim. A GIS shapefile of the WestSim subregion boundaries was used to define new catchments for the WARMF-SJR model (Figure 4-2).



Note: Catchment boundaries outlined in blue.

Figure 4-2. WestSim Subregions and Westside WARMF Catchment Boundaries

Significant differences were identified between the previous WARMF-SJR catchment boundaries and the WestSim boundaries to determine if the WestSim subregion boundaries could be used directly or if modifications were necessary to maintain hydrologic flow patterns. However, since natural overland flow potentially occurs only during very high rainfall events, and drainage patterns otherwise follow the agricultural canal network, it was determined that modifications were not warranted. Because of the highly altered and managed nature of the hydrology in the region, flow patterns were approximated using best available information. Thus, no modifications were made to the WestSim subregion boundaries for use in WARMF. The preexisting WARMF catchment boundaries were deleted and new catchment boundaries were imported. Additional catchments were delineated and imported to include the headwater areas of the foothills, which contribute winter runoff to the streams of the Westside Region. The WARMF catchments that were altered or added for this project are highlighted in Figure 4-3. As shown in Figure 4-3, the WARMF domain extends south to the contributing area of Panoche Creek, and excludes area further south that does not contribute flow to the San Joaquin River. WestSim subregions located south of Panoche Creek (or not contributing to the San Joaquin River), were not imported as catchments into WARMF. After updating the model setup, WARMF included a total of 78 catchments on the westside of the San Joaquin River, 58 of which corresponded to WestSim subregions and 20 of which were headwater catchments outside the WestSim domain. River segments remained unchanged from the preexisting version of the WARMF San Joaquin River application.



Note: Black lines identify catchment boundaries, blue lines indicate rivers or canals, and brown lines represent county boundaries.

Figure 4-3. Updated WARMF Model Domain

The WARMF-SJR model of the San Joaquin River and its tributary land area between the gages at Lander Avenue and Vernalis was previously calibrated during other studies for flow and water quality.[12] Simulation results from this area were combined in the model with simulated inflows from the updated Westside Region to predict flow and water quality at Vernalis.

Managed Wetland Simulation

The WetManSim model was developed for Reclamation at Lawrence Berkeley National Laboratory. WetManSim relies on descriptions of operations for wetlands, provided by water masters, refuge water supply coordinators, and refuge managers for Federal, State, and private wetlands within the San Joaquin Valley (Quinn and Tulloch, 2002). The model considers the following wetland areas: Grassland Water District (combining the North and South Grassland wetland areas); San Luis, West Bear Creek, East Bear Creek, Freitas, and Kesterson units of the San Luis National Wildlife Refuge; Salt Slough and China Island units of the North Grasslands Wildlife Management Area; Los Banos Wildlife Area; and Volta Wildlife Management Area.

WetManSim tracks the fate of monthly applied water within the San Joaquin Valley wetlands by considering a variable flooded area of variable ponded depth. The model considers three distinct periods of different water operations, as follows:

- **August to October: Flood-Up Period** – Flooded area and flooded depth gradually increase.
- **November to February: Maintenance Period** – Flooded area is assumed constant; applied water is used to maintain a constant ponded depth of 12 inches.
- **March to July: Drawdown Period** – Seasonal marshes are drawn down; irrigation occurs to encourage seed propagation.

For the Westside Salt Assessment, WetManSim was used to support the WestSim model in estimating ponding operations within managed wetlands. WetManSim was modified based on WestSim’s subregion definitions. WetManSim’s region-based ponding operations, in terms of maintained water depth, were applied and converted to WestSim element-based ponding operations within the managed wetlands.

[12] Water quality calibration performed for the San Joaquin River in past projects used a broader array of constituents. Water quality calibration for the WSA project was focused on salt and nitrate only.

Chapter 5
Model Input and Data Sources

This chapter briefly summarizes model inputs and data sources that will be used for the water budget analyses. Discussion of data and data sources in this chapter is limited to data needed for model updates and refinement. This chapter does not discuss data already obtained or developed for WestSim and WARMF-SJR (e.g., soils data, agronomic data, groundwater aquifer properties).[13,14]

Meteorological Data

The following sections describe meteorological data used to update the WARMF model for the water budget analysis. Meteorology data for four stations in the Westside Region were collected from the California Irrigation Management Irrigation System (CIMIS) database, and were used to estimate precipitation and ET in the WARMF model. These stations include Kesterson, Los Banos, Panoche, and Firebaugh. The CIMIS Modesto station was used for some parts of the northern Westside Region since no stations north of Kesterson are located west of the San Joaquin River. The periods of record of the data already include the time period specified for the Westside Salt Assessment project (water years 2000 to 2007). The WestSim model consisted of precipitation data from three stations: Tracy Carbona, Los Banos, and Kettleman City. These stations are described further below and were used to obtain precipitation data for the C2VSim model. Thus, no updates were necessary to meteorological data within the WestSim model.

When meteorology stations are imported into WARMF, the nearest station is assigned to each catchment, and a precipitation weighting factor and temperature lapse rate are automatically calculated to account for regional climate variation. After the 78 updated catchments were added to WARMF for the Westside Salt Assessment, meteorology stations were reimported to recalculate the precipitation weighting factors and temperature lapse rates for the entire WARMF domain.

[13] Previous report on WestSim, *WESTSIM: Groundwater conjunctive use, agricultural drainage and wetland return flow simulation on the west-side of the San Joaquin Basin,* is available at http://esd.lbl.gov/files/research/programs/erwr/WESTSIM-A%20surface%20groundwater%20simulation%20model.pdf

[14] Previous report on WARMF, *CV-SALTS Work Plan for Salt and Nitrate Sources Pilot Implementation Study,* is available at www.cvsalinity.org/index.php/documents

Precipitation

Daily precipitation records for 32 National Climatic Data Center (NCDC) weather stations in California's Central Valley have been assembled by DWR for October 1921 through December 2007 as part of C2VSim (Brush, 2008). Table 5-1 summarizes sources of daily data.

Table 5-1. Precipitation Gage Data Sources for Westside Region

Location	Station ID	Station Name	Lat.	Long.	Elevation (feet)	Source	Start	End
Tracy Carbona	NCDC 9001	Tracy Pumping Plant	37 48'	120 35'	61	NCDC	10/1/1969	12/31/2005
	NCDC 8999	Tracy Carbona	37 42'	121 25'	140	UCD	1/1/2006	9/30/2007
Los Banos	NCDC 5118	Los Banos	37 03'	120 52'	120	EarthInfo	10/1/1969	12/31/2004
	NCDC 5118	Los Banos	37 03'	120 52'	120	UCD	1/1/2006	9/30/2007
Kettleman	NCDC 4536	Kettleman Station	36 04'	120 05'	508	DRI	10/1/1969	12/31/2005
	CIMIS 21	Kettleman CIMIS	35 52'	119 54'	340	UCD	1/1/2006	9/30/2007

Key:
CIMIS=California Irrigation Management Information System
DRI=Desert Research Institute
ID = identification
Lat. = latitude
Long. = longitude
NCDC=National Climatic Data Center
UCD=University of California at Davis

Evapotranspiration

Monthly values of reference ETo are available from CIMIS. Table 5-2 summarizes stations within or adjacent to the study area. DWR has also developed ETo spatial data on a 2-kilometer grid. These data were reviewed to determine the significance of the ET spatial variation across the study area. The four stations mentioned above, including Kesterson, Los Banos, Panoche, and Firebaugh, were used to identify meteorological parameters that were inputs to the WARMF model to calculate ET. The initial simulations using WestSim were conducted using estimates of ET for different crop types found in the literature. ET values were updated in WestSim for subsequent simulations; with average ET values by model subregion estimated using the WARMF model.

Table 5-2. Available CIMIS Meteorological Stations

Station Name	Station ID	Latitude	Longitude	Elevation (feet)	Start	End
Five Points	2	36 20' 11"	120 06' 47"	285	06/1982	To date
Firebaugh/Telles	7	36 50' 04"	120 35' 25"	185	09/1982	To date
Stratford	15	36 09' 27"	119 51' 00"	193	10/1982	To date
Kettleman	21	35 52' 08"	119 53' 39"	340	11/1982	To date
Los Banos	56	37 05' 36"	120 45' 39"	95	06/1982	To date
Modesto	71	37 38' 43"	121 11' 16"	35	06/1982	To date
Kesterson	92	37 13' 55"	120 52' 51"	75	11/1982	To date
Westlands	105	36 38' 00"	120 22' 55"	191	04/1982	To date
Panoche	124	36 53' 25"	120 43' 55"	183	07/1982	To date
Patterson	161	37 26' 24"	121 08' 20"	183	08/1982	To date
Tracy	167	37 43' 34"	121 28' 26"	82	09/1982	To date

Source: CIMIS, 2010`

Key:
CIMIS = California Irrigation Management Information System

Land Use

Land-use data are central to development of the water budgets. These data are needed to estimate stormwater runoff, ET, and irrigation demands. Data on land use are available from several sources discussed below.

DWR County Land-Use Surveys

DWR surveys of land use began in the early 1950s for specific projects and investigations. By the mid-1960s, DWR had started an ongoing program to perform land-use surveys every year. Since 1950, DWR has conducted over 250 land-use surveys of all, or parts of, California's 58 counties.

The main emphasis of DWR's land-use surveys is mapping agricultural land. Over 70 different crops or crop categories are included in the surveys.[15] Urban and native vegetation (undeveloped) areas are mapped, but not with the detail used for agricultural land. Land-use surveys are conducted by county, and are updated approximately every 7 years.[16] County surveys available for the west side of the San Joaquin Valley are listed in Table 5-3.

[15] Land use classifications for these surveys are described in the *Standard Land Use Legend* (DWR, 1993).
[16] These data are available from DWR's Division of Planning and Local Assistance at http://www.landwateruse.water.ca.gov/basicdata/landuse/digitalsurveys.cfm

Table 5-3. County Land-Use Surveys

Counties Intersecting Study Area[1]	Years Land-Use Surveys Performed
San Joaquin	1988,1996
Stanislaus	1996, 2000
Merced	1995, 2002
Fresno	1986, 1994, 2000
Kings	1991, 1996, 2003

Note:
[1] The model domain covers parts of San Joaquin, Stanislaus, Merced, Fresno, and Kings counties.

DWR Water Plan Data

DWR's land and water use database comprises annual data related to agricultural, managed wetlands, and urban lands for the *California Water Plan Update* (DWR, 2009).[17] Available data include annual agricultural land use for 20 crop categories for water years 1998 through 2005. These land-use data are derived from the county land-use surveys described above, and interpolation extrapolation based on agricultural commissioners' reports. The data are not georeferenced, but are organized by Detailed Analysis Unit (DAU) and by county. The valley floor part of the study area comprises part of DAU 186 (the portion that lies within the Delta), DAU 216, and part of DAU 244.

As part of the *California Water Plan Update*, DWR staff have completed annual water balances for the Central Valley for water years 1998 through 2005 (DWR, 2009). These land-use-based water balances include information on area and types of habitat for managed wetlands in the San Joaquin Valley.

USGS Land-Use Data

Derived from early to mid-1990s Landsat Thematic Mapper satellite data, the USGS National Land Cover Data (NLCD) are a 21-class land cover classification scheme applied consistently over the United States (USGS, 2010c). Spatial resolution of the data is 30 meters, and data are mapped in the Albers Conic Equal Area projection, North American Datum 83. The NLCD are provided on a state-by-state basis. For the Westside Salt Assessment, the NLCD contains more land classes for undeveloped lands in the upstream watersheds.

Water Agency Data

Water districts receiving water from the CVP report annual crop acreage to Reclamation. These data are based on projected acreage before planting. Actual crop acreage depends on CVP water allocations for south-of-Delta contractors. The following extract from the *Westside Integrated Water Resources Plan* (SLDMWA, 2006) illustrates the difficulty in obtaining accurate estimates of crop acreage.

[17] These data are available from the Division of Planning and Local Assistance at http://www.landwateruse.water.ca.gov/annualdata/datalevels.cfm

Irrigated acreage data for 1999 was obtained from district records. The data is actually harvested acreage, including acres harvested more than once (multiple-cropped acres) in 1999. For example, if an acre of lettuce is harvested in the spring and the same acre is replanted to grains and harvested in the fall, two irrigated acres are counted. Therefore, the amount of harvested acres typically exceeds the amount of land irrigated to produce those harvests. The 1999 harvested acreage data did not include acreage that was not harvested because of a water shortage in 1999. The shortage, reflective of a CVP allocation 30 percent below full contract entitlement, is representative of the chronic shortages experienced by the region.

The Westside districts estimated 49,709 acres were fallowed in 1999 as a result. This acreage was added into the total 1999 acreage to obtain an estimate of potential irrigated acreage if water supply had not been a limiting factor.

Irrigated pasture is not actually harvested but is included as irrigated acreage in the analysis. However, the 1999 harvested acreage data did not include other irrigated acreage that was not harvested. This acreage is primarily immature, non-bearing fruit trees and vines that did not produce a crop in that year. Westside water users estimated an additional 30,000 acres for this irrigated land in 1999. The acreage data also allowed for 14,000 acres of land retired under the Westlands Water District land acquisition program. The acreage was not included in the 1999 total.

Wildlife refuges that have entered into water supply contracts with Reclamation as a result of the CVPIA are required to prepare Refuge Management Plans. These Refuge Management Plans are updated every 5 years, and were first prepared in 2005; updates are due in 2010. The refuges also submit annual updates to Reclamation describing actions taken in implementing the Refuge Management Plan for the previous year, and forecast implementation actions and proposed changes for the current year. The annual update is limited to reporting on best management practices. The 2005 Refuge Management Plans (revised 2006) report habitat acreage for 2004.

Land-Use Categories

Categories of land use and land cover vary between data sources, as follows:

- DWR county land-use data contain about 167 separate land cover designations
- NLCD contains about 15 separate land cover designations
- CV-SALTS selected 33 land cover classes

Correlation between CV-SALTS and DWR California Water Plan, land cover classes, and the proposed land cover classes for this study, is shown in Table 5-4.

WestSim Model Land-Use Update Methodology

A spatial analysis was completed to develop GIS land-use layer information from a mosaic of DWR county land-use surveys at two representative times. In the water budget analysis study, the first representative time (Time 1) is 2000, and the second representative time (Time 2) is 2007. DWR completed surveys in different years for the counties of interest. Therefore, surveys from years with the most complete datasets and closest date to Time 1 and Time 2 were selected for each county. Consequently, for Time 1, the following years were used for the associated counties:

- Fresno – 1994
- Kings – 1996
- Madera – 1995
- Merced – 1995
- San Joaquin – 1988
- Stanislaus – 1996

And for Time 2, the following years were used for the associated counties:

- Fresno – 2000
- Kings – 2003
- Madera – 2001
- Merced – 2002
- San Joaquin – 1996
- Stanislaus – 1996

For some counties, only a single survey year was available electronically, or the older data were too old to be considered.

The next step in the process to update the land-use information in the WestSim model involved condensing the DWR land-use classes into more generalized classes. The land-use data were next intersected with WestSim model element polygons to obtain land use for each model element. Finally, a tabular analysis was completed to approximate land use for model subregions using data produced on an element level. A linear interpolation was then used to approximate land use in years between Time 1 (~2000) and Time 2 (~2007).

Table 5-4. Land-Use Classes

CV-SALTS	California Water Plan	WestSim	DWR Land-Use ID	Westside Salt Assessment
Perennial forages	Alfalfa	Alfalfa	P1	Alfalfa
Orchard	Almonds/pistachios	Orchard	D12, D14	Almonds/pistachios
Cotton	Cotton	Cotton	F1	Cotton
Warm season cereals and forages	Corn	Field crops	F6	Corn
Other row crops	Cucurbits	Truck crops	T9	Cucurbits
Other row crops	Beans (dry)	Field crops	F10	Beans
Warm season cereals and forages	Other field	Field crops	F, F4, F7, F8	Other field
Other row crops	Other field	Field crops	F3, F9, F11, F12	Other field
Winter grains and safflower	Grain	Grain	G, G1, G2, G3, G6	Grain
Other row crops	Onions and garlic	Truck crops	T10	Onions and garlic
Orchard	Other deciduous	Orchard	D, D1-D10, D13	Other deciduous
Perennial forages	Pasture	Pasture	P, P2-P7	Pasture
Other row crops	Potatoes	Truck crops	T12	Potatoes
Rice	Rice	Rice	R	Rice
Other row crops	Sugar beets	Sugar beets	F5	Sugar beets
Winter grains and safflower	Safflower	Field crops	F2	Safflower
Olives, citrus, and subtropicals	Subtropical	Citrus and olives	C, C1, C8, C9, C10	Subtropical
Other row crops	--	Citrus and olives	C9	--
Other row crops	Tomatoes, hand-picked	Tomatoes, hand-picked	T15	Tomatoes, hand-picked
Other row crops	Tomatoes, machine-picked	Tomatoes, machine-picked	T15	Tomatoes, machine-picked
Other row crops	Other truck	Truck crops	T, T1, T11, T13, T14, T17, T18, T19, T20-T25	Other truck
Flowers and nursery	Other truck	Truck crops	T16	Other truck
Vines	Vineyards	Vineyards	V, V1, V2, V3, F4, C8, T19	Vineyards
Marsh	--	Seasonal wetland	NR4	Seasonal wetland – irrigated
Marsh	--	Permanent wetland	NR5	Permanent wetland – irrigated
Marsh	--	Permanent wetland	NR1, NR2, P5	Permanent wetland – nonirrigated

Table 5-4. Land-Use Classes (contd.)

CV-SALTS	California Water Plan	WestSim	DWR Land-Use ID	Westside Salt Assessment
Paved areas	--	Urban	UV4, UV6	Paved areas
Urban residential	--	Urban	U, UR, UR3, UR4, UR21-UR24, UR31-UR34, UR41-UR44	Urban residential
Urban landscape	--	Urban	UL, UC8, UI12, UL1-UL4, Z	Urban landscape
Urban commercial and industrial	--	Urban	UC, UC1-UC7, UI, UI1-UI3, UI7-UI11	Urban commercial and industrial
Urban C&I, low impervious surface	--	Urban	UI6, UI14, UI15, UV, UV1, UV3	Urban C&I, low impervious surface
Farmsteads	--	Urban	S1, S3, UR1, UR2, UR11-UR14	Farmsteads
Farmsteads	--	Urban	S1, S3	Farmsteads
Other CAFOs	--	Urban	S2, S4	Other CAFOs
Sewage treatment plant, including ponds	--	Urban	UI13	Sewage treatment plant, including ponds
Native classes unsegregated	--	Native vegetation	E, NC, NS	Native classes unsegregated
Deciduous forest	--	Riparian	NR, NR3, C10	Deciduous forest
Fallow	--	Native vegetation	I1, I2	Fallow
Shrub/scrub	--	Native vegetation	NB1, NV2-NV4	Shrub/scrub
Barren land	--	Native vegetation	NB, NB2-NB5	Barren land
Mixed forest	--	Native vegetation	NV5, NV6	Mixed forest
Evergreen forest	--	Native vegetation	Not used (NLCD class)	Evergreen forest
Grassland/herbaceous	--	Native vegetation	NV, NV1, NV7	Grassland/herbaceous
Water	--	Native vegetation	NW	Water

Key:
-- = Not applicable
C&I = Commercial and Industrial
CAFO = Concentrated Animal Feed Operations
CV-SALTS – Central Valley Salinity Alternatives for Long-Term Sustainability
DWR = California Department of Water Resources
NLCD = National Land Cover Data
WestSim = Westside Simulation Model

WARMF Model Land-Use Update

A total of 30 land-use classes occurred within the 58 new WARMF catchments. Of the 30 classes, 18 corresponded to land-use classes defined in the previous WARMF application and were simply renamed to match the WestSim classification. The remaining 12 classes were added to WARMF, resulting in a total of 44 land-use classifications defined in WARMF (32 previous classes plus 12 new classes). Land-use data for the 20 headwater catchments were obtained from the USGS NLCD. All of the land-use classes occurring in the headwater catchments were previously defined in WARMF. The final 44 WARMF land-use classes, along with the corresponding classes from WestSim and the preexisting version of WARMF, are listed in Table 5-5.

Table 5-5. Updated WARMF Land-Use Classifications

Updated WARMF Land-Use Class	WestSim Land-Use Class	Previous WARMF Class
Alfalfa	Alfalfa	N/A
Almonds	Almonds	N/A
Bare Soil	Bare soil	Barren land
Beans	Beans	N/A
Corn	Corn	Warm season cereals and forages
Cotton	Cotton	Cotton
Cucurbits	Cucurbits	N/A
Evergreen forest	N/A	Evergreen forest
Facility	N/A	Facility
Fallow	N/A	Fallow
Farmsteads	Farmsteads	Farmsteads
Flowers and nursery	N/A	Flowers and nursery
Grain	Grain	N/A
Lagoon	N/A	Lagoon
Land construction dairy land application	N/A	Land construction dairy land application
Mixed forest	N/A	Mixed Forest
Grassland/herbaceous	Native vegetation	Grassland/Herbaceous
Onions and garlic	Onions and garlic	N/A
Open water	Open water	Water
Other CAFOs	Other CAFOs	Other CAFOs
Other deciduous	Other deciduous	Orchard
Other field	Other field	N/A
Other truck	Other truck	Other row crops
Pasture	Pasture	Perennial forages
Paved areas	N/A	Paved areas
Permanent wetland	Permanent wetland	Marsh
Pistachios	Pistachios	N/A
Potatoes	Potatoes	N/A
Resting dairy land application	N/A	Resting dairy land application
Rice	Rice	Rice
Riparian	Riparian	Deciduous forest
Safflower	Safflower	Winter grains and safflower
Seasonal wetland	Seasonal wetland	N/A
Sewage treatment plant including ponds	Sewage treatment plant, including ponds	Sewage treatment plant including ponds
Shrub/scrub	N/A	Shrub/scrub
Subtropical	Subtropical	Olives, citrus, and subtropicals
Sugar beets	Sugar beets	N/A
Tomatoes	Tomatoes	N/A
Unconstructed dairy land application	N/A	Unconstructed dairy land application
Urban C&I, low impervious	N/A	Urban C&I, low impervious

Table 5-5. Updated WARMF Land-Use Classifications (contd.)

Updated WARMF Land-Use Class	WestSim Land Use-Class	Previous WARMF Class
Urban community/industrial	N/A	Urban community/industrial
Urban landscape	N/A	Urban landscape
Urban residential	Urban	Urban residential
Vineyards	Vineyards	Vines

Key:
C&I = Commercial and Industrial
CAFO = Concentrated Animal Feed Operations
WARMF = Watershed Analysis Risk Management Framework
WestSim = Westside Simulation Model

Irrigation and Refuge Water Supply

An important task in updating the WestSim and WARMF models for the Westside Salt Assessment was identifying irrigation sources, and allocating irrigation water to each individual subregion or catchment. The sources of irrigation water used in the WestSim and WARMF models included CVO reports of monthly surface water deliveries to CVP contractors and San Joaquin River diversions.

CVO data was available for all the study area watersheds therefore this data was used for the water budgets for the entire Westside Salt Assessment. CVO Monthly Delivery Tables provide data on deliveries from the DMC, Mendota Pool, and Joint Reach of the California Aqueduct (2010), as provided in Table 5-6.

The WARMF model includes 21 irrigation districts, 4 cities, and several unincorporated areas in the Westside Region that receive irrigation water to support agriculture. In addition, the region includes 10 units of federal, state, or private refuges that receive water for flooding ponds to maintain seasonal wetlands and to irrigate seasonal wetlands. Water sources for these districts, cities, and refuges are diversions from the DMC (via San Luis Canal or at the Mendota Pool) and San Joaquin River, as well as pumped groundwater.
Table 5-6 lists the mean annual deliveries (Water Years 2000 to 2007) for diversions from the DMC, Mendota Pool and San Luis Canal., obtained from CVO Tables 24, 25, and 26 (Reclamation, 2010). DMC diversions with outflow points above the O'Neill Forebay (canal mile 70.01) are specified as "Upper DMC" diversions, while those with outflow points below the Forebay are "Lower DMC" diversions. Table 5-7 lists the mean annual deliveries for diversions from the San Joaquin River, along with WestSim diversion numbers from which the data were obtained.

Table 5-6. Delta-Mendota Canal, Mendota Pool, and San Luis Canal Diversions from Central Valley Operations Tables

Water Source	CVO Table	Receiving Entity	Mean Annual Delivery (acre-feet/year)
Upper DMC	25	Banta-Carbona ID	1,964
Upper DMC	25	Byron Bethany ID	3,277
Upper DMC	25	CCID Above Check 13	15,245
Upper DMC	25	Centinella WD	41
Upper DMC	25	City of Tracy	8,242
Upper DMC	25	Del Puerto WD	80,462
Upper DMC	25	Patterson WD	5,947
Upper DMC	25	West Stanislaus WD	32,679
Upper DMC	25	Westside ID	825
Upper DMC	25	Grassland WD (Volta)	37,186
Upper DMC	25	Kesterson NWA (Volta)	4,085
Upper DMC	25	Volta WMA	7,911
Lower DMC	25	Broadview WD	6,487
Lower DMC	25	CCID Below Check 13	77,727
Lower DMC	25	Eagle Field WD	2,446
Lower DMC	25	Firebaugh Canal Co.	26,652
Lower DMC	25	Mercy Springs WD	1,478
Lower DMC	25	Oro Loma WD	1,088
Lower DMC	25	Panoche WD	6,375
Lower DMC	25	San Luis WD	11,158
Lower DMC	25	Widren WD	66
Lower DMC	25	China Island Unit – N. Grasslands WA	2,976
Lower DMC	25	Freitas Unit – San Luis NWA	3,472
Lower DMC	25	Grassland WD (76.05L)	60,249
Lower DMC	25	Kesterson NWA (76.05L)	1,651
Lower DMC	25	Los Banos WMA	5,135
Lower DMC	25	Salt Slough Unit – N. Grasslands WA	4,718
Mendota Pool	24	CCID	421,013
Mendota Pool	24	Columbia Canal Co.	53,535
Mendota Pool	24	Firebaugh Canal Co.	33,564
Mendota Pool	24	San Luis Canal Co.	138,846
Mendota Pool	24	China Island Unit – N. Grasslands WA	4,821
Mendota Pool	24	Freitas Unit – San Luis NWA	5,600
Mendota Pool	24	Grassland WD	129,549
Mendota Pool	24	Kesterson NWA	2,424
Mendota Pool	24	Los Banos WMA	15,565
Mendota Pool	24	Salt Slough Unit – N. Grasslands WA	6,513
Mendota Pool	24	San Luis Unit – San Luis NWA	31,646
San Luis Canal	26	Pacheco WD	7,633
San Luis Canal	26	Panoche WD	52,175
San Luis Canal	26	San Luis WD	65,735
O'Neill Forebay	26	San Luis WD	9,179

Source: Reclamation 2010
CCID = Central California Irrigation District
DMC = Delta-Mendota Canal
ID = Irrigation District
NWA = National Wildlife Area
WA = Wildlife Area
WD = Water District
WMA = Wildlife Management Area

Table 5-7. San Joaquin River Diversions from WestSim

Receiving Entity	WARMF Diversion Name	WestSim Diversion	Mean Annual Delivery (acre-feet/year)
Freitas Unit – San Luis NWA	SJR Frietas	WestSim Diversion 1	1,511
China Island Unit – N. Grasslands WA	SJR China Island	WestSim Diversion 2	7,920
Unincorporated Area – Catchment 955	SJR Riparian 955	WestSim Diversions 4+5+6	6,155
City of Crows Landing	SJR Crows Landing	WestSim Diversion 7	1,350
Patterson WD	SJR Patterson	WestSim Diversions 8+9+11+12	40,765
Unincorporated Area – Catchment 188	SJR Riparian 188	WestSim Diversion 13+14	4,574
West Stanislaus WD	SJR West Stanislaus	WestSim Diversions 15+16+18	13,179
Catchment 188 & West Stanislaus ID	SJR Riparian 188 & 200	27% of WestSim Diversion 17	11,010
Byron Bethany ID	SJR Byron Bethany	WestSim Diversions 19+21	5,752
El Solyo WD	SJR El Solyo	WestSim Diversion 20	22,004
Banta Carbona ID	SJR Banta Carbona	WestSim Diversions 23+24	37,770

Key:
ID = Irrigation District
NWA = National Wildlife Area
SJR = San Joaquin River
WA = Wildlife Area
WARMF = Watershed Analysis Risk Management Framework
WD = Water District
WestSim = Westside Simulation Model

Diversions from the DMC, Mendota Pool, and San Joaquin River are diverted from river and canal segments that are included in the WARMF model domain. WARMF diverts the quantity of water supply from its respective river or canal segments and uses the water quality within those segments for the water supply. A few districts in the Westside Region use irrigation water diverted from river and canal segments that are not a part of the WARMF model domain, namely from the O’Neill Forebay and California Aqueduct. For these diversions, the flow and water quality were directly input as irrigation supply to the appropriate catchments, rather than diverted from river segments within the WARMF model domain. The O’Neill Forebay delivery quantities were obtained from CVO tables, and DMC water quality data were used since no water quality data for the canal and forebay were readily available. The California Aqueduct diversion was included to supply irrigation water to Oak Flat Water District, which has a contract with the SWP. The contracted annual delivery amount of 5,700 acre-feet/year was used for the delivery quantity. It was assumed that the difference between DMC and California Aqueduct water quality would not have a measurable impact on results since the amount of water involved (5,700 acre-feet/year) was small relative to total DMC deliveries.

After the diversion data were collected, the next step was allocating irrigation water to each new Westside WARMF catchment. For agricultural areas, this process involved both analyzing the agricultural demand within each catchment and evaluating total delivery quantities. The agricultural demand, augmented to account for irrigation inefficiencies, was obtained from WestSim model output. The WestSim demand for each catchment is listed in
Table 5-8. The demand values presented in Table 5-8 for the wildlife refuge catchments are the crop demand for the small portion of agricultural land-use area within those catchments. The values do not include water applied to wetland areas; thus, total water applied significantly exceeds the demand listed.

Table 5-8. Average Annual WestSim Crop Demand, Applied Surface Water, Applied Groundwater, Allocation Logic, and Return Flow by Catchment

WestSim ID	WARMF ID	WestSim Demand (acre-feet/year)	Applied Surface Water (acre-feet/year)	Applied Groundwater (acre-feet/year)	Basis for Allocation Logic	Return Flow (acre-feet/year)
1	250	14,936	592	14,344	Surface Water	0
2	181	11,927	8,174	3,753	Surface Water	0
3	178	7,335	291	7,044	Surface Water	0
4	224	18,366	9,437	8,929	Surface Water	0
5	183	42,435	39,762	2,673	Surface Water	0
6	220	27,478	16,362	11,116	Surface Water	0
7	189	9,552	9,552	0	Surface Water	0
8	188	33,191	21,514	11,677	Surface Water	0
9	200	63,714	51,393	12,320	Surface Water	0
10	954	5,814	5,035	779	Surface Water	0
11	831	18,488	4,223	14,266	Surface Water	0
12	833	50,233	46,818	3,415	Surface Water	0
13	965	7,691	5,700	1,991	Surface Water	0
14	853	12,591	6,916	5,675	Surface Water	0
15	962	14,814	9,742	5,072	Surface Water	0
16	959	48,354	18,869	29,485	Groundwater	38,553
17	955	3,959	3,959	0	Surface Water	0
18	963	7,556	6,531	1,024	Surface Water	0
19	956	10,203	10,203	0	Surface Water	1,914
20	843	3,162*	15,355	3,071	Surface Water	0
21	964	4,551	3,253	1,298	Surface Water	0
22	850	75*	8,198	1	Surface Water	0
23	849	20*	11,039	20	Surface Water	0
24	848	0*	9,494	0	Surface Water	0
25	828	13,919	10,924	2,995	Surface Water	0
26	829	105,269	83,240	22,029	Groundwater	41,771
27	830	4,970*	138,027	4,970	Surface Water	0
28	957	1,083*	11,630	1,083	Surface Water	0
29	847	646*	22,152	646	Surface Water	0
30	815	13	0	13	Surface Water	0

Table 5-8. Average Annual WestSim Crop Demand, Applied Surface Water, Applied Groundwater, Allocation Logic, and Return Flow by Catchment (contd.)

WestSim ID	WARMF ID	WestSim Demand (acre-feet/year)	Applied Surface Water (acre-feet/year)	Applied Groundwater (acre-feet/year)	Basis for Allocation Logic	Return Flow (acre-feet/year)
31	823	6,240	6,189	51	Surface Water	0
32	818	1,515	41	1,474	Surface Water	0
33	846	1,611*	20,917	465	Surface Water	0
34	845	766*	7,646	766	Surface Water	0
35	819	2,622	2,601	22	Surface Water	0
36	844	57,805	34,770	23,035	Groundwater	33,876
37	798	106,975	85,899	21,076	Groundwater	52,947
38	966	7,524	0	7,524	Surface Water	0
39	790	41,568	20,322	21,246	Surface Water	0
40	792	46,551	26,693	19,858	Groundwater	28,588
41	796	201*	6,108	201	Surface Water	0
42	793	826*	81,143	547	Surface Water	0
43	839	4,110	4,110	0	Surface Water	771
44	417	160,811	121,241	39,570	Groundwater	69,729
45	780	11,746	11,175	571	Surface Water	0
46	778	5,242	2,585	2,657	Surface Water	0
47	777	3,148	1,447	1,701	Surface Water	0
48	761	15,516	10,807	4,709	Surface Water	0
49	776	16,012	0	16,012	Surface Water	0
50	779	12,438	7,633	4,805	Surface Water	0
51	468	6,345	6,302	43	Groundwater	43
52	471	2,985	74	2,911	Surface Water	0
53	446	18,306	18,181	125	Groundwater	125
54	415	32,143	9,705	22,438	Groundwater	43,830
55	338	95,600	58,445	37,155	Surface Water	0
56	386	24,467	7,831	16,636	Surface Water	0
57	389	25,616	25,429	187	Groundwater	187
59	21	55,280	54,560	720	Surface Water	0

Note:
*Demand values do not include irrigation requirement for maintenance of wetlands
Key:
WARMF = Watershed Analysis Risk Management Framework
WestSim = Westside Simulation Model

The available surface water for a given catchment was identified based on delivery data for the corresponding receiving entity from CVO Monthly Delivery Tables (irrigation district, city, or refuge). If more than one catchment is represented by a given entity (e.g., CCID catchments), the diversion for that entity was divided in proportion to the irrigation water demand within each catchment. Resulting surface water allocations for each catchment receiving irrigation water are listed in Table 5-9. Diversions are noted by the abbreviations DMC, MP, San Luis Canal (SLC), and SJR for the DMC, Mendota Pool, San Luis Canal, and San Joaquin River, respectively. Values in parentheses are fractions of a given diversion allocated to that catchment, weighted by area receiving the diversion. If no fraction precedes a diversion, 100 percent of the diversion was allocated. The allocations in Table 5-9 were used along with delivery totals in Tables 5-6 and 5-7 to result in the average annual amount of surface water available for irrigation in each catchment (but not necessarily the total applied).

In some catchments, groundwater pumping information was available to estimate the total amount of groundwater applied as irrigation. In such cases, the known amount of groundwater applied was compared to the total catchment average annual agricultural demand (Table 5-8). If the total demand exceeded the amount of groundwater available, the remaining demand was met by all or a portion of, the available surface water calculated, as described above. Any excess amount of surface water remaining was applied directly to the catchment's outflow river segment as return flow. When no groundwater information was available, the logic to allocate surface water and groundwater was reversed. The total available surface water was first compared to the average annual WestSim demand (Table 5-8). If the demand could not be entirely met by all available surface water sources for a given catchment, the remaining demand was assumed to be met by groundwater. If the available surface water exceeded the demand, only the portion of the surface water equal to the demand was applied as irrigation, and the remainder was assumed to enter the river segment as return flow. Table 5-8 lists the resulting average annual surface water and groundwater applied for each catchment, the allocation logic used (groundwater or surface water first), and the resulting amount of return flow.

Table 5-9. Sources and Allocations of Irrigation Water from Surface Diversions to Each Agricultural Catchment

WestSim ID Subregions	WARMF ID Catchment	Name	Surface Delivery Diversion Names and Allocations
1	250	Westside WD (West)	(0.67)DMC Westside WD
2	181	City of Tracy	DMC City of Tracy
3	178	Westside WD (East)	(0.33)DMC Westside WD
4	224	Byron Bethany ID	DMC Byron Bethany ID + SJR Byron Bethany ID
5	183	Banta-Carbona ID	DMC Banta-Carbona ID + SJR Banta Carbona ID
6	220	Hospital WD	(0.22)DMC Del Puerto WD
7	189	El Solyo WD	(0.43)SJR El Solyo WD
8	188	San Joaquin/Stanislaus Unincorp.	SJR Riparian 188 + (0.4)SJR Riparian 188 and 200 + (0.57)SJR El Solyo WD
9	200	West Stanislaus ID	SJR W. Stanislaus ID + (0.6)SJR Riparian 188 and 200 + DMC W. Stanislaus ID

Table 5-9. Sources and Allocations of Irrigation Water from Surface Diversions to Each Agricultural Catchment (contd.)

WestSim ID Subregions	WARMF ID Catchments	Name	Surface Delivery Diversion Names and Allocations
10	954	Kern Canyon WD	(0.06)DMC Del Puerto WD
11	831	Del Puerto WD	(0.05)DMC Del Puerto WD
12	833	Patterson WD	SJR Patterson WD + DMC Patterson WD
13	965	Oak Flat WD	CA Aqueduct Point Source
14	853	Sunflower WD	(0.09)DMC Del Puerto WD
15	962	Orestimba WD	(0.12)DMC Del Puerto WD
16	959	CCID (North)	DMC CCID Abv 13+(0.54)DMC CCID Below13
17	955	Stanislaus/Merced Unincorp.	(0.64)SJR Riparian 955
18	963	Foothill WD	(0.08) DMC Del Puerto WD
19	956	City of Newman	(0.16)DMC CCID Below13
20	843	China Island Unit	DMC China Island + MP China Island + SJR China Island
21	964	Davis WD	(0.04)DMC Del Puerto WD
22	850	San Luis/Kesterson NWA	DMC Kesterson-Volta + DMC Kesterson-76.05L + MP Kesterson
23	849	Freitas Unit	SJR Frietas + MP Frietas + DMC Freitas
24	848	West Bear Creek Unit	(0.3)MP San Luis NWR
25	828	Mustang WD	(0.14)DMC Del Puerto WD
26	829	CCID (North-Central)	(0.30)DMC CCID Below13 + (0.24)MP CCID
27	830	Grassland WD (North)	DMC Grassland-Volta + DMC Grassland-76.05L + (0.25)MP Grassland
28	957	Salt Slough Unit	DMC Salt Slough + MP Salt Slough
29	847	San Luis Unit – San Luis NWR	(0.7)MP San Luis NWR
30	815	Lansdale Water District	None
31	823	Quinto WD	(0.08)DMC Del Puerto WD
32	818	Centinella WD	DMC Centinella WD
33	846	Los Banos WMA	DMC Los Banos WMA + MP Los Banos WMA
34	845	Volta WMA	DMC Volta WMA
35	819	Romero WD	(0.03)DMC Del Puerto WD
36	844	CCID (South-Central)	(0.16)MP CCID
37	798	San Luis Canal Co.	MP San Luis Canal Co.
38	966	City of Los Banos	None
39	790	San Luis WD (DMC)	DMC San Luis WD + OFB San Luis WD
40	792	CCID (South)	(0.13) MP CCID
41	796	Gadwell Unit	(0.07)MP Grassland WD

Table 5-9. Sources and Allocations of Irrigation Water from Surface Diversions to Each Agricultural Catchment (contd.)

WestSim ID Subregions	WARMF ID Catchments	Name	Surface Delivery Diversion Names and Allocations
42	793	Grassland WD (South)	(0.68)MP Grassland WD
43	839	City of Dos Palos	(0.01)MP CCID
44	417	CCID	(0.45) MP CCID
45	780	San Luis WD (SLC – North)	(0.17)SLC San Luis WD
46	778	Eagle Field WD (South)	DMC Eagle Field WD
47	777	Oro Loma WD	DMC Oro Loma WD
48	761	San Joaquin River Improvement Project	DMC Mercy Springs WD + (0.35)DMC Firebaugh
49	776	Camp 13	None
50	779	Pacheco WD	SLC Pacheco WD
51	468	Firebaugh Canal Co. (West)	(0.25)DMC Firebaugh Canal Co.
52	471	Widren Water District	DMC Widren WD
53	446	Firebaugh Canal Co. (North)	(0.40)DMC Firebaugh + (0.24)MP Firebaugh
54	415	Columbia Canal Co.	MP Columbia Canal Co.
55	338	Panoche WD (DMC/SLC)	DMC Panoche WD + SLC Panoche WD
56	386	Broadview WD	DMC Broadview WD
57	389	Firebaugh Canal Co. (South)	(0.76)MP Firebaugh
59	21	San Luis WD (SLC – South)	(0.83)SLC San Luis WD

Key:
CA = California
CCID = Central California Irrigation District
DMC = Delta-Mendota Canal
ID = Irrigation District
MP = Mendota Pool
NWA = National Wildlife Area
NWR = National Wildlife Refuge
OFB = O'Neil Forebay
SJR = San Joaquin River
SLC = San Luis Canal
WARMF = Watershed Analysis Risk Management Framework
WD = Water District
WestSim = Westside Simulation Model
WMA = Wildlife Management Area

An alternate assumption 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 5-10 below describes the two irrigation scenarios. Although no direct information was obtained to validate this assumption, the modeling scenario was conducted to test the sensitivity of the calibration to these new assumptions.

Table 5-10. 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

The alternate scenario impacted irrigation and return flow amounts in seven catchments. The adjusted values from Table 5-8 for those seven catchments are listed in Table 5-11. Results are presented in Chapter 7 for both the original and the alternate irrigation scenarios.

Table 5-11. Adjusted Average Annual Crop Demand, Applied Surface Water, and Return Flow by Catchment for Alternate Irrigation Scenario (30% Irrigation Increase)

WestSim ID	WARMF ID	Adjusted Demand (+30%) (acre-feet/year)	Adjusted Applied Surface Water (acre-feet/year)	Adjusted Return Flow (acre-feet/year)
16	959	62,860	33,375	24,047
26	829	136,849	114,820	10,191
36	844	75,146	52,111	16,534
37	798	139,067	117,991	20,855
40	792	60,516	40,658	14,623
44	417	209,055	169,485	21,486
54	415	41,785	19,347	34,188

Key:
WARMF = Watershed Analysis Risk Management Framework
WestSim = Westside Simulation Model

For refuge (wetland management) areas, determination of applied irrigation water relied entirely on the calculated amount of surface water delivered (from CVO tables), since demand could be calculated for these areas. If more than one catchment corresponded to a given refuge or diversion, the diversion for that refuge was divided in proportion to the relative area of grassland contained in each catchment.

In a few cases, identifying diversions in the CVO tables corresponding to particular receiving entities was not straightforward because of changes in irrigation district boundaries or changes in how diversions were recorded in the tables over time. The first such case involved Del Puerto Water District. Before 1994, the area that is now Del Puerto Water District comprised 11 smaller districts. Around 1994, these 11 districts merged into 1 larger district. However separate catchments for each of the original 11 districts were maintained in WestSim and, thus, were also defined in WARMF. The DMC diversion for Del Puerto Water District in 2000 to 2007 included water for all 11 original districts. The diversion was divided among the 11 corresponding catchments based on the relative amounts of water they received in 1993 to 1994, and adjusted to meet the current crop demand.

A similar but opposite situation occurred in the Mendota Pool CVO tables for several of the refuge areas. Before 2005, a single large diversion was reported for Federal refuge areas and another for State refuge areas. From 2005 to 2007, the same Federal diversion (in the same table column) was substantially lower (>90 percent reduction), and the State diversion stopped reporting. However, that same year, diversions for two other individual Federal refuge units and four individual State refuge units began reporting. It was assumed that management of the refuge areas did not radically change in 2005 and instead, before this time, the Federal and State diversions included water for all three Federal and four State units, respectively. The pre-2005 diversions were divided based on 2005 to 2007 relative diversion amounts.

The monthly pattern and year-to-year variation of surface water applied for irrigation was assumed to be proportional to the patterns in the associated delivery tables. The diversions typically follow a seasonal pattern: near zero before February, increasing until midsummer, and then decreasing until November. In agricultural catchments, intra-annual variability in total deliveries is generally low. For groundwater applied to agricultural areas and wetland areas, average monthly patterns from the CVO diversions for agricultural and refuge areas, respectively, were assumed.

In all irrigated catchments, more than one land-use class received irrigation water. The total amount of irrigation applied to each catchment thus had to be apportioned to each different irrigated land use. Relative differences between typical water application rates were used to appropriately divide and allocate the total irrigation to each land-use class.

San Joaquin River Diversions

In general, surface water diversions from the San Joaquin River are poorly documented. The most comprehensive study was conducted in 1985 to 1986 by the Central Valley Water Board (CV Water Board, 1989). This study describes 89 points of water diversion along the 150-mile river reach from Mendota Dam, near the town of Mendota, to Mossdale Bridge near Tracy.

WestSim input files contain monthly surface water diversions/deliveries for 83 stream nodes. San Joaquin River stream nodes 1 through 24 represent stream nodes along the San Joaquin River within the model domain, while stream nodes 25 through 83 represent locations to which surface water deliveries are made from outside the model area (e.g., Joint Reach of the California Aqueduct, DMC[18]). Surface water diversion data (record numbers 1 to 24) are data outputs taken from SJRIO, developed by SWRCB.

Streamflow Data

Daily streamflow data are available from a variety of sources, including, but not limited to, USGS, DWR (the water data library and California data exchange center (CDEC)(DWR, 2009b), San Luis Water District, and interested stakeholders, and the Delta-Mendota Water Authority. Flow gages on the San Joaquin River and its tributaries are summarized in Table 2-1.

[18] Although the DMC lies partially within the model domain, it is not represented explicitly in WestSim.

Surface Agricultural Drainage

Surface agricultural drainage results from canal operational spills and tailwater (usually associated with flood or furrow irrigation). These flows are conveyed to the San Joaquin River through natural channels (e.g., Orestimba Creek) or artificial drains (e.g., Grayson Road Drain). Gaged flows on Salt Slough and Mud Slough measure a mix of agricultural drainage and drainage from managed wetlands. With the exception of Orestimba Creek, few gage data exist for the Westside Region tributaries and drains.

The Central Valley Water Board 1989 study lists 193 discharge points along the San Joaquin River between Mendota Dam and the Mossdale Bridge; approximately half of these are located between the Hills Ferry Road Bridge near Newman and Vernalis.

Gaged flows for Orestimba Creek provide the best data for calibrating agricultural return flows. Data for a limited time period are also available for Hospital Creek and Ingram Creek. Kratzer et al. (1987) identified 10 water districts that discharged agricultural drainage to the San Joaquin downstream from the Merced River confluence, as follows:

- Central California Irrigation District
- Del Puerto Water District
- Foothill Water District
- Hospital Water District
- Kern Canon Water District
- Orestimba Water District
- Patterson Irrigation District
- Salado Water District
- Sunflower Water District
- West Stanislaus Irrigation District

Patterson Irrigation District has two flow detention reservoirs and a tailwater recovery system to reduce discharge to the San Joaquin River from both West Stanislaus and Patterson irrigation districts. Kratzer et al. (1987) assumed that 30 percent of irrigation deliveries returned to the San Joaquin River. However, agricultural return flows from CVP water service contractors are likely to have significantly reduced return flows because of reduced CVP south-of-Delta allocations in recent years. Kratzer (Kratzer, 1987) identified agricultural drainage discharges from the Westside Region and mapped water districts to drainage channels.

Groundwater Elevations

Groundwater elevation data are available through the State DWR Groundwater Information Center Web site (http://www.water.ca.gov/groundwater/) and from independent measurements by private well owners, water districts, and municipal water purveyors. A database management system exists for the Westside Region study area, developed as part of the existing WestSim model. Updated groundwater elevation data for the 7-year period, from 2000 through 2007, will be downloaded from each of the available sources and stored in the existing data management system. These data can be used for future efforts to calibrate the groundwater model, and to illustrate regional trends in past and current groundwater elevations.

Deep Groundwater Recharge

The WARMF conceptual hydrologic model representation includes surface flow, infiltration into multiple shallow soil layers, and lateral shallow groundwater flow from these soil layers into the stream channel. WARMF does not simulate further vertical movement of water from shallow groundwater into a deeper, confined aquifer. This flux of water, referred to here as deep groundwater recharge, is a net loss from the system, meaning it is completely removed from the model domain (does not reach any river segment further downstream). Deep groundwater recharge must be estimated or modeled externally and specified as the lower boundary condition for WARMF.

In the initial project plan, deep percolation (groundwater recharge) output from WestSim was to be used directly as deep groundwater recharge input to WARMF. However, after evaluating WestSim output and the two model structures, it was determined that no WestSim model output directly corresponded to WARMF deep groundwater recharge. WestSim deep percolation is similar in that it is water that moves vertically from the root zone into the upper groundwater layer. However, the water can then travel laterally into a stream channel or another subregion's groundwater layer, or move vertically into the lower groundwater layer. Theoretically, some of this water corresponds to WARMF near-surface groundwater flow (which eventually reaches a stream channel) and some corresponds to WARMF deep groundwater recharge. However, no mechanism exists in WestSim to determine how much of the deep percolation in each subregion eventually reaches a stream channel and how much does not. Thus, it was necessary to find an alternative approach for estimating WARMF deep groundwater recharge.

As mentioned, on a mean annual basis, there are five major fluxes of water in a typical near-surface irrigated watershed system. These include two influxes – precipitation and irrigation, three outfluxes – ET, deep groundwater recharge, and streamflow at the watershed outlet. For three of the fluxes (precipitation, irrigation, and streamflow), good observed data were available for three subwatershed areas in the Westside Region: Mud Slough, Salt Slough, and San Luis Drain. ET was modeled in WARMF using the well-established Hargreaves method, and produced results that corresponded well with other published regional estimates. Thus, the final flux, deep groundwater recharge, could be estimated as the remaining outflux from the system by the following relationship:

$$R = P + I - ET - Q \tag{1.1}$$

Where

R is mean annual deep groundwater recharge

P is mean annual observed precipitation

I is mean annual observed irrigation deliveries

ET is mean annual modeled ET

Q is mean annual observed streamflow minus return flows

In watersheds where return flows were assumed to contribute to total flow in the downstream river segment, the portion of the observed streamflow resulting from near-surface outflow and surface runoff was calculated by subtracting return flow from observed streamflow. Results for the Mud Slough, Salt Slough, and San Luis Drain subwatershed areas are shown in Table 5-12. To obtain streamflow for the contributing area to Mud Slough (not including San Luis Drain), San Luis Drain streamflow was subtracted from Mud Slough streamflow. The same calculations were performed for the alternate (30 percent increase) irrigation scenario (Table 5-13).

For each of the subwatershed areas, the ratio of WARMF calculated deep groundwater recharge to the total WestSim deep percolation for the summarized area was determined. This ratio was applied to the WestSim deep percolation monthly time series for each catchment within the subwatershed area. By doing so, the relative spatial and temporal distribution of vertically percolating water simulated in WestSim was maintained, but scaled down to obtain a volume representative of only the deep groundwater recharge component needed for WARMF.

Table 5-12. Annual Fluxes, Deep Groundwater Recharge, and Adjustment Ratio Applied to WestSim Deep Percolation Output for Original Irrigation Scenario

Subwatershed	P (acre-feet/year)	I (acre-feet/year)	ET (acre-feet/year)	Q (acre-feet/year)	R (acre-feet/year)	WARMF Recharge Adjustment Ratio	WARMF R (acre-feet/year)
Mud Slough	94,233	295,235	244,504	32,888	112,075	0.92	103,109
Salt Slough	158,419	452,051	516,391	-15,767	109,845	0.67	73,596
San Luis Drain	61,502	234,860	249,464	26,789	20,110	0.34	6,837

Key:
ET = evapotranspiration
I = mean annual observed irrigation deliveries
P = mean annual observed precipitation
Q = mean annual observed streamflow minus return flows
R = mean annual deep groundwater recharge
WestSim = Westside Simulation Model

Table 5-13. Annual Fluxes, Deep Groundwater Recharge, and Adjustment Ratio Applied to WestSim Deep Percolation Output for Alternate Irrigation Scenario

Subwatershed	P (acre-feet/year)	I (acre-feet/year)	ET (acre-feet/year)	Q (acre-feet/year)	R (acre-feet/year)	WARMF Recharge Adjustment Ratio	WARMF R (acre-feet/year)
Mud Slough	94,233	311,056	251,080	49,515	104,694	0.86	90,037
Salt Slough	158,419	545,610	570,820	77,048	56,161	0.35	19,656
San Luis Drain	61,502	234,860	249,464	26,789	20,110	0.34	6,837

Key:
ET = evapotranspiration
I = mean annual observed irrigation deliveries
P = mean annual observed precipitation
Q = mean annual observed streamflow minus return flows
R = mean annual deep groundwater recharge
WestSim = Westside Simulation Model

Model Work Flow

Each of the models described above (WestSim, WARMF, and WetManSim) requires, as input, a unique dataset derived from measured data, engineering and scientific assumptions, or output of validated models. This assessment relies heavily on all three of these categories of impact, with the greatest emphasis on the use of output from validated models to ultimately arrive at a water budget for the Westside region at a resolution commensurate with the need to assess salt and nitrate sources and their fate and transport.

With each model, a number of input and output files were common or, at a minimum, shared for purposes of comparison. Table 5-14 lists only relevant files that were shared, with emphasis on using the best data available for each model.

Table 5-15 conveys the interdependency of the models being used in this assessment. The data files identified in this table include only those that were shared among models and described in Table 5-14. The prefix identifies the origin of the file data (i.e., model name) and whether the data are time series data (i.e., prefix followed by TS_). The flow of modeling is predominantly from left to right, with model runs shaded in grey. Shared output files follow the model run and are shown as input files in subsequent models. In some cases, iterations among two or more models take place to converge on a solution that provides consistency between models.

Table 5-14. Shared File Descriptions and Purpose

Model	Shared File Name	Shared File Description	Purpose
WetManSim (WMS)	WMS_Wetland Operations	Input – Wetland operations for wet/dry hydrologic year-types	Understand and reflect managed wildlife refuge/preserve (wetland) water use operations
WARMF	WRMF_TS_ET	Output – Calculated ET over study area	Shared ET file for consistency between WestSim and WARMF
	WRMF_TS_Surface Water Flows by Stream/River Reach	Output – Calculated surface water flows by stream/river reach	Shared surface water flow data for comparison with WestSim and measured stream/river flows
	WRMF_TS_Water Budget by Catchment/Subregion	Output – Water Budget for each catchment area	Water budget data used for model calibration across model platforms and final deliverable from Task 2
WestSim (WstSm)	WstSm_Eastside Boundary Conditions	Input – Groundwater and surface water boundary conditions along the eastside	Eastside surface water inflow data from river/stream flows and agricultural return flows
	WstSm_Elements/ Subregions	Input – Geometry of model to define catchment areas	Shared geometry data of catchment/subregion areas for consistency between WestSim and WARMF
	WstSm_Stream/ River Nodes	Input – Stream node locations identifying stream location and reach definitions	Shared to identify resolution of stream/river definitions and reach descriptions
	WstSm_Lake Routine	Input – Lake operations data for use in simulating wetlands	Shared lake operations data with WARMF
	WstSm_TS_CropType by Subregion	Input – Crop acreage data over model simulation (up to predefined number of crop types)	Calculated crop acreage based on interpolated/extrapolated best available crop inventory data
	WstSm_TS_Landuse by Element	Input – Four (4) classification land-use data (agriculture, urban, native, and riparian) by element	Spatial land-use data for consistency with WARMF
	WstSm_TS_Groundwater Budget by Subregion	Output – Groundwater budget for subregions	Groundwater budget for use by WARMF in water budget

Key:
-- = not applicable
WARMF = Watershed Analysis Risk Management Framework
WestSim = Westside Simulation Model
WetManSim = Watershed Management Simulation Model

Table 5-15. Model Work Flow and Data Sharing

Numerical Models					
WetManSim (WMS)		**WestSim (WstSm)**		**WARMF**	
Input Files	**Output Files**	**Input Files**	**Output Files**	**Input Files**	**Output Files**
--	--	WRMF_TS_ET	WstSm_Eastside Boundary Conditions	WstSm_Eastside Boundary Conditions	WRMF_TS_Water Budget by Catchment/Subregion
--	WMS_Wetland Operations	WMS_Wetland Operations	WstSm_Elements/ Subregions	WstSm_Elements/ Subregions	WRMF_TS_Surface Water Flows by Stream/River Reach
--	--	--	WstSm_Stream/ River Nodes	WstSm_Stream/ River Nodes	--
--	--	--	WstSm_TS_CropType by Subregion	WstSm_TS_CropType by Subregion	--
--	--	--	WstSm_TS_Landuse by Element	WstSm_TS_Landuse by Element	--
--	--	--	WstSm_TS_Groundwater Budget by Subregion	WstSm_TS_Groundwater Budget by Subregion	--

Key:
-- = not applicable
WARMF = Watershed Analysis Risk Management Framework

Model development throughout the water budget analysis worked in parallel, and data were shared, as they became available, between the WestSim and WARMF models. Other models, such as WetManSim, were completed at the beginning of the assessment period.

To maintain consistency between the water budget analysis and the salt and nitrate budget analysis, the WARMF model water budget is considered representative for both purposes. The WARMF model water budget and streamflow data were used to understand the volume and makeup of water from each source (i.e., CVP water from the DMC, CVP water from the Mendota Pool, and groundwater), including subsurface groundwater inflows to rivers and streams.

Data Management

Data were managed in a consistent DSS format and were reviewed for quality control. All time-series data were uploaded into a DSS database file in both daily (when available) and monthly formats. The DSS database platform was selected because of its extensive use in CalSim and WestSim. Other file formats that can be exported from DSS include delimited text and Microsoft Excel files. The naming convention for each dataset follows rules of nomenclature that are based on CalSim 3.0 for consistency throughout the study area. Nomenclature includes, but is not limited to, the list of prefixes shown in Table 5-16.

Table 5-16. Data Management Prefix Nomenclature

Data Prefix	Data Type
C_	Channel
D_	Diversion
R_	Return-flow
S_	Storage
SG_	Channel-seepage
SP_	River-spills
C	Flow-channel
D	Flow-delivery
S	Storage
R	Flow-return
L	Flow-delivery
G	Flow-channel
DN_	SW_delivery-net
DG_	SW_delivery-gross
GP_	GW-pumping
RP_	Riparian deliveries
RU_	Reuse
DL_	Delivery-loss
SR_	Surface-runoff
CT_	Closure-term
I_	Inflow
DEMAND_	Demand
I	Flow-inflow
R_	Demand unit-return flow
AW_	Applied-water
UD_	Urban-demand

Notes:
Nomenclature prefixes based on CalSim 3.0.

Key:
GW = groundwater

Chapter 6
Hydrologic Calibration

The hydrologic calibration period for the WARMF model water budget analysis discussed in this report extends from October 1, 1999 to September 30, 2007 (water years 2000 to 2007). Table 6-1 presents average annual flows for water years 2000 to 2007 at Vernalis and the percentile of average annual flows based on flow records from 1984 to 2007.

Table 6-1. Average Annual Flows at Vernalis for Water Years 2000 to 2007

Water Year	Water Year Type1	Average Flow at Vernalis (cfs)	Percentile (based on 1984 – 2007)
2000	Wet	3,920	62
2001	Normal	2,390	48
2002	Dry	1,930	38
2003	Dry	1,920	33
2004	Dry	1,890	29
2005	Wet	5,230	71
2006	Wet	10,153	96
2007	Dry	2.198	39

Note:
[1] Water Year Type percentiles based on data at Vernalis from 1984 to 2007.
Key:
cfs = cubic feet per second

Year 2000 was a wet year at the 62nd percentile. Year 2005 was also a wet year at 71st percentile, while 2006 was the second wettest in the 24-year record analyzed; 2002, 2003, 2004, and 2007 were dry years at 38th, 33rd, 29th, and 39th percentiles, respectively. Year 2001 was a normal year at the 48th percentile. It appears that the San Joaquin River has not experienced any critically dry years since the drought of 1988 – 1992. Even though there were no extreme dry and wet years, the simulation years cover a variety of flow conditions, ranging from the 29th percentile to the 96th percentile.

Simulated flow was compared to observed data at the outlet of the eight subwatershed areas shown in Figure 1-2. Figures 6-1 through 6-8 show the comparison of simulated and observed hydrographs for these eight locations. Simulation results for the two irrigation scenarios discussed in Chapter 5 (Irrigation Scenario 1 and Irrigation Scenario 2, with 30 percent increased irrigation) are shown, where applicable. Scenario 1 results are shown in Figures 6-1 through 6-8 in blue lines, Scenario 2 results are shown in green lines, and observed data are shown in black circles. If only a green line is visible, there was little to no difference between the two scenarios; therefore, the blue line is directly underneath the green line. Differences in the simulations and observations occur because of a combination of model error (e.g., due to model approximations of complex natural processes), data and input error (e.g., incorrect assumptions about irrigation application, drainage patterns, return flows), and data measurement uncertainty (e.g., error in measured precipitation or streamflow data).

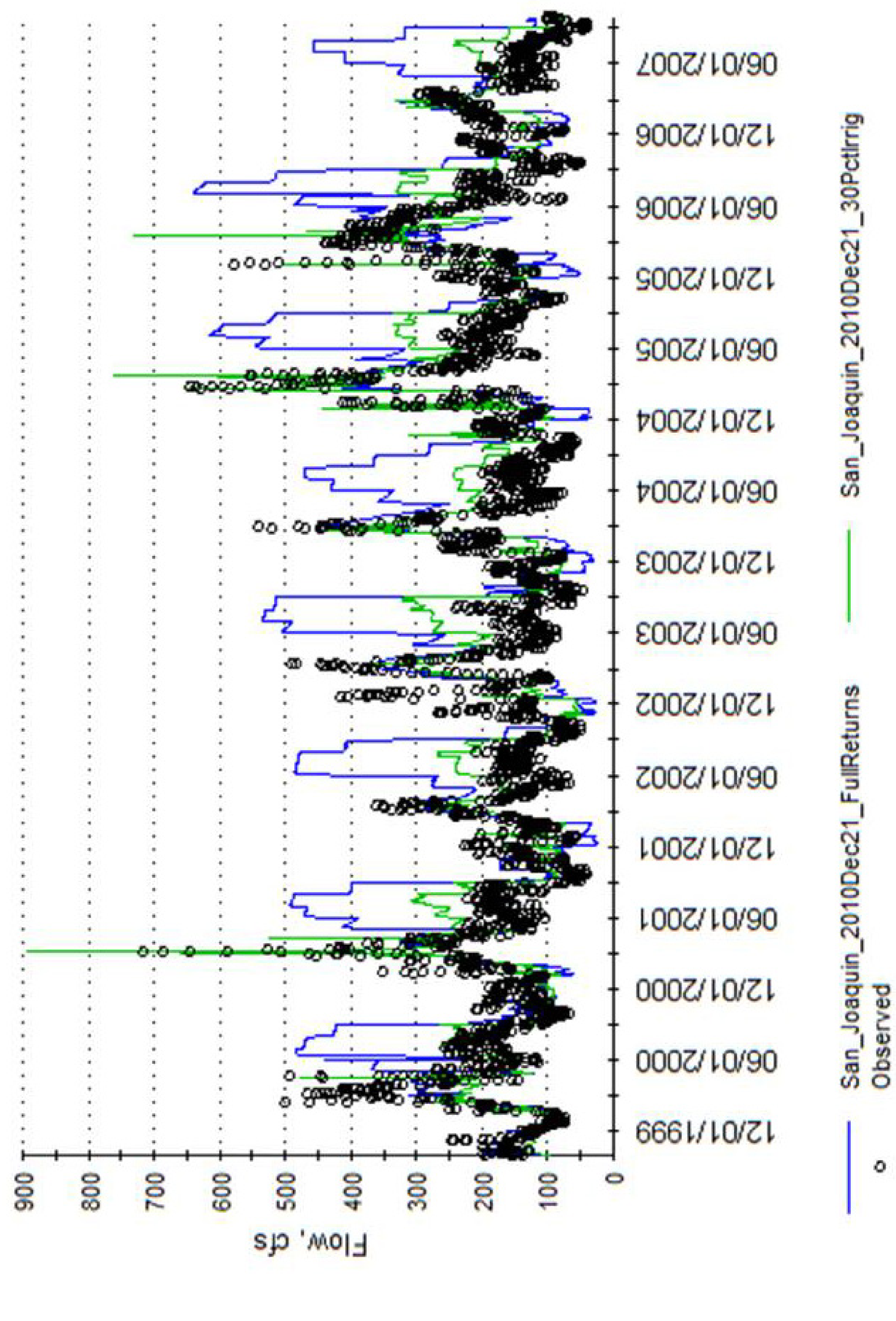


Figure 6-1. Salt Slough Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

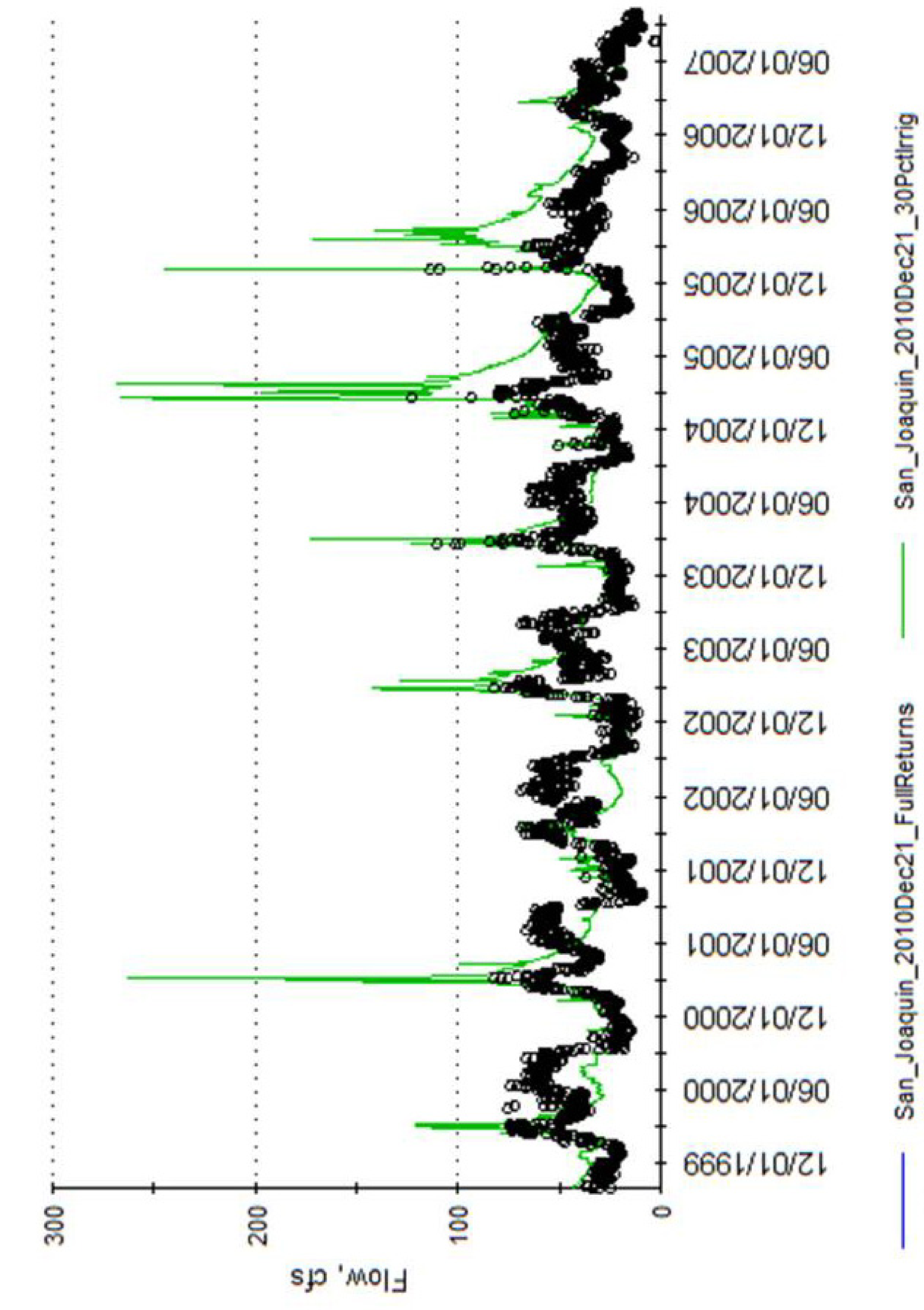


Figure 6-2. San Luis Drain (Grassland Bypass) Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

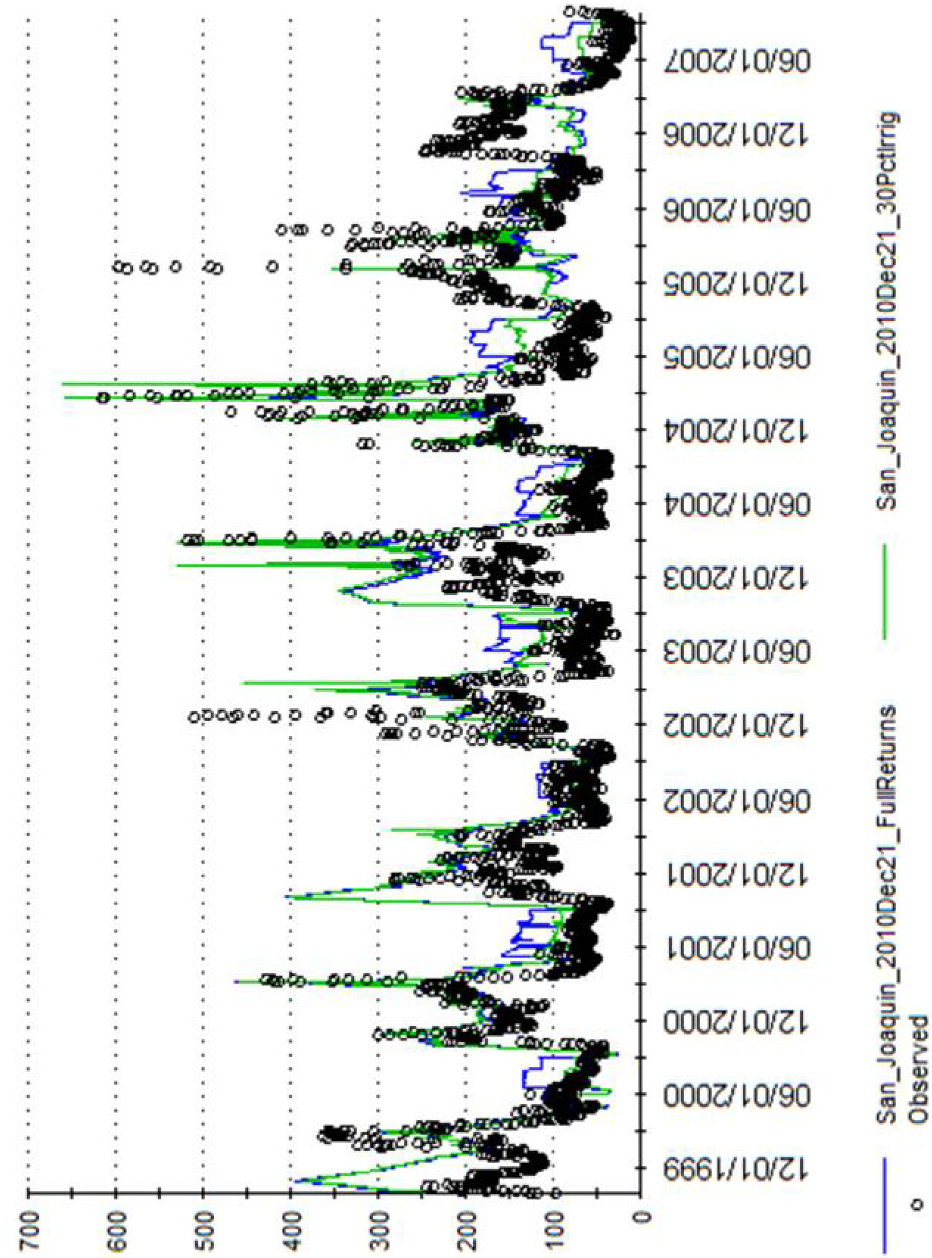


Figure 6-3. Mud Slough Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

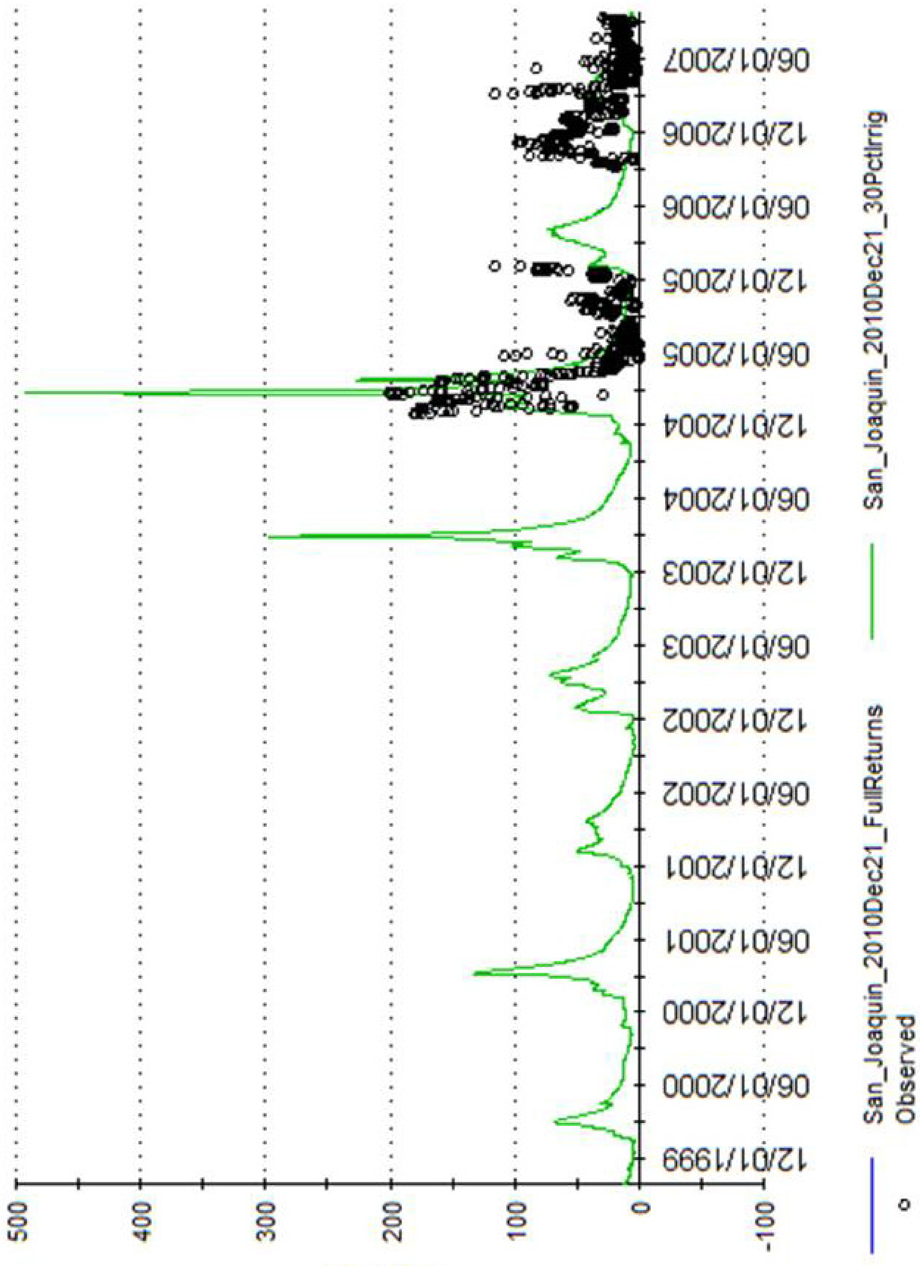


Figure 6-4. Los Banos Creek Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

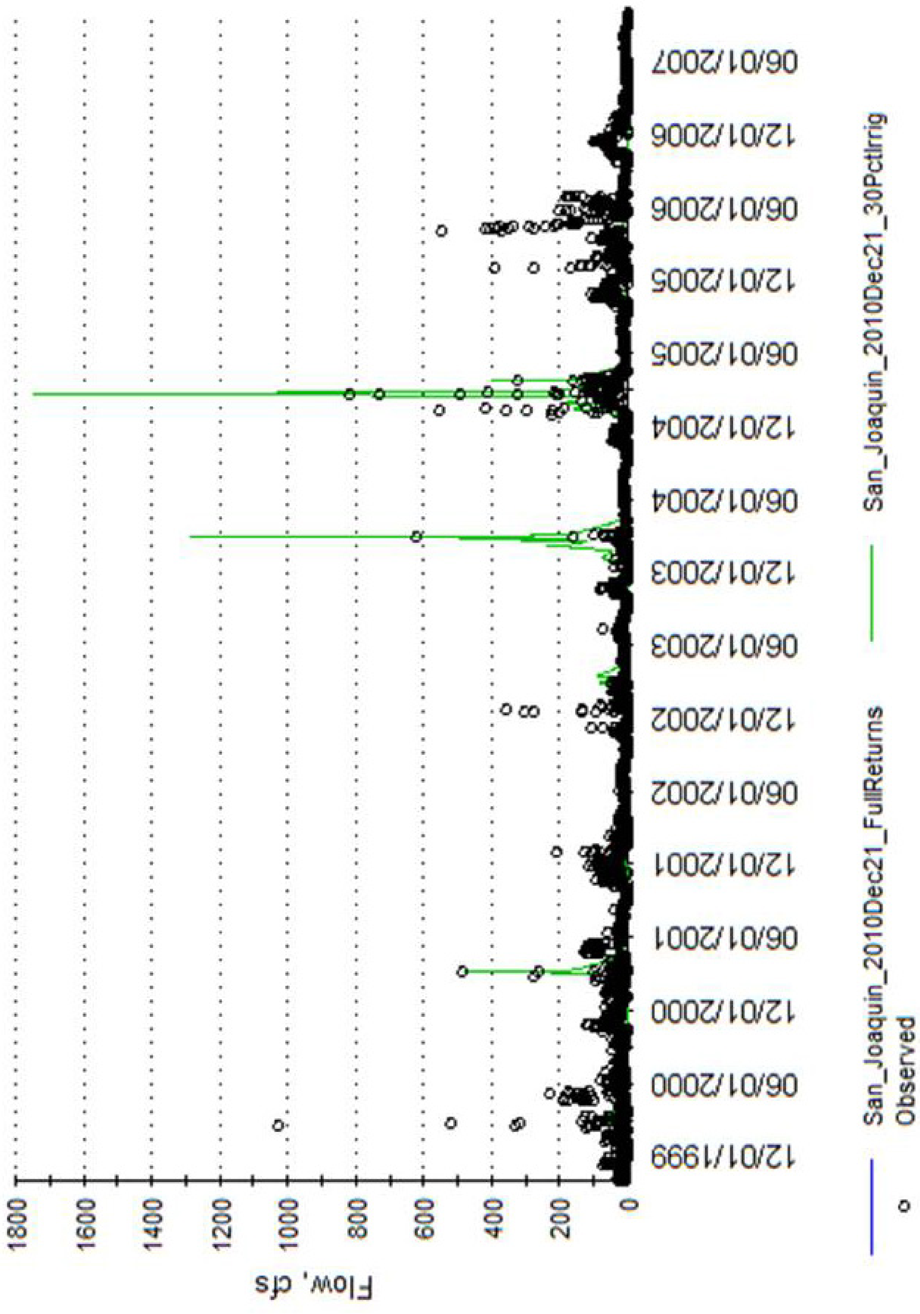


Figure 6-5. Orestimba Creek Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

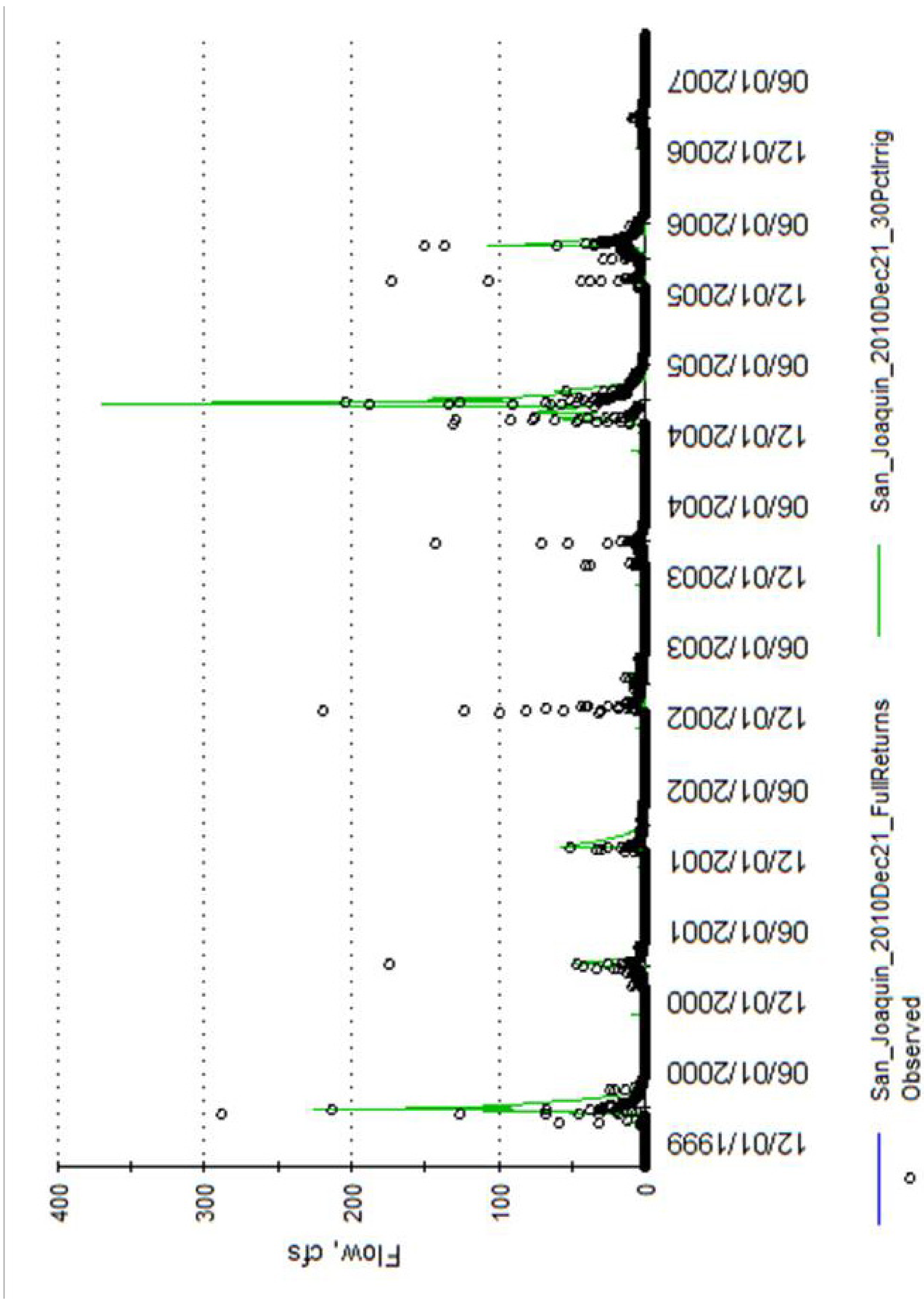


Figure 6-6. Del Puerto Creek Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

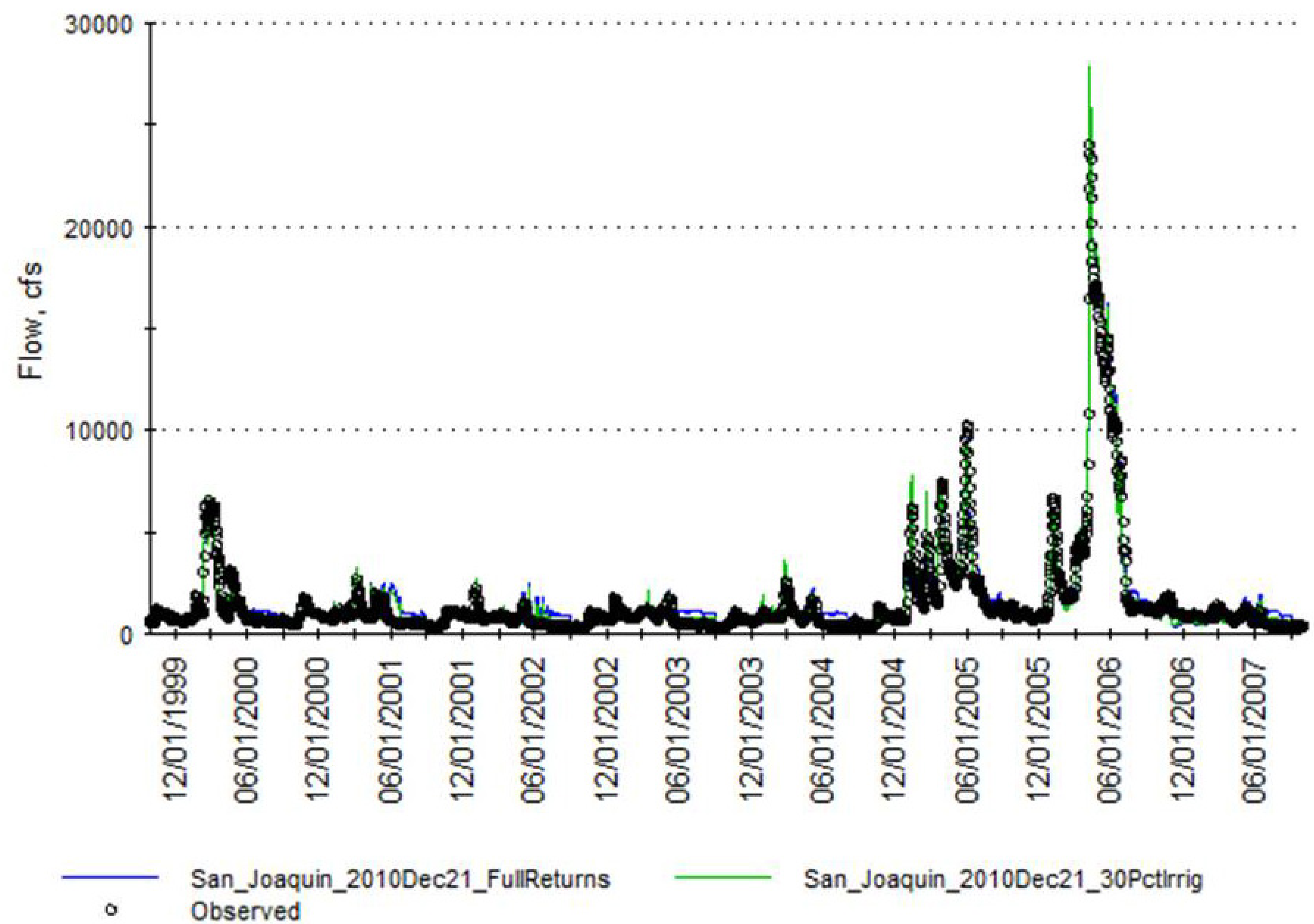


Figure 6-7. San Joaquin River at Crows Landing Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

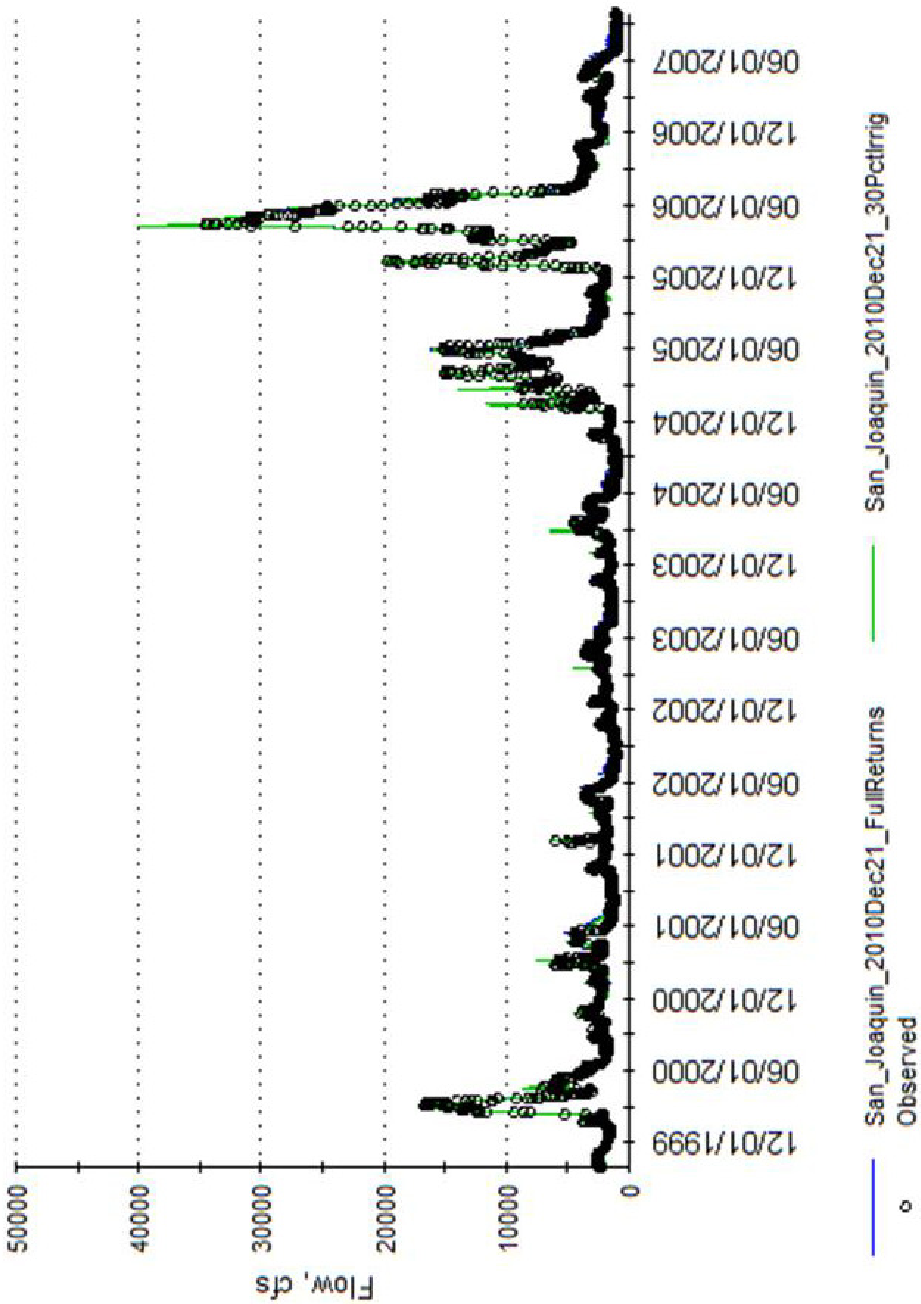


Figure 6-8. San Joaquin River at Vernalis Simulated Flow for Scenario 1 (blue line) and Scenario 2 (green line) Versus Observed Flow (black circles)

Tables 6-2 and 6-3 summarize average annual simulated and observed flows and statistics of model errors. Values are not given for Los Banos Creek because not enough observed data were available at the gage to calculate reliable calibration statistics. Relative error is the average of the deviations between simulated and observed. Typically, the goal of calibration is to have the relative error below 5 percent to 10 percent of the observed flow. Overall relative errors are high for the Westside Region calibration points, which could be potentially attributed to factors such as uncertainty regarding irrigation practices, water transfers, and drainage patterns. Results for Scenario 2, showed substantial improvement over Scenario 1 at Salt Slough and moderate improvement at Mud Slough, Crows Landing, and Vernalis. However, it should be noted that Scenario 2 assumed irrigation was increased by 30 percent when a surplus of surface water was available, and subsequently resulted in simulated crop ET that varied from Scenario 1. Thus, it is likely that calibration results would improve further throughout the Westside Region if more detailed and accurate information became available regarding irrigation practices, water transfers, and drainage patterns.

Table 6-2. Scenario 1 – Average Annual Simulated and Observed Flow and Statistics of Model Errors

Gaging Station	Simulated Flow (acre-feet/year)	Observed Flow (acre-feet/year)	Relative Error
Salt Slough at Highway 165	190,982	132,920	+43.7%
San Luis Drain at Mud Slough	28,879	27,149	+6.4%
Mud Slough near Gustine	116,848	92,233	+26.7%
Los Banos Creek at Highway 140	20,633	N/A	N/A
Orestimba Creek near Crows Landing	16,144	20,611	-21.7%
Del Puerto Creek at Vineyard	3,740	2,693	+38.9%
San Joaquin River at Crows Landing	1,257,531	1,137,352	+10.6%
San Joaquin River at Vernalis	2,779,309	2,683,745	+3.6%

Key:
N/A = not available

Table 6-3. Scenario 2 – Average Annual Simulated and Observed Flow and Statistics of Model Errors

Gaging Station	Simulated Flow (acre-feet/year)	Observed Flow (acre-feet/year)	Relative Error
Salt Slough at Highway 165	142,404	132,920	+7.1%
San Luis Drain at Mud Slough	28,879	27,149	+6.4%
Mud Slough near Gustine	110,188	92,233	+19.5%
Los Banos Creek at Highway 140	20,633	N/A	N/A
Orestimba Creek near Crows Landing	16,144	20,611	-21.7%
Del Puerto Creek at Vineyard	3,740	2,693	+38.9%
San Joaquin River at Crows Landing	1,182,962	1,137,352	+4.0%
San Joaquin River at Vernalis	2,704,740	2,683,745	+0.8%

Key:
N/A = not available

Chapter 7 Results

This chapter provides results from simulated water budget analyses for the Study Area using the WARMF model. The flow predictions from WARMF discussed in the hydrologic calibration section of Chapter 6 are useful for checking simulations against observed data. The model also provides information about how the watershed behaves, in terms of the relative size or importance of each element of the water balance, which can help in the formulation of appropriate management alternatives.

Water budget results presented in this chapter include land area based results, CVP water accounting results, and subwatershed based results 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.

Land Area Based Water Budget Results

The following section provides water budget results for the land areas associated with the Study Area. In the WARMF model, the water budget components for a catchment's land area include two influxes – precipitation and irrigation, and three outfluxes – evapotranspiration, deep groundwater recharge, and catchment outflow. Catchment outflow is the volume of water that leaves a catchment and enters a river segment, either from the land surface as overland flow, or from the soil layers as near-surface groundwater flow. Table 7-1 lists the land area water budget components in the WARMF model, indications of influx or outflux (+ or -), and source descriptions.

Table 7-1. Water Budget Components for Land Area

Water Budget Component	Source Description
Precipitation (+)	Model input from regional meteorology stations, adjusted by subcatchment in WARMF to account for local climate variation.
Irrigation (+)	Initial model input of prescribed flow from CVP diversion tables and groundwater pumping estimates applied to meet specified agricultural demand. Surface diversions for irrigation may be altered within WARMF if sufficient water is not available in the source river segments.
Evapotranspiration (-)	Potential ET is calculated within WARMF by the Hargreaves method, then actual ET is simulated based on water availability on the land surface (from rainfall or irrigation) and in the soil layers.
Deep groundwater recharge (-)	Initial model input of prescribed outflow is calculated as described in Chapter 1. Actual recharge is simulated within WARMF based on water availability in the lower soil layer.
Catchment outflow (-)	Surface runoff and near-surface groundwater flow simulated by WARMF.

Key:
+ = influx
- = outflux
CVP = Central Valley Project
ET = evapotranspiration
WARMF = Watershed Analysis Risk Management Framework

The water budget components for surface water (or the river network) in WARMF include four influxes – inflow from catchments, upstream inflows, point sources and irrigation returns, and three outfluxes – diversions, evaporation, and stream outflow. These six components are described in Table 7-2. Water budget components for near-surface groundwater include four influxes – atmospheric deposition, irrigation, fertilizer/land application, and point sources, and three outfluxes – uptake/decay, outflow to surface, and deep groundwater recharge. These components are described in Table 7-3. Water budget components for deeper groundwater include two influxes – recharge from near-surface groundwater, and rock wells, and three outfluxes – irrigation pumping, municipal and industrial pumping, and other pumping. Deeper groundwater components are described in Table 7-4.

Table 7-2. Water Budget Components for Surface Water

Water Budget Component	Source Description
Inflow from catchments (+)	Simulated by WARMF; equal to catchment outflow in the land area water budget.
Upstream inflows (+)	Either simulated streamflow from subwatersheds located upstream, or model input of prescribed inflow from outside the model domain boundary.
Point sources (+)	Model input of prescribed inflow to streams from point sources.
Irrigation returns (+)	Simulated as the unused portion of irrigation diversions.
Diversions (-)	Model input of prescribed diversion flow; may be adjusted by WARMF if sufficient water is not available in the diversion's source river segment.
Evaporation (-)	Evaporation is simulated within WARMF as part of comprehensive heat budget calculations.
Stream outflow (-)	Simulated by WARMF; outflow to downstream.

Key:
+ = influx
- = outflux
WARMF = Watershed Analysis Risk Management Framework

Table 7-3. Water Budget Components for Near-Surface Groundwater

Water Budget Component	Source Description
Atmospheric Deposition (+)	Precipitation.
Irrigation (+)	Applied water to crops, either by diversions or irrigation pumping.
Fertilizer / Land Application (+)	Water in 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.
Uptake / Decay (-)	Plant uptake.
Outflow to Surface (-)	Lateral flow contributions to surface water.
Deep Groundwater Recharge (-)	Vertical percolation and recharge to deeper groundwater.

Key:
+ = influx
- = outflux

Table 7-4. Water Budget Components for Deeper Groundwater

Water Budget Component	Source Description
Recharge from Near-Surface Groundwater (+)	Vertical recharge from near-surface groundwater.
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.

Key:
+ = influx
- = outflux

The land area and surface water budget components described above were calculated for each of the WARMF subwatersheds. Results are presented for Scenarios 1 and 2, as described in Chapter 6. Results are summarized in Tables 7-5 through 7-8.

Table 7-5. Land Area Water Budget for Subwatersheds, Scenario 1 (acre-feet/year)

Subwatershed	Precipitation	Irrigation	Evapo-transpiration	Deep Recharge	Catchment Outflow
Salt Slough	158,419	452,051	516,391	48,269	45,809
San Luis Drain	61,502	234,860	249,464	15,225	31,673
Mud Slough	94,233	295,235	244,504	90,468	54,496
Los Banos Creek	94,505	69,902	140,298	3,286	20,823
Orestimba Creek	89,292	34,416	104,724	2,764	16,219
Del Puerto Creek	41,071	0	37,375	0	3,743
SJR Stevinson to Crows Landing	122,077	271,238	319,121	22,021	52,173
SJR Crows Landing to Vernalis	318,073	650,295	774,731	48,869	154,468
SJR Stevinson to Vernalis	979,172	2,007,996	2,386,608	230,856	379,404

Key:
SJR = San Joaquin River

Table 7-6. Land Area Water Budget for Subwatersheds, Scenario 2 (acre-feet/year)

Subwatershed	Precipitation	Irrigation	Evapo-transpiration	Deep Recharge	Catchment Outflow
Salt Slough	158,419	545,610	570,820	42,876	90,332
San Luis Drain	61,502	234,860	249,464	15,225	31,673
Mud Slough	94,233	311,056	251,080	89,444	64,766
Los Banos Creek	94,505	69,902	140,300	3,285	20,822
Orestimba Creek	89,292	34,416	104,724	2,764	16,219
Del Puerto Creek	41,071	0	37,375	0	3,743
SJR Stevinson to Crows Landing	122,077	317,615	336,749	22,305	80,638
SJR Crows Landing to Vernalis	318,073	650,295	774,731	48,869	154,468
SJR Stevinson to Vernalis	979,172	2,163,753	2,465,242	224,722	462,663

Key:
SJR = San Joaquin River

Table 7-7. Surface Water Budget for Subwatersheds, Scenario 1 (acre-feet/year)

Subwatershed	Inflow from Catchments	Upstream Inflow	Point Sources	Irrigation Returns	Diversions	Evapo-ration	Stream Outflow
Salt Slough	45,809	0	0	148,687	0	3,223	191,272
San Luis Drain	31,673	0	0	360	0	411	31,623
Mud Slough	54,496	31623	0	32,197	0	1,539	116,776
Los Banos Creek	20,823	0	0	0	0	168	20,655
Orestimba Creek	16,219	0	0	0	0	24	16,195
Del Puerto Creek	3,743	0	0	0	0	3	3,740
SJR Stevinson to Crows Landing	52,173	1,170,604	12,648	80,131	19,562	384,64	1,257,531
SJR Crows Landing to Vernalis	154,468	3,262,438	12,018	84,041	623,643	104,222	2,785,101
SJR Stevinson to Vernalis	379,404	2,826,874	24,666	345,416	643,205	148,054	2,785,101

Key:
SJR = San Joaquin River

Table 7-8. Surface Water Budget for Subwatersheds, Scenario 2 (acre-feet/year)

Subwatershed	Inflow from Catchments	Upstream Inflow	Point Sources	Irrigation Returns	Diversions	Evapo-ration	Stream Outflow
Salt Slough	90,332	0	0	55,872	0	3,800	142,404
San Luis Drain	31,673	0	0	360	0	411	31,623
Mud Slough	64,766	31,623	0	15,570	0	685	111,274
Los Banos Creek	20,822	0	0	0	0	168	20,655
Orestimba Creek	16,219	0	0	0	0	24	16,195
Del Puerto Creek	3,743	0	0	0	0	3	3,740
SJR Stevinson to Crows Landing	80,638	1,116,234	12,648	33,670	19,562	39,218	1,184,410
SJR Crows Landing to Vernalis	154,468	3,189,318	12,018	84,041	623,643	104,946	2,711,256
SJR Stevinson to Vernalis	462,663	2,826,874	24,666	189,513	643,205	155,770	2,711,256

Key:
SJR = San Joaquin River

Central Valley Project Water Accounting

The WARMF model has the capability to add conservative tracers to water sources to track the source of water from specific points in the watershed. To track CVP water through the Westside Region to the San Joaquin River at Vernalis, 1 milligram per liter of one tracer was added to DMC water, while a different tracer was added at the same concentration to all other non-DMC water sources entering the watershed, including San Joaquin River water, groundwater, and return flow from irrigated lands and wetlands. The tracers were modeled conservatively but they became more concentrated when water evaporated. The WARMF flux output was used to track the tracers through catchments via irrigation, precipitation, deep recharge, and outflow. After calculating the DMC contribution to catchment outflow, it is possible to estimate the portion of inflows to surface waters that originated in the DMC. Tables 7-5 through 7-8 show the total volume of water for each element in the water budget. Tables 7-9 and 7-10 show the percent of water for each of those water budget elements that are coming from the DMC for each of the two irrigation scenarios listed in Table 6-6. The percentages of DMC water in the water budgets for the subareas are similar between the two scenarios, but Scenario 2 produces more total water volume coming from the catchment outflow of three subareas, leading to a higher DMC proportion in catchment outflows for the entire watershed, from Stevinson to Vernalis.

Table 7-9. Land Area Water Budget Fractions from Delta Mendota Canal, Scenario 1

Subwatershed	Precipitation	Irrigation	Evapo-transpiration	Deep Recharge	Catchment Outflow
Salt Slough	0%	67%	49%	54%	57%
San Luis Drain	0%	32%	26%	27%	24%
Mud Slough	0%	61%	41%	60%	44%
Los Banos Creek	0%	49%	29%	16%	29%
Orestimba Creek	0%	67%	18%	48%	16%
Del Puerto Creek	0%	0%	0%	0%	0%
SJR Stevinson to Crows Landing	0%	44%	29%	31%	36%
SJR Crows Landing to Vernalis	0%	17%	11%	11%	14%
SJR Stevinson to Vernalis	0%	42%	27%	43%	28%

Key:
SJR = San Joaquin River

Table 7-10. Land Area Water Budget Fractions from Delta Mendota Canal, Scenario 2

Subwatershed	Precipitation	Irrigation	Evapo-transpiration	Deep Recharge	Catchment Outflow
Salt Slough	0%	68%	51%	54%	58%
San Luis Drain	0%	32%	26%	27%	24%
Mud Slough	0%	61%	43%	60%	44%
Los Banos Creek	0%	49%	29%	16%	29%
Orestimba Creek	0%	67%	18%	48%	16%
Del Puerto Creek	0%	0%	0%	0%	0%
SJR Stevinson to Crows Landing	0%	44%	31%	31%	36%
SJR Crows Landing to Vernalis	0%	17%	11%	11%	14%
SJR Stevinson to Vernalis	0%	43%	28%	42%	32%

Key:
SJR = San Joaquin River

The land area water budgets shown above were used as inputs to calculate the fraction of DMC water in surface waters. This analysis was performed for the combined river segments within each of the eight WARMF subwatersheds (Table 5-13) and the two scenarios of irrigation (Table 6-6). On average, 9 percent of the flow at Vernalis originated in the DMC for Scenario 1 and 7 percent of Vernalis flow was from the DMC in Scenario 2. The difference stems from the large returns of unused DMC water in Scenario 1.

Irrigation returns in Table 7-11 and 7-12 are the amount of surface water available in excess of the crop demand minus groundwater applied. The returns are not reapplied to the land, but are added into the downstream river segment.

Table 7-11. Surface Water Budget Fractions from Delta Mendota Canal for Subwatersheds, Scenario 1

Subwatershed	Inflow from Catchments	Upstream Inflow	Point Sources	Irrigation Returns	Diversions*	Evapo-ration*	Stream Outflow
Salt Slough	57%	NA	NA	86%	NA	79%	79%
San Luis Drain	24%	NA	NA	100%	NA	25%	25%
Mud Slough	44%	25%	NA	86%	NA	50%	50%
Los Banos Creek	29%	NA	NA	NA	NA	29%	29%
Orestimba Creek	16%	NA	NA	NA	NA	16%	16%
Del Puerto Creek	0%	NA	NA	NA	NA	0%	0%
SJR Stevinson to Crows Landing	36%	18%	0%	96%	24%	24%	24%
SJR Crows Landing to Vernalis	14%	9%	0%	0%	9%	9%	9%
SJR Stevinson to Vernalis	28%	0%	0%	45%	9%	9%	9%

Note:
* Fraction of diverted and evaporated water from DMC assumed to be the same as fraction of outflow.
Key:
DMC = Delta-Mendota Canal
NA = Not applicable/not available
SJR = San Joaquin River

Table 7-12. Surface Water Budget Fractions from Delta Mendota Canal for Subwatersheds, Scenario 2

Subwatershed	Inflow from Catchments	Upstream Inflow	Point Sources	Irrigation Returns	Diversions	Evapo-ration*	Stream Outflow
Salt Slough	58%	NA	NA	86%	NA	69%	69%
San Luis Drain	24%	NA	NA	100%	NA	25%	25%
Mud Slough	44%	25%	NA	86%	NA	44%	44%
Los Banos Creek	29%	NA	NA	NA	NA	29%	29%
Orestimba Creek	16%	NA	NA	NA	NA	16%	16%
Del Puerto Creek	0%	NA	NA	NA	NA	0%	0%
SJR Stevinson to Crows Landing	36%	14%	0%	96%	17%	17%	17%
SJR Crows Landing to Vernalis	14%	6%	0%	0%	7%	7%	7%
SJR Stevinson to Vernalis	32%	0%	0%	33%	7%	7%	7%

Note:
* Fraction of evaporated water from DMC assumed to be the same as fraction of outflow.
Key:
DMC = Delta-Mendota Canal
NA = Not applicable/not available
SJR = San Joaquin River

Subwatershed Water Budget Results

This section presents the flows simulated in WARMF related to salt and nitrate loads for each of the 8 WARMF subwatersheds in the Study Area (Figure 7-2). Surface water flows are presented for the minimum and maximum monthly loads from the period of record (2000-2007) and the mean load from the period of record. Flows are shown for irrigation Scenarios 1 and 2 for Salt Slough and the San Joaquin River from Stevinson to Vernalis.

San Joaquin River from Stevinson to Vernalis

Table 7-13 and 7-14 present the surface water flows for the San Joaquin River from Stevinson to Vernalis. Near-surface groundwater flows are presented for the mean loads in Table 7-15. The pattern that emerged in all subwatersheds showed that minimum loads occurred at times of low flows in mid-autumn, while maximum loads occurred at times of high flows in late winter and early spring. Inflows for this subwatershed are dominated by surface flow from upstream, and outflows are dominated by surface flow to downstream.

Table 7-13. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for the San Joaquin River from Stevinson to Vernalis, Scenario 1

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2002		March 2005	September 2002		February 2005
Total Inputs	**1,299**	**4,062**	**8,246**	**1,299**	**4,062**	**7,267**
Inflows from Upstream	953	3,019	7,177	953	3,019	5,429
Imported Water	52	362	0	52	362	24
Inflows from Near-Surface Groundwater	294	664	1,029	294	664	1,751
Point Sources	0	17	40	0	17	63
Reaction Product/Scour	NA	0	0	0	0	0
Total Outputs	**1,299**	**4,062**	**7,269**	**1,299**	**4,062**	**7,267**
Uptake/Decay/ Settling	5	92	31	5	92	70
Diversions	333	273	69	333	273	28
Outflow to Downstream	960	3,697	7,169	960	3,697	7,169

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

Table 7-14. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for the San Joaquin River from Stevinson to Vernalis, Scenario 2

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2002		April 2006	September 2002		February 2005
Total Inputs	**1,179**	**3,959**	**32,076**	**1,179**	**3,959**	**7,181**
Inflows from Upstream	851	3,019	31,208	851	3,019	5,471
Imported Water	22	232	5	22	232	7
Inflows from Near-Surface Groundwater	307	691	864	307	691	1,641
Point Sources	0	17	0	0	17	63
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**1,179**	**3,959**	**32,076**	**1,179**	**3,959**	**7,181**
Uptake/Decay/ Settling	33	92	299	33	92	180
Diversions	335	273	416	335	273	28
Outflow to Downstream	811	3,594	31,361	811	3,594	6,973

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

Table 7-15. Near-Surface Groundwater Flows Associated with Simulated Mean Salt and Nitrate Loads over the Study Period by Subwatershed

	SJR Stevinson to Vernalis (Scenario 1)	SJR Stevinson to Vernalis (Scenario 2)	Salt Slough (Scenario 1)	Salt Slough (Scenario 2)	San Luis Drain (Scenario 1)	Mud Slough (Scenario 1)	Los Banos Creek (Scenario 1)	Orestimba Creek (Scenario 1)	Del Puerto Creek (Scenario 1)	SJR Stevinson to Crows Landing (Scenario 1)	SJR Crows Landing to Vernalis (Scenario 1)
	Flow at Mean Load (cfs)										
Near-Surface Groundwater											
Total Inputs	**4,564**	**4,693**	**761**	**890**	**409**	**538**	**227**	**171**	**57**	**714**	**1,688**
Atmospheric Deposition	1,508	1,508	206	206	85	130	130	123	57	173	604
Irrigation	3,033	3,162	555	684	324	408	96	48	0	541	1,061
Fertilizer/Land Application	0	0	0	0	0	0	0	0	0	0	0
Point Sources	23	23	0	0	0	0	0	0	0	0	23
Septic Systems	0	0	0	0	0	0	0	0	0	0	0
Reaction Product	0	0	0	0	0	0	0	0	0	0	0
Total Outputs	**4,568**	**4,695**	**763**	**890**	**407**	**538**	**227**	**171**	**57**	**711**	**1,689**
Uptake/Decay	3,585	3,659	654	728	344	337	194	145	52	543	1,316
Outflow to Surface	664	691	42	69	41	73	31	23	5	138	306
Deep Groundwater Recharge	319	345	67	93	21	125	5	4	0	30	67
Change in Storage	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

Key:
cfs = cubic foot per second
NA = Not applicable/not available
SJR = San Joaquin River

Salt Slough Watershed

Figure 7-1 outlines the area modeled in WARMF-SJR for the Salt Slough subwatershed. Surface water flows for irrigation Scenarios 1 and 2 are presented in Tables 7-16 and 7-17, respectively. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the Salt Slough subwatershed, imported water dominates the inflows. Downstream outflows and some diversions comprise the surface water outflows for Salt Slough.

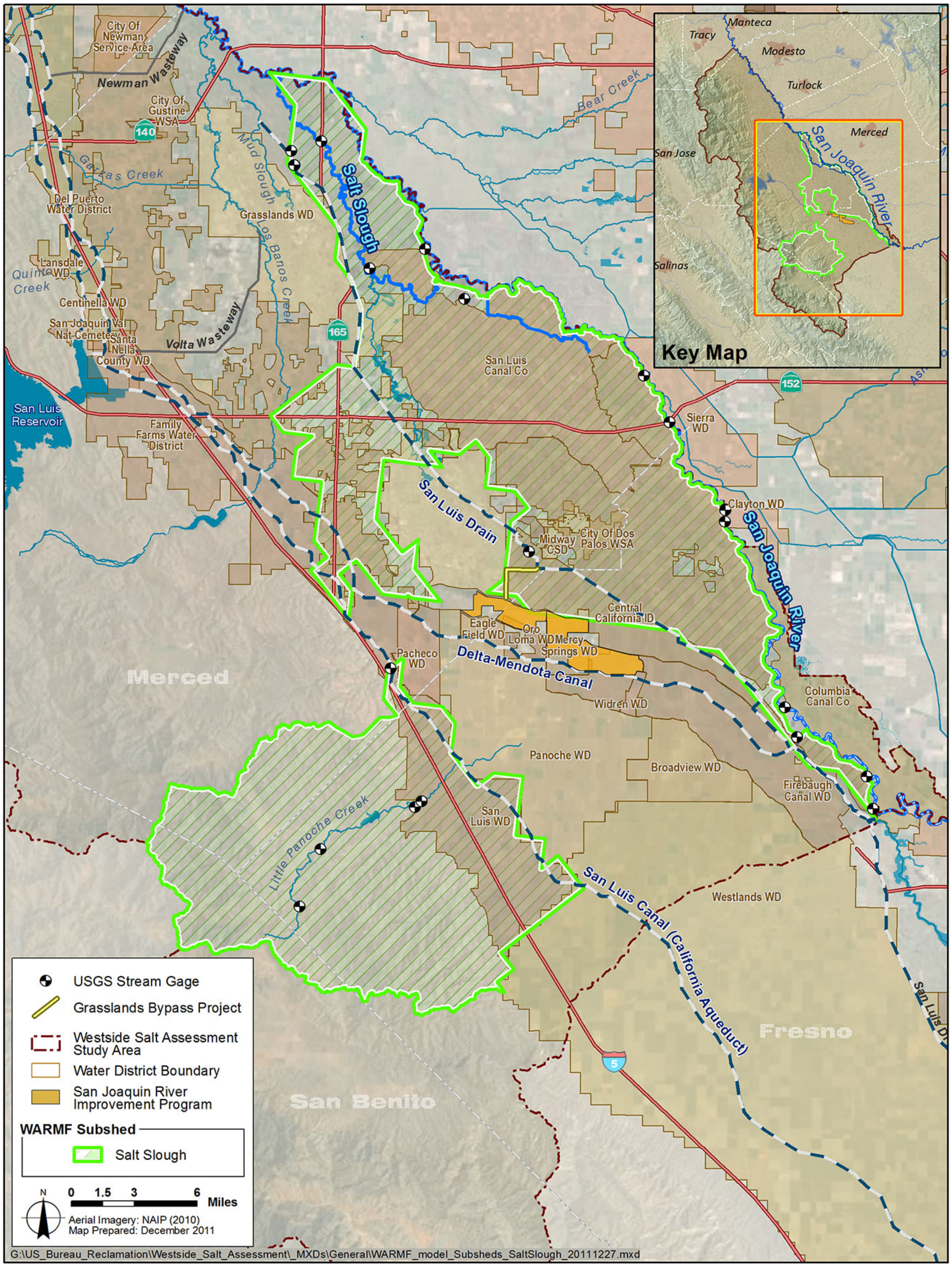


Figure 7-1. Salt Slough Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 7-16. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for Salt Slough, Scenario 1

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	November 2002		March 2005	September 2007		March 2005
Total Inputs	**32**	**249**	**381**	**124**	**249**	**381**
Inflows from Upstream	0	0	0	0	0	0
Imported Water	24	207	129	117	207	129
Inflows from Near-Surface Groundwater	8	42	252	7	42	252
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**33**	**249**	**381**	**126**	**249**	**381**
Uptake/Decay/ Settling	0	0	0	0	0	0
Diversions	0	0	0	0	0	0
Outflow to Downstream	33	249	381	126	249	381

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

Table 7-17. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for Salt Slough, Scenario 2

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2007		March 2005	September 2007		March 2005
Total Inputs	**68**	**146**	**324**	**68**	**146**	**324**
Inflows from Upstream	0	0	0	0	0	0
Imported Water	44	78	48	44	78	48
Inflows from Near-Surface Groundwater	24	69	276	24	69	276
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**68**	**146**	**325**	**68**	**146**	**325**
Uptake/Decay/ Settling	0	0	0	0	0	0
Diversions	0	0	0	0	0	0
Outflow to Downstream	69	146	325	69	146	325

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

San Luis Drain Watershed

Figure 7-2 outlines the area modeled in WARMF-SJR for the San Luis Drain subwatershed. Surface water flows are presented in Table 7-18. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the San Luis Drain subwatershed, near-surface groundwater dominate the inflows to surface water, while outflow to downstream is the only surface water outflow.

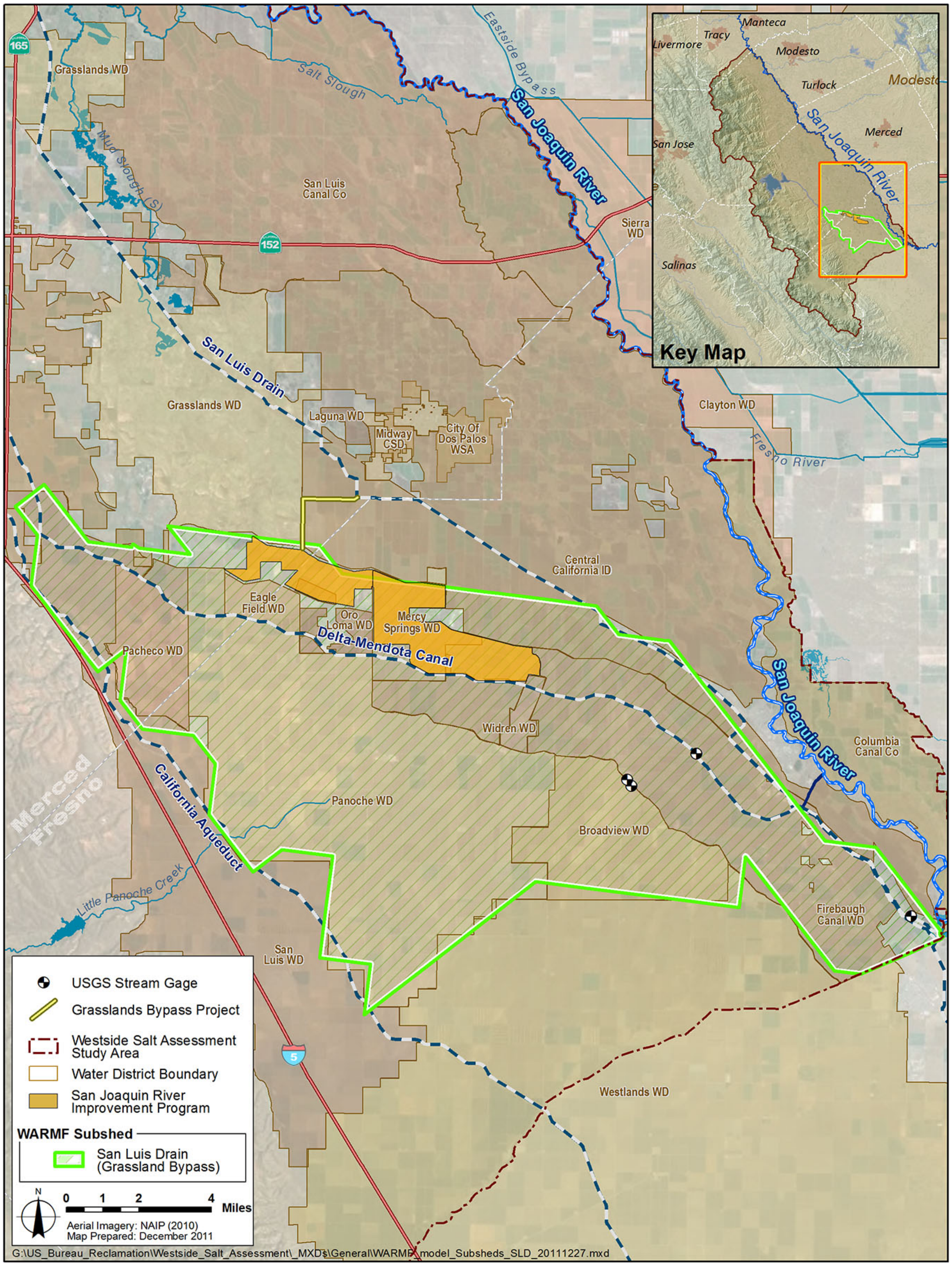


Figure 7-2. San Luis Drain Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 7-18. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for San Luis Drain

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2007		April 2005	January 2000		March 2005
Total Inputs	**13**	**41**	**95**	**25**	**41**	**100**
Inflows from Upstream	0	0	0	0	0	0
Imported Water	0	0	0	0	0	0
Inflows from Near-Surface Groundwater	13	41	95	25	41	100
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**13**	**41**	**95**	**25**	**41**	**100**
Uptake/Decay/ Settling	0	0	0	0	0	0
Diversions	0	0	0	0	0	0
Outflow to Downstream	13	41	95	25	41	100

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

Mud Slough Watershed

Figure 7-3 outlines the area modeled in WARMF-SJR for the Mud Slough subwatershed. Surface water flows are presented in Table 7-19. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the Mud Slough subwatershed, inflows to surface water are dominated by imported water during times of low flow, and by near-surface groundwater during times of high flow. Outflow to downstream is the only surface water outflow.

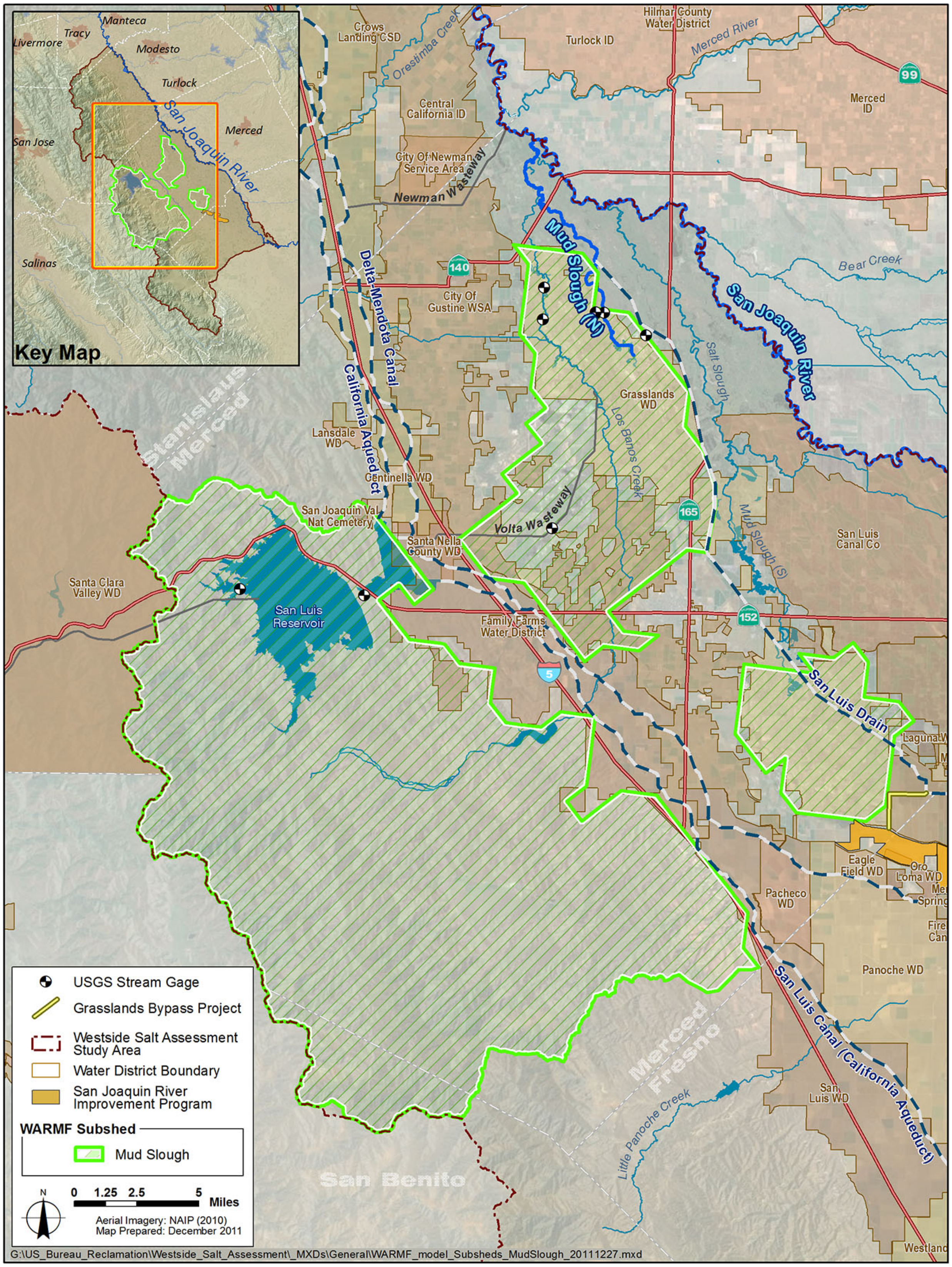


Figure 7-3. Mud Slough Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 7-19. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for Mud Slough

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2007		March 2005	September 2000		March 2005
Total Inputs	**38**	**157**	**259**	**88**	**157**	**259**
Inflows from Upstream	13	41	100	21	41	100
Imported Water	23	43	33	3	43	33
Inflows from Near-Surface Groundwater	1	73	127	66	73	127
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**38**	**157**	**259**	**88**	**157**	**259**
Uptake/Decay/ Settling	0	0	0	0	0	0
Diversions	0	0	0	0	0	0
Outflow to Downstream	38	157	259	88	157	259

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

Los Banos Creek Watershed

Figure 7-4 outlines the area modeled in WARMF-SJR for the Los Banos Creek subwatershed. Surface water flows are presented in Table 7-20. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the Los Banos Creek subwatershed, inputs to surface water are dominated by inflows from near-surface groundwater. Outflow to downstream is the only surface water outflow.

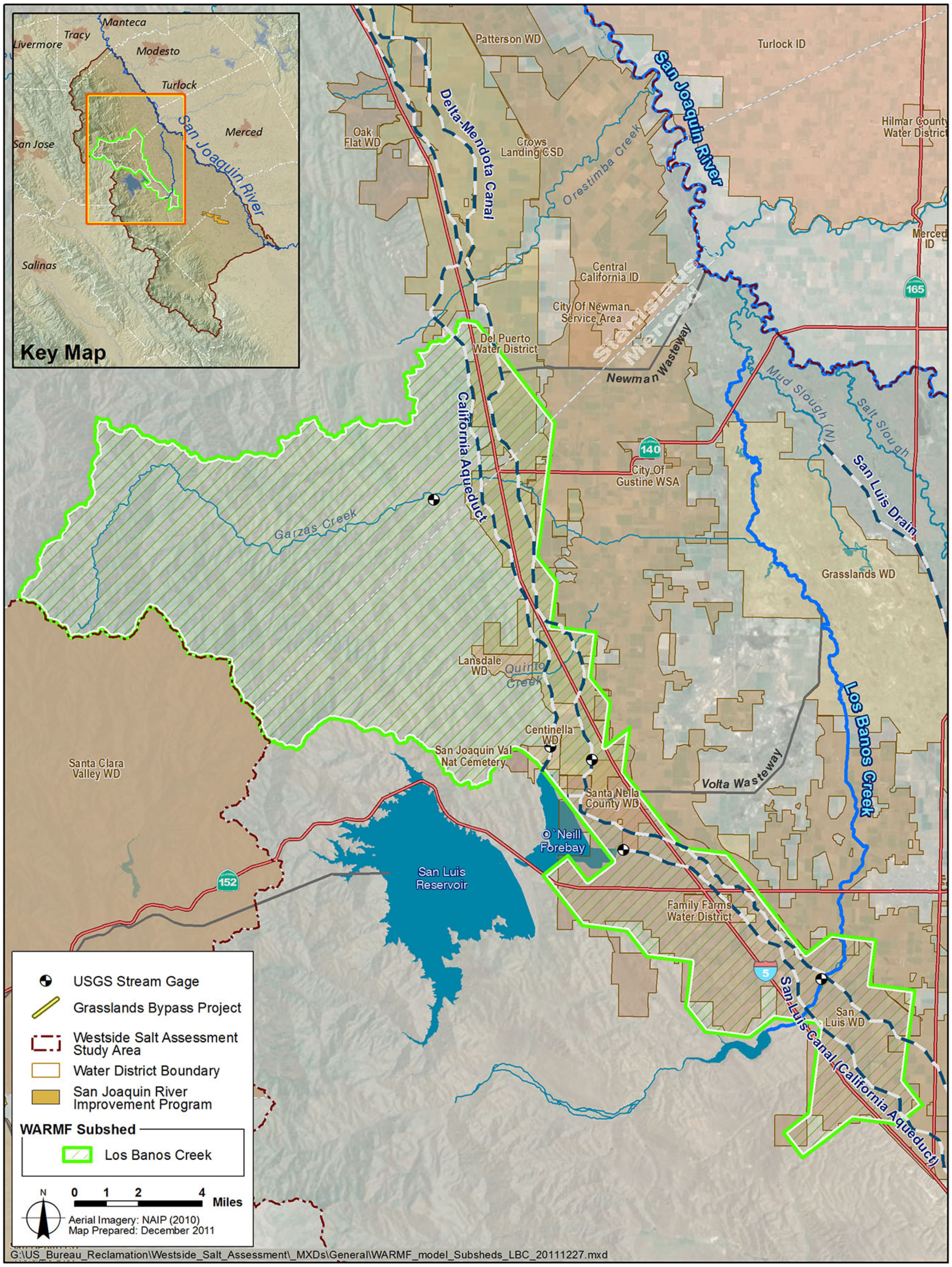


Figure 7-4. Los Banos Creek Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 7-20. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for Los Banos Creek

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2007		March 2005	September 2000		March 2005
Total Inputs	**5**	**31**	**161**	**9**	**31**	**161**
Inflows from Upstream	0	0	0	0	0	0
Imported Water	0	0	0	0	0	0
Inflows from Near-Surface Groundwater	5	31	161	9	31	161
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**5**	**31**	**162**	**9**	**31**	**162**
Uptake/Decay/ Settling	0	0	0	0	0	0
Diversions	0	0	0	0	0	0
Outflow to Downstream	5	31	162	9	31	162

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

Orestimba Creek Watershed

Figure 7-5 outlines the area modeled in WARMF-SJR for the Orestimba Creek subwatershed. Surface water flows are presented in Table 7-21. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the Orestimba Creek subwatershed, inputs to surface water are dominated by near-surface groundwater inflows. Outflow to downstream is the only surface water outflow.

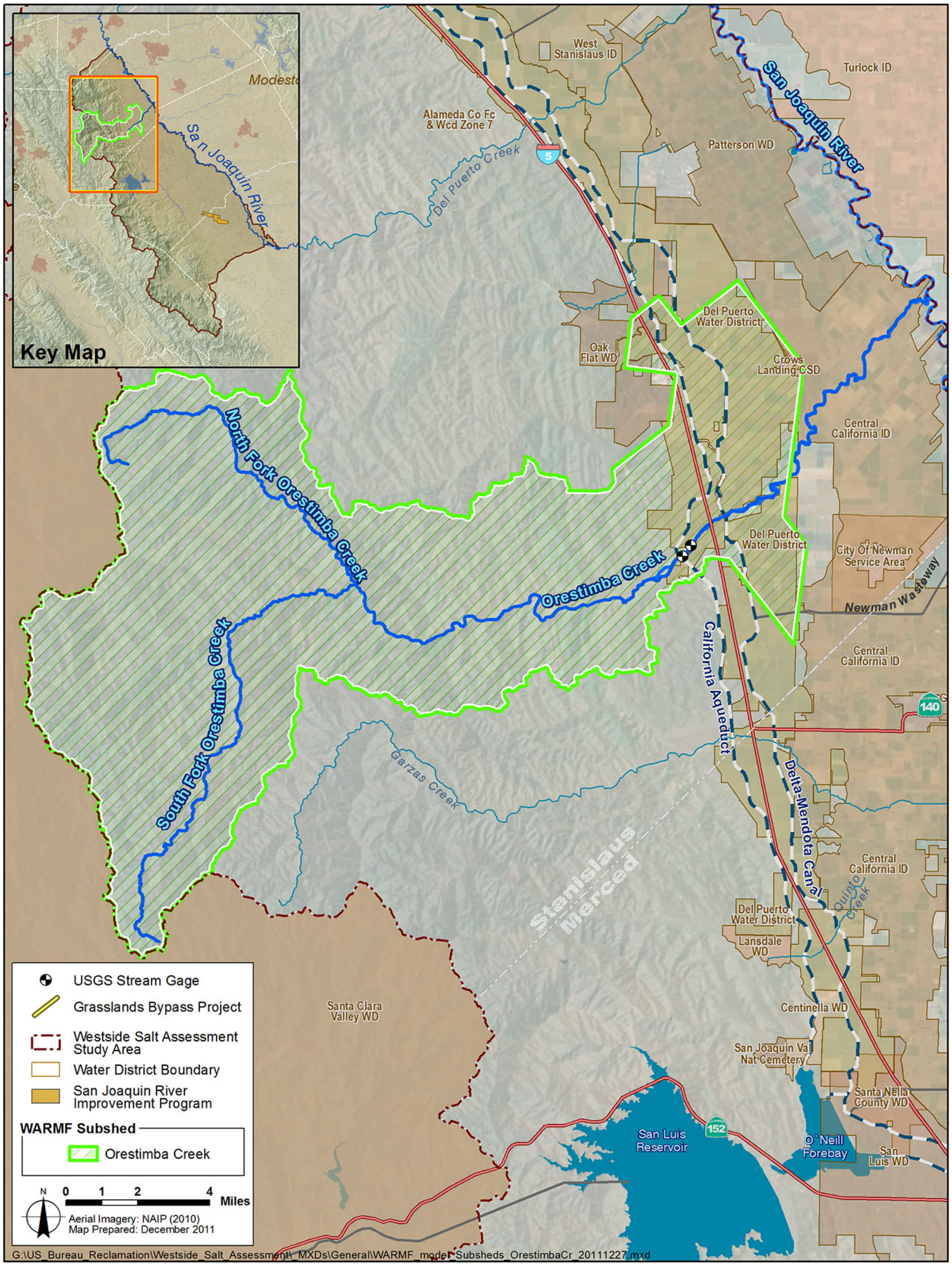


Figure 7-5. Orestimba Creek Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 7-21. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for Orestimba Creek

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2007		February 2004	October 2000		February 2005
Total Inputs	**2**	**23**	**288**	**3**	**23**	**438**
Inflows from Upstream	0	0	0	0	0	0
Imported Water	0	0	0	0	0	0
Inflows from Near-Surface Groundwater	2	23	288	3	23	438
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**2**	**23**	**286**	**3**	**23**	**438**
Uptake/Decay/ Settling	0	0	0	0	0	0
Diversions	0	0	0	0	0	0
Outflow to Downstream	2	23	286	3	23	438

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

Del Puerto Creek Watershed

Figure 7-6 outlines the area modeled in WARMF-SJR for the Del Puerto Creek subwatershed. Surface water flows are presented in Table 7-22. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the Del Puerto Creek subwatershed, inputs to surface water are dominated by near-surface groundwater inflows. Outflow to downstream is the only surface water outflow.

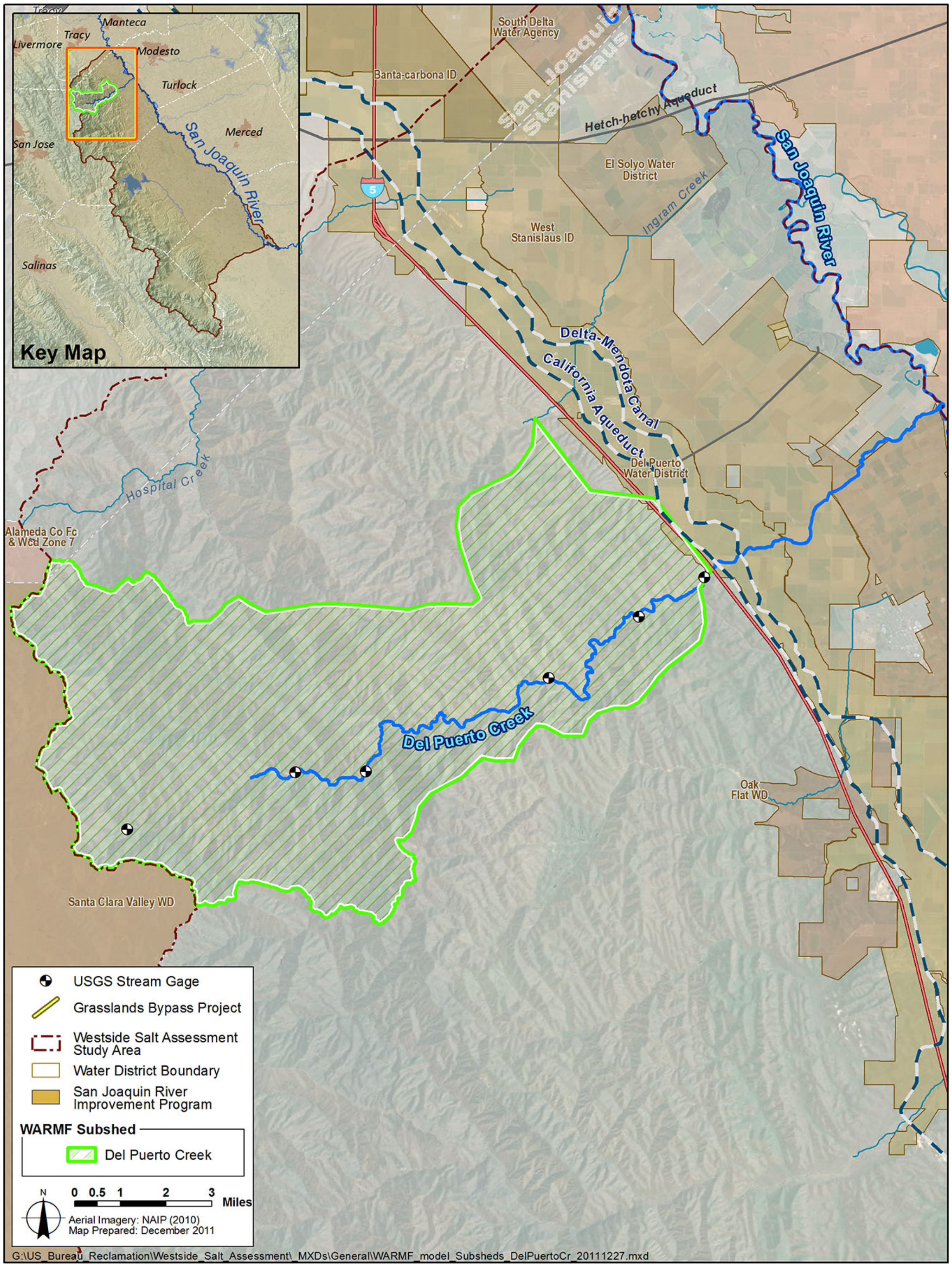


Figure 7-6. Del Puerto Creek Subwatershed Area Applied for Salt and Nitrate Budget Analysis

Table 7-22. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for Del Puerto Creek

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	August 2007		February 2005	August 2007		February 2005
Total Inputs	**0**	**5**	**128**	**0**	**5**	**128**
Inflows from Upstream	0	0	0	0	0	0
Imported Water	0	0	0	0	0	0
Inflows from Near-Surface Groundwater	0	5	128	0	5	128
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**0**	**5**	**127**	**0**	**5**	**127**
Uptake/Decay/ Settling	0	0	0	0	0	0
Diversions	0	0	0	0	0	0
Outflow to Downstream	0	5	127	0	5	127

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

San Joaquin River from Stevinson to Crows Landing

Figure 7-7 outlines the area modeled in WARMF-SJR for the subwatershed of the San Joaquin River from Stevinson to Crows Landing. Surface water flows are presented in Table 7-23. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the San Joaquin River from Stevinson to Crows Landing, inputs to surface water are dominated by inflows from the Merced River and other upstream tributaries. Outflows to downstream dominate surface water outflows.

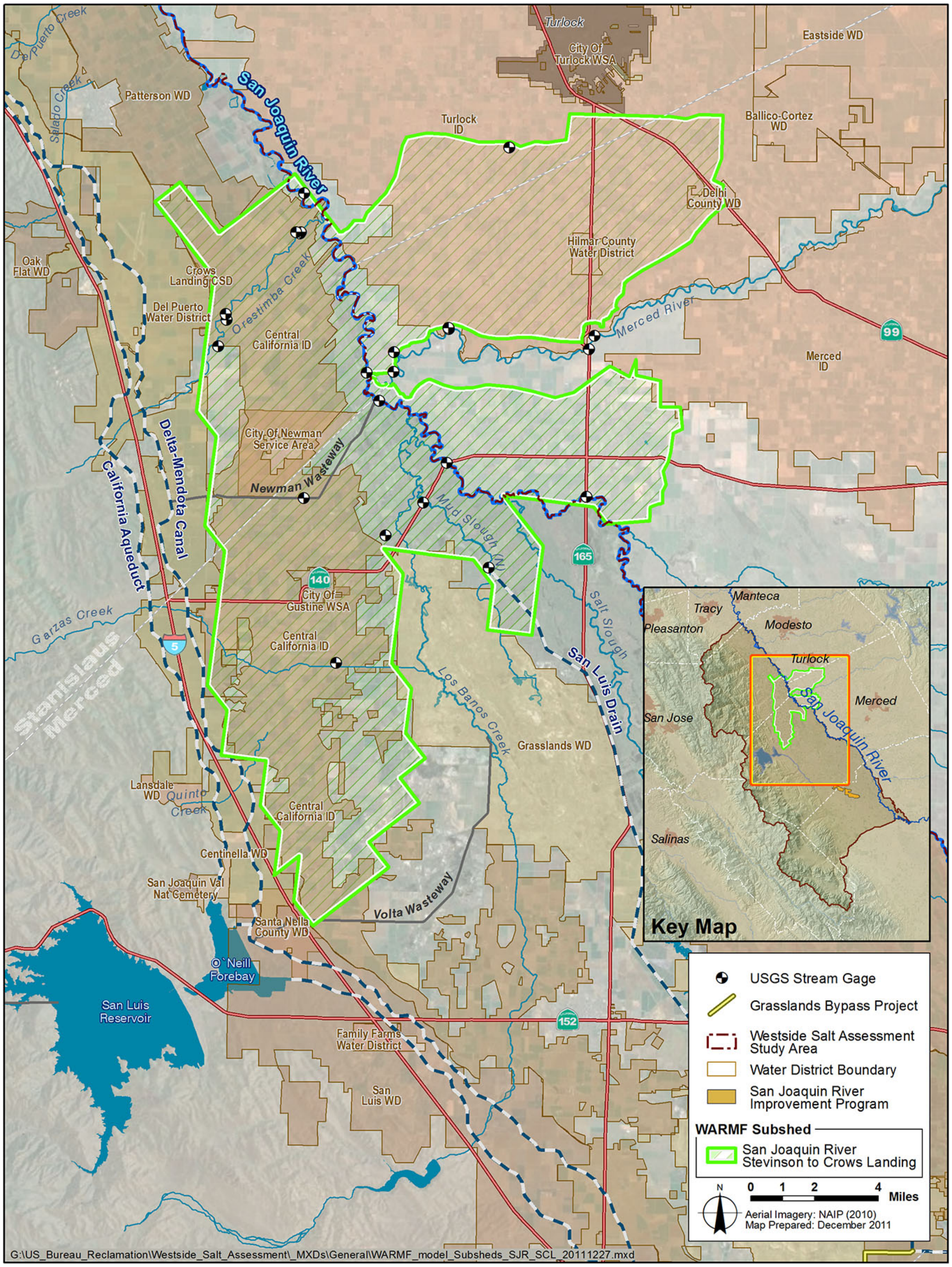


Figure 7-7. San Joaquin River from Stevinson to Crows Landing Area Applied for Salt and Nitrate Budget Analysis

Table 7-23. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for the San Joaquin River from Stevinson to Crows Landing

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2002		March 2005	September 2002		February 2005
Total Inputs	**412**	**1,796**	**3,599**	**412**	**1,796**	**2,863**
Inflows from Upstream	317	1,541	3,101	317	1,541	2,273
Imported Water	52	112	43	52	112	24
Inflows from Near-Surface Groundwater	43	143	455	43	143	565
Point Sources	0	0	0	0	0	0
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**412**	**1,794**	**3,599**	**412**	**1,796**	**2,863**
Uptake/Decay/ Settling	0	0	31	0	2	11
Diversions	66	61	42	66	61	11
Outflow to Downstream	347	1,734	3,526	347	1,734	2,841

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

San Joaquin River from Crows Landing to Vernalis

Figure 7-8 outlines the area modeled in WARMF-SJR for the subwatershed of the San Joaquin River from Crows Landing to Vernalis. Surface water flows are presented in Table 7-24. Near-surface groundwater flows are presented for the mean loads in Table 7-15. In the San Joaquin River from Crows Landing to Vernalis, inputs to surface water are dominated by inflows from upstream. Outflows to downstream dominate surface water outflows.

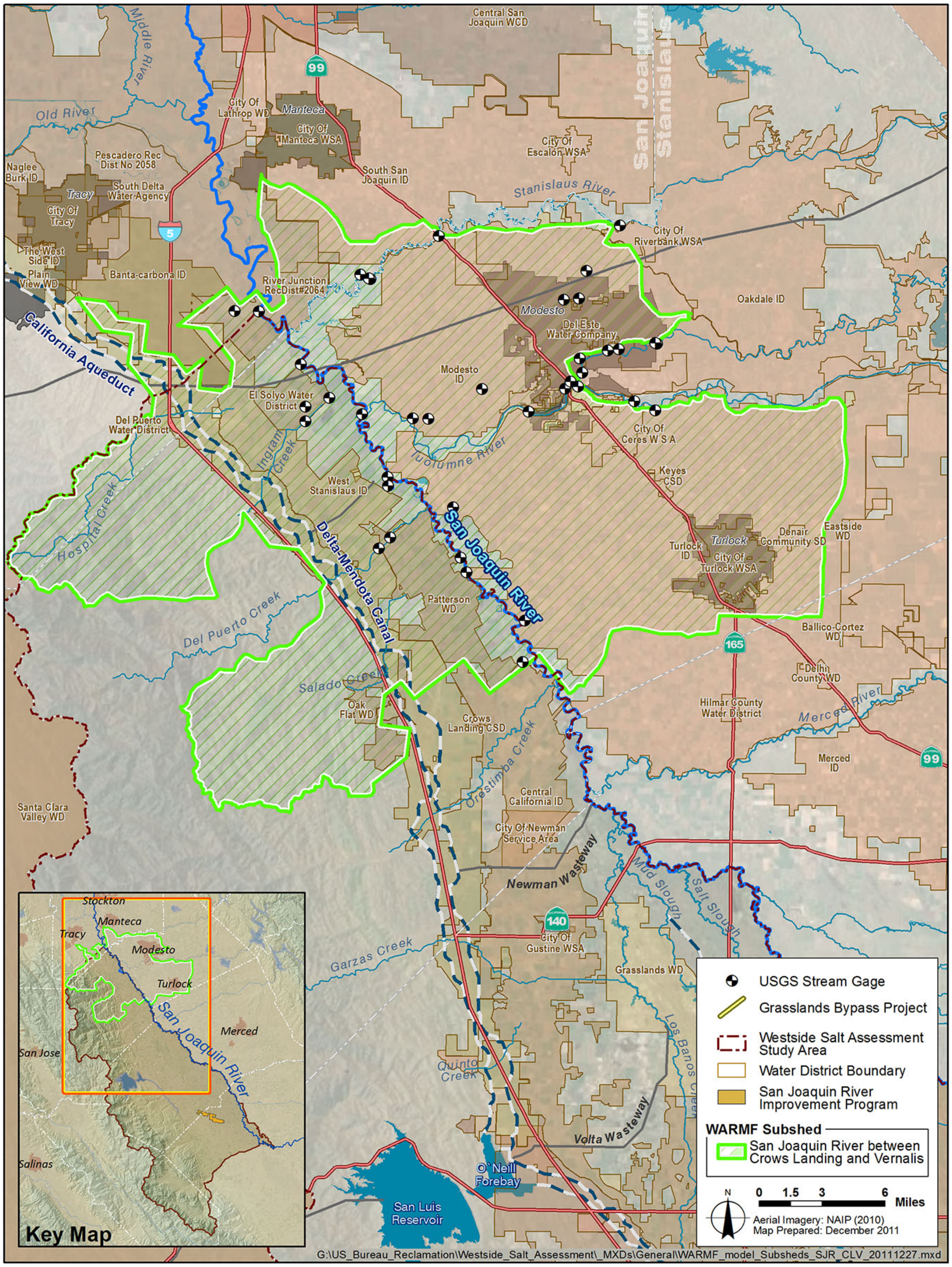


Figure 7-8. San Joaquin River from Crows Landing to Vernalis Area Applied for Salt and Nitrate Budget Analysis

Table 7-24. Surface Water Flows Associated with Minimum, Mean and Maximum Salt and Nitrate Loads over the Study Period for San Joaquin River from Crows Landing to Vernalis

	Flow at Min Load TDS (cfs)	Flow at Mean Load TDS (cfs)	Flow at Max Load TDS (cfs)	Flow at Min Load Nitrate (cfs)	Flow at Mean Load Nitrate (cfs)	Flow at Max Load Nitrate (cfs)
	September 2002		February 2005	September 2002		February 2005
Total Inputs	**1,233**	**4,001**	**7,245**	**1,233**	**4,001**	**7,245**
Inflows from Upstream	982	3,678	5,997	982	3,678	5,997
Imported Water	0	0	0	0	0	0
Inflows from Near-Surface Groundwater	251	306	1,186	251	306	1,186
Point Sources	0	17	63	0	17	63
Reaction Product/Scour	NA	NA	NA	NA	NA	NA
Total Outputs	**1,233**	**4,001**	**7,245**	**1,233**	**4,001**	**7,245**
Uptake/Decay/ Settling	5	92	59	5	92	59
Diversions	267	212	17	267	212	17
Outflow to Downstream	960	3,697	7,169	960	3,697	7,169

Key:
cfs = cubic foot per second
NA = Not applicable/not available
TDS = total dissolved solids

This TM presents the water budget that includes surface and groundwater supplies for the subwatersheds identified in Table 1-1 and located on the Westside region of the San Joaquin Valley (Figure 1-1). The water budget data was necessary to inform the WARMF model in demonstrating the salt and nitrate budget for the Westside Salt Assessment (Reclamation, 2012b). The limitations of the modeling effort as depicted in Chapter 1 should be considered when evaluating this data.

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Chapter 8
Recommendations for Further Analysis

As described above, this TM developed the water budget that supports the methodology used to develop the salt and nitrate budgets reported in the Salt and Nitrate Sources Pilot Implementation Study Report (CV-SALTS, 2010). The TM 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. Recommendations for further analyses are described below.

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, including:

The water 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.

- 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 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, 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.

Chapter 9
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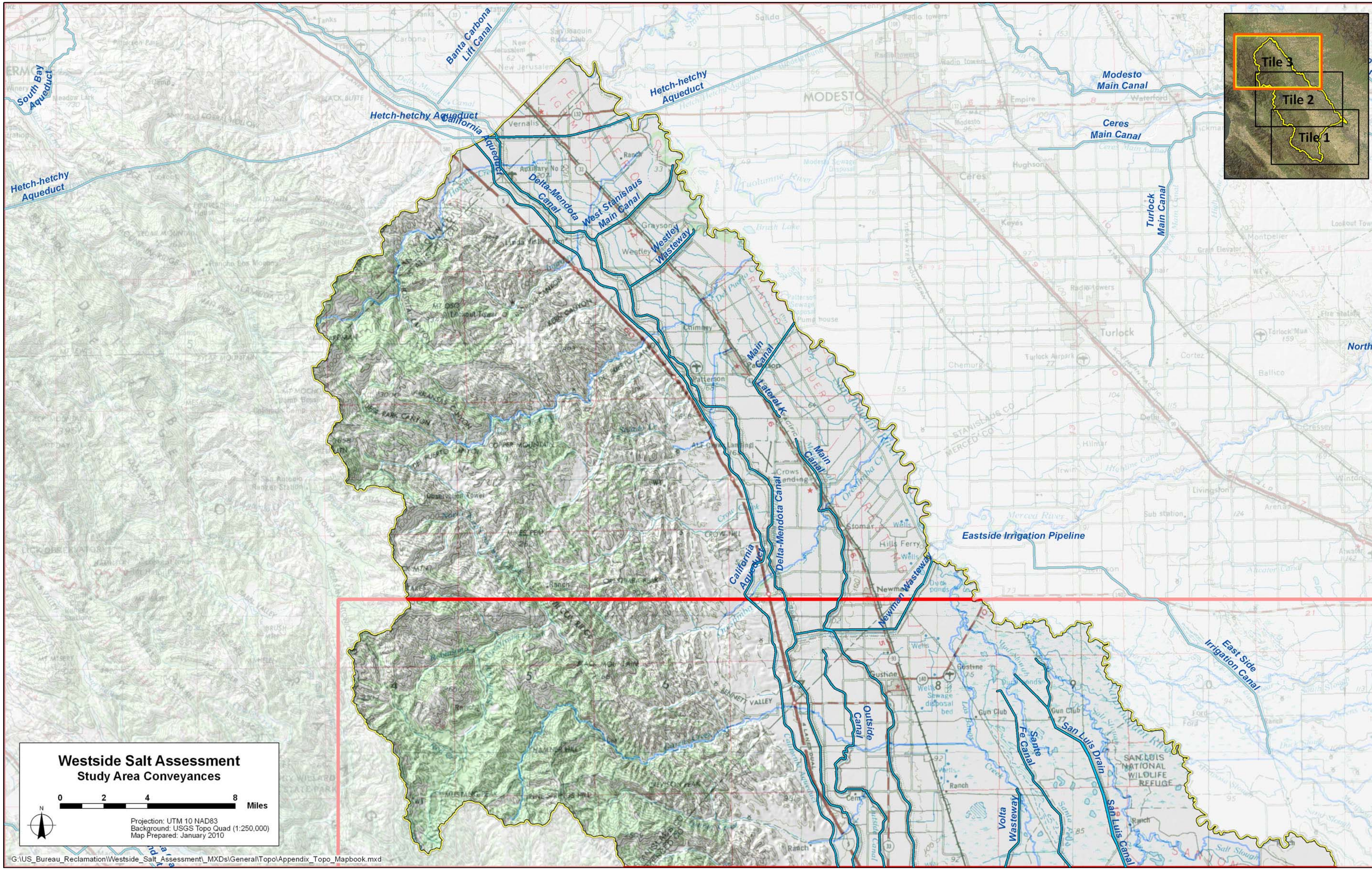

Plate 1. Canal and Drainage System, Sheet 1 of 3

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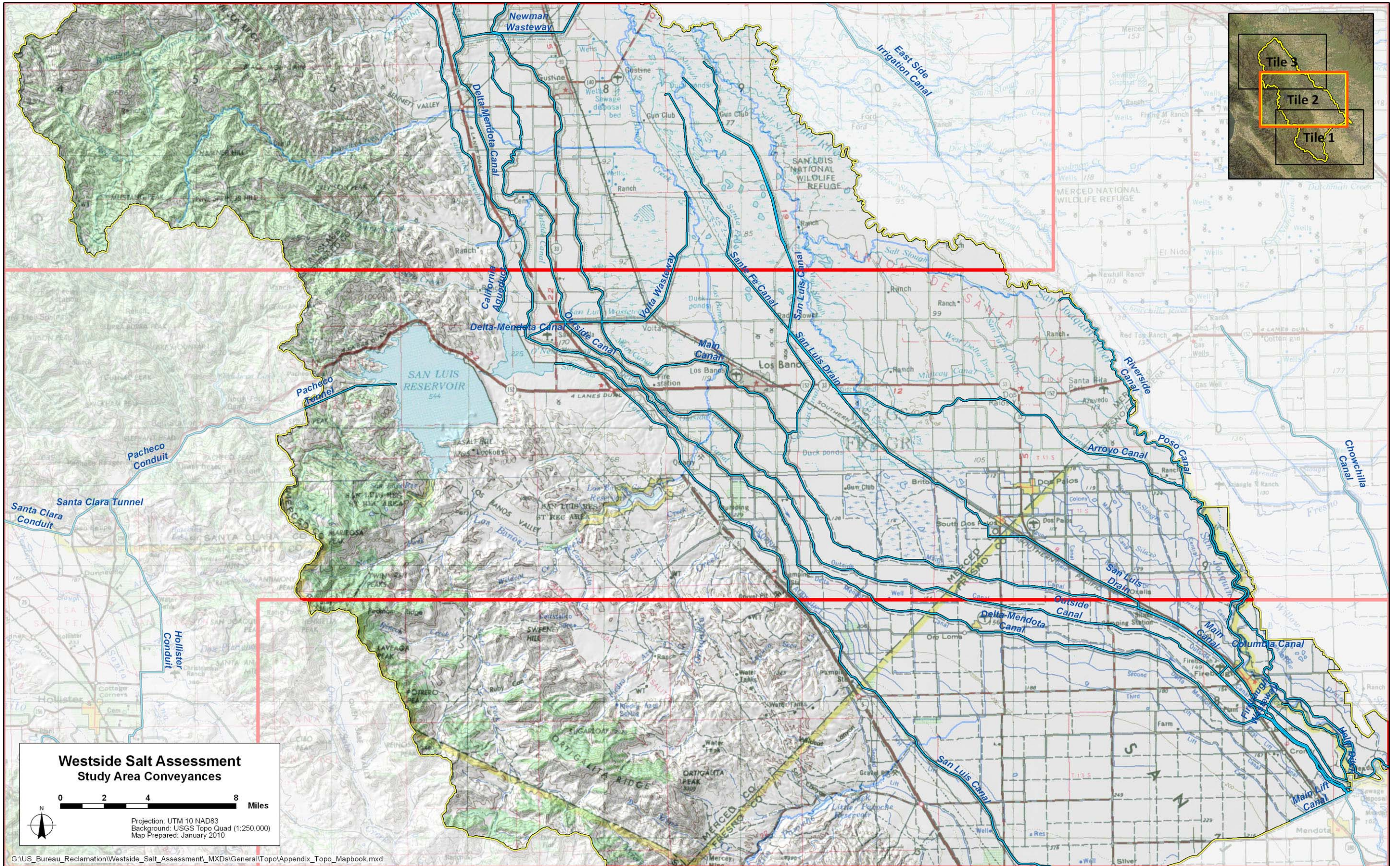

Plate 2. Canal and Drainage System, Sheet 2 of 3

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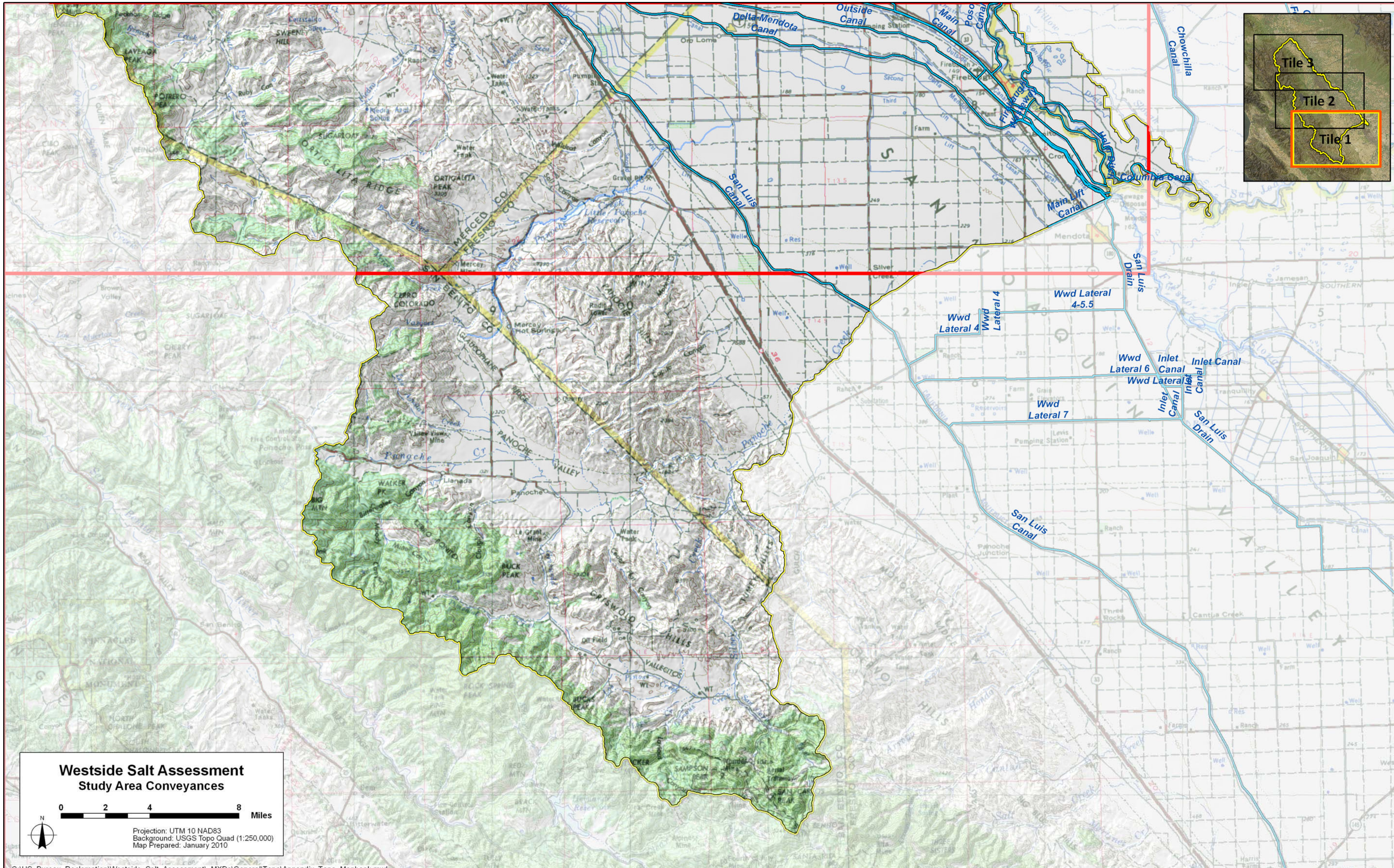

Plate 3. Canal and Drainage System, Sheet 3 of 3

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