Appendix H

Modeling

Draft
Program Environmental Impact Statement/Report

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List of Abbreviations and Acronyms

°C	degrees centigrade
°F	degrees Fahrenheit
µS/cm	microSiemen per centimeter
ARB	California Environmental Protection Agency Air Resources Board
Banks Pumping Plant	Harvey O. Banks Pumping Plant
C2VSIM	California Central Valley Groundwater-Surface Water Simulation Model
CACMP	Common Assumptions Common Modeling Package
CBOD	carbonaceous biochemical oxygen demand
CCC PP	Contra Costa Canal Pumping Plant
CCWD	Contra Costa Water District
CEQA	California Environmental Quality Act
cfs	cubic foot per second
CNP	conditional non-exceedence probability
CO_2	carbon dioxide
CP	control point
CVHM	Central Valley Hydrologic Model
CVO	Central Valley Operations
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CVPM	Central Valley Production Model
D-1641	State Water Resources Control Board Water Right Decision 1641
D-1485	State Water Resources Control Board Water Right Decision 1485
Delta	Sacramento San Joaquin Delta
DFG	California Department of Fish and Game
DICU	Delta Island Consumptive Use
DMC	Delta-Mendota Canal
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
EAD	expected annual damages
EC	electrical conductivity
EDT	Ecosystem Diagnosis and Treatment

FDA	Flood Damage Assessment
FDHGM	Friant Dam Hydropower Generation Model
FNA	Future No-Action
Friant Division	Friant Division of the Central Valley Project
HEC-2	U.S. Army Corps of Engineers River Analysis System which was replaced by HEC-RAS
HEC-FDA	Flood Damage Analysis Model, U.S. Army Corps of Engineer's River Analysis System
HEC-RAS	U.S. Army Corps of Engineers Hydrologic Engineering Center – River Analysis System
I/O	input/output
Jones Pumping Plant	C.W. "Bill" Jones Pumping Plant
Km	kilometers
kWh	kilowatt-hour
LFP	Likely Failure Point
LIDAR	light detection and ranging
LOD	level of development
M&I	Municipal and Industrial
M&S	Marshall & Swift
MAF	million acre-feet
MEI	Mussetter Engineering, Inc.
MWQI	Municipal Water Quality Investigation
NEPA	National Environmental Policy Act
NO_X	nitrous oxide
NRDC	Natural Resources Defense Council
OCO	Operations Control Office
P&G	Principles and Guidelines
PEIS/R	Program Environmental Impact Statement/Report
PG&E	Pacific Gas and Electric Company
PM_{10}	particles of 10 micrometers or less
PM_{25}	particles of 25 micrometers or less
RCE	Sacramento Metropolitan Air Quality Management District's Roadway Construction Emissions Model
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RED	Regional Economic Development
RM	river mile
RMSE	root mean squared error

ROG	reactive organic gas
SJR5Q	San Joaquin River Temperature Model
SJRRP	San Joaquin River Restoration Program
State	State of California
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
TAF/day	thousand acre-feet per day
TCD	temperature control device
USACE	U.S. Army Corps of Engineers
USAN	Upper San Joaquin River Basin Model
USGS	U.S. Geological Survey
USJRBSI	Upper San Joaquin River Basin Storage Investigation
V9B	Version 9B
VAMP	Vernalis Adaptive Management Plan
W2	CE-QUAL-W2
WMA	Water Management Area
WMWG	Water Management Work Group
WQCP	Water Quality Control Plan
WY	Water year

1.0 Introduction

The San Joaquin River Restoration Program (SJRRP) was established in late 2006 to implement the Stipulation of Settlement (Settlement) in *NRDC et al. v. Kirk Rodgers et al*. The U.S. Department of the Interior, Bureau of Reclamation (Reclamation), as the Federal lead agency under the National Environmental Policy Act (NEPA), and the California Department of Water Resources (DWR), as the State lead agency under the California Environmental Quality Act (CEQA), are preparing this joint Program Environmental Impact Statement/Report (PEIS/R) to implement the Settlement. This PEIS/R evaluates potential significant impacts on the environment at a program level resulting from implementing the Settlement and the Act. The PEIS/R also analyzes the effects of the Interim and Restoration flows component of the SJRRP at a project level of detail, and includes feasible and available mitigation measures to avoid, minimize, rectify, reduce, or compensate for significant adverse impacts.

Numerical modeling has been used to develop much of the quantitative data required for the evaluation of potential environmental consequences. This Appendix documents modeling performed in support of the SJRRP PEIS/R development process. This Appendix includes documentation of the overall modeling process, specific models and tools used, major assumptions required to implement the models, and types of outputs generated. This Appendix does not include any analysis of the modeling results.

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2.0 Modeling Process

This section documents the overall modeling process, and describes quantitative modeling performed in support of the SJRRP PEIS/R.

2.1 Need for Quantitative Modeling

Resource areas required for National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) compliance were evaluated in the SJRRP PEIS/R to identify potential effects that would result from implementing program alternatives. Resource areas evaluated for potential effects of alternatives include the following:

- Air Quality
- Biology – Fisheries
- Biology – Vegetation and Wildlife
- Climate Change
- Cultural Resources
- Environmental Justice
- Geology and Soils
- Hydrology – Flood Management
- Hydrology – Groundwater
- Hydrology – Surface Water Supplies and Facilities Operations
- Hydrology – Surface Water Quality
- Indian Trust Assets
- Land Use Planning and Agricultural Resources
- Noise
- Paleontological Resources
- Power and Energy
- Public Health and Hazardous Materials
- Recreation
- Socioeconomics
- Transportation and Infrastructure
- Utilities and Service Systems
- Visual Resources

Resource area evaluations for program alternatives were based on quantitative and qualitative assessments using output from model simulations, other analysis tools, previous studies, or other existing information. Each resource area was evaluated by applying one or more of the following methods:

- **Comparison of quantitative simulations** – Some modeling tools used for PEIS/R resource area evaluations provide quantitative output used for direct comparisons between the Existing Conditions or No-Action Alternative and the program alternatives to identify effects on resources from program implementation. For example, output from system water supply operations model (CalSim) simulations was directly compared to identify changes in river flow, water supply deliveries to Friant Division of the Central Valley Project (Friant Division) long-term contractors, and other effects to Central Valley Project (CVP) and State Water Project (SWP) operations that would result from Interim and Restoration flow releases from Friant Dam.

- **Interpretation/extrapolation from quantitative simulations** – Many of the quantitative models providing output for direct comparisons of effects on resources, as described above, were used to interpret/extrapolate effects on other resources. For example, output from CalSim simulations informs the evaluation of effects to fisheries due to changes in river flows. Similarly, other models were used solely to provide quantitative data for interpretation or extrapolation from quantitative simulations.

- **Interpretation/extrapolation from available data or previous studies** – Existing data and information from previous studies were used to interpret/extrapolate the effects on resources when model simulations were not needed or not feasible. For example, implementation effects on cultural resources were identified in part through a review of previously conducted archaeological and historical studies.

- **Qualitative description with limited or no data** – When available data or previous studies were limited or unavailable, a qualitative description of the effects were developed using professional judgment and any limited data that were available.

A variety of models and other analysis tools were used to identify the effects of implementing the program alternatives. Table 2-1 summarizes the approaches and tools used to evaluate the effects of implementing the program alternatives on the resource areas identified above.

Table 2-1.
Evaluation Approach for Identifying Potential Effects of Implementing SJRRP Alternatives

Resource Area	Models and Analytical Tools													
	CalSim (Water Operations)	HEC-RAS (Steady State)	SRH-ID (Sediment)	SRH-IDV (Vegetation)	DSM2 (Delta Hydrodynamics)	CE-QUAL-W2 (Millerton Lake Water Temperature)	SJR5Q (SJ River Temperature)	MODFLOW Near-River Model	Regional Groundwater Tool	CVPM (Ag Economics)	IMPLAN (Regional Economics)	SWP-Power/ Long_Term_Gen	EDT (Ecosystem Diagnostic Tool)	Other Analysis Tools
Air Quality														3
Biology - Fisheries	2	2	2		1	2	2						2	
Biology - Vegetation and Wildlife	2,3			2,3										
Climate Change														3,4
Cultural Resources														3
Environmental Justice											2			
Geology and Soils	2,3		2,3											
Hydrology - Flood Management		2												2
Hydrology - Groundwater								2	1					
Hydrology - Surface Water Supply/Facilities Operations	1				1									
Hydrology – Surface Water Quality	1				1	1	1							
Indian Trust Assets														4
Land Use Planning and Agricultural Resources										1,2				3
Noise														4
Paleontological Resources														4
Power and Energy	1											1		3
Public Health and Hazardous Materials														4
Recreation	2,3													
Socioeconomics											2			
Transportation and Infrastructure														3,4
Utilities and Service Systems														4
Visual Resources														4

Notes:
1. Assessment Method: Comparison of quantitative simulation results
2. Assessment Method: Interpretation of and extrapolation from quantitative simulations
3. Assessment Method: Interpretation of and extrapolation from available data or previous studies
4. Assessment Method: Qualitative description with limited or no data

Key:
CVP = Central Valley Project
CVPM = Central Valley Production Model
DSM2 = Delta Simulation Model 2
HEC-RAS = U.S. Army Corps of Engineer’s River Analysis System

2.2 Quantitative Assessment Tools

The flow of data between models and analysis tools for the identified resource areas is shown in Figure 2-1. CalSim simulates monthly water supply operations under existing and potential future conditions expected in 2030, as defined by the program alternatives. CalSim output serves as direct input for use in other models and analysis tools, or is postprocessed as appropriate before serving as input. Models and other analysis tools are summarized in the following sections.

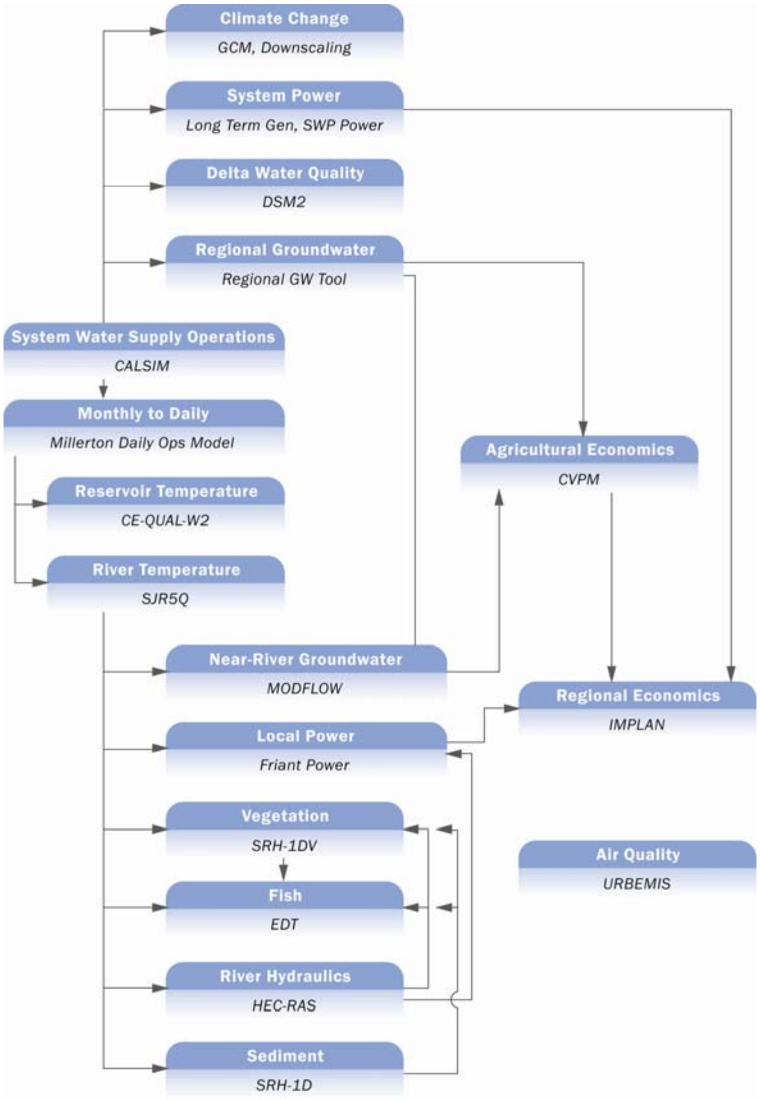


Figure 2-1.
Schematic of Data Flow Between Models and Tools Used to Identify Effects of Program Alternatives

2.2.1 Water Supply Operations

System water supply operations effects would result from the program alternatives for two major reasons:

- Restoration Flows have the potential to change flows between the San Joaquin River upstream from Friant Dam to the Sacramento-San Joaquin Delta (Delta). The Delta is a crucial component of the CVP and SWP. Any change to San Joaquin River inflow to the Delta can potentially affect operations of the CVP and SWP, and thereby affect water supply to the majority of the State of California (State).

- The Settlement includes a goal to minimize water supply effects to local Friant Settling Parties. Water management actions to address this goal may have water supply effects.

CalSim is a water supply operations model that includes CVP, SWP, and Friant Division water supply operations. The model simulates an 82-year period of hydrologic record (1922 to 2003) on a monthly time step. CalSim assumes a constant set of demands, facilities, and operation rules appropriate for each alternative for all 82 years.

CalSim was used to simulate potential water supply operations of the program alternatives. Results of the model were used directly for water supply impact analyses, and indirectly to set overall water operation guidelines for other analyses.

2.2.2 Delta Water Quality

The Delta Simulation Model 2 (DSM2) was used with CalSim results to describe Delta water quality for program alternatives. DSM2 is a hydrodynamic model of the Delta developed by DWR that simulates flow and salinity changes throughout the Delta caused by changes in Delta inflow or CVP/SWP pumping. The model uses monthly CalSim results and produces mean monthly flow and salinity values.

2.2.3 Regional Groundwater

Two custom tools, developed in Excel, were used with simulated flow and delivery data to generate descriptions of regional depth to groundwater and groundwater pumping. One regional groundwater tool is based on relationships describing annual groundwater pumping and resulting groundwater level change developed during litigation studies by Dr. Schmidt (2005 a, b). A second tool is based on regional aquifer parameters and available groundwater elevation information available from the DWR Water Data Library and Bulletin 118-03 (DWR 2003, 2010). These tools are not full groundwater models but used a water balance approach based on CalSim delivery output to produce the regional groundwater description.

2.2.4 System Power

System power operations, both power generation and power use for pumping, are being described using two power models. Long _Term_Gen and SWP_Power are Excel-based models developed by the U.S. Department of the Interior, Bureau of Reclamation (Reclamation), and DWR to model CVP and SWP system power generation and pumping, respectively. These models use monthly water operations from CalSim to simulate monthly CVP and SWP plant and system power operations.

2.2.5 Daily Disaggregation

An adequate evaluation of many of the resource areas required data at a finer time step than the monthly output provided by CalSim. To meet this need, monthly water operations from CalSim were disaggregated into daily water operations that are still bound by overall monthly limits.

The Millerton Daily Operations Model was used to simulate daily water operations of Millerton Lake. This model, developed in Excel, interpolated between the monthly CalSim boundary water operations of Millerton Lake (inflow, diversions, and long-term snowmelt flood releases) to generate a potential set of daily values that still meets the monthly operations boundaries. These daily operations were then used with a simplified flood routing procedure to generate a set of daily releases from Millerton Lake to the San Joaquin River.

2.2.6 Reservoir Temperatures

Daily Millerton Lake water operation data were used in a temperature model developed for the Upper San Joaquin River Basin Storage Investigation (USJRBSI), to generate daily release temperatures into the Friant-Kern Canal, Madera Canal, and San Joaquin River. The reservoir temperature model is a two-dimensional model based on the CE-QUAL-W2 (W2) modeling platform. The model uses daily water operations data from the daily disaggregation tool and historical meteorology to simulate temperatures every 6 hours from January 1, 1980, to September 30, 2003. This time period is shorter than the CalSim model time period to reduce the volume of output, allow acceptable model execution times, and still cover the full range of temperature operations expected over the longer CalSim time period.

2.2.7 River Temperatures

Daily Millerton Lake San Joaquin River release flows and temperatures were used in a temperature model of the San Joaquin River from Millerton Lake to the Merced River. The river temperature model, developed during the Settlement process, routes releases through the system and computes the temperature at various locations. The river temperature model is based on the HEC-5Q modeling platform. The model performs two separate functions. The first, based on the HEC-5 model embedded in the HEC-5Q modeling platform, routes water through the San Joaquin River and bypass system from Millerton Lake to the confluence with the Merced River. This portion of the model handles the physical diversion of water between the Chowchilla, Eastside, and Mariposa bypasses and the San Joaquin River, local accretions and depletions along the channels, and hydrologic routing of water to develop daily flows throughout the system. The second function uses flows and historical meteorology to simulate temperatures every 6 hours from January 1, 1980, to September 30, 2003.

2.2.8 Near-River Groundwater

A model of groundwater flows near the San Joaquin River was used to describe the local surface water/groundwater interface throughout the system, especially river seepage losses and occurrence of high groundwater elevations or water-logging on lands close to the river. This high-resolution near-river groundwater model is based on the MODFLOW modeling platform, and uses flow data from surface water routing models and groundwater elevations from historical data.

2.2.9 Local Power

Power operations at Friant Dam are being described using an Excel-based model of generation facilities at Friant Dam. This model is based on the power simulation methodology used in the USJRBSI. This model uses monthly water operations from CalSim to simulate power operations at Friant Dam.

2.2.10 Vegetation

System riparian vegetation is being evaluated using a vegetation model (SRH-1DV) that links dominant river processes and the morphology of the channel to the dispersal, establishment, growth, expansion, and removal/mortality of riparian vegetation. Both native and invasive species response are addressed with representative plant types from both groups. SRH-1DV uses daily flow, sedimentation, and hydraulic information from other tools described in this section to simulate riparian vegetation response to SJRRP alternatives.

2.2.11 Fisheries

Fisheries conditions in the San Joaquin River will be evaluated using Ecosystem Diagnosis and Treatment (EDT). The EDT tool is a framework that views salmon as the indicator or diagnostic species for the ecosystem, and was used primarily to describe fisheries performance criteria in multiple reaches throughout the San Joaquin River from Millerton Lake to the Merced River as part of the SJRRP Fisheries Management Plan. Because salmon can be viewed as a diagnostic species for other fish species, EDT output informs effects on existing fisheries from implementation of program alternatives. EDT uses San Joaquin River flows and temperatures, river hydraulics, sediment, and riparian vegetation data from other tools described in this section to draw conclusions about the fisheries response to program alternatives.

As of September 30, 2009, initial model development was complete, though the model was not applied to any of the alternatives; therefore, it is not included in this document.

2.2.12 River Hydraulics

River hydraulics is important in developing the description of some of the resource areas. The river hydraulics are being evaluated using a hydraulic model based on the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center – River Analysis System (HEC-RAS) modeling platform. This analysis is independent of daily flows from the SJRRP alternatives; it describes the relationship between flow and hydraulic parameters such as depth, top width, velocity, etc., that may be required for other analyses.

2.2.13 Sediment

Sediment transport and deposition are being described using a model that links the dominant flow patterns and morphology of the channel to sediment conditions. The model, based on the HEC-RAS modeling platform, uses daily flow from other tools described in this section to simulate sediment behavior in the river channel resulting from SJRRP alternatives.

2.2.14 Flood Hydraulics

Flood hydraulics are important in developing the description of resource areas such as flood damage economics. Flood hydraulics were described using a hydraulic model based on the UNET modeling platform. Although flood hydraulics differences between the program alternatives will not depend on water operations data, they do depend on the physical configuration assumptions in the program alternatives. The model was used to describe potential flooding locations and magnitudes throughout the system.

2.2.15 Flood Damage Economics

Flood damage economics were evaluated using a model based on the HEC-Flood Damage Assessment (FDA) modeling platform. This model used results of the flood hydraulics description to develop the description of the flood damage economics.

2.2.16 Agricultural Economics

Agricultural economics are being described using a model based on the Central Valley Production Model (CVPM) modeling platform. Based on the changes in water availability expected with each SJRRP alternative, CVPM predicts cropping patterns, land use, and water use in the Central Valley. These predictions are then used to calculate expected changes in net income resulting from each SJRRP alternative. This model uses CalSim water delivery output and groundwater levels from the regional groundwater tool.

2.2.17 Recreation

Recreation impacts were evaluated using a custom developed use-estimating spreadsheet model of the Upper San Joaquin River. The model extrapolates estimates of existing use for sites along the river with similar flow conditions, with adjustments made for expected differences in conditions between the sites. The model uses flow estimates from the water operation modeling.

2.2.18 Regional Economics

Regional economics are being simulated using a model based on the IMPLAN modeling platform. IMPLAN modeling uses a branch of economics known as input/output (I/O) analysis. I/O models are based on data tables that trace the linkages of inter-industry purchases and sales within a given region, and within a given year. The I/O model yields “multipliers” that are used to calculate the total direct, indirect, and induced effects on jobs, income, and output generated per dollar of spending on various types of goods and services in the regional economic study area. This model uses output from the CVPM agricultural economics model, and could also use output from other models.

2.2.19 Model Integration – Data Processing Between Models

A number of impacts to the Friant Division area depend on how much of the losses due to the Restoration Flows are offset by water management actions that attempt to return the flows to the Friant Division. This would impact regional ground water levels, agricultural economics, and power requirements to get water back to the Friant Division. In order to bracket the possible range of potential impacts, a greatest impact and least impact scenario was evaluated for each alternative:

1. The greatest impact to the Friant Division assumed none of the Restoration water was returned

2. The least impact to the Friant Division assumed all of the Restoration water was returned.

There are three potential sources for returns to the Friant Division:

1. **Delta pumping** – This is not modeled directly in CalSim but is assumed to be equal to the difference in total South-of-Delta deliveries between the alternative and the baseline. This water is modeled as being transported and delivered to the CVP/SWP contractors and not returned to the Friant Division.

2. **San Joaquin River Exchange** – This is computed in CalSim, removed from the San Joaquin River, routed through the system using available capacity to a location near the Cross Valley Canal, and delivered to an undefined user. This means the CalSim results include transport of this water, but do not include return of the water to the Friant Division.

3. **San Joaquin River pumping** – CalSim handles this water the same way as the San Joaquin River exchange return.

The regional groundwater, CVPM, IMPLAN, and power models all need to consider potential return in their application to evaluate high and low impact options for each program alternative. CalSim data was post-processed in order to correctly reflect potential return to the Friant Division for each program alternative.

Post-processing CalSim data required several additional assumptions:

- Average annual volumes are returned each year.

- The Delta return is made only in low impact scenarios.

- The San Joaquin River Exchange and San Joaquin River pumping returns are made in both high and low impact scenarios.

- 30 percent of the return goes to surface delivery, 70 percent goes to groundwater recharge.

- Return is distributed over the 7 Water Management Areas (WMA) in the Friant Division based on reduction in contract delivery due to Restoration Flows.

Table 2-2. shows potential return that should be included in each alternative. Additional details on this post processing are included in the appropriate model descriptions

Table 2-2.
Potential Return Included in Program Alternatives

Alternative	Potential Return		
	Delta	**SJR Exc**	**SJR Pump**
Alt A High	No	N/A	N/A
Alt A Low	Yes	N/A	N/A
Alt B High	No	Yes	N/A
Alt B Low	Yes	Yes	N/A
Alt C High	No	Yes	Yes
Alt C Low	Yes	Yes	Yes

Key:
Alt = Alternative
N/A = not applicable
SJR = San Joaquin River

3.0 Water Operations Modeling

The CVP and SWP operate several large reservoirs and canals serving both agricultural and municipal clients throughout California. Water supplies in the State are governed by complex and layered cycles of supply and demand, legal conditions, transfer agreements, and regulations. Infrastructure for the CVP and SWP are tied together through regulations for the Delta – a conveyance feature and ecological system that is undergoing rapid changes in regulation.

3.1 CVP/SWP System Operation Modeling (CalSim)

The Settlement includes specific flow requirements for the San Joaquin River below Millerton Lake. Meeting these requirements will require a substantial increase in the current release patterns for Millerton Lake. These changes in releases are expected to result in a significant change in Millerton operations. The water operations model was used to simulate revised Millerton operations, diversions into the Friant-Kern and Madera canals, and flow in the San Joaquin River.

Currently, portions of the San Joaquin River run dry during certain times of the year, effectively disconnecting Millerton operations from the Delta and the CVP/SWP systems. Implementation of the Settlement is intended to reestablish a connection between the Friant Division system and the rest of the Central Valley water system, including the CVP and SWP. Changes to the pattern, volume, and timing of releases along the San Joaquin River are likely to affect water releases throughout the Central Valley. It will be necessary for the SJRRP to evaluate subsequent, reactive operation changes of the CVP, SWP operations, and other water Central Valley water systems, and their associated impacts.

Evaluation of the impacts to these systems, and to the environment, required detailed information on water operations resulting from the program alternatives. CalSim was selected as the basis for evaluating the impacts program alternatives flow releases on the water supply and water operations of these systems. Water operations under the program alternatives were compared with water operations under the Existing Conditions and No-Action Alternative for two distinct purposes. One purpose was to evaluate direct impacts to water operations, including the following:

- Millerton Lake elevation, storage, and release
- Diversions to the Friant-Kern and Madera canals
- Flow in the downstream San Joaquin River
- Reservoir operations and streamflows on San Joaquin tributaries

- Delta inflow
- CVP/SWP operations, including both Sacramento River Valley and Delta operation impacts

Results of water operations modeling were also used to supply input data required for other analysis areas in the evaluation of program alternatives, including the following:

- Sediment
- Hydropower
- Groundwater along the banks between Friant Dam and the Merced River
- Regional groundwater
- Habitat
- Economics
- Water quality

3.1.1 Model Description

CalSim is a planning model designed to simulate operations of the CVP and SWP reservoirs and water delivery system for current and future facilities, flood control operating criteria, water delivery policies, and instream flow and Delta outflow requirements. CalSim is the best available tool for modeling the CVP and SWP and is the only system-wide hydrologic model being used by Reclamation and DWR to conduct planning and impact analyses of potential projects.

CalSim is a level-of-development type model. It simulates operation of the CVP and SWP for a set of physical conditions and regulatory requirements that is the same for each year. The model simulates these conditions using 82 years of historical hydrology adjusted to reflect the constant level of development (LOD), from water year 1922 through 2003 CalSim operates the CVP and SWP using a mixed-integer linear programming solver that maximizes an objective function for each month of the simulation.

CalSim modeling for this project is built on the Common Assumption Common Modeling Package (CACMP) Version 9B (V9B), developed jointly by Reclamation and DWR. At this time, V9B is presents the most appropriate depiction of system facilities and operations for this evaluation. Project-specific modifications to this version of CalSim were required to simulate the Restoration program; these modifications are documented throughout this appendix.

CalSim simulates and accounts for the effects of various regulatory requirements by running as multiple steps. CalSim simulate the operations of the CVP/SWP system under select regulatory requirements and agreements. The model is run for 1 year for each step and end-of-year conditions from that year's final step become input to start the first step of the next year. V9B model contains five steps:

1. **D-1641** – State Water Resources Control Board (SWRCB) Water Right Decision D-1641 (D-1641) was issued in 1999, revised in 2000, and specifies how the *1995 Water Quality Control Plan* (WQCP) (SWRCB 1995) is to be implemented. D-1641 provides both flow and water quality requirements at key Delta locations. Many requirements in D-1641 are based on Sacramento Valley Water Year-Type, which is calculated based on the current and previous year's unimpaired runoff of the Sacramento, Feather, Yuba, and American rivers. D-1641 is the current basis for most regulatory requirements governing the Delta, which, in turn, affects how the SWP and CVP operate upstream reservoirs and Delta export pumps. CalSim simulates the system under these regulations and stores the resulting operations for comparison and use with results from other steps.

2. **D-1485** – SWRCB Water Right Decision D-1485 (D-1485) was replaced by D-1641 and is no longer used for Delta standards or for operation of the CVP or SWP. However, Section b(2) of the Central Valley Project Improvement Act (CVPIA) dedicated 800 thousand acre-feet (TAF) of water to be made available for environmental purposes. This b(2) water is split into two separate accounts: non-discretionary and discretionary. Non-discretionary b(2) water represents either additional releases from upstream reservoirs or water available but not exported from the Delta and can constitute all or part of the 800,000 acre-feet. Non-discretionary b(2) water is calculated by taking the difference in water cost needed to meet the more stringent requirements of D-1641 and the water cost needed to meet the previous requirements of D-1485 Therefore, CalSim simulates operations of the system under both D-1641 and D-1485 for the purpose of determining this difference in water costs.

3. **CVPIA b(2)** – The CVPIA b(2) step compares operations of the system under both D-1641 and D-1485 to determine the non-discretionary portion of CVPIA b(2) water. The use of the remaining volume of water, the discretionary account, is simulated in the b(2) step. Discretionary b(2) water may include additional winter releases from upstream reservoirs or export reductions in the weeks before and after the reductions that occur in the spring as part of the Vernalis Adaptive Management Plan (VAMP). CalSim results at the end of the b(2) step depict operation of the system under D-1641 and CVPIA b(2). Under Future No-Action (FNA) conditions, the operation of the California Aqueduct-Delta-Mendota Canal (DMC) Intertie is simulated in the b(2) step. These results are used as the basis for simulation of additional operations in the following steps.

4. **Conveyance** – The conveyance step of CalSim is primarily used to simulate specific aspects of Project operations, as opposed to regulatory requirements simulated in the preceding steps. CVPIA b(2) actions and costs are "fixed" to those simulated in the b(2) step. For the FNA condition, the conveyance step simulates stage 1 water transfers. Stage 1 transfers are included in the CVP and SWP allocations and include transfers associated with the Phase 8 Settlement and the Lower Yuba River Accord.

5. **Transfer** – Similar to the conveyance step, the transfer step is primarily used to simulate specific aspects of Project operations, as opposed to regulatory requirements. The transfer step layers Stage 2 water transfers onto the operations and simulates Joint Point of Diversion operations for the CVP and SWP (Joint-Point). Stage 2 transfers are region-specific acquisitions made by municipal users to supplement project water supplies, and are private party-transfers moved through the Delta as a last priority for export capacity. Joint-Point operations increase the flexibility of CVP and SWP exports by allowing both Projects to use available export capacity each other's pumps. The transfer step also includes the wheeling of CVP water for Cross Valley Canal contractors at the Harvey O. Banks Pumping Plant (Banks Pumping Plant).

For the purpose of this analysis, a Conveyance single-step study was used with the addition of Joint-Point and Cross Valley Canal wheeling from the Transfer step. The reason is that the Conveyance step is the last point where a dynamic link between San Joaquin River operations and the rest of the CVP/SWP systems exists. (At the Transfer step, all San Joaquin River operations have already been predetermined at the Conveyance step.) Since potential exists for some Restoration Flows to be captured downstream from Vernalis and returned to the Friant Division using CVP and SWP facilities, the dynamic link needs to be maintained.

The other option was to run a multistep study, with all key Restoration Flows operations still occurring in the Conveyance step. This would have required significantly more modeling effort with no significant change in results or conclusions. The single-step Conveyance study lacks a dynamic CVPIA b(2) operation and Stage 2 water transfers. As for b(2), upstream releases and export limits are applied just as in the CACMP V9B baseline; however, the Restoration Flows might alter the costs of such actions. With the changes in costs, a dynamic b(2) operation might cause different CVPIA b(2) action decisions. In the case of the Stage 2 transfers, they occur during the summer months of droughts.

Friant Division

CalSim incorporates a dynamic operation of Friant Division water diversions and operations. Canal diversions vary from year to year based on an annually variable water supply, and consider the current protocols for providing three categories of water supply. Under the current contracts (without implementing Restoration Flows) the Class 1 water supply is considered the “firm supply” from the Friant Division and amounts to the first 800 TAF of yield from the San Joaquin River and reservoir storage. Class 2 deliveries are developed after Class 1 deliveries are met. These deliveries are highly variable because of variable hydrology. Deliveries that occur when water is unstorable are also modeled. Monthly distribution of the annual diversion is based on historical delivery practices of the contractors. Minimum required releases below Friant Dam for riparian and contractor users are modeled as a constant annual requirement, consistent with recent records of operations.

Flood control operations for Millerton Lake and the lower San Joaquin River are based on rain-flood space reservation requirements specified by USACE. Flood control operations during the snowmelt runoff period recognize the competing objectives of water supply and flood control. The operations attempt to maximize water supply carryover storage (into summer) while reducing the potential for downstream flooding.

San Joaquin River Inflow to Millerton Lake

Above Friant Dam, the San Joaquin River drains an area of approximately 1,676 square miles and has an average annual unimpaired runoff of 1.7 million acre-feet (MAF). The median historical unimpaired annual runoff is 1.4 MAF, with a range of 0.4 to 4.6 MAF. Several reservoirs in the upper portion of the San Joaquin River watershed, including Mammoth Pool and Shaver Lake, regulate runoff primarily for hydroelectric power generation. These storage facilities have a combined storage capacity of approximately 620 TAF. Operation of these reservoirs affects inflow to Millerton Lake. Figure 3-1 identifies the San Joaquin River watershed upstream from Millerton Lake.

Millerton Lake inflow is derived from the modeling output of the Upper San Joaquin River Basin Model (USAN), which simulates current San Joaquin River operations from headwaters to Millerton Lake (Madeheim 2000). USAN is a daily time step model, and its Millerton Lake inflow data have been converted to monthly average values for CalSim. The USAN simulation incorporated into CalSim is referred to as the “Base Plan” as described in “Evaluation of Potential Increases in Millerton Lake Water Supply Resulting in Changes in Upper San Joaquin River Basin Projects Operation, Phase 2” (USBR 2000a). Reservoirs simulated by USAN are labeled in Figure 3-1.

Modifications of CACMP VB9 CalSim

The CACMP V9B CalSim baseline was modified to allow San Joaquin River Restoration operations to be implemented.

- A sectional representation of the Friant-Kern Canal was added with contractor demands and diversions disaggregated by WMA to provide canal capacity and demand constraints for 16(a) and 16(b) water.

- In V9B, Class 1 and Class 2 deliveries to the Madera and Chowchilla irrigation districts were reduced due to flood control releases being made from Hidden and Buchanan dams. In V9B, this water was mistakenly reallocated to other contractors. Historically, potential flood control releases are typically stored in Millerton Lake to increase water supply reliability for Friant Division deliveries at a later date. This was fixed for the Restoration baseline and studies.

- Some of the exchange and refuge diversions in CalSim were being made from the Mendota pool that are actually made at Sack Dam downstream from the pool. With Restoration Flows, the location of these diversions is important because there would be mixing of DMC and San Joaquin River water upstream from Sack Dam, affecting water quality downstream from Sack Dam. These diversions were moved downstream to a different node representing Sack Dam.

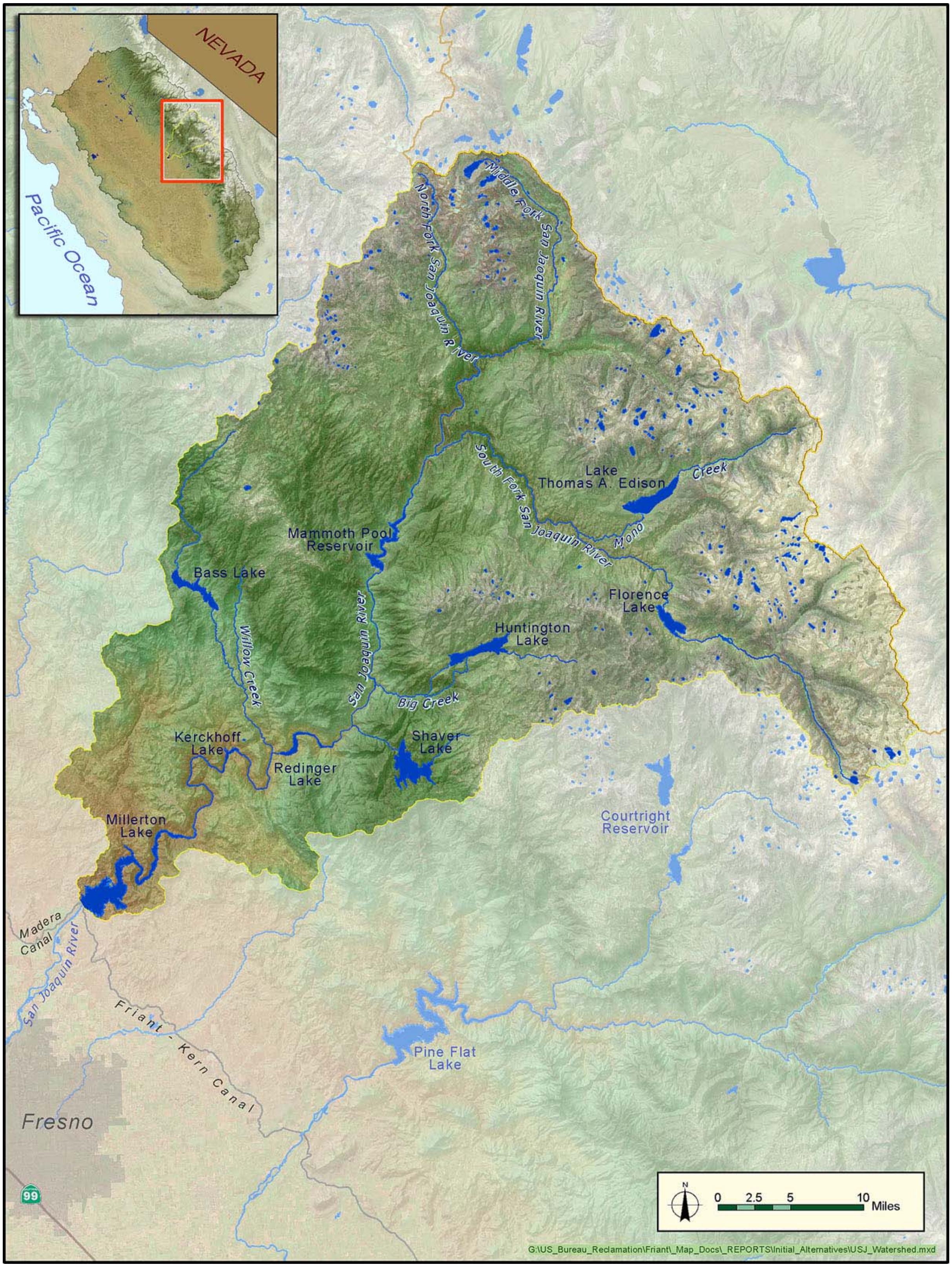


Figure 3-1.
San Joaquin River Watershed Upstream from Millerton Lake

3.1.2 Suitability of CalSim

CalSim, and explicitly the component of CalSim that depicts the San Joaquin River basin, is currently being used in ongoing water supply planning efforts of Reclamation and DWR, including the Upper San Joaquin River Basin investigation, Los Vaqueros Reservoir Expansion Investigation, and others. Use of CalSim for this analysis provides consistency among the several planning initiatives throughout the State.

Representation of the San Joaquin River within CalSim has undergone extensive Peer Review and testing through a Peer Review process (CALFED Science Program 2006). The specific model logic and algorithms embedded in studies for the SJRRP contain several enhancements specifically needed for evaluation of the Restoration Program. Enhancements are summarized in Section 3.1.1.

The Friant Division's water delivery logic is included in CalSim. The following plots compare historical operations to CalSim simulation results. These plots provide comparisons between 1975 and 2003.

Figure 3-2 through Figure 3-5 compare historical and simulated Millerton Lake storages, Friant Dam river releases, and canal diversions for the Friant Division. While at times noticeable differences occur between historical and simulated annual delivery and river release volumes, the differences are reconciled in many instances and are largely due to the limitations of the model reflecting discretionary and intermittent actions, such as flood management and canal maintenance.

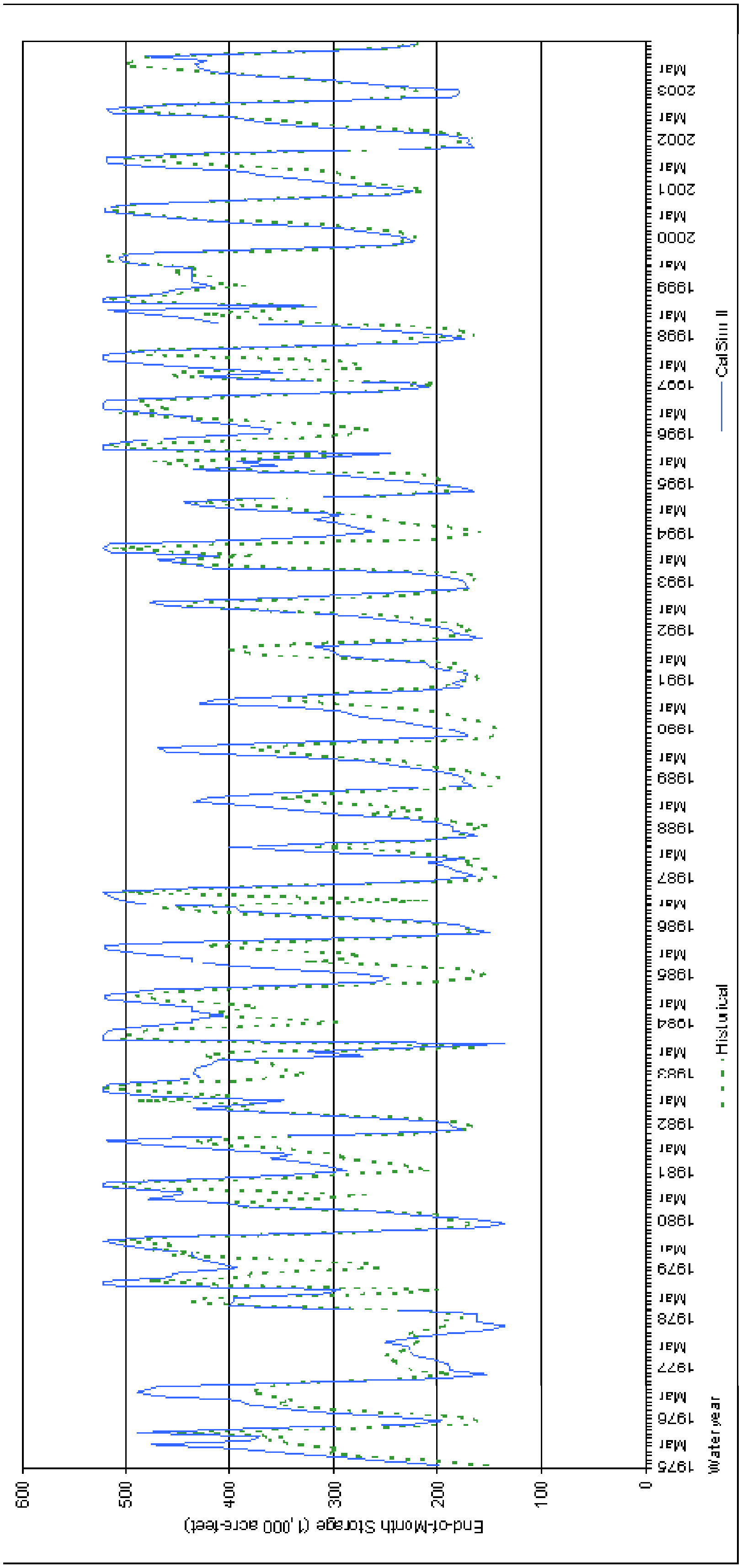


Figure 3-2.
Millerton Lake Storage

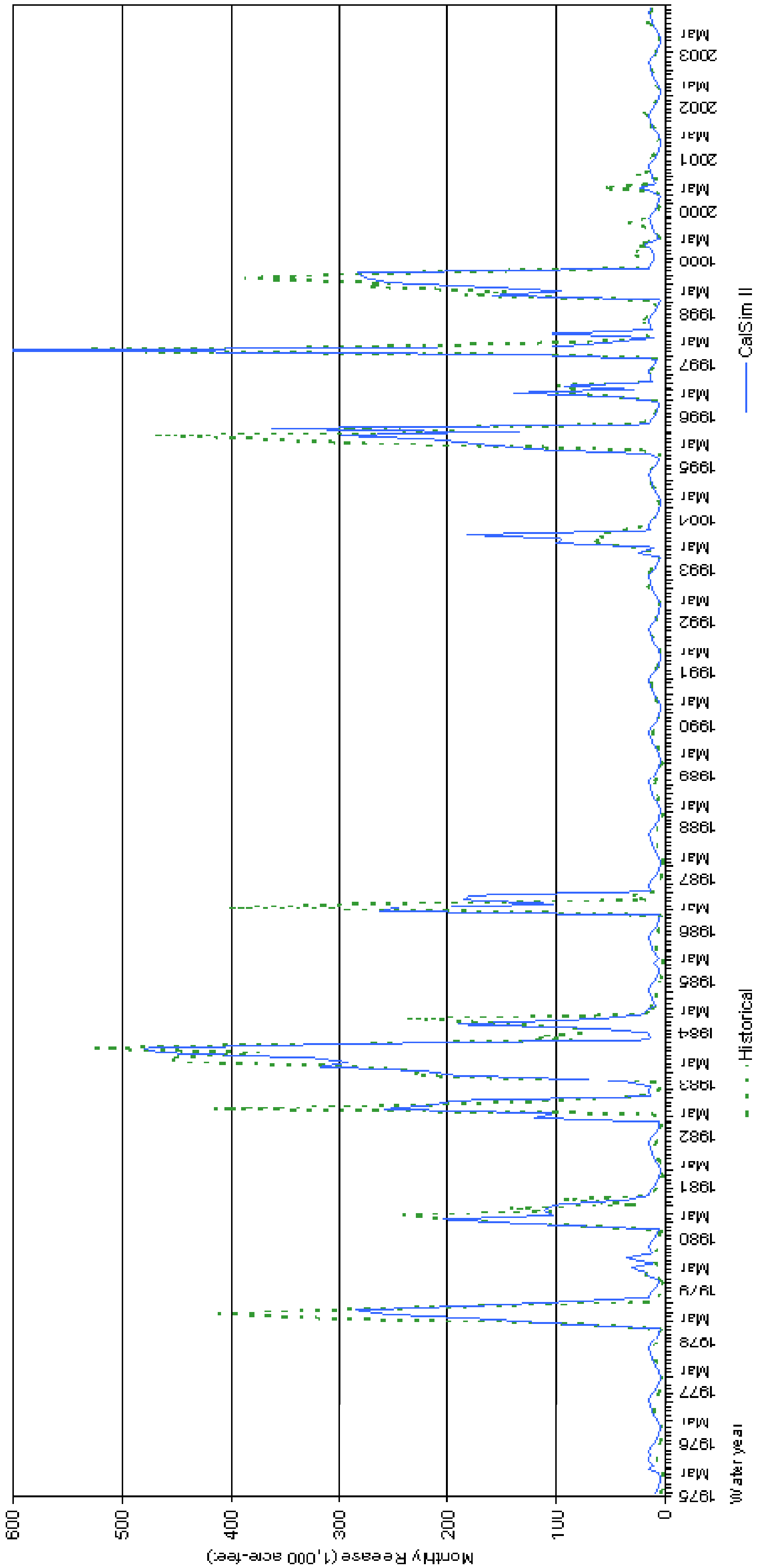


Figure 3-3.
Total Friant Dam River Releases

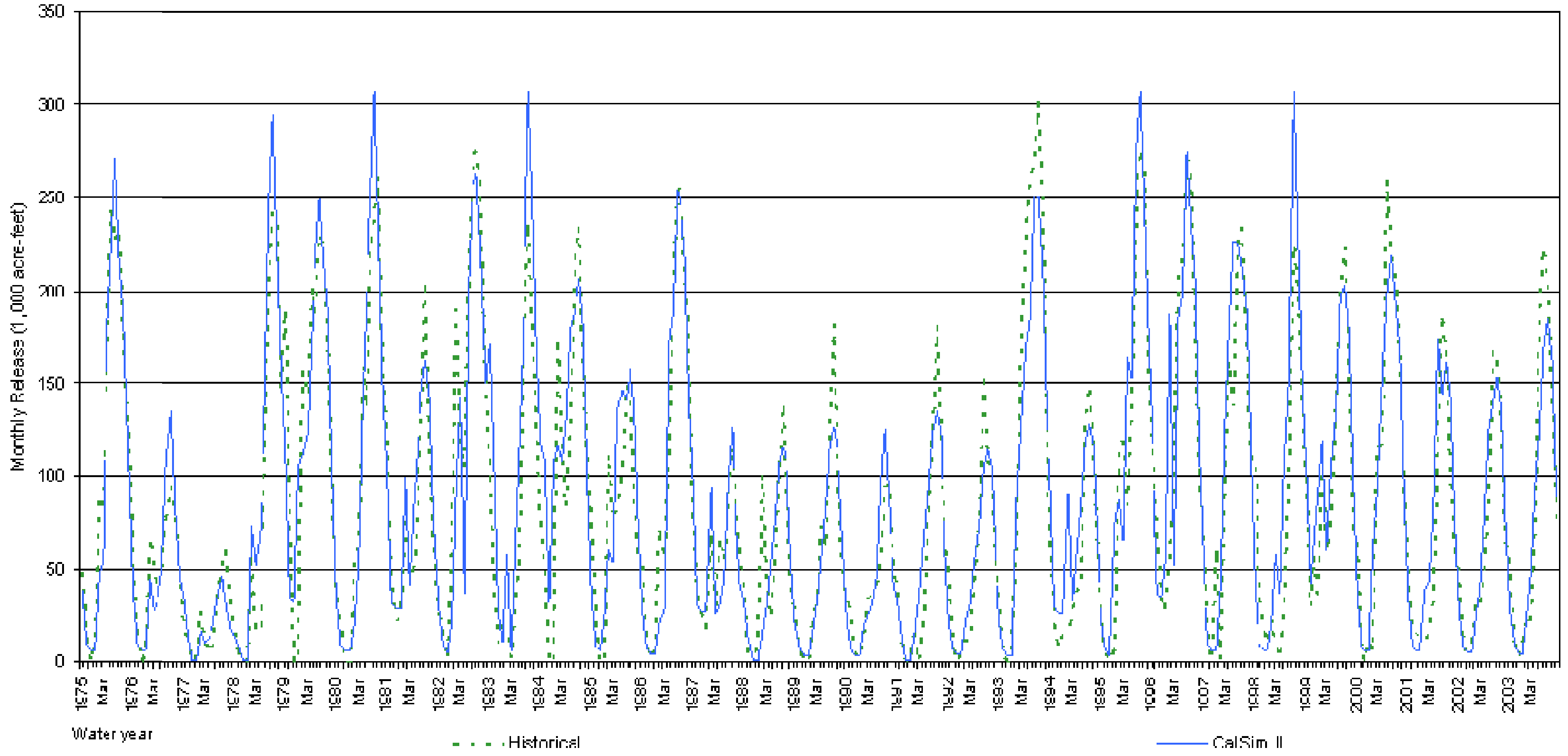


Figure 3-4.
Friant-Kern Canal Diversions

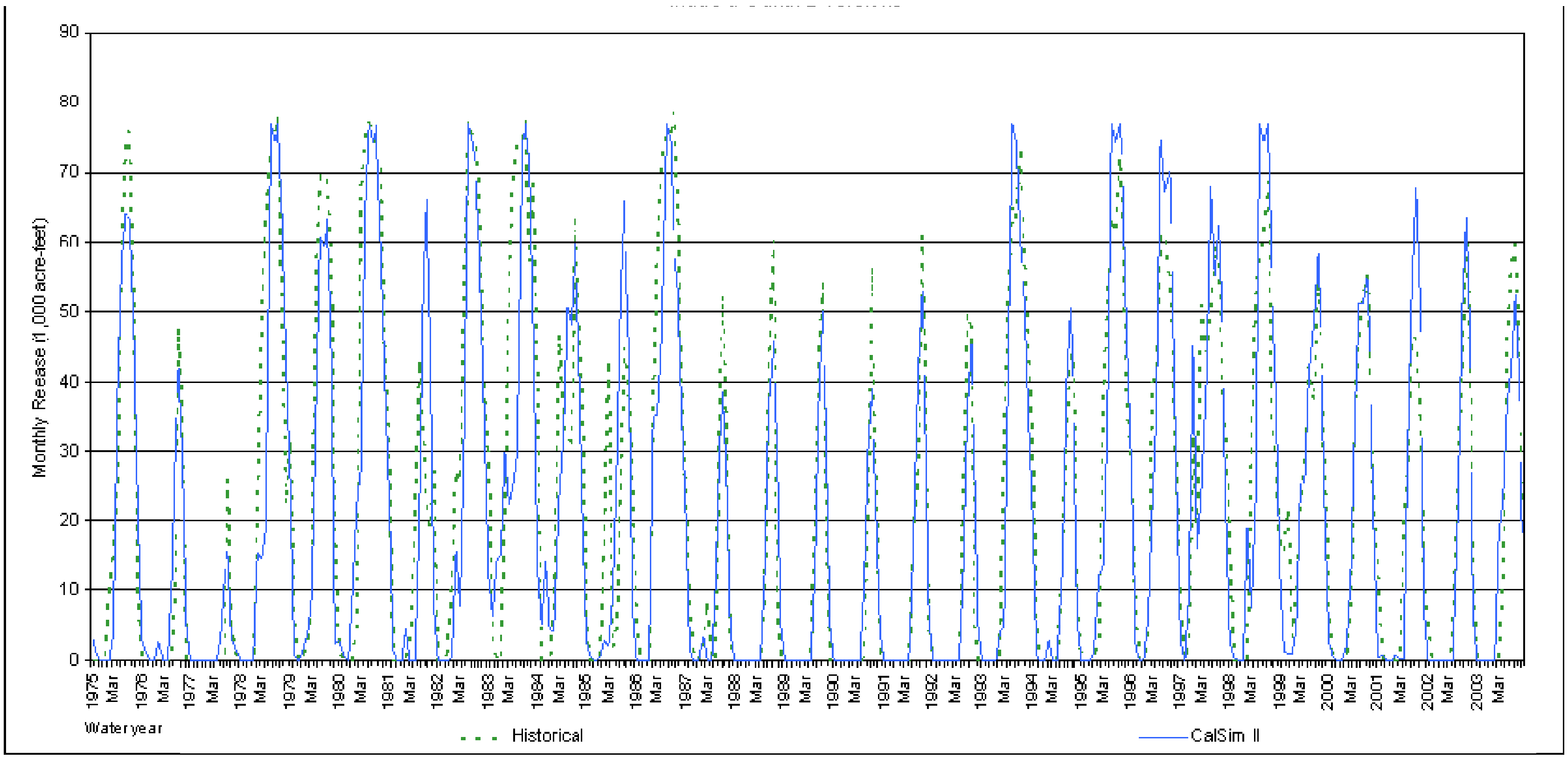


Figure 3-5.
Madera Canal Diversions

The Peer Review process suggested that one aspect of CalSim that could require further refinement is the water quality depiction of the San Joaquin River. Of particular concern is the calculated sensitivity at the Stanislaus River confluence due to the river's influence on New Melones Project operation.

Figure 3-6 is a plot of San Joaquin River electrical conductivity (EC) and San Joaquin River flow, as depicted by CalSim and recorded for October 1995 through September 2003. This graphic is representative of the accuracy of CalSim in depicting flow and water quality conditions in the San Joaquin River upstream from the Stanislaus River confluence, a location typically referred to as the "Maze" Boulevard crossing of the river. A flow and quality recorder exists at this location and provided information for calibrating CalSim. CalSim provides an adequate simulation of San Joaquin River flow and water quality conditions, and is the best available tool for such a depiction (CALFED 2006). The water quality components were not modified for this program.

CalSim is also appropriate to analyze the interaction between San Joaquin River flow and quality conditions, as affected by Restoration and operation of the New Melones Project.

Figure 3-7 compares the annual historical and simulated flow at Vernalis. Comparison of simulated and historical monthly San Joaquin River flows at Vernalis are identified in Figure 3-8.

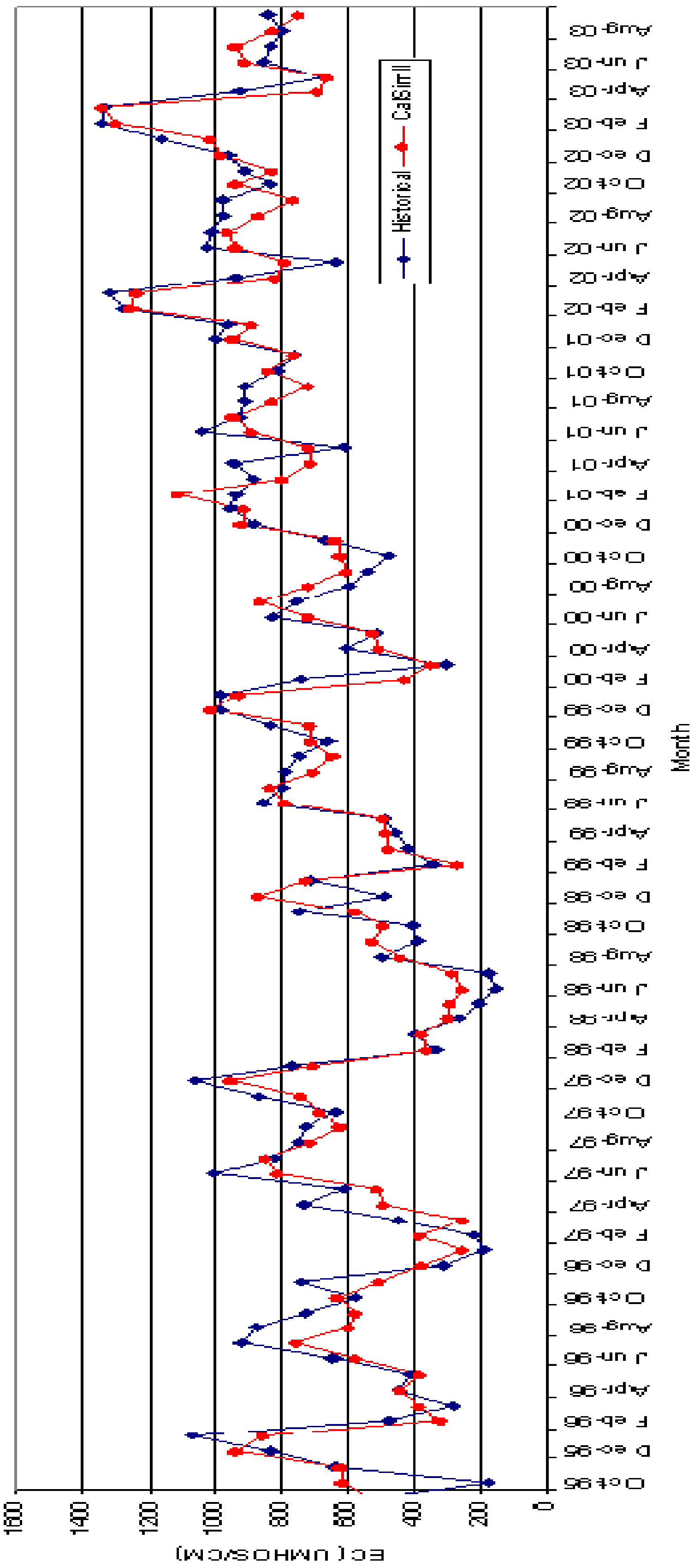


Figure 3-6.
Electrical Conductivity - San Joaquin River at Maze

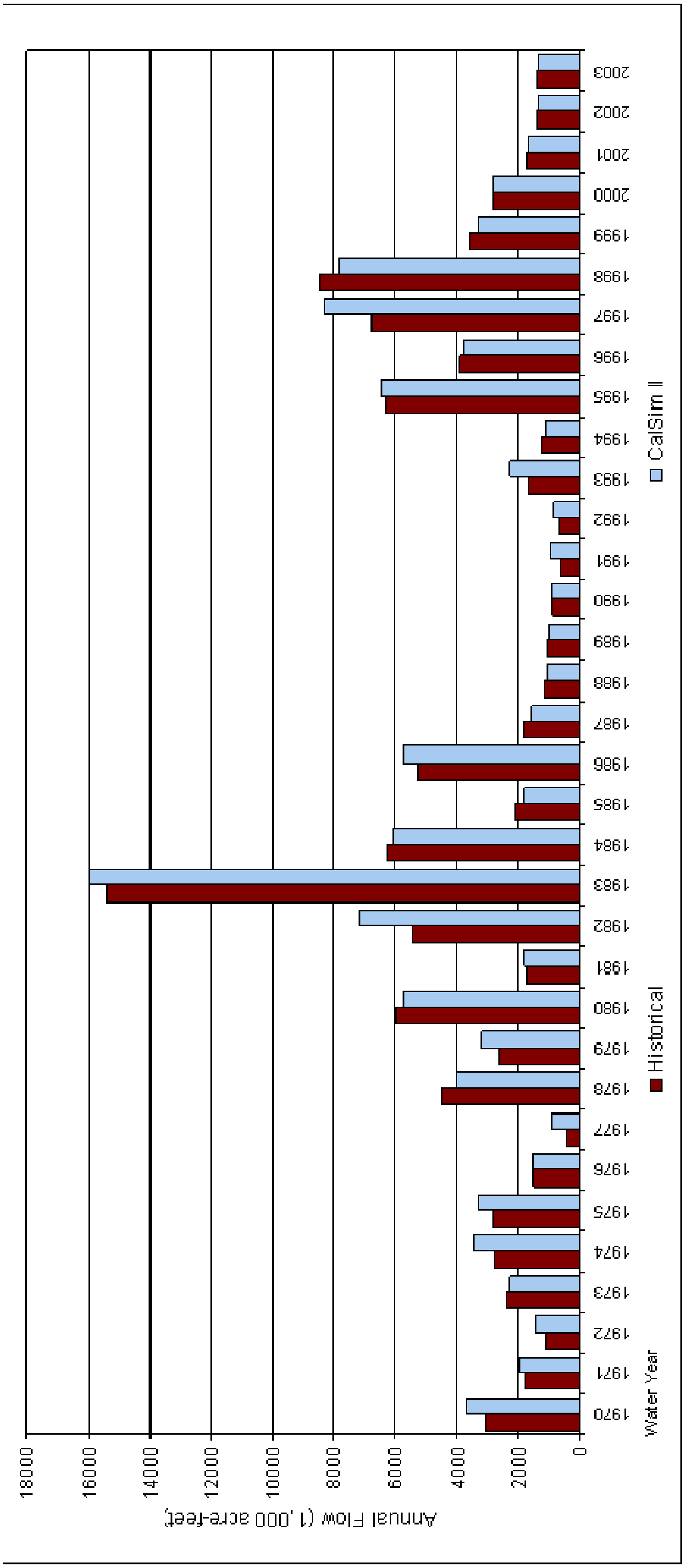


Figure 3-7.
Annual San Joaquin River Flow Volume at Vernalis

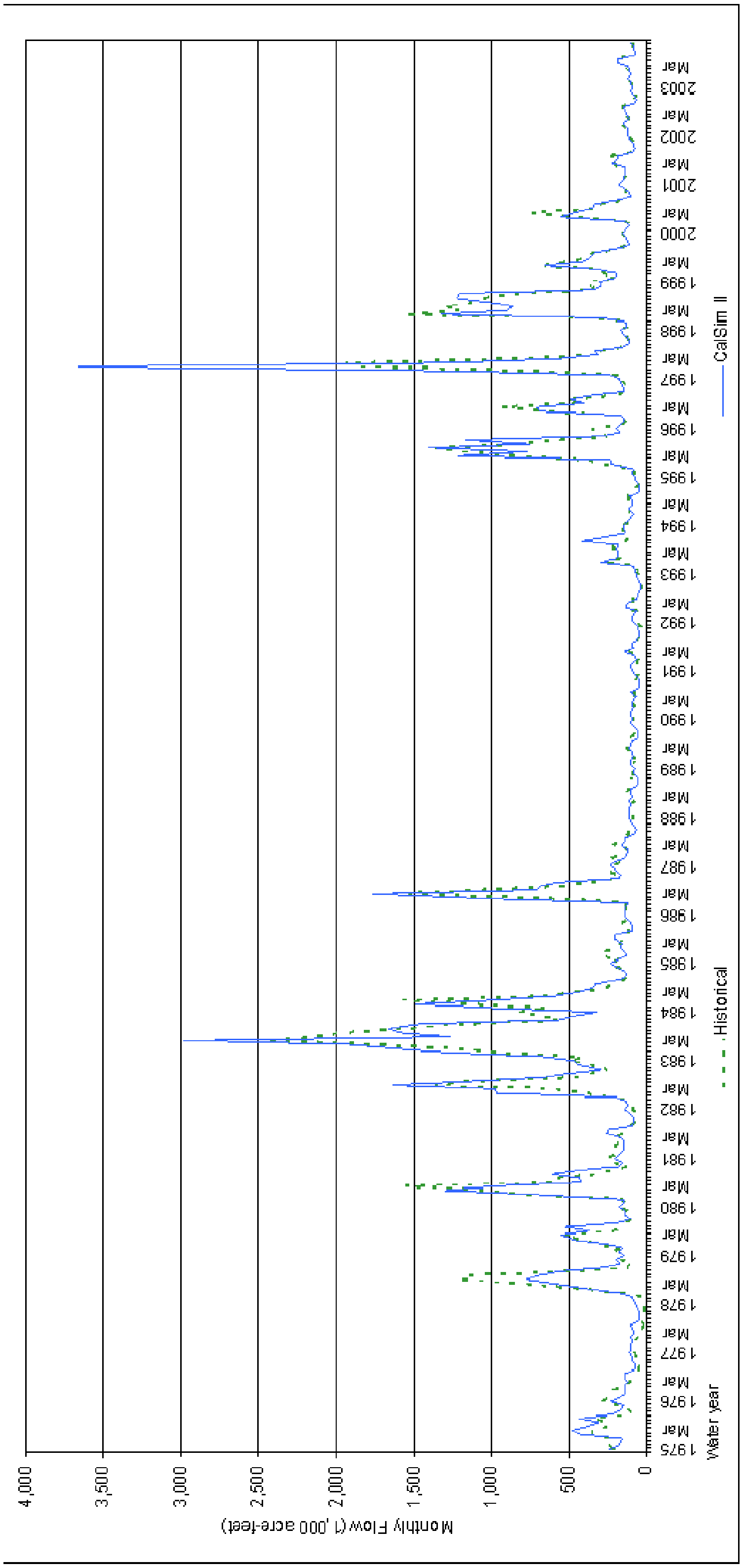


Figure 3-8.
San Joaquin River Flow Volume at Vernalis

3.1.3 Modeling Assumptions

A complete description of CalSim assumptions requires descriptions of how operations for both the CVP and SWP throughout the State are being handled. The CACMP V9 CalSim baseline has a well documented series of tabulated assumptions that are presented in the CalSim Assumptions for Existing Conditions and No-Action Alternative attachment.

Existing Minimum San Joaquin River Flow Requirement

For all CalSim model runs, a number of modifications were made to capture SJRRP operations between Friant Dam and the Merced River confluence. Release from Friant Dam to the San Joaquin River is normally limited to that amount necessary to maintain diversions by riparian and contractor users below Friant Dam to a location near Gravelly Ford. Water diverted to the fish hatchery below Friant Dam and returned to the river partially serves that purpose. Review of historical operation records (Reclamation monthly reservoir operation reports) provided guidance in estimating the minimum downstream release. From an analysis of the historical record (1990 – 1994) for periods when no flood control releases were made, an annual release of 116,700 AF was estimated to be the current minimum release necessary to meet downstream diversions (including seepage). Table 3-1 illustrates the assumed monthly distribution of this release requirement.

Table 3-1.
Estimated Friant Dam Minimum River Release Requirement (TAF)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
10.1	7.4	6.7	4.5	5.0	6.6	9.0	10.9	12.9	14.4	15.7	13.4
Total 116.7 TAF											

Key:
TAF = thousand acre-feet

Levels of Development

CalSim simulations at a projected LOD show how the modeled water system might operate with an assumed physical and institutional configuration imposed on a long-term sequential hydrologic trace. An existing LOD study assumes that current land use, facilities and operational objectives are in place for each year of simulation (1922 through 2003). The results of the existing LOD study are a depiction of the current environment, which provides a basis for comparing project effects for the CEQA analysis. A 2030 LOD study is needed to explore how the system may perform under an assumed future set of physical and institutional circumstances. This future setting is developed by assuming 2030 LOD land use, facilities and operational objectives, and is used for the FNA condition for the NEPA analysis.

Existing Level of Development. Parameters used to describe existing LOD hydrologic conditions and operating rules for the San Joaquin River basin water system were developed using recent historical data and current established operational objectives and requirements. These criteria are described in the *Draft CalSim-II San Joaquin River Model* documentation (Reclamation 2007). The results provide a CalSim simulation of the system depicting current operations.

Future No-Action (2030) Level of Development. Projecting availability of facilities, institutional and regulatory requirements, and practices that would affect management of future water supplies and demands is a daunting task, at times fraught with speculation. However, assumptions must be made regarding these items to provide a projection of 2030 conditions.

The San Joaquin River Basin has experienced numerous physical and institutional changes over the decades and is continuing to experience change. The following changes addressed in this version of the 2030 LOD lead to substantive changes in hydrologic outcome as compared to the current LOD simulation.

- Land use conversion from agricultural demand to urban demand
- The source of water to meet the change in land use

Drainage to the San Joaquin River. The following operational assumptions remain constant between the current and 2030 LOD but could lead to significantly different results:

- All current tributary and San Joaquin River mainstem flow requirements and other regulatory requirements remain in place for the 2030 LOD.
- All current water exchanges, transfers, and sales explicitly or implicitly modeled in the current LOD remain in place for the 2030 LOD.
- Water use efficiency remains the same between the current and 2030 LOD.

Tributary inflow (rim flows) remains the same.

Drainage from the San Joaquin River

Drainage and return flows from the San Joaquin River for the existing LOD are described in the *Draft CalSim-II San Joaquin River Model* documentation, particularly in the discussion of the water quality module (Reclamation 2007). Several salinity EC characteristics of drainage and return flow components were explicitly modeled in CalSim. One such component was the discharge of the Grassland Bypass Project. This project, now incorporated into the *West Side Regional Drainage Plan*, continues to operate to reduce selenium discharges to the San Joaquin River (San Joaquin River Exchange Contractors Water Authority et al. 2003). Current efforts and plans lead to an eventual elimination of selenium, and incidental reduction of salt discharges to the river. This program anticipates the total removal of currently modeled discharge from the river prior to 2030. To incorporate this anticipated change, the CalSim input parameters for the Grassland Bypass Project were reduced to zero discharge (from an existing LOD discharge of approximately 30,000 acre-feet per year).

National Marine Fisheries Service 2009 Operations Criteria and Plan Biological Opinion

The National Marine Fisheries Service (NMFS) 2009 Operations Criteria and Plan (OCAP) Biological Opinion (BO) and other recent BOs for Delta smelt, salmon, steelhead, and green sturgeon were not included in the modeling. No accepted interpretation of how these should be implemented in the CalSim modeling is currently available to allow analysis. These BOs are expected to restrict pumping in the program alternatives, and to reduce the opportunity for Delta recapture and recirculation of Restoration Flows. The BOs will have no impact on San Joaquin River operations in the Restoration area. All real time operations will comply with these BOs, as well as all other applicable regulations at the time of implementation of the Restoration Flows.

3.1.4 Alternatives Formulation

Three action alternatives were implemented at both Existing and Future LODs.

All alternatives include the Restoration minimum Friant Dam release requirements as derived using Method 3.1 and Transformation Pathway “alpha.” Complete descriptions of Method 3.1 and the alpha pathway are provided in an attachment to the Plan Formulation Technical Memorandum titled *Restoration Flow Management Actions*.

All alternatives include 16(b) operations for capture of Upper San Joaquin River surplus. A complete description of these actions is included as an attachment to the Plan Formulation Technical Memorandum titled *Water Management and Fisheries Actions*.

The CalSim alternative evaluations differ in the implementation of 16(a) operations. 16(a) operations represent the recapture of San Joaquin Restoration flow downstream from the Merced River confluence. The following three alternatives show these differences:

- **Alternative A** (no Federal action for 16(a) recapture), Restoration Flows enter the Delta and are divided between Delta outflow and capture by the SWP and CVP according existing physical and regulatory constraints.

- **Alternative B** adds a diversion exchange with upper DMC contractors that also have points of diversion on the San Joaquin River. The contractors divert Restoration flow on the San Joaquin River in-lieu of receiving water from the DMC, and the increment of water in the DMC is delivered to the Friant-Kern Canal through connections in the southern San Joaquin Valley. CalSim was modified to compute the exchange volume and water delivery to a location on the aqueduct near Cross Valley Canal. Water is not returned to Friant in the CalSim model.

- **Alternative C** adds a pump station on the San Joaquin River downstream from Vernalis at Banta Carbona to capture Restoration Flows. The pump station was assumed to have direct connections to the DMC and California Aqueduct and water was transported and delivered to the same location as the diversion exchange. The pump station only operates when it would not degrade water quality in the aqueduct system.

The potential return of recaptured water to Friant pursuant to 16(a) is not fully modeled in CalSim. Additional restoration inflows to the Delta are treated the same as any other Delta inflow within CalSim. This results in a re-operation of the CVP/SWP system under physical and regulatory limits within the model. Actual results are a relatively small re-operation of the system north of the Delta and increased Delta pumping and CVP/SWP delivery south of the Delta. For modeling purposes the average annual increase in south of Delta deliveries is assumed to represent the upper limit of potential return of Delta 16(a) recapture.

Alternatives B and C each include recapture upstream from the Delta via exchange or direct diversion respectively in the CalSim model. This water is not returned to Friant or to other CVP/SWP contractors in the model. In these alternatives, potential return is defined as the annual average of internal recapture and the annual average increase in south of Delta deliveries.

Restoration Flow Implementation

Restoration Flows were implemented as a minimum required release from Friant Dam. The Restoration release schedule was pre-processed using Method 3.1 and includes the 117 thousand acre-feet (TAF) annual pre-restoration release for downstream riparian diversions and losses. In the months of March, April, and November, the Restoration flow schedule calls for flow pulses measured in days and weeks. Day-weighted average flows for the months of March and November were used for the monthly time-step simulation. However, because of the synchronization of the April Restoration Flows with downstream releases for VAMP, a split month operation was implemented to quantify downstream impacts.

Scheduled Restoration releases were incorporated into Friant water supply and flood control operations. Planned releases were used to reduce the forecasted water supply for Class 1 and Class 2 deliveries. Surplus forecasts also took scheduled Restoration releases into account thereby reducing snowmelt releases, Section 215 deliveries, and 16(b) deliveries.

16(b) Assumptions

Paragraph 16(b) of the San Joaquin River Restoration Settlement allows for delivery of surplus water to Friant contractors for $10/AF. Both 16(b) and Section 215 deliveries are limited to otherwise “unstorable” water. This includes forecasted snowmelt releases and imminent flood releases. Typically, when surplus is available, demand for water is low. Therefore, development of a system of groundwater banks serviceable from the Friant-Kern and Madera Canals was assumed to allow for greater capture of available surplus. The groundwater banks have different recharge mechanisms including in-lieu, direct recharge, and winter irrigation of permanent crops.

Section 215 deliveries on the Madera Canal were given priority over surplus water to avoid reoperation of Hidden and Buchanan dams. It was assumed that 16(b) groundwater banking operations would not directly cause drawdown of the Fresno and Chowchilla river reservoirs by reducing 215 deliveries in a given month. (Hidden Dam forms Hensley Lake on the Fresno River, and Buchanan Dam forms Eastman Lake on the Chowchilla River). Section 215 deliveries from Madera Canal can meet the same demands as upstream releases on the Fresno and Chowchilla Rivers. In the baseline, surplus from the San Joaquin River will be delivered before reservoirs on the Hensley and Eastman Lakes are drawn down. If 16(b) were given priority on the Madera Canal, there are times when the San Joaquin River surplus would be put in developed water banks and releases would be made from Hidden and Buchanan Dams to meet the resulting unmet demand.

Overall, priority to San Joaquin River surplus was as follows:

- Madera Canal 215
- Friant-Kern Canal 16(b)
- Friant-Kern Canal 215
- Madera Canal 16(b)

Each time-step, if any surplus water was available through scheduled snowmelt forecast releases or flood, first Section 215 water would be routed down the Madera Canal until one of three constraints was reached: 1) demand, 2) channel capacity, 3) available surplus. If surplus remained, 16(b) water was then routed down the Friant-Kern Canal until one of the three same capacity constraints was reached. This logic continues with Friant-Kern Canal 215 deliveries and Madera Canal 16(b).

On the Friant-Kern Canal, groundwater banks were implemented at each WMA for the capture of 16(b) water. The groundwater banks at the lower reaches of the canal were given higher priority than upstream banks. The purpose was to highlight any potential channel capacity limitations. This does not reduce the total amount of surplus captured. In each time-step, capture of surplus is maximized under the assumed constraints.

Alternatives Assumptions

For Alternative A, no Federal action for 16(a) recapture, the key assumptions are as follows:

- Restoration flow releases as developed with Method 3.1
- 16(b) surplus flow capture as described above
- Between Friant Dam and the confluence of the Merced, Restoration Flows are reduced by riparian diversions and in-stream losses
- Mendota Pool Bypass is added with a capacity of 4,500 cubic feet per second (cfs)
- New Melones Reservoir is allowed to respond to changes in flow and water quality at Vernalis
- No Restoration flow is captured for direct return to the Friant Division
- CVP and SWP operations respond to changed Delta inflow at Vernalis according to existing physical and regulatory constraints and operating rules. This includes both Delta exports and south-of-Delta CVP/SWP storage, conveyance, and delivery

systems. This assumption means that any additional Delta inflow is modeled as being available for CVP/SWP export and delivery. Additional Delta inflow that is not exported will become Delta outflow.

Alternative B is the same as Alternative A except that Restoration flow is allowed to be recaptured under the following assumptions:

- Two diversions on the San Joaquin River are added: one for the Patterson and West Stanislaus Irrigation Districts (ID) and the other for the Banta Carbona ID
- Each month, the total diversions cannot exceed the Restoration release minus the riparian diversions and losses
- Patterson and West Stanislaus diversions cannot exceed 31 percent of their respective monthly delivery allocations from the DMC (exchangeable demand constraint)
- Banta Carbona diversions cannot exceed 33 percent of its monthly DMC allocation (exchangeable demand constraint)
- At Future LOD, the DMC-California Aqueduct intertie can be used for 16(A) recapture
- 16(a) recapture is limited on an annual basis to that year's reductions in Class 1 and Class 2 allocations due to Restoration releases
- Restoration recapture is delivered from the California Aqueduct to a location near Cross Valley Canal or Arvin-Edison Intertie using existing available capacity. The water is not delivered back to the Friant Division.
- Restoration recapture can be temporarily held in San Luis Reservoir if space is available
- Any remaining Restoration flow can be picked up in the Delta by the CVP or SWP

Alternative C is the same as Alternative B except that Restoration flow is allowed to be recaptured under the following assumptions:

- Pump station with 1,000 cfs capacity located at Banta Carbona
- Pump station diverts Restoration Flows to both the DMC and California Aqueduct
- Each month, the total diversions cannot exceed the Restoration release minus the riparian diversions and losses
- Exporters have priority use of DMC and California Aqueduct capacity

- 16(a) recapture is limited on an annual basis to that year's reductions in Class 1 and Class 2 allocations due to Restoration releases
- No pumping is allowed when the water at Vernalis is of lower quality than that in the DMC and California Aqueduct
- Restoration recapture is delivered from the California Aqueduct to a location near the Cross Valley Canal or Arvin-Edison Intertie using existing available capacity. The water is not delivered back to Friant.
- Restoration recapture can be temporarily held in San Luis reservoir if space is available
- Any remaining Restoration flow can be picked up in the Delta by the CVP or SWP

3.1.5 Supplemental Evaluation Assumptions

Several supplemental evaluations were performed. All were based on Alternative A. Following are summary descriptions of the supplemental evaluations with specific modeling assumptions.

Exhibit B Flow Schedule

Implements Restoration Flow releases as documented in Exhibit B of the Settlement, without transformation. This evaluation was performed on Alternative A at Existing LOD. All other operations were held constant.

Flexible Flows (earlier and later)

Implements the maximum extent of Flexible Flows by shifting pulses for both Spring and Fall Flexible Flow Periods in two separate evaluations. The first evaluation shifts both periods one month earlier, the second evaluation shifts them one month later. Both evaluations were performed on Alternative A at Existing LOD. All other operations were held constant.

Buffer Flows

Implements the maximum extent of Buffer Flow utilization by uniformly increasing releases for each month by 10 percent. This evaluation was performed on Alternative A at Existing LOD. All other operations were held constant.

No Implementation of 16(b)

Prevents deliveries of surplus water for 16(b). Any available surplus was delivered as Section 215 water before being allowed to spill. This evaluation was performed on Alternative A at both Existing and Future LOD. All other operations were held constant.

Restored Friant-Kern Canal Capacity

Restores the Friant-Kern Canal reach capacities to design specifications. Table 3-2 presents a comparison of existing and design capacities for the Friant-Kern Canal. The capacity restoration was implemented in Existing LOD Alternative A. All other operations were held constant.

Table 3-2.
Friant-Kern Canal Reach Capacities

Water Management Area	Friant-Kern Canal Reach	Friant Contractors	Existing Limiting Canal Reach Capacity (cfs)	Restored Limiting Canal Reach Capacity (cfs)
2	Friant Dam to Kings River Check	Fresno City of Fresno Garfield International	5,300	5,300
3	Kings River check to Fifth Avenue Check	Orange Grove ID City of Orange Grove Stone Corral ID Tulare ID Exeter ID Ivanhoe ID City of Lindsay Lindsay-Strathmore ID Lewis Creek WD Lindmore ID	4,105	4,500
4	Fifth Avenue Check to Deer Creek Check	Porterville ID Lower Tule River ID Tea Pot Dome WD Saucelito ID Terra Bella ID	4,000	4,000
5N	Deer Creek Check to Poso Creek Check	Delano Earlimart Southern San Joaquin Municipal Utility District	3,500	3,500
5S	Poso Creek Check to Shafter-Wasco Check	Shafter Wasco	2,170	2,500
7	Shafter-Wasco Check to Kern River Check	Arvin Edison	2,170	2,500

Key:
cfs = cubic feet per second
ID = irrigation district
WD = water district

Channel Constrained Releases

Implements Restoration Flows using capacity restrictions in existence at time of document publication. Complete descriptions of non-damaging capacities for the Restoration Area are included as an attachment to the Plan Formulation Technical Memorandum titled *Restoration Area Channel Capacity Evaluations*.

This evaluation limits Reach 2B to a capacity of 1,300 cfs. Restoration Flows in Reach 2B take priority over surplus flow to the Mendota Pool and no Restoration Flows were routed through the Chowchilla Bypass. Since scheduled Restoration releases in many years can be larger than 1,300 cfs, the release schedule was reduced so that Restoration release resulted in flows equal to or less than 1,300 cfs in Reach 2B. Losses and diversions upstream from Reach 2B were taken into account in the rescheduling. Additionally, Reach 4B is assumed to have zero (0) cfs capacity and Restoration Flows are routed through the Eastside Bypass. The capacity restoration was implemented in Existing LOD Alternative A. All other operations were held constant.

Old and Middle River Flow Restrictions

This evaluation imposes a flow restriction on Old and Middle Rivers. Banks and Jones Delta pumping can impact the flows in the western Delta, in some cases actually reversing the net from flowing towards the ocean to away from the ocean towards the pumps. A constraint that limited pumping to maintain a net flow of greater than -750 cfs, (a negative flow indicates flow from west to east) was added to the CalSim model. The -750 cfs limitation was selected as representative of potential restrictions that could be imposed from actions currently under consideration. This reduced Delta pumping such that the existing delivery logic in CalSim required modifications to produce a reasonable system response for use in the analysis.

3.1.6 Output Description

The Water Operations Modeling Output – CalSim Attachment presents monthly CalSim modeling results at representative locations as comparison tables and data tables. Comparison tables present simulated monthly averages at each location for each water year type. Data tables present simulated monthly values from water years (WY) 1922 through 2003 at each location. Table 3-3 lists all CalSim parameters presented in the Water Operations Modeling Output – CalSim Attachment.

Table 3-3.
Parameters Presented in Attachment –
Water Operations Modeling Output – CalSim

Location	Parameter
Millerton Lake	Storage
Friant-Kern Canal Diversions	Flow
Madera Canal Diversions	Flow
Merced River Inflow To San Joaquin River	Flow
San Joaquin River Below Merced River	Flow
San Joaquin River Below Tuolumne River	Flow
New Melones Reservoir	Storage
Stanislaus River Inflow to San Joaquin River	Flow
San Joaquin River Flow Upstream from Vernalis	Flow
San Joaquin River Inflows to Delta	Flow
Delta Outflow	Flow
Exports Through Banks and Jones Pumping Plants	Flow
Old and Middle River Flow	Flow
Previous Month X2 Position	Distance
Mendota Pool	EC
San Joaquin River below Sack Dam	EC
Eastside Bypass	EC
San Joaquin River at Merced River Confluence	EC
San Joaquin River at Tuolumne River Confluence	EC
San Joaquin River at Vernalis	EC
San Luis Reservoir	Storage

Key:
EC = electrical conductivity

3.2 Millerton Daily Operation Modeling

As mentioned, the SJRRP used the monthly time step model CalSim to model basic water operations anticipated under the program alternatives to determine how well they would meet the water management goal. Once basic water operations were determined, they underwent additional analysis to determine how well they would meet the Restoration Goal, and to support evaluation of potential SJRRP PEIS/R impacts. Much of this further analysis required estimates of water operations on a shorter, daily, time step.

A transparent, consistent, repeatable process to estimate a reasonable set of daily water operations that maintain the overall water operational constraints from CalSim results was required to perform the analysis, and facilitate comparisons between alternatives.

The USJRBSI developed an Excel-based spreadsheet to disaggregate monthly CalSim water operations into a daily set of water operations for use in further analysis. These daily values are not intended to represent proposed or optimal daily water operations. Instead, USJRBSI analyses represent a potential set of daily water operational values that can be used for further analysis in support of comparisons between alternatives.

The USJRBSI baseline CalSim simulation includes the Settlement flow schedule. This simulation was selected for use in the evaluation, modification, and verification of the spreadsheet for use in SJRRP modeling scheme. All values, tables, and figures presented in this report are based on this CalSim simulation and are presented here for example purposes only, and may not represent the final values used in the SJRRP PEIS/R analysis.

Water operations data from 1983 of the USJRBSI baseline CalSim simulation were used to generate examples of the procedure followed for each year. This year was chosen because it is a very wet year, and includes flood releases from Millerton Lake.

3.2.1 Model Description

The spreadsheet tool generates the daily set of water operations using a two step process:

- Monthly-to-daily interpolation process
- Simplified daily rainflood operation

Initial Restoration Modifications

As used in the USJRBSI, the spreadsheet includes the capability to include the potential Fine Gold and Temperance Flat reservoirs evaluated as part of that project. Although these reservoirs can be “turned off” in the tool for evaluations of Millerton Lake alone, the spreadsheet was extremely large and complex with long recalculation times, and a greatly increased chance of error. Therefore, the spreadsheet tool was modified to remove the Fine Gold and Temperance Flat reservoirs.

A number of additional charts were added to allow comparison of final computed daily values to monthly CalSim input values to allow verification that the spreadsheet produces reasonable results. Figure 3-9 is an example of a chart showing how the CalSim monthly values correspond to the final daily values.

Figure 3-10 shows three example charts comparing the San Joaquin River release component computation and the final total San Joaquin River release between the CalSim monthly values and the final daily values. There are simular charts for the Friant-Kern Canal and Madera Canal diversions.

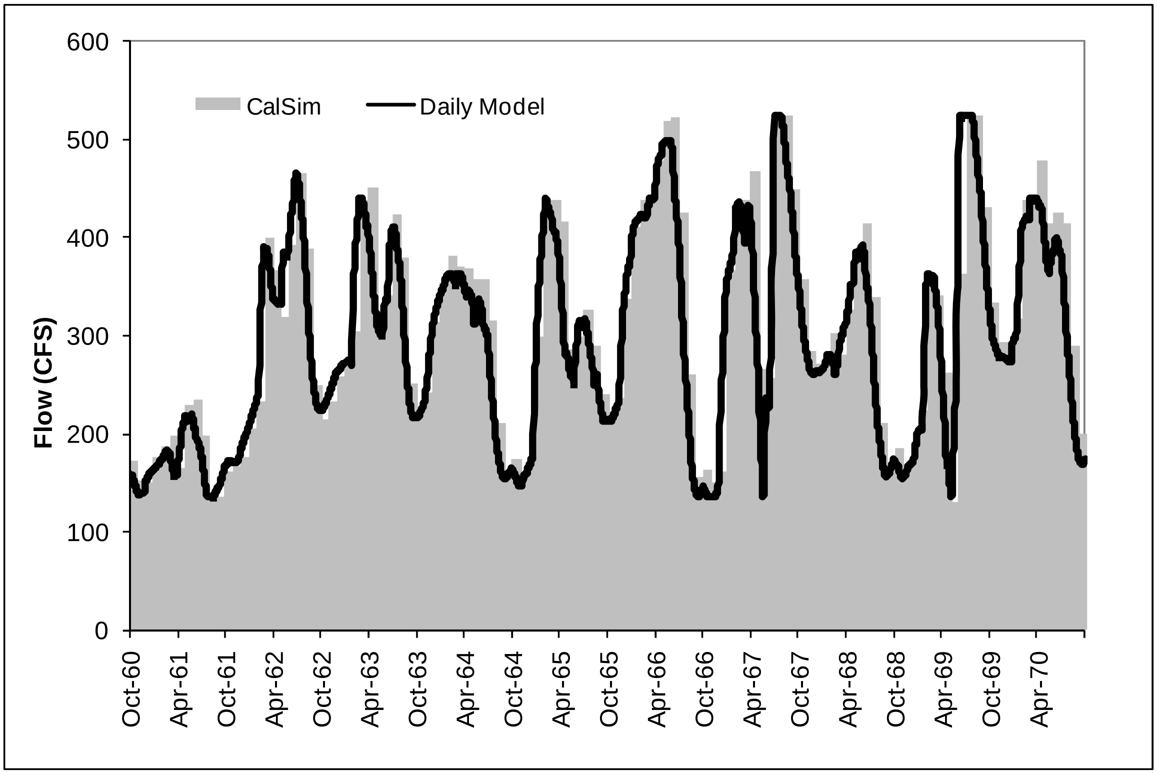


Figure 3-9.
Example Millerton Lake Storage Operation Monthly-to-Daily Comparision

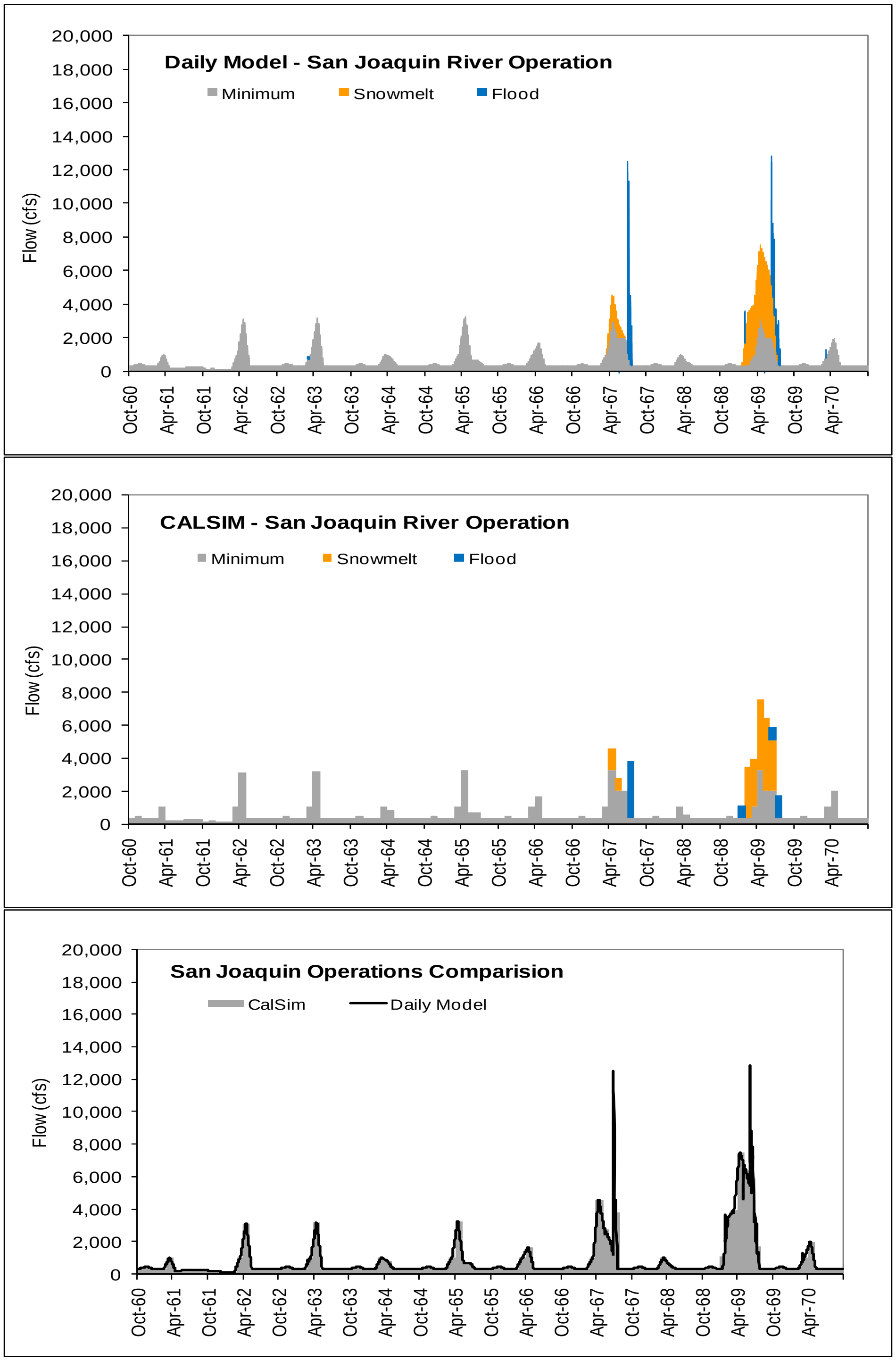


Figure 3-10.
Example Millerton Release to the San Joaquin River Monthly-to-Daily Comparison

3.2.2 Model Assumptions

Several assumptions are made in the spreadsheet tool to produce daily time-step Millerton Lake operations simulations. These include, as described below, assumptions regarding interpolation processes, flood operations, and flow routing.

Monthly to Daily Interpolation Process

Simplified daily rainflood operations require boundary or input data on a daily basis. These data include the following:

- San Joaquin River inflow to Millerton Lake
- Friant-Kern Canal diversion
- Madera Canal diversion
- Snowmelt flood control release
- San Joaquin River minimum flow release (Settlement flow schedule)
- Millerton Lake evaporation
- Mammoth Pool storage

Initial boundary condition data are extracted from the appropriate monthly CalSim simulation results and converted into a daily rate through dividing the volume by the number of the days in the month. It is assumed that this daily rate is the rate on the 15th of each month. Final daily rates are linearly interpolated from the middle of one month to the middle of the next. The linear change prevents a stair-step type operation in which the rate changes dramatically at the beginning of each month. The change for the second half of the month, from the 16th to the end of the month, is adjusted to account for the different number of days in each month. Details of the computation are included in a separate report (MBK 2006). Figure 3-11 illustrates this process.

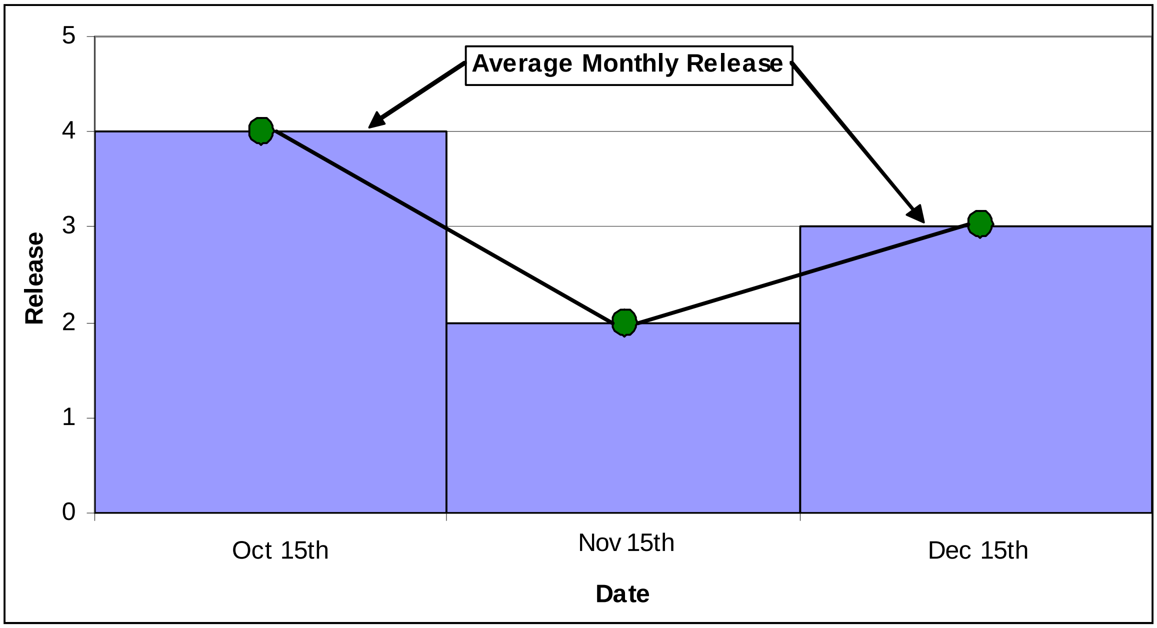


Figure 3-11.
Conceptual Depiction of Monthly-to-Daily Interpolation

It is recognized that this method sets the minimum and peak daily values at the mean monthly value and may not capture the expected minimum and peak daily values; however, this method provides a reasonable level of detail for the evaluations of the program alternatives. The following sections describe how the interpolation process is applied to specific boundary condition data.

San Joaquin River Inflow to Millerton Lake. The spreadsheet tool uses daily Millerton Lake inflows from the USAN model. As mentioned, the USAN model is an operations model of the upper San Joaquin River basin typically used to predict inflows to Millerton Lake. These daily inflows were summed and used to generate monthly inflows for use in CalSim. Since daily inflows are available, no interpolation from monthly to daily values is required.

Friant-Kern Canal Diversion. The Friant-Kern Canal in CalSim only diverts for delivery; there is no flood release component. The simplified daily rain-flood operations may add flood releases to the Friant-Kern Canal.

Madera Canal Diversion. The Madera Canal diversion in CalSim includes both the actual diversion for delivery, and diversion of flood control releases to protect the San Joaquin River. The interpolation process is only performed on the Madera Canal diversion for delivery. Diversions of flood control releases are recomputed in the simplified daily rain-flood operations.

Snowmelt Flood Control Release. The snowmelt flood release in CalSim is determined by predicting the expected inflows to Millerton Lake from February 1 to June 30, subtracting the expected diversions for the same period, and releasing the difference over the period in an attempt to minimize spills from the reservoir. CalSim monthly values are disaggregated using the interpolation process.

San Joaquin River Minimum Flow Release. San Joaquin River minimum flow requirements are specified as mean monthly values for use by CalSim. These CalSim monthly values are disaggregated using the interpolation procedure.

Millerton Lake Evaporation. Millerton evaporation is computed in CalSim based on an assumed evaporation rate and mean monthly surface area. These CalSim monthly values are disaggregated using the interpolation procedure.

Mammoth Pool Storage. Flood control operations at Millerton Lake can take credit for up to 85 TAF of available storage capacity in the upstream Mammoth Pool Reservoir. Daily Mammoth Pool storage is obtained from the USAN model and input into the spreadsheet tool as a data time series (TS) to allow the spreadsheet tool to compute the available credit space at Mammoth Pool.

Simplified Daily Rain-Flood Operation

Rain-flood routing is performed assuming that the total controlled release from Millerton Lake is the sum of all the nonrainflood releases (Madera Canal delivery, Friant-Kern Canal delivery, San Joaquin River minimum flow requirement and San Joaquin River snowmelt flood release).

If making this release would reduce Millerton Lake storage below a minimum allowable storage of 135 TAF, then the total release is reduced to leave Millerton Lake storage at the minimum value. The reduction is distributed to the Friant-Kern Canal, Madera Canal, and San Joaquin controlled release based on their percentage of the total controlled release.

To simulate daily rain-flood operations, the spreadsheet tool calculates daily required flood storage space based on the reservoir operation curve, and any available credit space in the upstream Mammoth Pool. The daily required flood storage space in Millerton Lake is subtracted from the maximum Millerton Lake storage to obtain daily maximum storage. Rain-flood releases are made to prevent Millerton Lake storage from exceeding this daily maximum storage. The rain-flood release is then allocated to the following:

- Unused capacity in the Friant-Kern Canal (up to 1,200 cfs)
- Unused capacity in the Madera Canal (up to 100 cfs or 7.69 percent of the total rain-flood release in February through October, none in November through January)
- Available channel capacity in the San Joaquin River (up to 8,000 cfs total release to the river)
- Millerton Lake flood control storage encroachment, up to the maximum reservoir storage

San Joaquin River Release

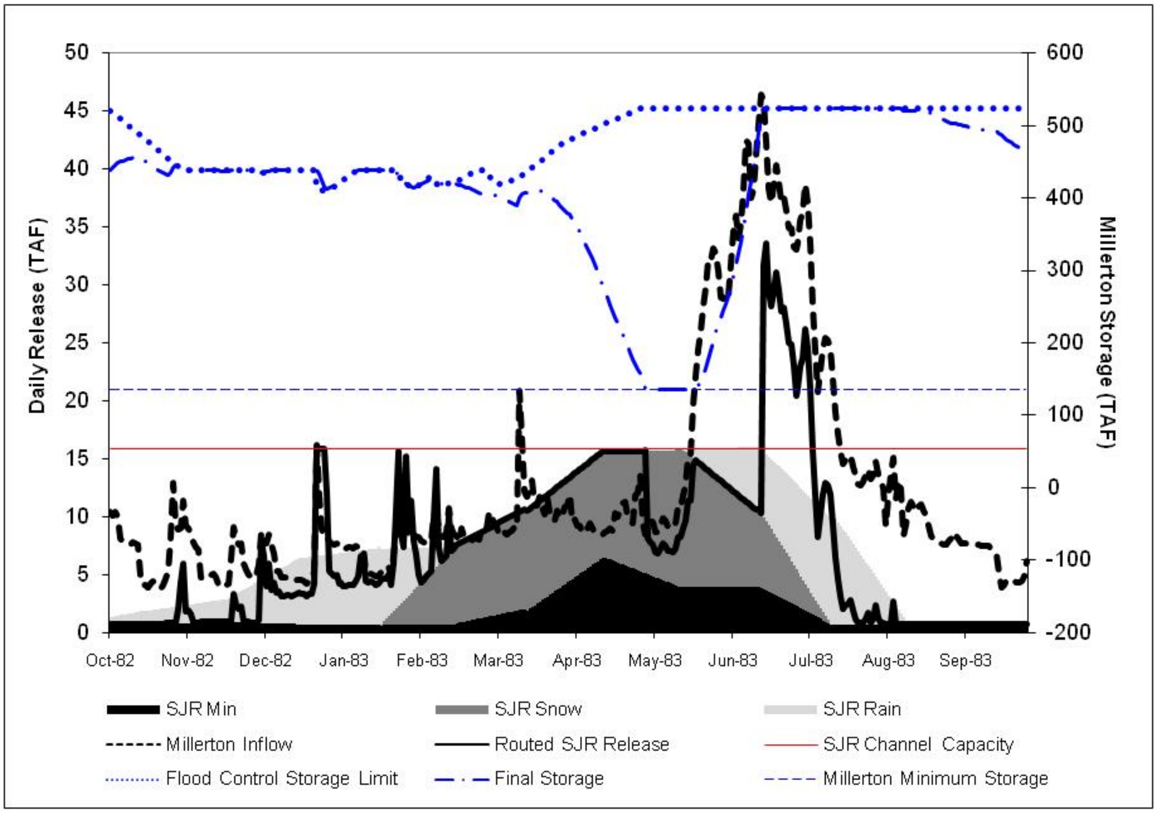
Flood space in Millerton Lake is evacuated, at a maximum rate of 8,000 cfs, as soon as possible after reservoir inflow decreases. All releases to the San Joaquin River are made through dam outlets, unless the reservoir is full and spilling. When this occurs, the spill is assumed to be “release” to the San Joaquin River.

Figure 3-12 is an example of the results of the routing process for Millerton Lake operations and releases to the San Joaquin River.

During the January through March period, the flood control storage limit fluctuates because of variable flood control storage in the upstream Mammoth Pool. During this period, flood control releases occur when final releases are greater than interpolated releases, corresponding to short term peaks in the inflow.

In the January -to - March time period, the daily release to the San Joaquin River peaks at the 8,000 cfs channel capacity limit (15.84 TAF/day). The daily release during this period was at the San Joaquin River channel capacity limit of 8,000 cfs because sufficient storage was available in Millerton Lake to capture additional flood inflows. In late June through early July, the daily release to the San Joaquin River peaks at about 33.6 TAF/day (16,940 cfs), or more than double the San Joaquin River channel capacity. This is because Millerton Lake had filled to capacity and was unable to store additional inflows in excess of downstream channel capacity. During this time, the CalSim monthly release to the San Joaquin River was at channel capacity. This discrepancy is caused by the timing of when the reservoir fills and the duration of the flood control release on a daily basis versus a monthly basis.

Actual storage drops from the flood control level in April to minimum storage in May, then increases to maximum storage by the end of June. This variability in Millerton Lake storage is due to the small storage capacity of Millerton Lake relative to inflow volume, which results in aggressive operations to maximize water supply.



Key: Millerton = Millerton Lake SJR = San Joaquin River TAF = thousand acre-feet

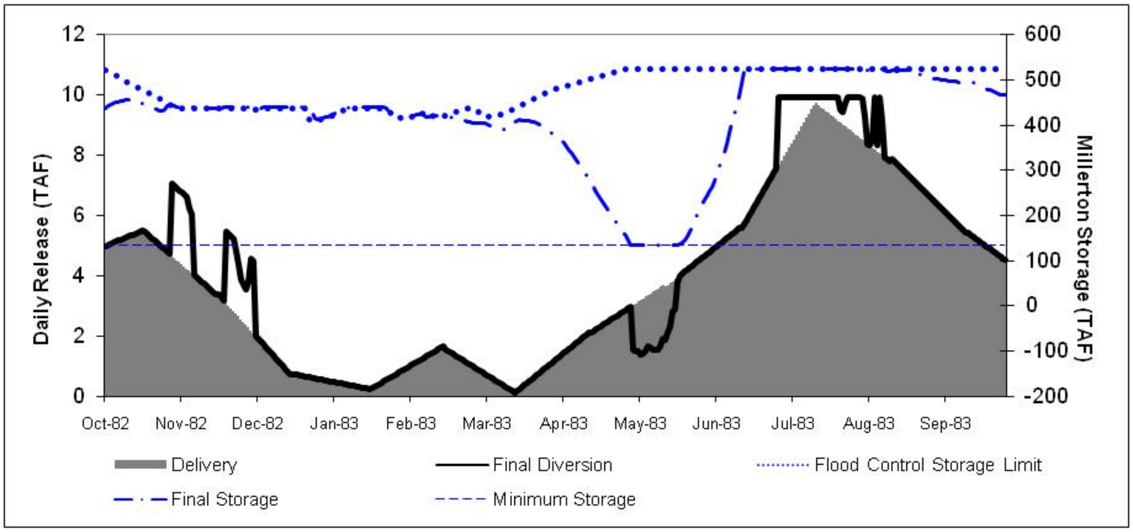
Figure 3-12.
Example Millerton Lake Operations and 1983 San Joaquin River Release Routing Example

In May, the routed San Joaquin River release dropped below the linear interpolated release. This is because Millerton Lake storage reaches the minimum allowable, and releases are cut back to maintain the minimum pool.

Friant-Kern Diversion Routing

Figure 3-13 is an example of the routing process results for Millerton Lake operations and diversions to the Friant-Kern Canal.

The operation of the Friant-Kern Canal is very similar to operation of the Madera Canal, with flood control releases during early winter, and the same decrease in May when Millerton Lake is at minimum storage.



Key: TAF = thousand acre-feet

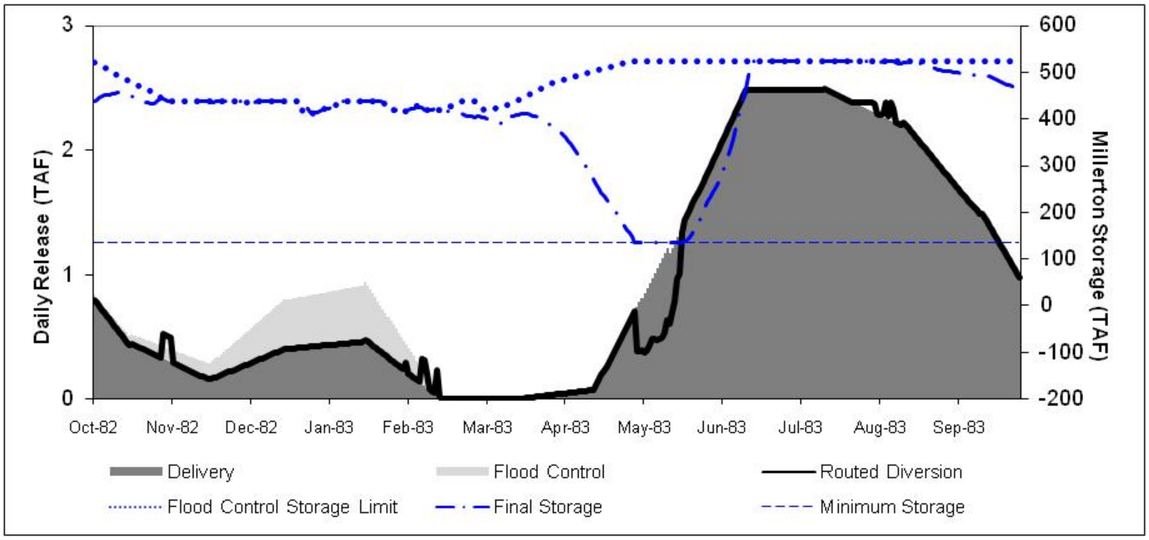
Figure 3-13.
Example Millerton Lake Operations and 1983 Friant-Kern Canal Diversion Routing

Madera Canal Diversion Routing

Figure 3-14 is an example of the results of the routing process for Millerton Lake operations and diversions to Madera Canal.

As can be seen in Figure 3-14, flood control releases to the Madera Canal in late October and the February-through-April period are similar to the timing of flood control releases to the San Joaquin River.

In May, the routed Madera Canal diversion dropped below the linear interpolated diversion, which implies a cutback in delivery through the Madera Canal. This is because Millerton Lake reaches the minimum allowable storage, and the diversions are cut back to maintain the minimum pool.

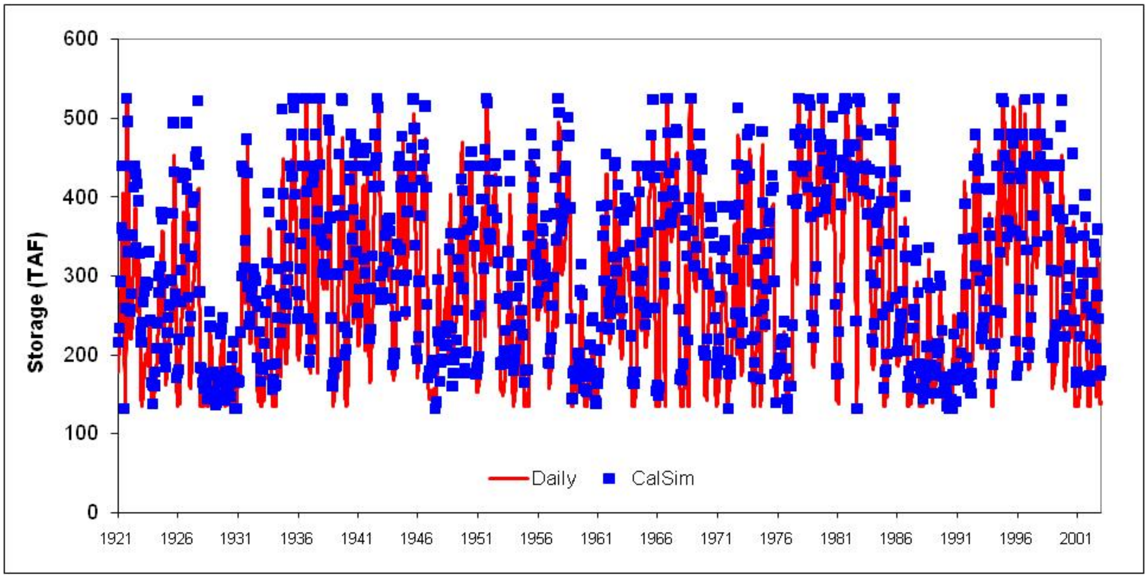


Key: TAF = thousand acre-feet

Figure 3-14.
Example Millerton Lake Operations and 1983 Madera Canal Diversion Routing

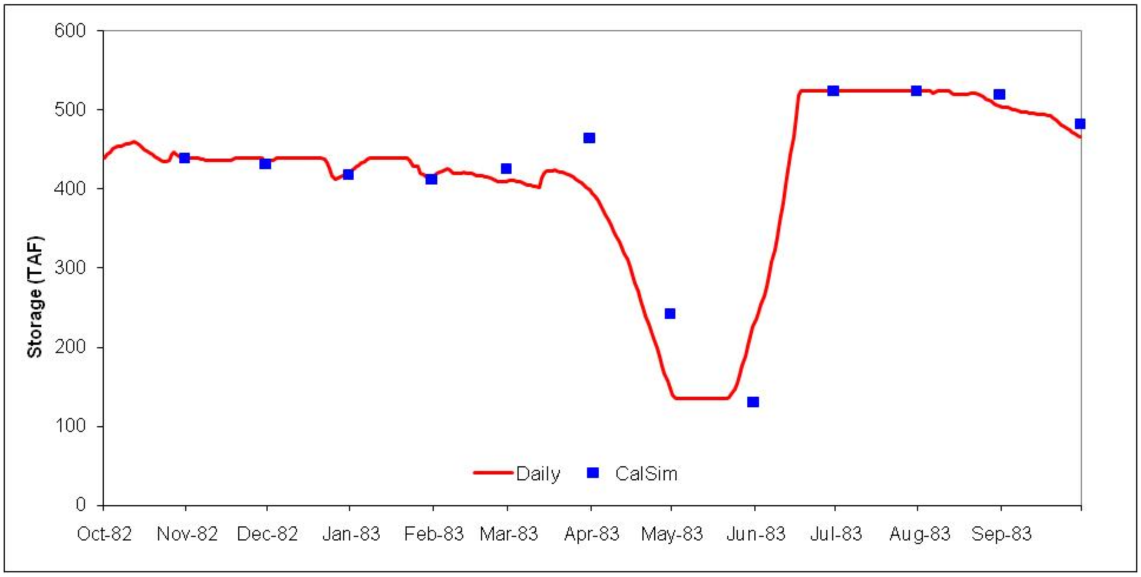
3.2.3 Consistency with CalSim Results

Final daily water operations from the spreadsheet tool, while not expected to exactly match CalSim monthly results, are expected to be within the range of water operations from the CalSim simulation. The total monthly inflow from this tool and the CalSim simulation are the same because the CalSim inflows were computed by summing the USAN daily inflow values used in the example. This implies that if the storage operations are similar, the overall operations must be similar, and storage can be used to evaluate how well the daily operations from the spreadsheet tool fall within the range of water operations from CalSim. Figures 3-15 and 3-16 show the comparison of the CalSim monthly storage and simulated daily storage operations for the period of record, and for example year 1983, respectively.



Key: TAF = thousand acre-feet

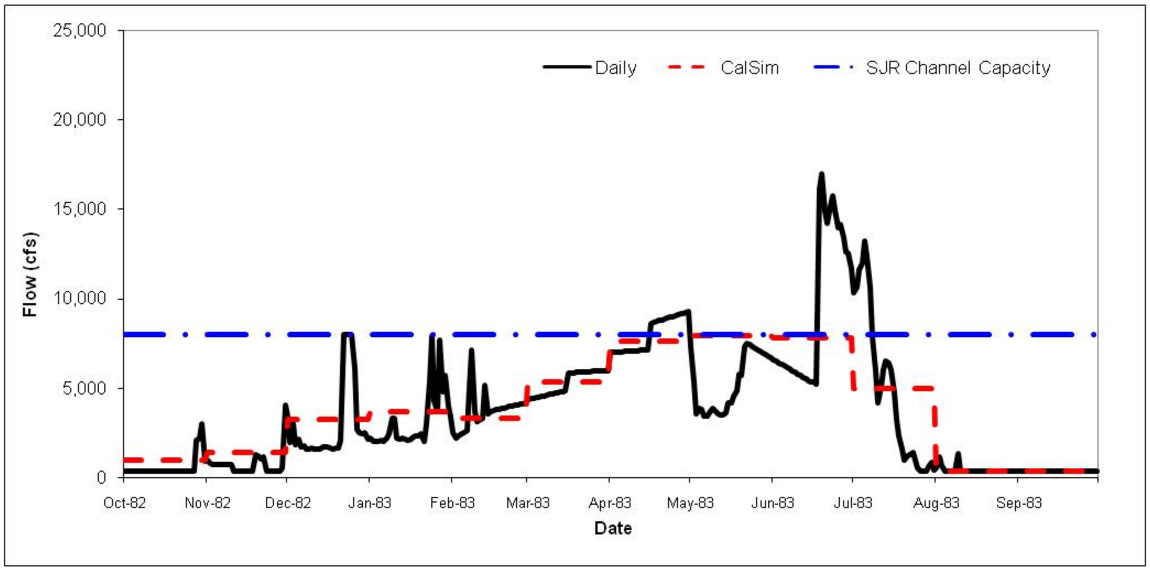
Figure 3-15.
Period of Record Comparison of Daily Spreadsheet Tool and CalSim Simulated Millerton Lake Storage



Key: TAF = thousand acre-feet

Figure 3-16.
Example Year 1983 Comparison of Daily Spreadsheet Tool and CalSim Simulated Millerton Lake Storage

Figure 3-17 is an example comparison of the daily spreadsheet tool releases compared to CalSim simulated San Joaquin River releases.



Key: cfs = cubic feet per second

Figure 3-17.
Example 1983 Daily Spreadsheet Tool vs. CalSim San Joaquin River Release

The general shape of the curves is similar. The major difference is in the May through July period. This discrepancy is due, in part, to differences in reservoir storage. Another key difference is the impact of simulated daily flows versus mean monthly flows. Disaggregating mean monthly flows to simulated daily flows results in different impacts to operation triggers.

3.2.4 Comparison with Historic Hydrology

As mentioned, the spreadsheet tool was used to develop daily flows from the USJRBSI baseline CalSim simulation. This CalSim simulation is a future level simulation using the Settlement hydrographs as minimum flows in the San Joaquin River.

These daily results were then compared to historical Millerton Lake releases from 1974 to 2004. The magnitude of the flows cannot be compared because the historical data reflect different operational assumptions than in the CalSim simulation, especially related to demands and minimum San Joaquin River flow requirements. The comparison evaluates whether general patterns in the disaggregated data appear reasonable for use. Figure 3-18 summarizes comparison results for 1974 through 2007.

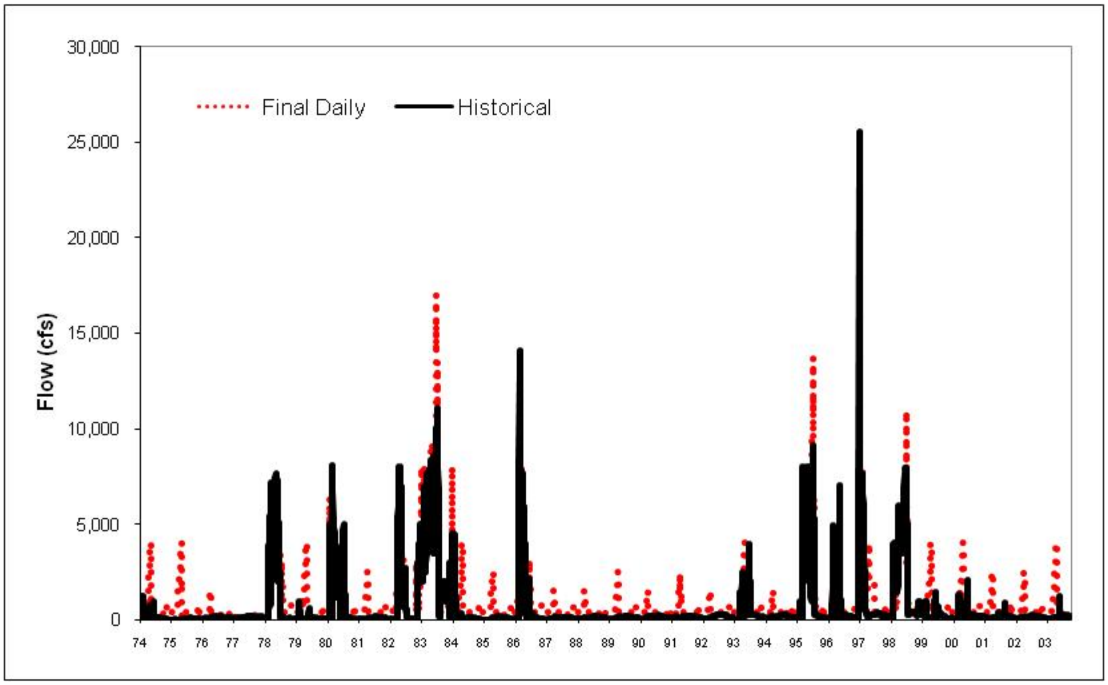


Figure 3-18.
Historic vs. Disaggregated San Joaquin River Flow

As can be seen in the figure, the procedure resulted in a set of daily flows that closely follows the general flow regime of the San Joaquin River. The individual high-flood peaks appear to be higher in the future. This is not expected in real-time operations because the lower storages should imply that the available flood control space at any given time is equal to or greater than without the project. The disaggregation does not use historical inflows, diversions, or releases to the San Joaquin River, and the flow magnitudes cannot be directly compared.

The increase in small flood peaks is due to the increase over historical values in the San Joaquin River minimum flow requirement from the Settlement flow schedule.

Figure 3-19 compares the results of the disaggregation process with the CalSim San Joaquin River releases. The figure shows that the overall patterns correspond well. The higher peak flows in daily results are due to the difference between using daily and mean monthly values. Averaging flows over a monthly time step in CalSim smoothes out the flow peaks.

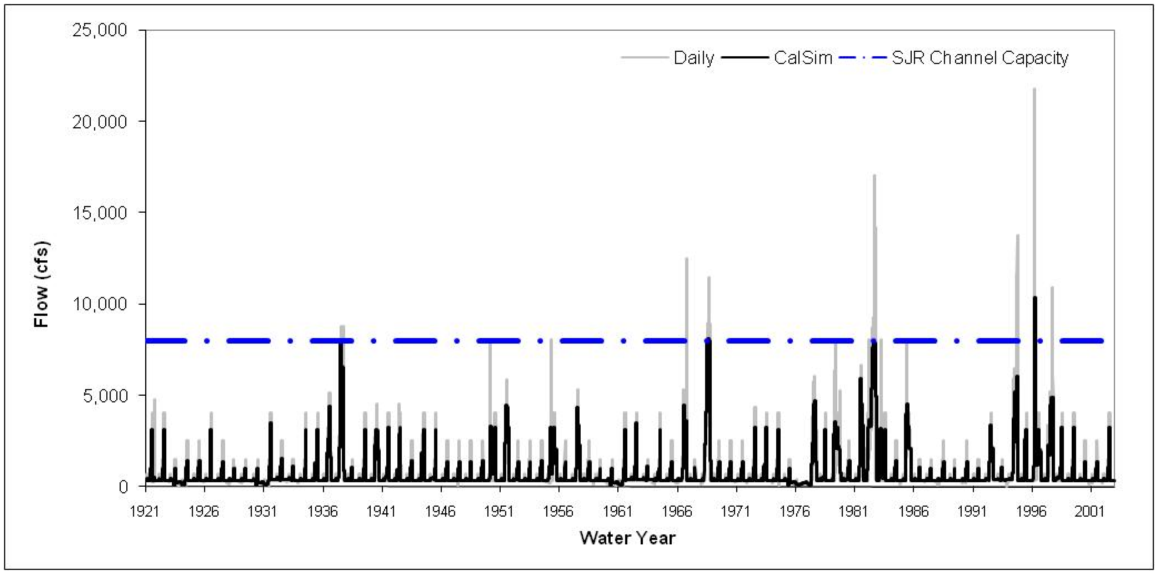


Figure 3-19.
Disaggregated Flows vs. CalSim San Joaquin River Flow

3.2.5 Model Output

The primary output from this model is daily Millerton Lake storage, diversions, and San Joaquin River release values for use in other models and analysis. Output ranges from October 1, 1921, to September 30, 2003.

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4.0 Water Quality Modeling

This Section documents the modeling tools and modeling analysis performed to provide data on water quality in the impacts study area. Areas and water quality parameters modeled include the following:

- Millerton Lake – temperature
- San Joaquin River from Millerton Lake to the Merced River – temperature
- Lower San Joaquin River at Vernalis – salinity
- Delta – salinity

4.1 Millerton Lake Temperature Modeling

The Restoration program would include increased minimum flow requirements in the San Joaquin River. These requirements would result in changes to Millerton Lake water operations, which may affect the temperature of water released to the San Joaquin River, and subsequent temperatures in downstream river reaches. The Millerton Lake temperature model provides a method to evaluate potential changes in Millerton release temperatures.

The Millerton Lake temperature model was originally developed for Reclamation during the *NRDC, et al., v. Kirk Rodgers, et al.,* litigation period, and has since been updated and modified to include the capability to model temperature control devices (TCD) on the Friant-Kern Canal and Madera Canal diversions as well as the San Joaquin River outlets.

4.1.1 Model Description

The Millerton Lake temperature model is based on the W2 modeling platform. W2 is a two-dimensional (longitudinal and vertical) water quality and hydrodynamic model for rivers, estuaries, lakes, reservoirs, and river basin systems. W2 consists of directly coupled hydrodynamic and water quality transport models. Developed for reservoirs and narrow, stratified estuaries. W2's capabilities include longitudinal and vertical hydrodynamics and water quality in stratified and nonstratified systems; multiple algae, epiphyton/periphyton, zooplankton, macrophyte, carbonaceous biochemical oxygen demand (CBOD), and generic water quality groups; internal dynamic pipe/culvert modeling; hydraulic structure (weirs, spillways) algorithms, including submerged and two-way flow over submerged hydraulic structures; and a dynamic shading algorithm based on topographic and vegetative cover. For this application, only temperature is modeled. Several inputs are required for the model, as described below.

Meteorological Data

Meteorological input data used in the Millerton Lake temperature model include air temperature, dew point, wind speed, wind direction, cloud cover, and solar radiation. The main source of data is historical observations recorded at the Fresno Airport weather station, the nearest representative long-term weather station to the project area (approximately 15 miles southwest of Millerton Lake).

Bathymetry

Bathymetry data for Millerton Lake include light detection and ranging (LIDAR) elevation data from a 2001 aerial survey of the study area for ground surface elevations above the Millerton Lake water level (about 500 feet above mean sea level) during the period of the aerial survey, and bathymetric data for Millerton Lake based on a recent sonar survey. The Millerton Lake bathymetric data used in the temperature model are consistent with updated data used in the Reclamation temperature model of Millerton Lake.

Inflow Temperatures

At Kerckhoff Lake, on the San Joaquin River upstream from Millerton Lake, much of the river's flow is diverted into a tunnel and through the Kerckhoff and Kerckhoff No. 2 powerhouses before the water returns to Millerton Lake. The remaining San Joaquin River flow continues down the river channel into Millerton Lake. The water flow in the San Joaquin River channel is subject to heating that the water flow in the tunnel bypasses. Therefore, the temperature of the San Joaquin River inflow is typically higher than the temperature of water from the powerhouses.

San Joaquin River temperature data below Kerckhoff Lake from Pacific Gas and Electric (PG&E) were used to develop San Joaquin River inflow temperature data. Temperature data at Kerckhoff Lake were used to develop powerhouse inflow temperature data. Missing data were estimated using an algorithm that attempts to match temperature data across similar years.

4.1.2 Model Calibration

Initial model calibration compared simulated results to measured temperature profiles 0.53 kilometers (km) from the dam in 2004 and 2005. The model was later recalibrated using Reclamation-measured temperature profiles and release temperatures gathered from 2004 through 2006. The final calibration produced results with differences of less than 1 degree Celsius (°C) from the measured profile and release temperatures. An absolute mean error of less than 1°C is often used as a basis for determining an acceptable calibration (Cole and Wells 2006). Based on a review of the calibration methods and results, Reclamation approved the Millerton Lake Temperature model for use in the USJRBSI.

4.1.3 Modeling Approach and Assumptions

The Millerton Lake temperature model was applied to the different program alternatives by varying the water operation boundary conditions as appropriate for each alternative. Other boundary conditions such as meteorology and inflow temperatures remained constant between alternatives.

Period of Record

The desired simulation period for Restoration use is from 1980 to 2003 with 1-day flow and 6-hour temperature time steps to allow analysis of diurnal temperature fluctuations.

The actual period simulated in the model is 1977 to 2003, on a 1-hour time step. The initial three years (1977-1979) are a “warm-up period” to capture appropriate antecedent conditions in the lake. The hourly outputs are averaged over the final desired flow and temperature time steps after model execution has completed.

Water Operations Data

The Millerton Lake temperature model uses daily water operations data for San Joaquin River inflow, Friant-Kern Canal and Madera Canal diversions and controlled release and spill to the San Joaquin River.

San Joaquin River inflows are from the USAN model. The USAN model is a daily operational model of the San Joaquin River system upstream from Millerton Lake. These daily flows are also used to define monthly Millerton Lake inflows for the CalSim water operations model. CalSim is used to define the overall Millerton Lake water operations boundaries.

Millerton Lake diversions to the Friant-Kern and Madera canals and releases to the San Joaquin River come from a daily disaggregation process applied to CalSim monthly time series data. This process is described in greater detail in Section 3.2.

4.1.4 Output Description

The Millerton Lake temperature model simulates reservoir temperature profiles, the temperature of diversions to the Friant-Kern and Madera canals, and release to the San Joaquin River.

Output data for the Existing Condition, Future No-Action, and Alternative A simulations are included in the Temperature Modeling Output – W2 Attachment. Since Millerton operations are the same for Alternatives A, B, and C, Alternatives B and C were not modeled.

The outputs included are as follows:

- San Joaquin River release temperature
- Friant Kern Canal diversion temperature
- Madera Canal diversion temperature
- Cold-water pool volume less than 52 degrees Fahrenheit (°F) and less than 60°F

4.2 San Joaquin River Temperature Modeling

Temperatures in the San Joaquin River downstream from Millerton Lake are important to the success of the Restoration Program. The San Joaquin River Temperature Model (SJR5Q) provides a method to evaluate the temperatures in this reach of the river.

The SJRRP includes increased minimum flow requirements in the San Joaquin River. These requirements would result in changes to Millerton Lake water operations, which may affect the temperature of water released to the San Joaquin River, and subsequent temperatures in downstream river reaches. SJR5Q provides a method to evaluate the temperatures in the San Joaquin River downstream from Millerton Lake.

4.2.1 Model Description

SJR5Q covers the San Joaquin River downstream from Millerton Lake to the confluence with the Merced River. The model was developed using the USACE HEC-5Q modeling tool, which can be used for simulating water flow and quality of reservoirs and streams. SJR5Q uses the river modeling capabilities of HEC-5Q to model both flow and temperature in the San Joaquin River. The HEC-5Q users manual (HEC 1986) has a more complete description of the water quality relationships included in the model.

Model Representation of the Physical System

SJR5Q represents the San Joaquin River as a network of discrete segments (reaches and/or layers, respectively) for application of HEC-5 for flow simulation, and HEC-5Q for temperature simulation. Within this network, control points (CP) are designated to represent selected stream locations where flow, elevations, and volumes are computed. In HEC-5, flows and other hydraulic information are computed at each control point. Figure 4-1 is a schematic of the HEC-5 representation of the San Joaquin River from Millerton Lake to the confluence with the Merced River.

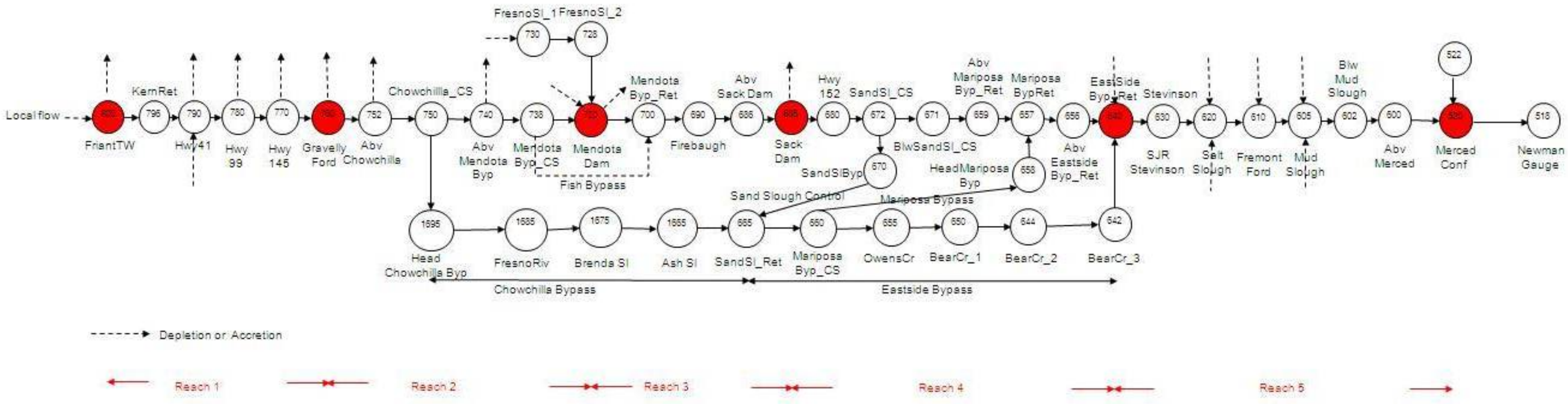


Figure 4-1.
SJR5Q Model Schematic

Model Representation of Streams

River or stream reaches are represented conceptually as a linear network of segments or volume elements. The length, width, cross-sectional area, and a flow-versus-depth relationship characterize each element. A cubic polynomial curve fit of all input data provides a continuous relationship between flow and the hydraulic parameter defining each cross section. Cross sections are defined at all control points and at intermediate locations where data are available. Element lengths typically range from a few hundred feet to several thousand feet.

The flow versus depth relation is developed external to SJR5Q using available cross section data and appropriate hydraulic computations. For the San Joaquin River and bypasses, the USACE Comprehensive Study was used (USACE 2002). This detailed data set incorporates all control structures, bridge restrictions and critical sections that control or restrict flow.

Stream Accretions and Depletions

HEC-5Q requires that flow rates and water quality be defined for all inflows. Available data were evaluated and processed to define all hydrologic inputs for an evaluation period of 1980 through 2003. The following flow assumptions are used in SJR5Q:

- **San Joaquin River above the Mendota Pool** – Partial flow records for Cottonwood tributary stream and Little Dry Creek and river gage locations (Friant Dam, Donny Bridge, Skaggs Bridge and Gravelly Ford) were evaluated to develop estimates of time-dependent inflows and seasonal depletions above Gravelly Ford. Total depletions were distributed within the model based on gage data tendencies. Diversions to the Chowchilla Bypass are computed within the model as a function of river flow.

- **Mendota Pool to Sack Dam** – Seasonal diversions from Mendota Pool and Sack Dam into Arroyo Canal were developed from available flow records (e.g., San Joaquin River at Mendota 1999 – 2006, U.S. Geological Survey (USGS)). These demand assumptions, plus observed James Bypass USGS flows and computed San Joaquin River inflow were used to compute the required DMC flows by mass balance. The mass balance computation assumed a January 1 through February 15 maintenance drawdown of the Mendota Pool.

- **San Joaquin River below Sack Dam** – Observed data at Stevinson USGS, partial Bear Creek flow data, and computed flow to the Eastside Bypass and below Sack Dam were used to compute net accretions/depletions considering flow attenuation consistent with routing coefficients used in the model.

- **San Joaquin River between Stevinson and the Merced River** – Flow records for the San Joaquin River at Stevinson and Newman, Mud and Salt Sloughs and the Merced River at Stevinson were used to compute net accretions and depletions for this section of the river. Flows from the two sloughs and other accretions dominate temperatures in this area during low San Joaquin River flows, and are an important influence on temperature at moderate river flows.

Temperature Boundary Conditions

There is very limited availability of temperature data on accretions in this reach of the San Joaquin River. Historic temperature data were used to the maximum extent possible to develop relationships that fill in data gaps.

Meteorological Data

Hourly air temperature, wind speed, relative humidity, and cloud cover for each day were used to compute the average equilibrium temperature, surface heat exchange rate, solar radiation flux, and wind speed at 6-hour intervals for input to the SJRQ5.

For temperature simulation using HEC-5Q, specification of water surface heat exchange data requires meteorological zones to be designated within the study area. Each CP within the system or subsystem used in temperature or water quality simulation must be associated with a defined meteorological zone.

Six meteorological zones were developed for SJR5Q. Heat exchange coefficients for each zone were computed to reflect typical environmental conditions. For sheltered stream sections, wind speed was reduced and shading was assumed to reflect riparian canopy conditions. Reduced wind speed decreases evaporative heat loss and results in higher equilibrium temperatures and lower heat exchange rates, and vice versa for increased wind speed. Shading reduces solar radiation, resulting in lower equilibrium temperatures and lower heat exchange rates.

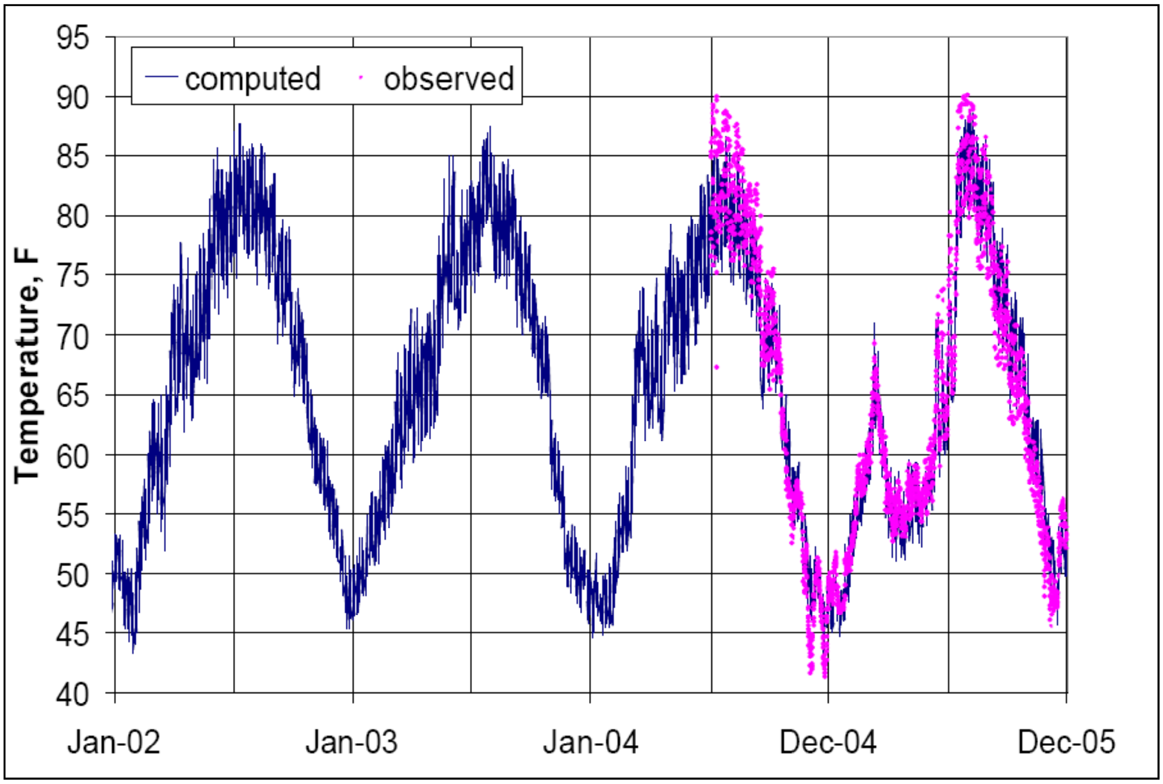
The meteorological data collected as part of the SJRRP were used in determining the heat exchange adjustments to individual stream sections. Information pertaining to the meteorological zones and their descriptions can be found in a 2007 report (RMA).

Model Calibration

SJR5Q was calibrated for the period between 2000 and 2005 at nearly 15 different locations in the San Joaquin River downstream from Friant dam. Calibration of SJR5Q was performed by graphically and statistically comparing computed and observed river temperature time series. Different statistical measures such as Mean Error (bias), Mean Absolute Error, and Root Mean Squared Error were used to evaluate calibration results.

Figure 4-2 shows a graphical comparison between the model’s computed temperature and observed temperature at Gravelly Ford. Model-computed results are in good agreement with the observed values except during the summer when there is a difference between the computed and observed temperatures. The difference can be attributed to the assumption of a minimum flow of several cfs when there is no flow at this location (Reclamation 2007). A detailed documentation of the calibration methodology and results comparing computed and observed temperatures at various locations in the San Joaquin River can be found in Reclamation (2007).

Flows simulated by SJR5Q are heavily dependent on assumed accretions and depletions along the San Joaquin River. Figure 4-3 is a comparison of the total accretion/depletion along the San Joaquin River from Millerton Lake to the Merced River between CalSim and SJR5Q. Because of the lack of resolution in the CalSim model it was impossible to perform an acceptable comparison of the accretion/depletion between the values computed for the SJR5Q model and the CalSim model on a reach-by-reach basis.



Key: F = degrees Fahrenheit

Figure 4-2.
Computed and Observed Temperatures at Gravelly Ford

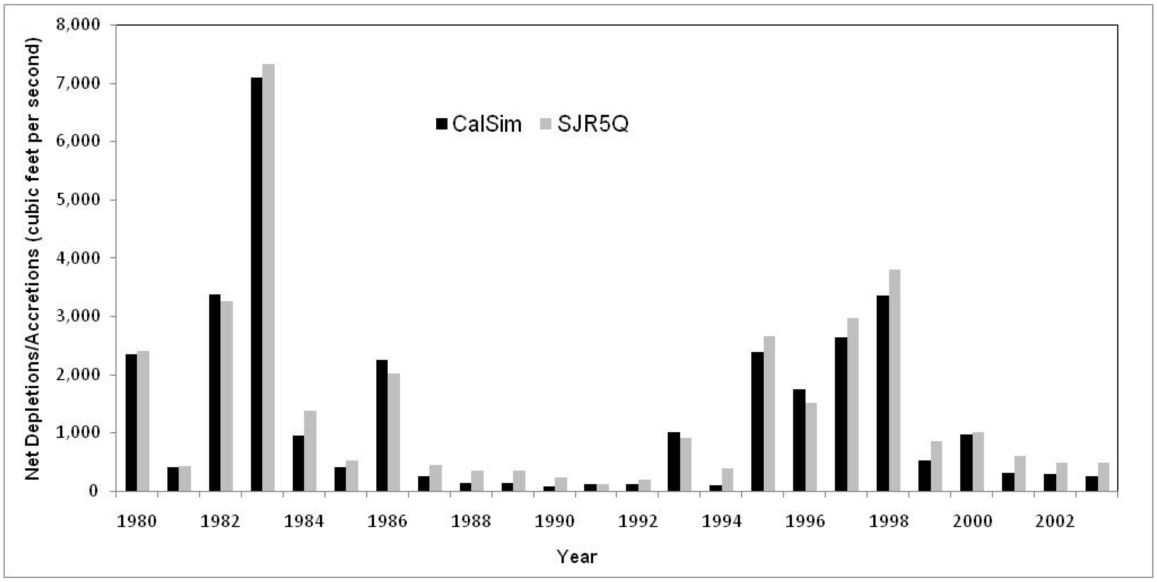


Figure 4-3.
Comparison of Net San Joaquin River Accretions/Depletions in CalSim and SJR5Q

4.2.2 Modeling Approach and Assumptions

The model was applied to the different program alternatives by varying the water operation boundary conditions, as appropriate, for each alternative. Other boundary conditions such as meteorology and accretions/depletions remain constant between alternatives.

Period of Record

The desired simulation period for SJRRP use is from 1980 to 2003, with 1-day flow and 6-hour temperature time steps to allow analysis of diurnal temperature fluctuations. This is the simulation period for SJR5Q.

Millerton Lake Release Temperature

The Millerton Lake release temperature at a 6-hour time step for the entire simulation period is obtained from the Millerton Lake temperature model for each alternative and used as input to SJR5Q. The temperature is a weighted average of the Millerton Lake spill, if any, and outlet release temperatures.

Flow Routing

There are three major controlled diversions in the San Joaquin River between Friant Dam and the Merced River: the San Joaquin River diversion to the Chowchilla Bypass, the San Joaquin River diversion at Sand Slough to the Eastside Bypass, and the Eastside Bypass diversion to the Mariposa Bypass. These diversions will be operated somewhat differently under the SJRRP than under the existing conditions.

Operational rules for flow routing were primarily modeled using routing procedures in the HEC model. However, certain rules are complicated at some decision points, and flow routing could not be easily performed in SJR5Q.

Chowchilla Bypass Diversion. The governing rules for the Chowchilla Bifurcation Structure operations are as follows:

- Leave the first 1,500 cfs in the San Joaquin River
- Divert the next 5,500 cfs into the Chowchilla Bypass
- Leave the next 1,000 cfs in the San Joaquin River for a total of 2,500 cfs
- If the inflow to the Mendota Pool from the James Bypass is greater than 2,000 cfs, increase the diversion to the Chowchilla Bypass to maintain a flow of 4,500 cfs below the Mendota Pool
- At higher San Joaquin River and/or Fresno Slough flows, perform operations to minimize flood damages in the local area

In reality, the rules were implemented differently, as described in a 2002 report (Mussetter Engineering, Inc.). The report describes a fairly complicated, multiple-step procedure used to develop the diversion to the Chowchilla Bypass in an attempt to prevent flood damage in the San Joaquin River, in both Reach 2B and Reach 3, by diverting as much water as possible down the bypass and then splitting any remaining Reach 3 flooding evenly between the bypass and the San Joaquin River.

Operations rules for all simulations are as follows:

- Divert the first 1,500 cfs to Reach 2B
- Divert the next 5,500 cfs to Chowchilla Bypass
- Divert the next 1,000 cfs to Reach 2B
- Additional flow is split 50/50 between the Chowchilla Bypass and Reach 2B
- If Reach 3 flow below Mendota Dam is greater than 1,300 cfs, make additional diversion to the bypass up to the minimum of the following after first filling unused bypass capacity:
  - Reach 3 flooding (flow over 1,300 cfs)
  - Unused bypass capacity
  - Reach 2B flow (remaining flow after initial diversion)
- If Reach 3 flow is still greater than 1,300 cfs, then make additional diversion to bypass up to the minimum of the following (split unavoidable flooding 50/50 between bypass and river):
  - Fifty percent of remaining Reach 3 flooding (remaining flow over 1,300 cfs)

  - Remaining Reach 2B flow

This rule is too complicated for the HEC-5 flow modeling capability to easily implement. In the SJRRP, flow routing was performed by running SJR5Q and allowing it to determine the diversion to the Chowchilla Bypass using the first four rules above, meaning without trying to increase the diversion to the Chowchilla Bypass to protect Reach 3. A spreadsheet was then used to extract flows from the SJR5Q output, and to compute new diversion each day, implementing the final two rules above. This new diversion is then input to a second run of the SJR5Q model as a fixed diversion to the Chowchilla Bypass.

Program actions impacting the Chowchilla Bypass operation included the following:

- 4,500 cfs bypass channel capacity around Mendota Pool
- 4,500 cfs conveyance capacity in Reach 2B
- 4,500 cfs conveyance capacity in Reach 3
- Must maintain Settlement flow schedule through reach 2B

Operation for SJRRP simulations was as follows:

- Leave first 4,500 cfs to reach 2B
- Divert next 5,500 cfs to Chowchilla Bypass
- Split additional flows 50/50 between Chowchilla Bypass and Reach 2B
- If Reach 3 flow below Mendota Dam is greater than 1,300 cfs, increase diversions to Chowchilla Bypass by up to the minimum of the following:
  - Reach 3 flow over 4,500 cfs
  - Unused Chowchilla Bypass capacity
  - Reach 2B flow minus Settlement flow schedule (remaining flow after initial diversion above flow requirement)
- If Reach 3 flows are still greater than 4,500 cfs, split these remaining flows 50/50 between the Chowchilla Bypass and Reach 2B up to the minimum of the following:
  - 50 percent of Reach 3 flow over 4,500 cfs
  - Reach 2B flow greater than Settlement minimum flows (remaining flow after initial diversion above flow requirement)

This is implemented using the same two-step process as for the No-Action Alternative scenario.

Sand Slough Control Structure (top of Reach 4B) The Sand Slough Control Structure operation rules limit downstream San Joaquin River flows to the 1,500 cfs flood control limit. The present capacity of the San Joaquin River channel is zero in some locations, and in actual operation, the entire San Joaquin River flow is diverted through the Sand Slough Control Structure into the Eastside Bypass. The control structure has not been operated to allow water to flow into the San Joaquin River for many years.

According to the Settlement, in Phase 1, the Sand Slough Control Structure must be capable of releasing 475 cfs to Reach 4B. This increases to 4,500 cfs in Phase 2. The operation for the Future No-Action alternative is to divert the entire San Joaquin River flow to the Eastside Bypass.

Operation for the Phase 1 project simulations is as follows:

- First 475 cfs remains in Reach 4B
- All remaining flow diverted to the Eastside Bypass

Operation for the Phase 2 project simulations is as follows:

- First 4,500 cfs remains in Reach 4B
- All remaining flow diverted to the Eastside Bypass

Mariposa Bypass Control Structure Operations rules call for flows of up to 8,500 cfs to be diverted into the Mariposa Bypass from the Eastside Bypass and back to the San Joaquin River. Recent operations however, allow 2,000 to 3,000 cfs to remain in the Eastside Bypass with 25 to 33 percent of any additional Eastside Bypass flow diverted into the Mariposa Bypass.

The settlement does make any provisions for modifications to this Bypass. With no modifications, the same operational rules are used for all alternatives.

Operation rules for all alternatives were as follows:

- First 2,500 cfs remain in the Eastside Bypass
- Thirty percent of additional Eastside Bypass flow is diverted to the Mariposa Bypass and back to the San Joaquin River

4.2.3 Output Description

San Joaquin River temperature modeling was performed on a 6-hour time interval from 1980 to 2003. Output data for the Existing Conditions, Future No-Action, and Alternative A simulations are included in the Temperature Modeling Output – SJR5Q Attachment.

Since Millerton operations are the same for Alternatives A, B, and C, Alternatives B and C were not modeled.

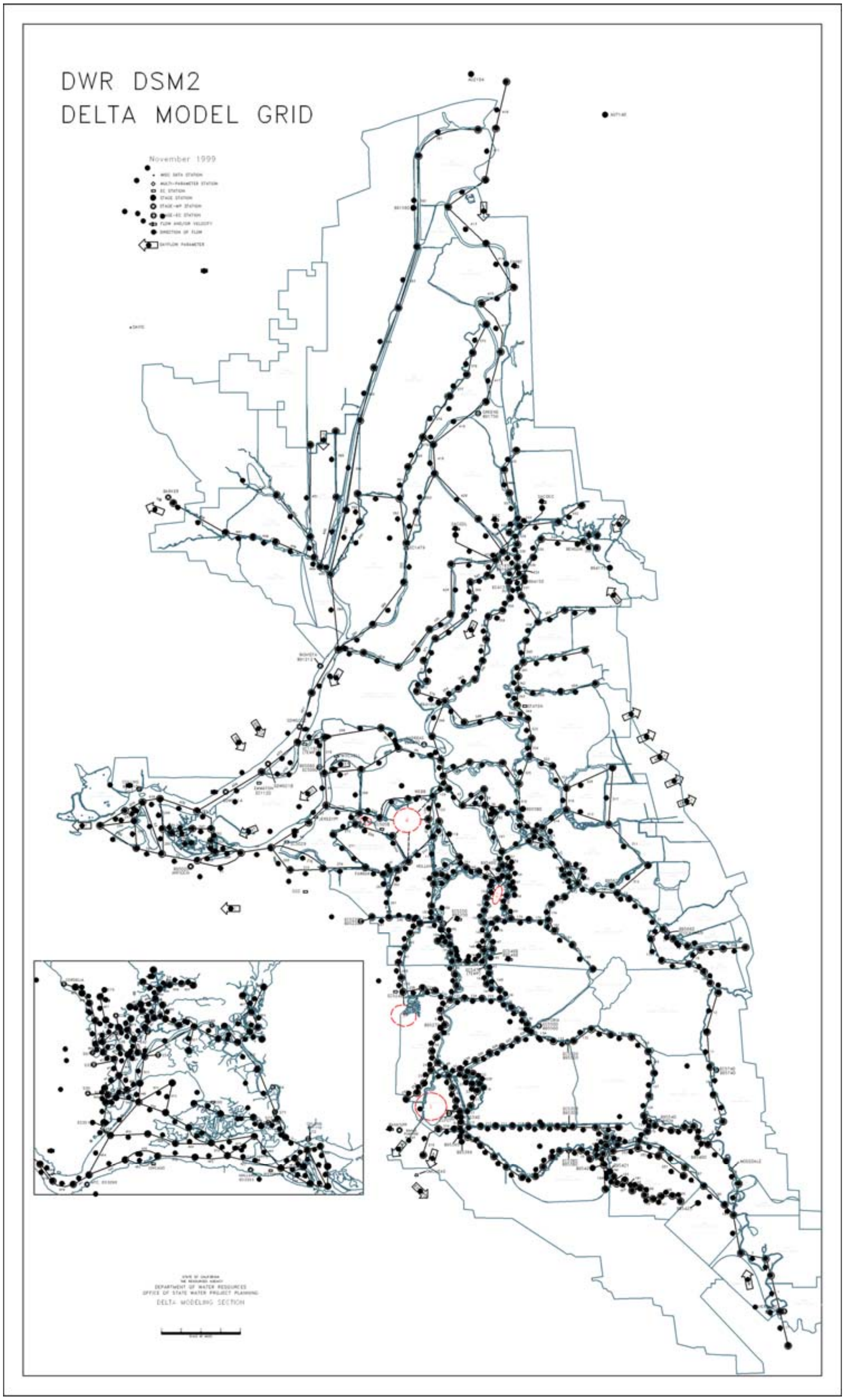
The main resource area concerned with water temperature in the San Joaquin River is fisheries. Exhibit B Restoration release schedules (as defined in Appendix A) were designed with required flows in specific time periods of the year based on the Chinook salmon life stage expected during that period. Since different life stages require different temperatures, the mean temperature during the period is of importance in using the data in the fisheries analysis.

4.3 Delta Water Quality (DSM2)

The DWR DSM2 is a branched one-dimensional, physically based numerical model of the Delta developed by DWR in the late 1990s. DSM2-Hydro, the hydrodynamics module, is derived from the USGS Four Point model. DSM2-Qual, the water quality module, is derived from the USGS Branched Lagrangian Transport Model. Details of the model, including source codes and model performance, are available from the DWR Bay-Delta Office, Modeling Support Branch Web site (DWR 2009). Documentation of model development is discussed in annual reports to SWRCB (DWR 2009).

A DSM2 schematic is shown in Figure 4-4. Key DSM2 inputs include tidal stage, boundary inflow and salinity concentration, and operation of flow-control structures. Table 4-1 summarizes basic input requirements and assumptions.

In DSM2 model simulations, EC is typically used as a surrogate for salinity. Results from CalSim are used to define Delta boundary inflows. CalSim-derived boundary inflows include Sacramento River flow at Hood, San Joaquin River flow at Vernalis, inflow from the Yolo Bypass, and inflow from eastside streams. Net Delta outflow from CalSim is used to calculate the DSM2 salinity boundary at Martinez.



Source: DWR, 2009

Figure 4-4.
DSM2 Schematic

Table 4-1.
DSM2 Input Requirements and Assumptions

Parameters	Assumptions
Period of simulation	October 1922 – September 2003
Boundary flows	CalSim output
Boundary stage	15-minute adjusted astronomical tide
Agricultural diversion and return flows	Delta Island Consumptive Use model, 2005/2020 LOD
Salinity	
Martinez EC	Computed from modified G-model, adjusted astronomical tide, and net Delta Outflow from CalSim
Sacramento River	Constant value = 175 μmhos/cm
Yolo Bypass	Constant value = 175 μmhos/cm
Mokelumne River	Constant value = 150 μmhos/cm
Cosumnes River	Constant value = 150 μmhos/cm
Calaveras River	Constant value = 150 μmhos/cm
San Joaquin River	CalSim EC estimate using modified Kratzer equation
Agricultural drainage	Varying monthly values that are constant year to year
Facility operations	
Delta Cross Channel	CalSim output
South Delta barriers	Temporary barriers/SDIP operation of permanent barriers

Key:
μmhos/cm = micromhosper centimeter
DSM2 = Delta Simulation Model 2
EC = electrical conductivity
LOD = level of development
SDIP = South Delta Improvements Program

4.3.1 Planning Tide at Martinez Boundary

Tidal forcing is imposed at the downstream boundary at Martinez as a time series of stage (for the hydrodynamic module) and salinity (for the water quality module). DWR has traditionally used a “19-year mean tide” (or “repeating tide”) in all DSM2 planning studies, in which the tide is represented by a single repeating 25-hour cycle.

An “adjusted astronomical tide” was later developed by DWR that accounts for the spring-neap variation of the lunar tide cycle for a 16-year period, from 1976 to 1991. (DWR 2001a). As part of the CACMP effort, an updated version of DSM2 was developed that simulates an 82-year (1922 through 2003) CalSim period of record using an adjusted astronomical tide.

4.3.2 Salinity Boundary Conditions

Salinity concentration is a key input to DSM2. The following salinity boundary conditions were used in SJRRP modeling efforts.

Martinez

Salinity at the Martinez downstream boundary reflects intrusion of saltwater into San Pablo Bay from the ocean. It is determined using an empirical model known as the modified G-model (DWR 2001b). The model calculates a 15-minute time series of salinity values based on the adjusted astronomical tide and net Delta outflow. Since these aggregate flows are available from CalSim, salinity at Martinez can be preprocessed and input to DSM2 as time series data. Each simulation has a different EC boundary condition at Martinez, reflecting the different inflows and exports from the Delta that occur in a particular scenario.

Sacramento River/Yolo Bypass/Eastside Streams

The inflow salinities for the Sacramento River, Yolo Bypass, and eastside streams (Mokelumne, Cosumnes, and Calaveras rivers) were assumed to be constant at 175, 175, and 150 micromhos per centimeter (μmhos/cm), respectively.

San Joaquin River at Vernalis

CALSIM II includes the Link-Node approach algorithm implemented in March 2004, to estimate San Joaquin River salinity at Vernalis by applying a series of salt balances from Friant Dam to Vernalis. The salt balances dynamically account for all inflows and outflows along a given reach, and assume perfect mixing of different waters. Westside inflows to the San Joaquin are disaggregated into various flow components and each assigned component assigned an EC value. The resulting EC values were used to define the inflow salinity for DSM2. Each simulation has a different EC boundary condition at Vernalis, reflecting different upstream operations on the San Joaquin River and its tributaries.

CalSim calculates EC for the San Joaquin River at Vernalis using a modified Kratzer equation. The resulting EC values were used to define the inflow salinity for DSM2. Each simulation has a different EC boundary condition at Vernalis, reflecting different upstream operations on the San Joaquin River and its tributaries.

Agricultural and Municipal and Industrial Return Flows

The salinity of agricultural return flows was based on an analysis of Municipal Water Quality Investigations (MWQI) data (DWR 1995). Monthly, regional representative EC values of drainage were determined for three regions in the Delta (north, west, and southeast regions). EC values vary by month, but are constant from year to year and are independent of the LOD. EC values were highest for the west region because of its proximity to the ocean. Monthly EC values follow a seasonal trend, with the highest concentrations occurring in winter and spring during the rainfall-runoff season (approximately 820 μS/cm to 1,890 μS/cm). Lowest drainage concentrations occur in July and August (approximately 340 μS/cm to 920 μS/cm).

4.3.3 Delta Channel Flow

Sacramento River water flows into the central Delta via the Delta Cross Channel and Georgiana Slough. The Delta Cross Channel, constructed in 1951 as part of the CVP, connects the Sacramento River to the Mokelumne River via Snodgrass Slough. Its purpose is to increase flow in the lower San Joaquin River and to reduce salinity intrusion and the movement of saline water from Suisun Bay toward Contra Costa Water District's (CCWD) Rock Slough intake and the C.W. "Bill" Jones Pumping Plant (Jones Pumping Plant). Two radial gates regulate flow through the Delta Cross Channel. When the gates are open, flow through the Delta Cross Channel is determined by the upstream stage in the Sacramento River. Similarly, flow through Georgiana Slough is a function of the upstream Sacramento River stage. Sacramento River water is also transported southward through Threemile Slough, which connects the Sacramento River, just downstream from Rio Vista, to the San Joaquin River.

The mouth of the Old River, located upstream from the mouth of the Mokelumne River, is the major conduit for water flowing from the Sacramento River through Georgiana Slough and the Delta Cross Channel via the Mokelumne River to the south Delta. Additional water for CVP/SWP export pumps moves through the mouth of the Middle River, Columbia Cut, Turner Cut, False River, Fisherman's Cut, and Dutch Slough. Net flows at the mouth of the Old River and Middle River are influenced by CVP/SWP exports and south Delta irrigation diversions (approximately 40 percent of total net Delta diversions). Previous DSM2 simulations indicate that about 45 percent of south Delta exports flows through the mouth of the Old River or through the False River. About 40 percent of the south Delta exports flows through the mouth of the Middle River, and about 10 percent of the flow is through Turner Cut. This division of flow is insensitive to the magnitude of exports (Jones and Stokes 2004).

4.3.4 Control Structures

A number of flow-control structures are currently operated seasonally in the Delta. These structures can affect water quality by changing the pattern of flow through the Delta.

Clifton Court Forebay

In all DSM2 simulations, the Clifton Court Forebay gates were operated tidally using "Priority 3." Under Priority 3, the gates are closed 1 hour before and 2 hours after the lower low tide. They are also closed from 2 hours after the high low tide to 1 hour before the high tide. Discharge is proportional to the square root of the head difference across the gates. Maximum flow was capped at 15,000 cfs. The discharge coefficient was set equal to 2,400, which results in a flow of 15,000 cfs for a 1.0-foot head difference.

Delta Cross Channel

The Delta Cross Channel has a major impact on salinity in the central and south Delta. CalSim calculates the number of days the Delta Cross Channel is open in each month. The 1995 WQCP (SWRCB 1995) specifies that the gates be closed for 10 days in November, 15 days in December, and 20 days in January, from February 1 to May 20, and for 14 days between May 21 and June 15. In addition, the gates must be closed to avoid scouring whenever Sacramento River flow at the Delta Cross Channel is greater than 25,000 cfs. For DSM2 simulations, all partial-month closings of the Delta Cross Channel were assumed to occur at the end of the month.

South Delta Barriers

DSM2 modeling of existing conditions includes the South Delta Temporary Barriers Project, which consists of four rock barriers that are temporarily installed across south Delta channels. The objectives of the project are as follows:

- Increase water levels, circulation patterns, and water quality in the south Delta area for local agricultural diversions.

- Improve operational flexibility of the SWP to help reduce fishery impacts and improve fishery conditions.

Details of the temporary barriers can be found on DWR's Website (2009). Of the four temporary barriers, the Head of Old River barrier serves as a fish barrier and has been in place most years, between September 15 and November 30, since 1963. The remaining three barriers serve as agricultural barriers and are installed between April 15 and September 30. Installation and removal dates of the barriers are based on the USACE Section 404 Permit, California Department of Fish and Game (DFG) 1601 Permit, and various Temporary Entry Permits required from landowners and local Reclamation Districts. Table 4-2 gives the assumed temporary barrier operation for modeling existing conditions.

Table 4-2.
Temporary Barrier Simulated Operation

Barriers	DSM2 Channel No.	Closure	Complete Removal
Head of Old River (spring)	54	April 15	May 15
Head of Old River (fall)	54	September 15	November 30
Middle River	134	April 15	November 30
Old River near Tracy	99	April 15	November 30
Grant Line Canal	206	May 15	November 30

Source: Reclamation and DWR 2005.
Key:
DSM2 = Delta Simulation Model 2

DSM2 modeling of future conditions includes the four proposed South Delta Improvement Program permanent operable barriers, one each at the head of the Old River, Grant Line Canal, Old River at Tracy Road Bridge, and Middle River at Old River (Reclamation and DWR 2005). These gates are intended to replace the existing temporary barriers to minimize the number of in- and out-migrating salmon moving toward export pumps, maintain adequate water levels for south Delta farmers to prevent cavitation from occurring in their irrigation pumps, and improve water quality in south Delta channels by providing better circulation. The DWR Delta Modeling Section developed three sets of operations for the gates: Plans A, B, and C. Plan A focused on achieving higher water levels, but did not result in significant improvement in water quality. Plan B modified Plan A gate operations, resulting in slight improvement in circulation and water quality compared to Plan A. Plan C gate operations evolved to achieve the objective of improving water quality with better flow circulation in south Delta channels, in addition to maintaining adequate water levels. Plan C permanent barrier operations were assumed for Future Condition DSM2 simulations. Tables 4-3 and 4-4 summarize the Plan C permanent barrier operation rules.

Table 4-3.
Operation of Head of Old River Gate

Condition	Head of Old River Gate
San Joaquin River > 10,000 cfs	Fully Open
Pre, VAMP and Post VAMP (April to November)	Fully Closed
Fall (October to November)	Partial leakage of flow
Summer (June to September) and 2,500 cfs > San Joaquin River > 800 cfs	Limit flow through Head of Old River to 500 cfs

Source: Reclamation and DWR 2005.
Key:
cfs = cubic feet per second
VAMP = Vernalis Adaptive Management Plan

Table 4-4.
Operation of Three Other Gates

<table>
<tr><th colspan="2">Barriers</th><th>Middle River</th><th>Old River at Tracy</th><th>Grant Line Canal</th></tr>
<tr><td colspan="2">If Head of Old River is opened</td><td>Operated</td><td>Operated</td><td>Operated</td></tr>
<tr><td rowspan="4">If Head of Old River is opened and Monthly flow (cfs)</td><td>SJR < 2,500</td><td>Operated</td><td>Operated</td><td>Operated</td></tr>
<tr><td>2,500 < SJR < 4,000</td><td>Fully Open</td><td>Operated</td><td>Operated</td></tr>
<tr><td>4,000 < SJR < 8,000</td><td>Fully Open</td><td>Fully Open</td><td>Operated</td></tr>
<tr><td>SJR > 8,000</td><td>Fully Open</td><td>Fully Open</td><td>Fully Open</td></tr>
</table>

Source: Reclamation and DWR 2005
Key:
cfs = cubic feet per second
SJR = San Joaquin River

Suisun Marsh Salinity Control Gate

The Suisun Marsh Salinity Control Gate limits flow in Montezuma Slough from Suisun Marsh during flood tide, and allows drainage from the marsh during ebb tide. The gates are not operated in the summer months (June through September) and are not operated at all in some wet years. Actual gate operations are triggered by salinity levels in Suisun Marsh. However, in DSM2 months, gate operations are an input to the model. Suisun Marsh diversion and drainage flows have relatively little effect on salinity upstream from Chipps Island.

4.3.5 Delta Island Consumptive Use

DSM2 uses the Delta Island Consumptive Use (DICU) model to develop agricultural diversions and return flows to each of 142 Delta subareas on a monthly time step. An associated routine allocates the diversions and return flows to approximately 250 diversion nodes and 200 drainage nodes in DSM2. The DICU model considers precipitation, seepage, evapotranspiration, irrigation, soil moisture, leach water, runoff, crop type, and acreage. Net DICU is computed as diversions plus seepage, less drainage. Positive values indicate a net depletion of water from the Delta channels; negative values indicate a net return flow from Delta islands into the channels. DICU follows the seasonal pattern of irrigation diversions during summer, and drainage return flows from winter runoff.

DSM2 net channel accretions and depletions match aggregated values used in CalSim so that net Delta outflow is consistent between the two models.

4.3.6 Water Quality Conversions

DSM2 uses EC as a substitute for salinity. However, other water quality constituents were needed to assess potential impacts of the proposed alternatives.

DWR derived relationships among EC, bromide, and chloride at Delta export locations for use in the In-Delta Storage Investigations (Suits 2001). Suits (2001) gives a regression equation for EC at the Old River at Rock Slough as a function of chloride at Contra Costa Canal Pumping Plant (CCC PP) No. 1, and a regression equation relating EC to chloride at the Los Vaqueros Intake. The relationship between EC and chloride in the vicinity of the Clifton Court Forebay and DMC Intake is more complex. In general, the relationship depends on whether source water is derived from the San Joaquin River or Sacramento River. The regression equation established by Suits is conservative, giving high values of chloride for a given EC (2001). The relationship between chloride and bromide is fairly uniform, with little site-specific variation (Suits 2001). Therefore, a single regression equation can be used for different export locations. Regression equations used to convert EC to chloride are given in Table 4-5.

Table 4-5.
Relationship Between Salinity Parameters

Location	Slope	Intercept
CCWD Pumping Plant No. 1	0.268	-24.0
Clifton Court Forebay	0.273	-43.9
DMC Intake	0.273	-43.9

Source: Suits 2001
Key:
CCWD = Contra Costa Water District
DMC = Delta-Mendota Canal
No. = Number

4.3.7 Output Description

Simulated monthly averages of DSM2 modeling results at representative locations are presented in the Delta Simulation Modeling Output – DSM2 Attachment. Table 4-6 lists the parameters presented in the attachment.

Table 4-6.
DSM2 Parameters in Delta Simulation Modeling Output – DSM2 Attachment

Location	Parameter
Sacramento River at Collinsville	EC
Sacramento River at Emmanton	EC
Sacramento River at Jersey Point	EC
San Joaquin River at Brandt Bridge	EC
San Joaquin River at Vernalis	EC
Old River near Tracy Road Bridge	EC
Old River at Middle River	EC
Old River at Hwy 4 (CCWD Intake)	EC
Old River at Bacon Island	EC
Delta-Mendota Canal at Tracy Pumping Plant	EC
Contra Costa Canal Pumping Plant No. 1	EC, CL
West Canal at mouth of CC Forebay Intake	EC
Middle River at Victoria Canal	EC
Delta-Mendota Canal at Tracy Pumping Plant No. 1	Cl
West Canal at mouth of CC Forebay Intake	Cl
Old River near Tracy Road Bridge	Stage
Middle River near Howard Road Bridge	Stage
Grant Line Canal above Grant Line Canal Barrier	Stage
East of Coney Island	Stage
Doughty Cut above Grant Line Canal Barrier	Stage

Key:
CC = Clifton Court
CCWD = Contra Costa Water District
Cl = chloride
DSM2 = Delta Simulation Model 2
EC = electrical conductivity
Hwy = highway

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5.0 Groundwater Modeling

5.1 Near River Seepage Modeling

The near-river modeling analyses of groundwater and seepage conditions associated with alternatives for the PEIS/R of the SJRRP quantify differences between a defined baseline condition and elements of SJRRP restoration alternatives with respect to:

- River seepage losses
- Subsurface flux (groundwater movement) between the near-river groundwater zone and the surrounding region
- The occurrence of higher groundwater elevations that may be associated with water-logging on lands in proximity to the river

The approach involves application of existing high-resolution groundwater models for river reaches between Friant Dam and the confluence of the San Joaquin River with the Merced River, with preliminary application of numerical models focused on Reach 2, which extends from Gravelly Ford to the Mendota Pool. Preliminary assessments in other reaches include qualitative analysis, drawing from simulation results in Reach 2 where useful analog is provided; and, other available data in conjunction with analysis of earlier model runs where they may reasonably inform this process.

Figure 5-1 shows the area covered by Reach 2 of the groundwater model.

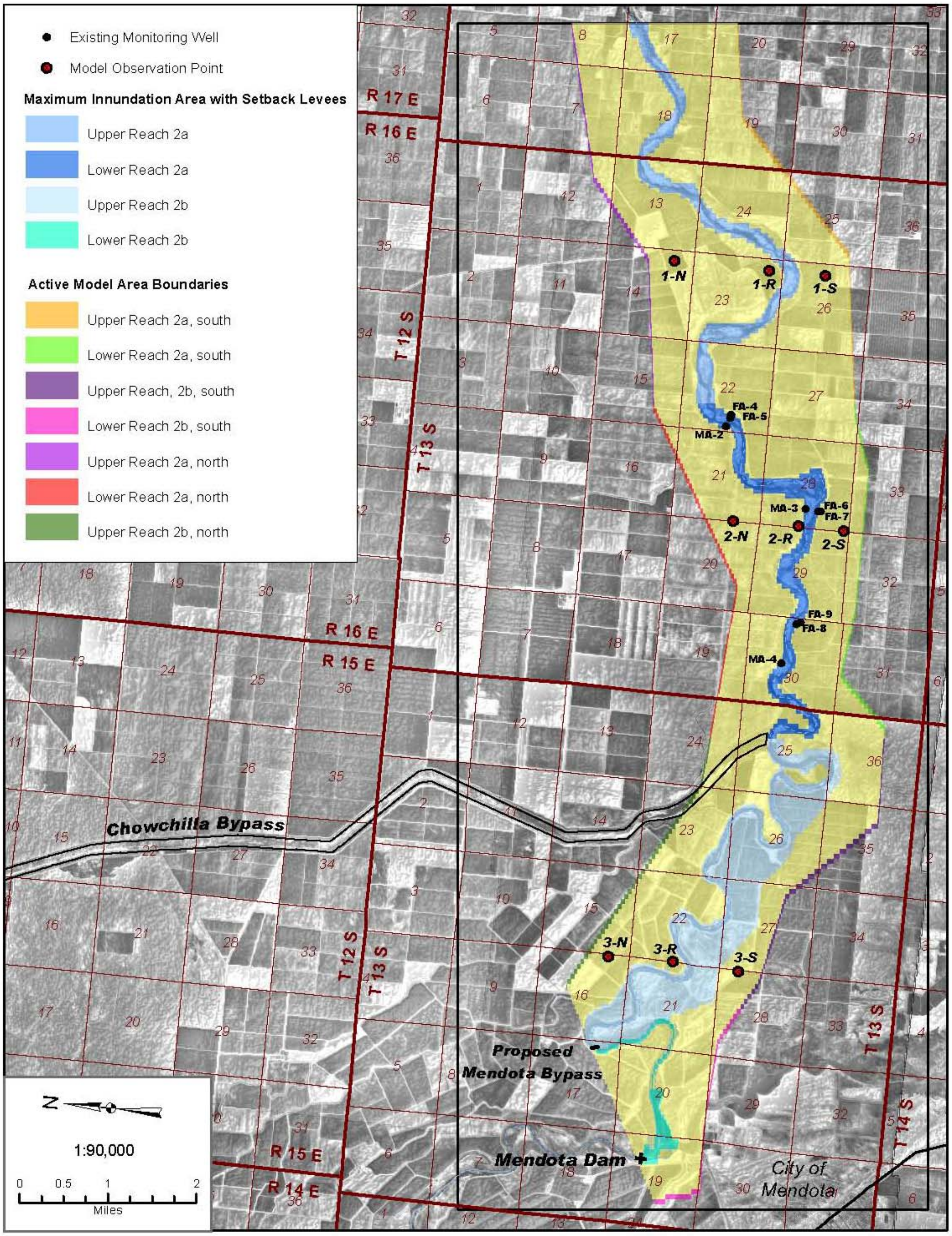

Figure 5-1.
San Joaquin River Riparian Groundwater Model, Reach 2

5.1.1 Model Description

The high-resolution riparian zone groundwater models for the near-river zone were developed in MODFLOW and employ river water boundary conditions developed in USACE's River Analysis System (HEC-2 or HEC-RAS) surface water routing models. These models, termed riparian groundwater models, have been constructed for each of the San Joaquin River Reaches 1 through 5 located between Friant Dam and the Merced River (SSPA 2000). Three of the five models were updated in 2005 (Reaches 1, 2 and 4). Models for Reach 1 and 2 were calibrated using available flow and alluvial monitoring well data from the 2004 to 2005 period, including data collected during the large flood releases in May of 2005 (SSPA 2005). The models evaluate near-river groundwater and groundwater/surface water interaction at a high spatial and temporal resolution. Grid spacing is 300 by 50 feet, with an active model domain extending to about one half mile to each side of the river within three vertical layers. Lateral boundary head conditions are specified to correspond to regional groundwater elevations and can be modified as desired according to the simulation objectives. The original version of these models (SSPA 2000) used up to 13 vertical layers; these were aggregated into three model layers in the 2005 model update for reasons of practicality and efficiency in analyzing seepage loss from the San Joaquin River under restoration flow conditions.

The riparian groundwater models are sensitive to the following conditions:

- River flow levels (river stage and width of channel)
- Regional groundwater elevations (impacts of pumping or recharge)
- Vegetative conditions in the channel and overbank areas
- Channel and levee configuration (as controls on channel width)
- River operational rules (impacting downstream flows given a particular Friant release)
- Antecedent conditions (i.e., a dry year following a wet year will manifest differently than a dry year following a dry year)

For the initial analyses of program alternatives, the primary factor evaluated in screening alternatives prior to detailed evaluation was the level of flow below Friant Dam. Other factors considered in structuring the evaluations were operational rules and channel configuration.

Flow of the San Joaquin River, below Friant Dam and at points downstream as modeled for the PEIS/R, were reviewed for selected alternatives to determine whether differences were sufficiently large to warrant separate simulation in the analysis of near-river seepage and groundwater impacts. The review and outcomes included:

- **Base Case, Existing and Future Condition –** The flows below Friant Dam and flow above Mendota Bypass were compared for both base cases and found to be indistinguishable in a visual comparison of flow vs. time for a representative sampling of modeled years. Therefore, in the near-river assessment, the Base Case results can be extended to either the existing or the future condition, with respect to flow levels impacting the assessment.

- **Alternative A, Existing and Future Condition –** The flows below Friant Dam and flow above Mendota Bypass were compared for Alternative A under both existing and future conditions and were found to be indistinguishable in a visual comparison of flow vs. time for a representative sampling of modeled years. Therefore, in the near-river assessment, the Alternative A results can be extended to either the existing or the future condition, with respect to flow levels impacting the assessment.

The foregoing analysis revealed several significant differences between the Base Case and Alternative A (under either the Existing or the Future Condition) that would affect near-river seepage and groundwater conditions in Reach 2. These included different Friant releases and alternate operational rules. The alternate operational rule relevant to this analysis is in the handling of flow diversion to the Chowchilla Bypass at the Bifurcation Structure. In Alternative A, for a given Friant release, more water flows downstream from the Chowchilla Bypass. Whereas for the Base Case, flow below the Bifurcation Structure rarely exceeded 1,500 cfs; under Alternative A, flow in wet years frequently falls within the range of 1,500 cfs to 4,500 cfs in Reach 2b (between the Bifurcation Structure and the Mendota Bypass above Mendota Pool).

Comparative modeling of seepage and groundwater conditions in this near-river analysis requires alternate handling of river flows below Friant; and, alternate routing of water below the Bifurcation Structure. For this reason, two series of HEC routing models were obtained and used to configure MODFLOW River Packages for the comparative simulations.

5.1.2 Modeling Assumptions

Selection of Benchmark Years for Alternative Analyses

Simulated daily flow data below Friant Dam and at downstream points were available to this analysis for 24 hypothetical years modeled based on hydrologic characteristics of the 1980 to 2003 period. These years were grouped into characteristic year types (wet, normal-wet, normal-dry and dry) by other team members based on programmatic definitions. For reasons of practicality, only one representative year of each year type was selected for quantitative modeling of impacts. For each year type, flow hydrographs of all of the available hypothetical years were examined. From each group, one “representative year” was selected that exhibited centralized tendencies in terms of both magnitude and shape. The selected representative years are:

Wet Year Type:	1998
Normal-Wet Year Type:	2000
Normal-Dry Year Type:	2001
Dry Year Type:	1990

The alternatives analysis is conducted for each year type based on the flow hydrograph for the representative year, as corresponds to the Base Case and alternatives undergoing evaluation. Although no future year will be exactly like any past year, or exactly like the selected representative year, differences associated with these selected years will illustrate the kinds of differences to be expected for years of similar year type. For this reason, examination of projected impacts for the selected years provides a reasonable basis for assessing potential environmental impacts associated with the alternatives under evaluation.

River Flow and Channel Conditions for Alternatives Analyses

For each of the selected year types (wet, normal-wet, normal-dry and dry) a step-function hydrograph has been developed to approximate the daily flow data, using discrete flows (steps) that correspond to those available in the MODFLOW River Package Library. For each step defined on the step-function hydrograph, an alternate river boundary condition is defined for the transient model run of the representative year, under the given alternative. Tables 5-1 and 5-2 identify, for the Base Case and Alternative A, respectively, the river attributes for the model stress periods, with each stress period corresponding to one step on the step-function hydrograph. Hydrographs showing this information as a function of time are provided in the appendix. For each stress period, the stage and width of the river is re-specified to conditions that are projected to occur at the given level of Friant release. The projected stage and width for the given Friant releases are obtained from steady-state HEC model output for the referenced Friant flow level.

Table 5-1.
Model Stress Periods and Associated River Packages, Base Case

Stress Period	Beginning Date	End Date	Number of Days	Flow (cfs)*
Wet Year				
1	*Steady State*			*500*
2	February 1	February 4	4	1,000
3	February 5	February 26	22	4,000
4	February 27	April 13	46	2,000
5	April 14	June 23	71	4,000
6	June 24		1	8,000
7	June 25	July 1	7	12,000
8	July 2	July 11	10	8,000
9	July 12	July 25	14	4,000
10	July 26	January 31	190	200
Normal Wet Year				
1	*Steady State*			*500*
2	February 1	May 28	118	200
3	May 29	May 30	2	2,000
4	May 31		1	500
5	June 1	June 4	4	200
6	June 5		1	500
7	June 6	January 31	239	200
Normal Dry Year				
1	*Steady State*			*500*
2	February 1	January 31	365	200
Dry Year				
1	*Steady State*			*500*
2	February 1	January 31	365	200

Note:
* River package reference flow below Friant Dam.
Key:
cfs = cubic feet per second

Table 5-2.
Model Stress Periods and Associated River Packages, Alternative A

Stress Period	Beginning Date	End Date	Number of Days	Flow (cfs)*
Wet Year				
1	*Steady State*			*500*
2	February 1	February 17	17	350
3	February 18	March 3	14	500
4	March 4	March 23	20	1,000
5	March 24	April 11	19	2,000
6	April 12	May 30	49	4,000
7	May 31	June 27	28	2,000
8	June 28	July 3	6	10,000
9	July 4	July 11	8	8,000
10	July 12	July 25	14	4,000
11	July 26	November 4	102	350
12	November 5	November 26	22	500
13	November 27	January 31	66	350
Normal Wet Year				
1	*Steady State*			*500*
2	February 1	February 18	18	350
3	February 19	March 3	13	500
4	March 4	March 25	22	1,000
5	March 26	April 30	36	2,000
6	May 1	May 14	14	1,000
7	May 15	November 4	174	350
8	November 5	November 26	22	500
9	November 27	January 31	66	350
Normal Dry Year				
1	*Steady State*			*500*
2	February 1	February 17	17	350
3	February 18	March 3	14	500
4	March 4	April 30	58	1,000
5	May 1	May 12	12	500
6	May 13	November 4	176	350
7	November 5	November 26	22	500
8	November 27	January 31	66	350
Dry Year				
1	*Steady State*			*500*
2	February 1	February 17	17	350
3	February 18	March 3	14	500
4	March 4	March 28	25	1,000
5	March 29	April 11	14	500
6	April 12	January 31	295	350

Note:
* River package reference flow below Friant Dam.

Key:
cfs = cubic feet per second

River Boundary Conditions for the Base Case. To provide the river boundary conditions for the groundwater model, HEC simulation results have been obtained for a set of different flow levels. For example, HEC-2 steady-state model results were used in previous work (SSPA 2005) at flow levels of 200 cfs, 500 cfs, 1,000 cfs, 2,000 cfs and 8,000 cfs, and interpolated packages were developed for flows of 350 cfs. MODFLOW River Packages were developed in 2005 for each of these flow levels, and comprised the River Package Library for the existing condition. These HEC-2 simulations employed an operating rule whereby flow above 1,500 cfs is routed to the Chowchilla Bypass at the Bifurcation Structure. These HEC-2 runs, and others representing alternate assumptions, were reviewed as part of this evaluation for their suitability in producing a “river footprint” and water depth in the wetted channel area for the Base Case defined for this alternatives analysis, which represents the “without project” condition. For Reach 2A, these HEC-2 runs, along with an additional 4,000 cfs run that was applicable to the existing condition for Reach 2A, were considered reasonably representative of the Base Case conditions for this evaluation. As part of the review of suitability of existing HEC-2 model runs for Reach 2B, the programmatic modeled flows were examined. It was observed that flows to Reach 2B under the existing and future no-project conditions are typically limited to 1,500 cfs, except in cases where the Friant reference release exceeds 8,000. For this reason, as part of the Base Case defined for this analysis, the existing HEC-2 output for the 2,000 Friant release, which essentially resulted in this same condition, was also used to define the River Package within 2B for the 4,000 and 8,000 cfs cases. As part of this evaluation, additional River Packages were developed for Friant reference flows of 10,000 and 12,000 cfs by extrapolation. The extrapolation procedure involved increasing the downriver modeled depth corresponding to that of the 8,000 Friant release by 25 percent and 50 percent, respectively, for Friant releases of 10,000 and 12,000 cfs. This approach resulted in generally reasonable approximations in both reaches 2A and 2B. For Reach 2B, given that the 8,000 release simulation results in about 1,500 cfs below the Bifurcation Structure, this adjustment reflects a ramping up of flows in 2B from about 1,500 cfs with a Friant release of 8,000 cfs, to about 2,250 cfs at a Friant release of 12,000 cfs. These simplified assumptions do not represent all possible operations; on the other hand, they provide river conditions that are reasonably consistent with the downriver distribution of flows modeled for this PEIS/R and provide a reasonable approximation of the Base Case for purposes of comparing general differences among the alternatives.

River Boundary Conditions for the “With-Project” Analyses. Inspection of the programmatic modeled river flows below the Bifurcation Structure (for example, at “above Mendota Bypass”), indicates that under Alternative A, significant additional flow is routed into the river rather than into the Chowchilla Bypass. For this reason, the existing River Package Library, described above, is not suitable for modeling Reach 2B under Alternative A. MEI was approached to determine what existing runs might be available for this purpose. Previous HEC-2 models were updated to HEC-RAS models and HEC-RAS steady-state output was provided, including the wetted channel footprint and depth, at Friant reference flow levels of 350 cfs, 1,500 cfs, 2,000 cfs, 4,000 cfs and 8,000 cfs, under a modified operating rule that no longer restricted river flow below the Bifurcation Structure to 1,500 cfs. These simulations also assume that levees are set back and modified to accommodate these higher flows into Reach 2B. River Packages were developed for Reach 2B from the HEC-RAS output for 2,000 cfs, 4,000 cfs and 8,000 cfs, and by extrapolation, to 10,000 and 12,000 cfs, for use in the Alternative A analysis. Because conditions above the Bifurcation Structure are not impacted by the operating rule noted above, existing HEC-2 River Packages also are used for Reach 2A in the Alternative A analysis for reasons of consistency.

The HEC-RAS steady-state output described above, used for the Alternative A analysis, is premised on the assumption that below the proposed Mendota Pool Bypass, the river channel would not be used, rather, flow would be routed into the Mendota Pool Bypass. Channel conditions used in the MODFLOW River Packages for Alternative A reflect this assumption and specify the river as dry between the Mendota Pool Bypass and the Mendota Pool. However, it is worth noting that the "dry" reach below the Mendota Pool Bypass intercepts shallow groundwater in wetter years, that is, water that has seeped from the channel upstream from the bypass re-emerges in the unused portion of the channel below the bypass.

Generalized Regional Groundwater Assumptions for Alternatives Analyses

The near-river groundwater model domain is bounded on both sides of the river at the active model boundary (Figure 5-1) by specified heads corresponding to assumed conditions representing the regional groundwater condition. For this analysis, three boundary conditions are identified and used to illustrate a range of possible outcomes, as the future regional groundwater condition may vary over a significant range depending on multiple factors. The three hypothetical regional groundwater conditions are termed the *Low*, *Mid* and *High* conditions. These are not intended to represent the lowest, or the highest, or average conditions. Rather, they represent a wide range of conditions, and provide a means of examining the sensitivity of near-river model results under varying assumptions, all of which are likely to occur at some time in the future. The derivation of these conditions from historical information is briefly noted below.

Low Condition. During an earlier project (SSPA 2000) an initial set of heads for Reach 2 was developed by kriging groundwater elevations along the Reach 2 boundary, as represented in data collected and distributed by DWR for Spring 1996, and used as a "Base Case." In a later project phase (SSPA 2005) inspection of records of groundwater elevation indicted that groundwater elevations had raised in amounts of 20 feet or more in and around this region. It was concluded that the Spring 1996 values reflected a period of greater pumping, and/or less recharge, than was seen in subsequent years, and therefore, the spring 1996 representation in the vicinity of Reach 2 was characterized as a representation of a "Low-Range" regional groundwater condition. While lower groundwater elevations have been observed in the historical period (i.e., the 1990-94 period, see Appendix C of SSPA 2005) and certainly could be experienced in the future, the 1996 condition is used in this analysis as a "Low Range" condition. In future analyses, it may be of interest to evaluate potentially lower, or more extreme, conditions, depending on analysis objectives.

Mid-Range and High Condition. "Mid-Range" and "High" boundary heads have been constructed by addition of 10 feet, and 20 feet, respectively, to the Low Range Condition.

Initial Conditions

All simulations are initialized with output from a steady-state simulation of groundwater in the near-river zone. In all cases, the steady-state run assumes a continuous release at Friant Dam of 500 cfs and regional groundwater conditions equal to those used for the subsequent transient simulation.

Specification of Regional Groundwater Boundary Conditions in Transient Simulations

For the simulations undertaken as part of this analysis, the specified regional groundwater boundary condition is selected from one of three conditions, representing a range of historical conditions as described above. As presently configured, the near-river groundwater model uses the same regional groundwater boundary condition throughout the transient simulation. This specification represents a simplification of the actual system, which experiences change in regional groundwater elevations seasonally, that is, winter groundwater elevations tend to be higher and summer/fall elevations are typically lower due to dry-season pumping and other factors. This simplification may result in some underestimation of river seepage losses during late spring/summer peak flows, and similarly, in underestimation of returns to the river later in season when groundwater rises. Monthly projections of seepage losses and river gains can be improved by allowing this boundary condition to change over the course of the simulation, either by direct specification, or, through linkage to a regional groundwater model that explicitly simulates the seasonal change in groundwater elevations due to pumping and other factors in the surrounding region.

5.1.3 Output Description

Simulated Conditions in Reach 2

Model output is described and detailed results are shown in the Groundwater Modeling – Near River Analysis Attachment. Simulated annual river seepage conditions are summarized in Table 5-3 for specific river sub-reaches, under the Mid-Range regional groundwater boundary condition assumption, under four representative year types for the Base Case and for Alternative A. These results apply to both the Existing and the Future Condition assumptions with respect to each. Hydrographs showing the distribution of this seepage over time are provided in the appendix for these cases with three alternate assumptions for regional groundwater boundary conditions.

Simulated flux to the regional groundwater system is summarized in Table 5-4 for specific boundary sub-reaches under the four representative year types for both the Base Case and Alternative A. Appendix figures illustrate the boundary flux as a function of time for the northern and southern boundaries for the four representative year types and with three alternate assumptions for regional groundwater boundary conditions.

Table 5-3.
Reach 2 Annual River Seepage, Base Case and Alternative A, Mid-Range Regional Groundwater Elevation

Sub-Reach	ID	Wet		Normal Wet		Normal Dry		Dry	
		Base Case	Alternative A	Base Case	Alternative A	Base Case	Alternative A	Base Case	Alternative A
Upper 2A	1	6,556	7,739	3,488	6,882	3,157	6,765	3,157	6,649
Lower 2A	2	6,834	9,604	1,067	9,071	-132	9,034	-132	9,078
Upper 2B	3	13,313	16,403	2,771	10,860	0	8,395	0	6,139
Lower 2B	4	2,188	-361	1,947	1,364	1,767	1,528	1,767	1,617
Total		28,891	33,385	9,274	28,177	4,791	25,723	4,791	23,482

Note:
Seepage is summed for the one-year analysis period and shown in acre-feet for each sub-reach.

Table 5-4.
Reach 2 Annual Boundary Flux, Base Case and Alternative A, Mid-Range Regional Groundwater Elevation

Sub-Reach	ID	Wet		Normal Wet		Normal Dry		Dry	
		Base Case	Alternative A	Base Case	Alternative A	Base Case	Alternative A	Base Case	Alternative A
Upper 2A, South	5	-2,758	-2,739	-2,585	-2,684	-2,571	-2,674	-2,571	-2,666
Lower 2A, South	6	-3,330	-3,317	-2,982	-3,232	-2,914	-3,219	-2,914	-3,203
Upper 2B, South	7	-1,638	-1,846	-1,043	-1,587	-944	-1,353	-944	-1,255
Lower 2B, South	8	-716	-701	-601	-663	-583	-630	-583	-619
Upper 2A, North	9	-3,245	-3,228	-3,050	-3,163	-3,033	-3,152	-3,033	-3,143
Lower 2A, North	10	-4,943	-4,939	-4,567	-4,859	-4,494	-4,844	-4,494	-4,830
Upper 2B, North	11	-2,030	-1,953	-1,390	-1,799	-1,283	-1,736	-1,283	-1,626
Total		-18,661	-18,724	-16,218	-17,987	-15,823	-17,609	-15,823	-17,341

Notes:
1. Boundary flux is summed for the one-year analysis period and shown in acre-feet for each sub-reach.
2. Negative values indicate flux from the near-river zone to the regional groundwater system.

Appendix figures show simulated groundwater elevations at nine hypothetical observation points located along three hypothetical monitored cross-sections (as identified on Figure 5-1). The simulated groundwater elevations at these points are shown as a function of time through the simulated year, from February 1 to January 31. The figures illustrate the differences between the Base Case and Alternative A for each of the four year types (wet, normal-wet, normal-dry and dry) for the Mid-Range regional groundwater boundary assumption.

5.2 Regional Groundwater Modeling

This Section describes the groundwater analytical tools used to evaluate changes to regional groundwater conditions, approach and assumptions, and output data related to alternatives presented in the SJRRP PEIS/R. Assessments of regional groundwater levels will be made for the entire delivery area for the Friant-Kern Canal, Madera Canal, and areas adjacent to the Friant-Kern and Madera canal service areas.

The Water Management Work Group (WMWG) requires groundwater analytical tools for two critical needs:

- To evaluate changes to groundwater resources from implementing the SJRRP
- To determine whether seepage losses increase beyond the levels assumed in Exhibit B of the Settlement

The regional groundwater analysis addresses the first need by evaluating potential impact to groundwater resources as a result of alternatives identified in the SJRRP PEIS/R. Implementation of the SJRRP will result in changes to flows in the San Joaquin River below Friant Dam, and changes in surface water deliveries to water users within the Friant Division. These changed conditions would result in changes in groundwater-surface water interaction and changes in groundwater pumping. Groundwater conditions, including groundwater levels and groundwater quality, would respond to these changes. This Appendix documents the groundwater analytical tools used to evaluate the response of groundwater levels to changes in groundwater pumping, as reported in the SJRRP PEIS/R.

The second bullet is addressed above in Section 5.1 describing the Near-River Seepage Groundwater Model.

5.2.1 Model Description

Groundwater analytical tools often have the ability to simulate groundwater conditions for a regional area, such as a water agency service area, a county or multicounty area, or entire groundwater basin. For the purposes of assessing regional groundwater conditions within the Restoration Area, a review process was completed to identify analytical tools that could be used to evaluate regional groundwater conditions. A number of spatially distributed numerical models were identified as being under development or modified, but none were available to meet the schedule requirements associated with completing the SJRRP PEIS. Models removed from immediate consideration, but that may be reconsidered at a later date if available, when deemed suitable and practical, include the Central Valley Hydrologic Model (CVHM) (Faunt et al. 2008), California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) (DWR 2007a and 2007b), and HydroGeoSphere (DeMarco and Matanga 2007).

During litigation, studies were completed by experts to better understand potential implications of the Settlement on regional groundwater and seepage issues. Data and reports collected during this period are available for most of the Friant Division, but are not readily available for evaluating potential impacts of the program alternatives on non-Friant regions. Therefore, more information (data, analytical tools, and published reports) is generally available for the Friant Division than non-Friant Division regions. For this reason, a unique approach was developed for the Friant Division and non-Friant Division regions were evaluated qualitatively.

The following section discusses two analytical methods for describing regional groundwater responses in the Friant Division. The Schmidt Tool relies on testimony delivered during Settlement litigation which is dependent on historical groundwater levels and the Irrigation Training and Research Center estimated pumping for the Friant Division (Schmidt 2005a, Schmidt 2005b, Burt 2005). The Mass Balance Tool relies on published aquifer parameters and available groundwater elevation data from DWR's Water Data Library and Bulletin 118-03 (DWR 2003, 2010).

Schmidt Tool

A simplified numerical tool developed by Schmidt (2005b) during litigation was used to evaluate changes in groundwater conditions in the Friant Division as part of the regional groundwater analysis. This regional groundwater tool estimates the depth to groundwater within Friant Division contractor areas according to relationships describing annual groundwater pumping and resulting depth to groundwater developed by Dr. Schmidt (2005b). The report completed by Schmidt in 2005 presents the best available data describing the relationship between groundwater pumping and groundwater depth within the Friant Division as illustrated in Table 5-9. Relationships between groundwater pumping and groundwater depth within the Friant Division, as developed by Dr. Schmidt, are linear and describe annual aquifer drawdown. To estimate long-term aquifer drawdown for future conditions, annual drawdown within each district region was applied for a 25-year period to correspond to 2030 conditions. Key assumptions associated with using these relationships are described below.

Table 5-9.
Reported Changes in Groundwater Levels and Groundwater Pumping by District

District	Change in Groundwater Level (1987-1999, Existing Level) (feet/year)	Change in Groundwater Level (Spring-Run Hydrograph) (feet/year)	Change in Groundwater Pumping (Existing Deliveries) (acre-feet/year)	Change in Groundwater Pumping (Spring-Run Hydrograph) (acre-feet/year)
Chowchilla WD	-3.8	-8.8	93,000	127,000
Madera ID	-2.1	-5.1	153,000	197,000
Fresno ID	-0.9	N/A	N/A	N/A
Garfield WD	-1	N/A	N/A	N/A
International WD	N/A	N/A	N/A	N/A
Orange Cove ID	0.5	-16	41,000	49,000
Ivanhoe ID	-0.9	-3	16,000	19,000
Stone Corral ID	0.2	N/A	9,500	12,000
Tulare ID	-2.9	-8.7	137,000	163,000
Exeter ID	-0.6	-4.7	20,000	25,000
Lindsay-Strathmore ID	0.3	-2	7,000	13,000
Lindmore ID	-1	-7.4	34,000	44,000
Lower Tule River ID	-2.9	-7.9	134,000	181,000
Porterville ID	-0.5	-7.5	23,000	31,000
Teaport Dome WD	0.2	N/A	1,500	3,000
Terra Bella ID	N/A	N/A	12,000	18,000
Saucilito ID	-1.3	-7.5	15,000	24,000
Delano-Earlimart ID	-1	-8.3	26,000	54,000
Southern San Joaquin Municipal Utility District	-2.7	-3.5	49,000	75,000
Shafter Wasco ID	-3.1	-8.8	55,000	70,000
Arvin-Edison WSD	2.1	-14.5	186,000	239,000

Source: Schmidt, 2005b.

Key:
ID = Irrigation District
WD = Water District
WSD = Water Storage District

Regional groundwater analysis involved development of a spreadsheet model that uses the Schmidt (2005b) relationships together with simulated surface water deliveries from CalSim.

Mass Balance Tool

A mass balance tool was used to address potential changes in groundwater conditions within the Friant Division long-term contractor districts that did not have a Schmidt relationship. The mass balance tool provides a quantitative evaluation of the how the groundwater levels in the districts could potentially change as a result of a decrease in surface water deliveries using the best available information for these different Friant regions. The mass balance tool involved the development of a spreadsheet model that uses post-processed CalSim data as input to calculate the average change in simulated surface water deliveries from within each district, and to estimate the change in depth to groundwater within each region by assuming a uniform drainable porosity (specific yield), and a uniform change in depth to groundwater throughout the entire area overlying the basin. As with the Schmidt method, the changes in annual surface water deliveries were assumed to be offset by an increase in groundwater pumping.

Development of this tool involved identifying the groundwater subbasins underlying each of the districts to evaluate the subsurface conditions, and estimate an average uniform specific yield within each district. To evaluate the potential change in groundwater elevation, groundwater data from all groundwater wells within each district that store data publically on the DWR Water Data Library (WDL) was downloaded from the Web site (DWR 2010). The data were evaluated by district to estimate the average existing groundwater level condition for 2005. Although it is recognized that political boundaries do not control the physical environment, for the purposes of estimating conditions using the mass balance tool it was necessary to treat each district as a hydraulically closed system.

A description of the key assumptions associated with using the mass balance method is provided below in Section 5.3.2.

5.2.2 Modeling Assumptions

The following section describes the approach and key assumptions for regional groundwater analysis in the Friant Division and non-Friant Division regions.

Schmidt Tool Assumptions

The Schmidt Tool assumes a linear relationship is valid between contractor-wide pumping and drawdown. The relationships developed by Schmidt assume that each district is underlain by a homogeneous aquifer system that is a closed system and therefore is not hydraulically connected to surrounding areas. The Schmidt Tool assumes that the relationship between historical groundwater pumping and resulting groundwater levels holds true for future water management conditions resulting from program alternatives (Schmidt 2005b). Absolute values of changes in groundwater conditions (groundwater levels) will not be reported. Regional groundwater conditions will be assessed based on changes between program alternatives. The Schmidt Tool assumes that groundwater supplies exist in each district to make up for the average annual net reductions in surface water deliveries resulting from program alternatives. However, it is recognized that the projected drawdown in the aquifer may not be sustainable in some contractor areas within the Friant Division.

Potential drawdown of the aquifer within the Friant Division was estimated by Schmidt (2005b) using a linear relationship with groundwater pumping. During litigation, Burt (2005) estimated gross irrigation groundwater pumping for the Friant Division, which is not corrected for well inefficiencies, and is the estimate of pumping used for irrigation scheduling as opposed to the estimate that would be used in water balance calculations. The estimates of gross irrigation groundwater pumping for 1987 and 2003 from Burt (2005) were used by Schmidt to develop Friant Division contractor relationships with estimates of the average annual drawdown per year. Estimates of pumping under existing conditions for the PEIS/R are calculated as the current pumping condition (Schmidt 2005b) plus additional pumping needed to offset net reductions in Friant Division surface water deliveries.

Potential changes in groundwater quality, land subsidence, and drainage were expressed qualitatively based on a review of known groundwater quality, land subsidence and drainage issues, and estimated changes in groundwater conditions (groundwater levels) associated with program alternatives.

Mass Balance Tool Assumptions

The mass balance approach used to assess groundwater conditions in Friant areas similarly to the Schmidt Tool assumes a closed system, where each Friant District is underlain by a homogeneous aquifer system that is not hydraulically connected to the surrounding areas. This method also assumes that uniform changes in depth to groundwater and uniform drainable porosity will be applied across the entire Friant District under evaluation.

5.2.3 Calsim Interface to Regional GW (Schmidt) Model

The regional Ground Water model (Schmidt model) used in the analysis requires information on water deliveries, by delivery type, to each of Friant Contractors included in the model. The contracts with the Friant contractors specify several types of water delivery including Class 1 (C1), Class 2 (C2) and 215 water deliveries. The restoration program also includes two additional types of water delivery to Friant contractors:

- 16(a) - Lower SJR and/or Delta recapture and recirculation
- 16(b) – Additional or new delivery to potential new ground water facilities

Implementation Issues

The CalSim implementation of the San Joaquin River Restoration Project (SJRRP) does not directly implement the full 16(a) and 16(b) operations at a level of detail sufficient to directly interface with the Schmidt model. Specific issues include:

CalSim C1/C2/215 delivery implementation issues

- CalSim does not allocate delivery to individual contractors, it lumps deliveries to groups of contractors by Water Management Area (WMA).
- CalSim sometimes allocates more C1 water than is included in the Friant Contracts. (800,000 AF).
- CalSim sometimes makes C2 deliveries in years where C1 delivery is less than 800,000 af. C2 deliveries are only supposed to happen after full C1 deliveries are made.
- CalSim sometimes allocates Madera C1/C2 delivery greater than contract amounts.

16(a) - Delta recapture and recirculation issues

- CalSim simulates Lower San Joaquin River recapture; however, it does not re-circulate this water to Friant contractors.

- Delta recapture is not directly simulated, for purposes of the PEIS/R it is assumed to be the total change in SWP/CVP south of Delta delivery between with and without SJRRP CalSim simulations

- Re-circulation and distribution of 16(a) water and allocation to specific Friant contractors is not done in CalSim.

16(b) – Delivery to potential new ground water projects issues

- CalSim allocates 16(b) before 215 to maximize use of potential 16(b) facilities, resulting in relabeling some 215 in the no project run as 16(b) water in the project runs. The final 16(b) number from CalSim does not represent "new" water but a combination of new and relabeled water.

- CalSim allocates 16(b) water from the most downstream end of the Friant Kern Canal working upstream. This distribution of 16(b) does not meet the needs of the regional GW or subsequent economic analysis.

- CalSim 16(b) operations result in some changes in C1/C2 delivery computations in CalSim through the storage changes from the 16(b) operations yielding different Friant contract delivery decisions. This occurs mainly in the dryer years.

These issues were addressed through development of a post processing methodology.

Post Processing Methodology

The post processing methodology is based on number of major assumptions including:

- Millerton operations are not linked to Delta operations. This implies losses, C1, C2, 215, and 16(b) water availability is the same for Alternatives A, B, and C at the same level of development (Existing or Future). 16(a) water availability does vary between Alternatives A, B, and C due to recapture options.

- Losses, C1, C2, and 215 deliveries are not impacted by 16(b) operations.

- Total C1/C2/215 deliveries computed by CalSim will be split between Friant contractors based on their contracts assuming that any physical limitations on water distribution would be handled within Friant through internal procedures and agreements.

- 16(a) deliveries are computed in two parts:

    - 16(a) direct – Diversion from Lower San Joaquin River through new pumping stations or water transfers.

    - 16(a) delta – Change in total South of Delta SWP/CVP delivery due to additional Delta inflow from SJRRP

- 16(a) water is allocated to Friant contractors based on their C1 contracts. Remaining 16(a) water after the C1 contract totals are met are spread between Friant contractors based on their C2 contracts.

- 16(b) deliveries are computed as the increase in total diversion from Millerton as measured by the difference between CalSim simulations with and without 16(b), both with SJRRP. (Alt A No 16b – Alt A)

- 16(b) water is allocated to Friant contractors based on the percentages defined in the “Mediation document”.

Table 5-5.
Summarizes The Friant Contractor Contract Volumes and % Used In This Process

Friant Contractors Contract and Mediation Document Values					
District	C1	C2	C1	C2	Mediation
	(af)	(af)	(%)	(%)	(%)
Madera Irrigation District	85,000	186,000	10.625%	13.272%	12.536%
Chowchilla Water District*	55,000	160,000	6.875%	11.417%	10.153%
Gravelly Ford Water District*	0	14,000	0.000%	0.999%	0.721%
Madera County*	200	0	0.025%	0.000%	0.007%
Fresno Irrigation District	0	75,000	0.000%	5.352%	3.863%
City of Fresno*	60,000	0	7.500%	0.000%	2.086%
Garfield Water District*	3,500	0	0.438%	0.000%	0.122%
International Water District*	1,200	0	0.150%	0.000%	0.042%
Fresno County Water Works District No. 18*	150	0	0.019%	0.000%	0.005%
Orange Cove Irrigation District	39,200	0	4.900%	0.000%	1.363%
Stone Corral Irrigation District	10,000	0	1.250%	0.000%	0.348%
Ivanhoe Irrigation District	7,700	7,900	0.963%	0.564%	0.675%
Tulare Irrigation District	30,000	141,000	3.750%	10.061%	8.305%
Exeter Irrigation District	11,500	19,000	1.438%	1.356%	1.378%
Lindsay-Strathmore Irrigation District	27,500	0	3.438%	0.000%	0.956%
Lindmore Irrigation District	33,000	22,000	4.125%	1.570%	2.281%
City of Orange Cove*	1,400	0	0.175%	0.000%	0.049%
City of Lindsay*	2,500	0	0.313%	0.000%	0.087%
Lewis Creek Water District*	1,450	0	0.181%	0.000%	0.050%
Porterville Irrigation District	16,000	30,000	2.000%	2.141%	2.101%
Lower Tule River Irrigation District	61,200	238,000	7.650%	16.982%	14.386%
Saucelito Irrigation District	21,200	32,800	2.650%	2.340%	2.427%
Tea Pot Dome Water District	7,500	0	0.938%	0.000%	0.261%
Terra Bella Irrigation District	29,000	0	3.625%	0.000%	1.008%
Pixley Irrigation District**	0	0	0.000%	0.000%	
Delano-Earlimart Irrigation District	108,800	74,500	13.600%	5.316%	7.620%
Southern San Joaquin Municipal Utility District	97,000	50,000	12.125%	3.568%	5.948%
Shafter-Wasco Irrigation District	50,000	39,600	6.250%	2.826%	3.778%
Rag Gulch Water District**	0	0	0.000%	0.000%	
Kern-Tulare Water District**	0	0	0.000%	0.000%	
Arvin-Edison Water Storage District	40,000	311,675	5.000%	22.239%	17.444%
Total	**800,000**	**1,401,475**	**100.000%**	**100.000%**	**100.000%**

The process requires several CalSim simulations at each the Existing and Future levels to generate the basic data required. These simulations are:

- No Project – without restoration flow requirements
- Alt A – with restoration flow requirements, with 16(b) operations
- Alt A No 16b – with restoration flow requirements, no 16(b) operations

- Alt B – with restoration flow requirements, with 16(b) operations
- Alt C – with restoration flow requirements, with 16(b) operations

All examples shown in this document are for Existing level. Results for Future level are very similar.

The basic process begins with the CalSim simulation Alt A No 16b. This simulation includes the SJRRP flow requirements with no 16(a) direct recapture and no 16(b) implementation. This simulation represents the basis for the C1/C2 and 215 deliveries that are assumed to remain constant for all other alternatives.

Adjust For CalSim Allocation Issues. The CalSim C1/C2/215 delivery implementation issues are addressed by:

- Obtain total Friant C1 and C2 deliveries from the CalSim output
- If total C1 is greater than 800 TAF move the extra to C2 (Maximum C1 per contracts is 800,000 AF per year)
- If total C1 is less than 800 TAF move available C2 to C1 until C1 = 800,000 (No C2 delivery until full C1 delivery)
- Allocate C1 delivery to Friant contractors based on C1 contract % of total C1
- Allocate C2 delivery to Friant contractors based on C2 contract % of total C2
- Allocate 215 delivery to Friant contractors based on C2 contract % of total C2

This represents the anticipated C1, C2 and 215 deliveries, by Friant contractor without any 16(a) of 16(b) water. This should not change between alternatives, only the volume of 16(a) and 16(b) water will be different.

Define 16(a) and 16(b) Water. There are two types of 16(a) water.

Direct 16(a) water is water recaptured from the San Joaquin River upstream of the Delta either through exchanges with Lower San Joaquin CVP contractors or by direct pumping from the river to the Delta Mendota Canal. This varies by alternative depending on the specific facilities included in each. The volume of Direct 16(a) water is computed in the CalSim simulation and can be read from the CalSim output.

Delta 16(a) water comes from the increased South of Delta Delivery made possible by the change in San Joaquin River inflows to the delta caused by the restoration flows. The quantity of this water is defined as the difference in total CVP/SWP South of Delta Delivery from CalSim simulations with and without Restoration. Each alternative has slightly different Delta 16(a) water because of the different Direct 16(a) water in the alternative.

16(b) water comes from upgraded or new conjunctive use programs in the Friant area of use. These programs are included in the CalSim simulations and the results are reported in the CalSim outputs. However, for the reasons described in section 5.2.1 these results are not correct, mainly due to issues with the implementation of the 16(b) programs and the accounting between different types of delivery allocations. Since the only difference in the Friant demands is these new projects the change in total Friant delivery, or the change in total diversion to the Madera and Friant-Kern Canals, between the CalSim runs for Alternative A with and without the 16(b) projects implemented is assumed to represent the 16(b) delivery.

Figures 5-2 and 5-3 illustrate the computed 16(a) delivery year totals, under existing conditions, for the long term and summarized by water year type. Figure 5-4 illustrates the computed 16(b) delivery year totals summarized by water year type.

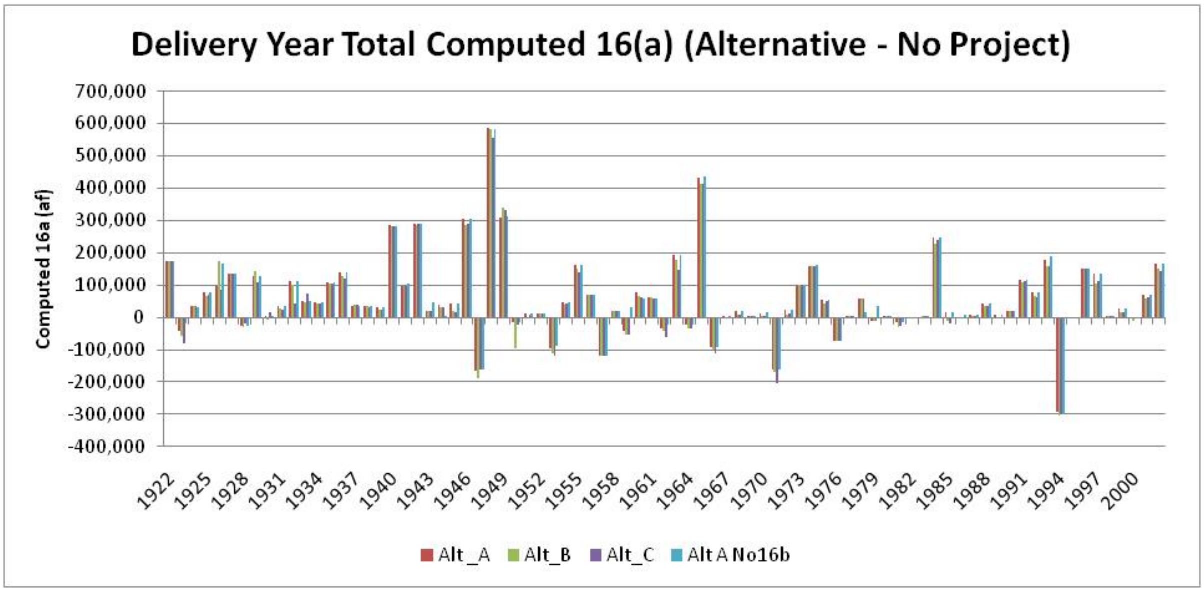

Figure 5-2.
Long Term Delivery Year Total 16(a) Summary For Existing Conditions

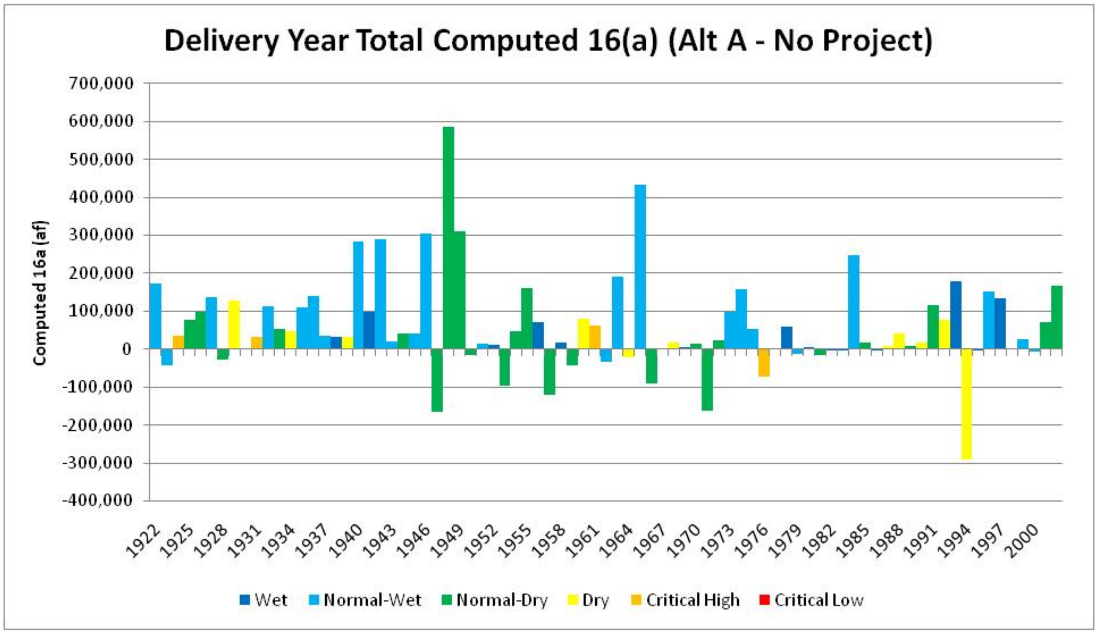

Figure 5-3.
Water Year Type Average Delivery Year Total Computed 16(a) Summary for Existing Conditions

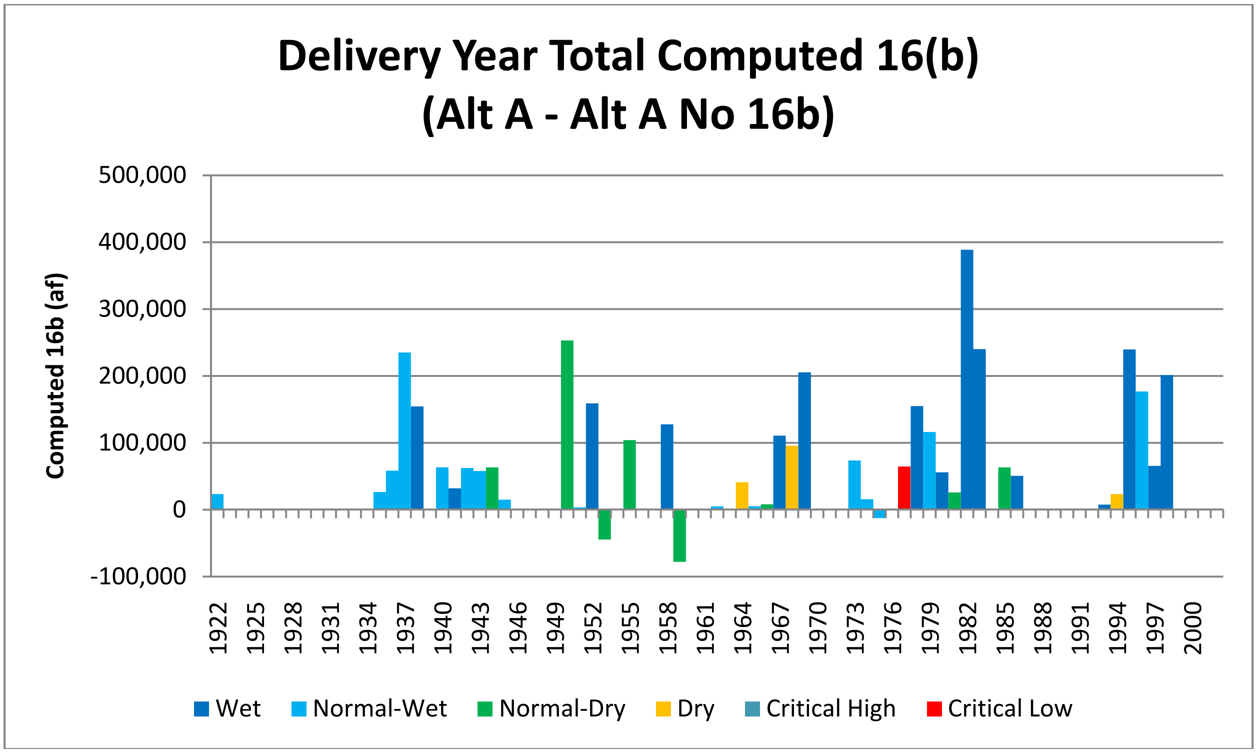

Figure 5-4.
Water Year Type Average Delivery Year Total Computed 16(b) Summary for Existing Conditions.

As can be seen in the figures there are years in the CalSim simulation with negative 16(a) and/or 16(b) totals. This is due to reservoir re-operation in both the San Joaquin and Sacramento basins within the CalSim simulations rules.

Because of these negative values, and because the interface to the Schmidt ground water model requires long term average values both the 16(a) and 16(b) values were converted to long term delivery year annual averages. Table 5-6 summarizes these long term averages.

Table 5-6.
Average Annual 16(a) and 16(b) Delivery for all Alternatives

			16(a)		16(b)	Total
			Delta (af)	Direct (af)	(af)	(af)
Existing Level	Alt A	High	0	0	46,262	46,262
		Low	59,124	0	46,262	105,386
	Alt B	High	0	5,859	46,262	52,120
		Low	52,605	5,859	46,262	104,726
	Alt C	High	0	20,597	46,262	66,859
		Low	50,548	20,597	46,262	117,407
	Alt A No16b	High	0	0	0	0
		Low	61,372	0	0	61,372
			16(a)		**16(b)**	**Total**
			Delta (af)	**Direct (af)**	**(af)**	**(af)**
Future Level	Alt A	High	0	0	46,262	46,262
		Low	58,525	0	46,262	104,787
	Alt B	High	0	7,909	46,262	54,170
		Low	48,182	7,909	46,262	102,352
	Alt C	High	0	29,469	46,262	75,731
		Low	46,675	29,469	46,262	122,405
	Alt A No16b	High	0	0	0	0
		Low	53,849	0	0	53,849

Allocate Delivery Types to Individual Friant Contractors. Allocate the annual volumes to the contractors by water type:

- Allocate total 16(a) to C1, up to contract limit. Split between contractors using C1 contract % from table 5-5.
- Allocate remaining 16(a) to C2 up to contract limit. Split between contractors using C2 contract % from table 5-5.

- Allocate total 16(b) delivery to the Friant contractors based on their mediation document % from table 1.

Adjust contractor Delivery for 215 – 16(b) Allocation Issue. As mentioned in section 5.2.1 the 16(b) implementation in CalSim results in re-labeling of 215 water as 16(b). The allocations up to this point have corrected the 16(b) allocation but used the 215 values directly from the CalSim simulation, which overstate the 215 allocation. An adjustment factor, computed as Base (No restoration) 215 minus Alt A no 16b 215, is allocated to the individual contractor's based on their C2 contract percentages to correct for the CalSim allocation issues.

The final annual averages for each alternative are then passed to the Schmidt groundwater model. Table 5-7 summarizes the average annual Delivery year total for all Friant contactors.

Table 5-7.
Mean Delivery Year Total Friant Delivery

Mean Delivery Year Total Passed to GW Model		
Alternative	Existing (AF)	Future (AF)
No Project	1,094,935	1,094,690
Alt A, High	946,332	946,342
Alt A, Low	1,005,456	1,004,867
Alt B, High	952,191	954,251
Alt B, Low	1,004,796	1,002,432
Alt C, High	966,930	975,811
Alt C, Low	1,016,982	1,020,833
Alt A, No16B, High	900,070	900,080
Alt A, No16B, Low	961,443	953,929

All of the above post processing is done in the worksheets Friant Diversion Component Analysis Existing Level.xlsm and Friant Diversion Component Analysis Future Level.xlsm

5.2.4 Output Description

Output from the analysis using the Schmidt tool and mass balance tool is discussed as follows.

Schmidt Tool

Output from the Schmidt Tool is summarized in this Draft PEIS/R in Chapter 12.0, "Hydrology – Groundwater." This chapter identifies the change in groundwater levels in feet per year and groundwater pumping by Friant Division long-term contractor using the Schmidt Tool. If recaptured Interim and Restoration flows are successfully recirculated to Friant Division long-term contractors, the increase in groundwater pumping due to reduced surface water supplies resulting from reoperating Friant Dam would be relatively low. Changes in groundwater pumping and groundwater levels associated with the low level of pumping increase using the Schmidt Tool are shown in this Draft PEIS/R in Chapter 12.0, "Hydrology – Groundwater."

If no water released as Interim and Restoration flows is recirculated to Friant Division long-term contractors, the increase in groundwater pumping due to reoperating Friant Dam would be relatively high. Changes in groundwater pumping and groundwater levels associated with the high level of pumping increase using the Schmidt Tool are shown in this Draft PEIS/R in Chapter 12.0, "Hydrology – Groundwater."

Not all of the 28 Friant Division contractors are represented in the output tables because historical information was not available for each of the contractors from Schmidt (2005b). Groundwater conditions for 15 contractors are represented in the attachment output tables. The remaining 13 Friant Division contractors were considered using the Mass Balance Tool and are shown this Draft PEIS/R in Chapter 12.0, "Hydrology – Groundwater."

Mass Balance

The output from the Mass Balance Tool is shown in this Draft PEIS/R in Chapter 12.0, "Hydrology – Groundwater." The chapter identifies the change in groundwater levels in feet per year and groundwater pumping by Friant Division long-term contractor using the Mass Balance Tool. As described above for the Schmidt Tool, changes in groundwater pumping and groundwater levels are presented for both low and high levels of pumping increases as shown in this Draft PEIS/R in Chapter 12.0, "Hydrology – Groundwater."

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6.0 Economics

This Section describes the methods and models used to addresses the economic effects associated with the action alternatives. The action alternatives have the potential to change surface water supply reliability to agricultural water users within the Friant Division of the CVP. In addition, the action alternatives may result in changes in M&I water supplies, recreation, hydropower, and flood damage reductions through changes in San Joaquin River flows and land use. The following sections address the economic effects to agricultural production, M&I water supply, recreation, flood management, and hydropower in the region.

6.1 Agricultural Economics (CVPM)

The action alternatives have the potential to change surface water deliveries to agricultural users in the Friant Division. Changes in surface water deliveries affect agricultural users through reduced crop production and higher production costs. For example, reductions in surface water supply may result in increased temporary crop idling and increased reliance on groundwater resources, among other effects. The reduced net farm income generated through reduced production opportunities and higher production costs would result in direct economic effects to the region. The CVPM can be applied to quantify these effects.

Regional agricultural water deliveries from CalSim are used as inputs to CVPM. In this analysis, changes in 2030 groundwater pumping lifts among alternative plans are estimated for the Friant Division and incorporated in the CVPM. Key output from the CVPM includes irrigated acres, net revenue, and gross revenue by agricultural production region. The following section provides a brief description of the CVPM.

Figure 6-1 illustrates the relationship between the water operations model, the regional groundwater model, the agricultural economics model, the recreation models, and the regional economic model. CalSim provides annual surface water deliveries by agricultural production region to the CVPM. In addition, CalSim water deliveries are used in the regional groundwater model to estimate changes in depth to groundwater within the Friant Division. Future analysis will consider the economic effects of changes in depth to groundwater on agricultural water users located outside of the Friant Division. The estimated changes in depth to groundwater are used as inputs in the CVPM. Gross and net revenue estimated by the CVPM are used by IMPLAN to estimate regional economic activity.

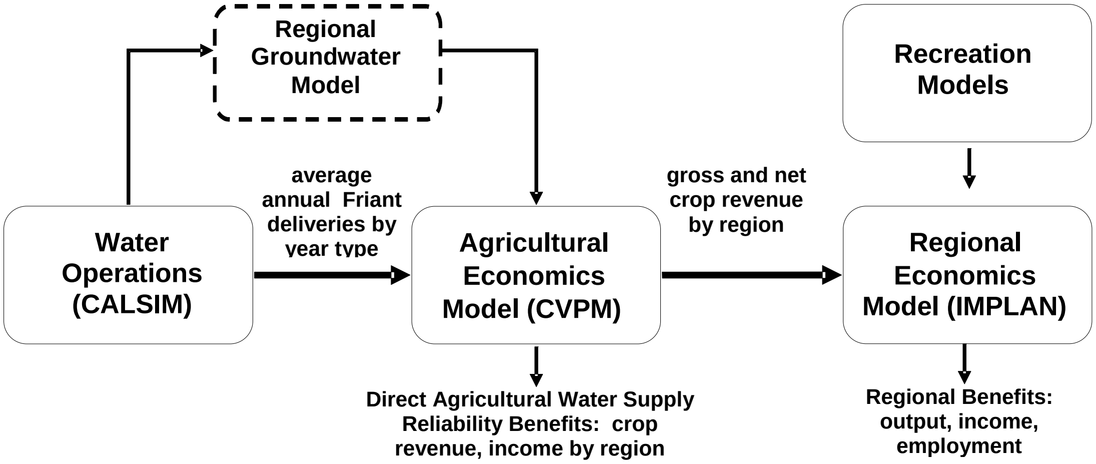


Figure 6-1.
Models Applied to Estimate Economic Effects

6.1.1 Model Description

CVPM is a regional model of irrigated agricultural production and economics that simulates the decisions of agricultural producers in the Central Valley of California. The model assumes that farmers maximize net revenue subject to resource, technical, and market constraints. Farmers sell and buy in competitive markets, and no one farmer can affect or control the price of any commodity. To obtain a market solution, the model's objective function maximizes the sum of producers' surplus (net income) and consumers' surplus (net value of the agricultural products to consumers) subject to the following relationships and restrictions:

1. Linear, increasing marginal cost functions estimated using the technique of positive mathematical programming. These functions incorporate acreage response elasticities that relate changes in crop acreage to changes in expected returns and other information.
2. Commodity demand functions that relate market price to the total quantity produced.
3. Irrigation technology tradeoff functions that describe the tradeoff between applied water and irrigation costs.
4. A variety of constraints involving land and water availability and other legal, physical, and economic limitations.

The model selects those crops, water supplies, and irrigation technology that maximize net revenue subject to the above equations and constraints. From No. 1 above, cost per acre increases as production increases. From No. 2 above, crop price and revenue per acre decline as production increases. No. 3 affects costs and water use through the selection of the least-cost irrigation technology. No. 4 is used to analyze the effects of the project alternatives that change water availability and cost.

6.1.2 Modeling Assumptions

The following sections discuss CVPM assumptions used in the SJRRP PEIS/R analyses.

Agricultural Production Regions

The CVPM divides agricultural production into production regions. In order to isolate effects of the action alternatives on the Friant Division, it was necessary to change production regions in the model. The number of CVPM production regions was expanded for this analysis to allow isolation of effects of action alternatives on the Friant Division from the rest of the Central Valley. The original CVPM model included 22 crop production regions in the Central Valley. For this study, the model area was disaggregated into 30 crop production regions consistent with those developed by FWA's economic expert report (McKusick, 2005). The primary criteria included access to groundwater and cropping pattern. Descriptions of the production regions are provided in Table 6-1. The crop production regions added to the CVPM are highlighted.

Table 6-1.
CVPM Regions and Descriptions

CVPM Region	Description of Major Water Users
1	CVP Users: Anderson Cottonwood, Clear Creek, Bella Vista, Sacramento River miscellaneous users
2	CVP Users: Corning Canal, Kirkwood, Tehama, Sacramento River miscellaneous users
3	CVP Users: Glenn Colusa ID, Provident, Princeton-Codora, Maxwell, and Colusa Basin Drain MWC
3b	Tehama Colusa Canal Service Area. CVP Users: Orland-Artois WD, most of County of Colusa, Davis, Dunnigan, Glide, Kanawha, La Grande, Westside WD
4	CVP Users: Princeton-Codora-Glenn, Colusa Irrigation Co., Meridian Farm WC, Pelger MWC, Reclamation District 1004, Reclamation District 108, Roberts Ditch, Sartain M.D., Sutter MWC, Swinford Tract IC, Tisdale Irrigation, Sacramento River miscellaneous users
5	Most Feather River Region riparian and appropriative users
6	Sacramento County north of American River. CVP Users: Natomas Central MWC, Sacramento River miscellaneous users, Pleasant Grove-Verona, San Juan Suburban
7	Yolo, Solano Counties. CVP Users: Conaway Ranch, Sacramento River Miscellaneous users
8	Delta Regions. CVP Users: Banta-Carbona, West Side, Plainview
9	Sacramento County south of American River, San Joaquin County
10	Delta Mendota Canal. CVP Users: Panoche, Pacheco, Del Puerto, Hospital, Sunflower, West Stanislaus, Mustang, Orestimba, Patterson, Foothill, San Luis WD, Broadview, Eagle Field, Mercy Springs, Pool Exchange Contractors, Schedule water rights
11	Stanislaus River water rights: Modesto ID, Oakdale ID, South San Joaquin ID
12	Turlock ID
13	Merced ID
13A	CVP Users: Madera, Chowchilla, Gravely Ford
14	CVP Users: Westlands WD
15	Tulare Lake Bed. CVP Users: Fresno Slough, James, Tranquility, Traction Ranch, Laguna, Reclamation. District 1606
16	Eastern Fresno County CVP Users: Friant-Kern Canal. Fresno ID, Garfield, International
17	Hills Valley, Tri-Valley
17A	CVP Users: Friant-Kern Canal Orange Cove
18	County of Fresno, Pixley ID, portion of Rag Gulch, Ducor, County of Tulare
18A	Lower Tule River ID, Tulare ID, Porterville ID, Stone Corral ID
18B	Delano-Earlimart ID
18C	Lindsay-Strathmore ID, Lindmore ID, Exeter ID, Ivanhoe ID, Lewis Creek ID
18D	Saucelito ID, Terra Bella ID, Tea Pot Dome WD
19	Kern County SWP Service Area.
20	CVP Users
20A	Southern San Joaquin MUD, Shafter Wasco ID
21	CVP Users: Cross Valley Canal
21A	Arvin Edison WSD

Note: Region 16 was not divided between Friant and non-Friant irrigated land. CVPM results for Region 16 were allocated according to the relative proportion of Friant Division acreage contained in the region.

Key:
CVP = Central Valley Project
IC = Irrigation Company
ID = Irrigation District
MWC = Mutual Water Company
WD = Water District
WSD = Water Service District

Irrigated Crops

The CVPM includes 20 crop categories that represent the wide variety of crops produced in the Central Valley. Table 6-2 summarizes crop categories and types of crops included in each.

Table 6-2.
CVPM Crop Groupings

Category	Proxy Crop[1]	Other Crops[2]	Unit of Measure
Grain	Wheat	Barley oats	Tons
Rice	Rice	----	Tons
Cotton	Upland cotton	Pima cotton	Bales
Sugar beets	Sugar beets	----	Tons
Corn	Corn silage	Other corn	Tons
Dry beans	Dry beans	Lima beans	Tons
Safflower	Safflower	----	Tons
Alfalfa	Alfalfa hay	Alfalfa seed, clover	Tons
Pasture	Irrigated pasture	----	Acres
Other field	Sudan grass	Sunflower, other misc. field and seed Crops	Tons
Processing tomatoes	Processing tomatoes	----	Tons
Fresh tomatoes	Fresh tomatoes	----	Tons
Cucumbers/Cantaloupe	Cantaloupe	Honeydew, watermelon, squash, cucumbers	Tons
Onions/Garlic	Dry onions	Dry and fresh onions, garlic	Tons
Potatoes	White potatoes	Other potatoes	Tons
Other truck	Broccoli	Carrots, cauliflower, lettuce, peas, spinach, peppers, asparagus, sweet potatoes, other truck vegetables	Tons
Almonds/Pistachios	Almonds	Pistachios	Tons
Other deciduous	English walnuts	Peaches, walnuts, nectarines, pears, cherries, apples	Tons
Subtropical	Oranges	Citrus, avocadoes, olives, figs, misc. subtropical	Tons
Vines	Wine grapes	Raisins, table grapes	Tons

Notes:
[1] Production costs, yields, and prices for this crop used in the CVPM.
[2] Acreage data for these crops summed with the proxy crop.
Key:
CVPM = Central Valley Production Model

Groundwater Supply

Within the CVPM calibration, groundwater availability by production region is estimated as the residual between crop irrigation demands and surface water availability. This estimation is primarily the result of limited information regarding groundwater availability within each region. During the estimation stage of the model, groundwater availability is generally assumed to be the same as the estimated volumes during the calibration stage. However, in some cases it is necessary to increase groundwater availability during the estimation stage for some regions to promote model solvability. In this study, groundwater availability was set at a level such that it did not impose a binding constraint within the model. The implicit assumption is that groundwater represents a complete buffer against reductions in surface water supply. As a result, the model will generally only idle acres if the cost of accessing groundwater is too high to generate positive net returns to crop production.

Groundwater Costs

The cost of groundwater is determined in the model according to the pump lift requirement. The model assigns a unit cost that accounts for the cost to lift 1 acre-foot of water by 1 foot. The unit cost includes the estimated power cost based on 70 percent pump efficiency and the amortized capital cost of well construction. Previously, the unit cost within the model was set at $0.26 for all production regions. For this study, a unit cost of $0.35 was applied to groundwater pumping in the Friant Division regions of the model to account for an average pump efficiency of 53.5 percent, as determined by experts in the *NRDC, et al., vs. Rodgers, et al.* litigation documents (NRDC 2006) (the $0.35 figure was derived by applying the estimated pump efficiencies within the Friant Districts as reported in FWA expert reports developed for the *NRDC, et al., vs. Rodgers, et al.* litigation). The unit cost of $0.26 was unchanged for all crop production regions outside of the Friant Division regions. This analysis assumes that the capital costs to pump groundwater are unaffected by changes in aquifer depth.

Depth to Groundwater

As described in Section 5.2, depth to groundwater within each of the Friant Division production regions was estimated according to relationships describing annual groundwater pumping and resulting depth to groundwater developed by Dr. Schmidt (2005a and 2005b). This information is the best available data describing the groundwater pumping – groundwater depth relationship within the Friant Division. The analysis relied on the assumption that changes in surface water deliveries are fully offset by changes in groundwater withdrawals as agricultural producers seek to satisfy crop water requirements. For this analysis, groundwater depth estimates were included as inputs in the CVPM and no iteration between the two models was conducted. In the future, such iterations may be completed to more fully capture the interaction between groundwater cost, groundwater pumping, and groundwater depth. However, the CVPM did not estimate large changes in irrigated acres and cropping pattern among action alternatives. As a result, iterating the models is unlikely to result in significant changes in estimated economic effects. Tables 6-3 and 6-4 provide the estimated groundwater pumping depths for each of the Friant Division regions by Alternative. Pumping depths at the individual contractor level were aggregated to the production region level by weighting the estimated depth in each contractor region according to irrigated acreage.

Table 6-3.
Depth to Groundwater by CVPM Region (feet)

				Existing Conditions (2005)				
CVPM Region	**Current Depth**	**Base**	**A1**	**A2**	**B1**	**B2**	**C1**	**C2**
13A	150	149	150	149	150	149	149	149
16A	85	85	85	85	85	85	85	85
17A	44	44	47	46	47	46	47	46
18A	124	127	128	128	128	128	128	128
18B	180	181	182	182	182	182	182	182
18C	71	71	72	72	72	72	72	72
18D	165	166	167	167	167	167	167	167
20A	231	234	234	234	234	234	234	234
21A	410	410	395	394	395	394	395	394

Key:
CVPM = Central Valley Production Model

Table 6-4.
Depth to Groundwater by CVPM Region (feet)

				Future Conditions (2030)				
CVPM Region	**Current Depth**	**Base**	**A1**	**A2**	**B1**	**B2**	**C1**	**C2**
13A	150	241	254	244	252	244	249	240
16A	85	85	85	85	85	85	85	85
17A	44	31	112	97	110	98	104	92
18A	124	192	228	221	227	222	225	219
18B	180	192	231	223	230	223	227	220
18C	71	86	113	108	112	108	110	107
18D	165	185	211	206	210	206	209	205
20A	231	303	314	311	313	311	312	310
21A	410	410	41	21	39	22	36	20

Key:
CVPM = Central Valley Production Model

6.1.3 CalSim Interface to CVPM Model

The CVPM model requires two types of data from the CalSim modeling, agricultural delivery data to different regions, and M&I delivery data. These are handled separately.

Implementation Issues

The CVPM model splits the California Central Valley into a number of regions for analysis. Figure ___ shows the current CalSim regions.

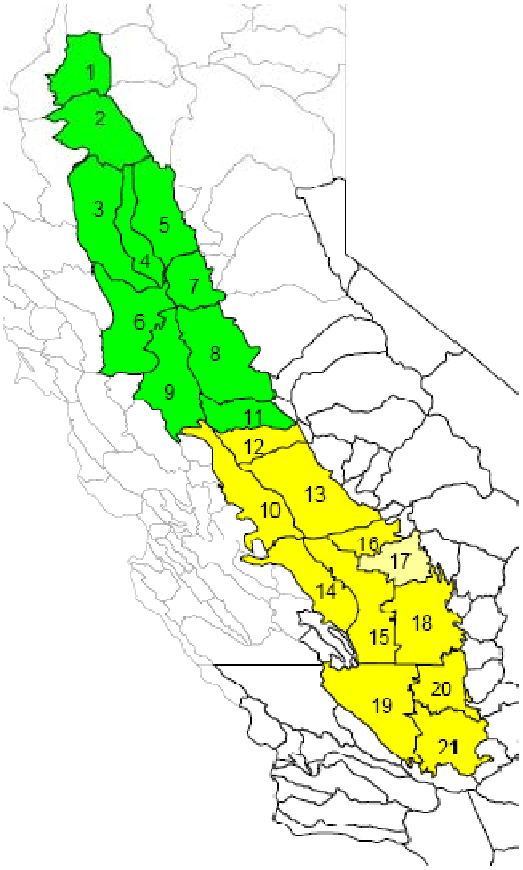


Figure 6-2.
CVMP Regions Defined in Calsim

The CVPM regions defined in CalSim are divided into three areas for this analysis:

- NOD – North of Delta (Green – 1,2,3,4,5,6,7,8,9,11)
- SOD – South of Delta except Friant area (Yellow – 10,12,14,15,19)
- Friant – Friant delivery area (Yellow - 13,16,17,18, 20, 21)

The CalSim model internally computes and outputs the total surface delivery, by delivery type, to each of these regions, as input to the CVPM model. Similarly to the interface with the Schmidt model the CalSim implementation of the SJRRP does not directly implement the full 16(a) and 16(b) operations at a level of detail sufficient to directly interface with the CVPM model. In addition to the issues described in section 5.2.1 there are two additional issues with using this data directly:

- 16(a) water is not explicitly modeled, as defined in section 5.2.1, it is the change in total south of Delta delivery due to the presence of restoration flows in the CalSim simulation. This means that the 16(a) water that should be returned to the Friant is actually delivered to the south of CVP/SWP system, and is spread over all south of Delta CVPM regions instead of being delivered only to the regions that include the Friant contractors.

- The CVPM regions that include the Friant contractors have been redefined for the current CVPM modeling.

Post Processing Methodology for Ag Input

The results for the NOD CVPM regions are useable directly as output by CalSim.

The SOD CVPM regions include any increase in SOD delivery due to the presence of Restoration flows, the potential 16(a) water. For alternatives that do not include return of the potential 16(a) to Friant these CVPM region values are correct, for alternatives that do include the return of the potential 16(a) they are too high. For these alternatives the SOD CVPM region values from the without restoration CalSim simulation are assumed to represent the expected delivery.

The CalSim Friant CVPM region output is based on the CalSim C1/C2/215 water allocations which can not be directly used because of the known CalSim water type allocation issues, and because they do not include the appropriate 16(a) and 16(b) water for each alternative. The water allocation issues are addressed in the Excel workbook developed to post process the CalSim results for use in the Schmidt model. This workbook was modified to also create the revised CalSim based CVPM region outputs using the revised water type allocations.

There was an existing Excel workbook that reads in the CalSim CVPM regional outputs directly from the CalSim output and re-format as required for use as input to the CVPM model. This workbook was modified to take the revised Friant CVPM regional outputs and modify them o split the Friant CalSim based CVPM regions from the other spreadsheet into the revised CVP regions required for this analysis. The final workbook is called CALSIM_CVPM_OUTPUT_SJRRP_1-4-2010.xlsm. Table 6-5 shows the Friant contractors included in the revised CVPM regions.

Table 6-5.
Friant Contractors in Revised CVPM Regions

Friant Contractors by CVPM Region

District	***Acre-Feet***		***Percent by WMA***		**CVPM Region**
	Class 1	**Class 2**	**Class 1**	**Class 2**	
Madera Irrigation District	85,000	186,000	60.6%	51.7%	13A
Chowchilla Water District*	55,000	160,000	39.2%	44.4%	13A
Gravelly Ford Water District*		14,000	0.0%	3.9%	13A
Madera County*	200		0.1%	0.0%	
Total	140,200	360,000	100.0%	100.0%	

Table 6-5.
Friant Contractors in Revised CVPM Regions (contd.)

Friant Contractors by CVPM Region					
District	***Acre-Feet***		***Percent by WMA***		**CVPM Region**
	Class 1	**Class 2**	**Class 1**	**Class 2**	
Fresno Irrigation District		75,000	0.0%	100.0%	16A
City of Fresno*	60,000		92.5%	0.0%	
Garfield Water District*	3,500		5.4%	0.0%	16A
International Water District*	1,200		1.9%	0.0%	16A
Fresno County Water Works District No. 18*	150		0.2%	0.0%	
Total	64,850	75,000	100.0%	100.0%	
Orange Cove Irrigation District	39,200		23.9%	0.0%	17A
Stone Corral Irrigation District	10,000		6.1%	0.0%	18A
Ivanhoe Irrigation District	7,700	7,900	4.7%	4.2%	18C
Tulare Irrigation District	30,000	141,000	18.3%	74.2%	18A
Exeter Irrigation District	11,500	19,000	7.0%	10.0%	18C
Lindsay-Strathmore Irrigation District	27,500		16.7%	0.0%	18C
Lindmore Irrigation District	33,000	22,000	20.1%	11.6%	18C
City of Orange Cove*	1,400		0.9%	0.0%	
City of Lindsay*	2,500		1.5%	0.0%	
Lewis Creek Water District*	1,450		0.9%	0.0%	18C
Total	164,250	189,900	100.0%	100.0%	
Porterville Irrigation District	16,000	30,000	11.9%	10.0%	18A
Lower Tule River Irrigation District	61,200	238,000	45.4%	79.1%	18A
Saucelito Irrigation District	21,200	32,800	15.7%	10.9%	18D
Tea Pot Dome Water District	7,500		5.6%	0.0%	18D
Terra Bella Irrigation District	29,000		21.5%	0.0%	18D
Pixley Irrigation District**			0.0%	0.0%	
Total	134,900	300,800	100.0%	100.0%	
Delano-Earlimart Irrigation District	108,800	74,500	42.5%	45.4%	18B
Southern San Joaquin Municipal Utility District	97,000	50,000	37.9%	30.5%	20A
Shafter-Wasco Irrigation District	50,000	39,600	19.5%	24.1%	20A
Rag Gulch Water District**			0.0%	0.0%	
Kern-Tulare Water District**			0.0%	0.0%	
Total	255,800	164,100	100.0%	100.0%	
None					
Arvin-Edison Water Storage District	40,000	311,675	100.00%	100.00%	21A

The workbook then selects the appropriate CVPM regional data for each alternative as defined in Table 6-6 and generates CVPM inputs for that alternative. Table 6-7 is an example of the CVPM input for a single alternative.

Table 6-6.
CVPM Input for Single Alternative

Fut, Alt A No 16B Low	🟨	CALSIM II data incomplete
Average of 1922-2003 Water Years (TAF/year)	▨	CALSIM II data non-existent

Region	NP	GW	CVPSC	CVP	FCL1	FCL2	F215	FRSA	SWP	SWP21	TOTAL
R1	NP	GW	CVPSC	CVP	FCL1	FCL2	F215	FRSA	SWP	SWP21	**0**
R2	26	96	121	25							**268**
R3	62	329	0	86							**477**
R3B		272	763	111							**1,146**
R4		409		188							**597**
R5		230	465	131							**826**
R6	740	594						924			**2,258**
R7	285	450	55	1							**791**
R8	379	311	115	24							**829**
R9	66	252		0							**319**
R10	1,266			19							**1,285**
R11	3		773	274							**1,051**
R12	597	173									**771**
R13	462	232									**694**
R13A					0	0	0				**0**
R14	455	636									**1,091**
R15				693							**693**
R16	31			30					115	41	**216**
R16A					0	0	0				**0**
R17				1							**1**
R17A					0	0	0				**0**
R18				2							**2**
R18A					0	0	0				**0**
R18B					95	72	14				**181**
R18C					88	15	5				**108**
R18D					66	8	4				**78**
R19				35							**35**
R20									415	0	**415**
R20A					0	0	0				**0**
R21				29					31		**60**
R21A					0	0	0				**0**
TOTAL	**4,373**	**3,986**	**2,291**	**1,651**	**248**	**95**	**23**	**924**	**561**	**41**	**14,194**

**Table 6-7.
Components of Water Supply for CVPM Analysis**

Scenario	CALSIM Simulation Used			Recapture Return to Friant		
	NOD	SOD	Friant	Delta	Exchange	SJR Pump
Existing Condition	Existing Conditions	Existing Conditions	Existing Conditions	N/A	N/A	N/A
Alt A High	Existing Alt A	Existing Alt A	Existing Alt A	No	N/A	N/A
Alt A Low	Existing Alt A	Existing Conditions	Existing Alt A	Yes	N/A	N/A
Alt B High	Existing Alt B	Existing Alt B	Existing Alt B	No	Yes	N/A
Alt B Low	Existing Alt B	Existing Conditions	Existing Alt B	Yes	Yes	N/A
Alt C High	Existing Alt C	Existing Alt C	Existing Alt C	No	Yes	Yes
Alt C Low	Existing Alt C	Existing Conditions	Existing Alt C	Yes	Yes	Yes
No Project	No-Action	No-Action	No-Action	N/A	N/A	N/A
Alt A High	Future Alt A	Future Alt A	Future Alt A	No	N/A	N/A
Alt A Low	Future Alt A	No-Action	Future Alt A	Yes	N/A	N/A
Alt B High	Future Alt B	Future Alt B	Future Alt B	No	Yes	N/A
Alt B Low	Future Alt B	No-Action	Future Alt B	Yes	Yes	N/A
Alt C High	Future Alt C	Future Alt C	Future Alt C	No	Yes	Yes
Alt C Low	Future Alt C	No-Action	Future Alt C	Yes	Yes	Yes

Key:
Alt. = Alternative
NOD = north of Delta
N/A = not applicable
SOD = south of Delta
SJR = San Joaquin River

An Excel workbook, CALSIM_CVPM_OUTPUT_SJRRP_1-4-2010.xlsm, was developed which performs the required post processing to prepare the CVPM input data from the CalSim simulation outputs. The component analysis spreadsheets described in section 5.2.1 compute the modified Friant WMA values for each alternative which are copied into this workbook. The then can be used to select the appropriate WMA values for each alternative and combine them to create the final required input to the CVPM model.

CVPM M&I Delivery Input Development. The M&I development is simpler since the potential return 16(a) return to Friant does not have an M&I component and has no impact on M&I delivery. An Excel workbook, CALSIM CVPM - MI Deliveries.xls, was developed to extract the required CalSim data and prepare the M&I delivery input for each CalSim simulation. The specific CVPM data required for each economic analysis, as specific in Table 5.8, was then extracted from this workbook.

6.1.4 Output Description

Key outputs from the CVPM include irrigated acres, gross revenue, net revenue, and water use by production region. The model can also provide detail on the acres planted to each of the 20 crop types and how the crop mix is affected by changes in water availability or production costs. Tables 6-8 and 6-9 contain a summary of the CVPM results for the program alternatives considered in this Appendix.

Table 6-8.
Long-Term Average Water Supply Impacts Existing Level

All CVPM Regions							
	Existing Conditions	Existing Alt A		Existing Alt B		Existing Alt C	
		Low	High	Low	High	Low	High
Irrigated Acres (Acres)	6,741	6,739	6,739	6,739	6,739	6,739	6,739
Surface Water Use (AF)	11,947	11,856	11,873	11,872	11,869	11,877	11,874
Ground Water Use (AF)	8,401	8,478	8,463	8,464	8,466	8,460	8,462
Total Water Use (AF)	20,348	20,333	20,336	20,336	20,335	20,337	20,336
Water/Acre (AF/Acre)	3.02	3.02	3.02	3.02	3.02	3.02	3.02
Gross Revenue	$16,974,523	$16,971,713	$16,972,341	$16,972,341	$16,972,363	$16,972,469	$16,972,469
Gross Revenue/Acre	$2,518	$2,519	$2,519	$2,518	$2,519	$2,518	$2,519
Net Revenue	$2,456,470	$2,444,526	$2,446,594	$2,446,751	$2,446,529	$2,447,320	$2,447,024
Net Revenue/Acre	$364	$363	$363	$363	$363	$363	$363
Consumer Surplus	$2,474,574	$2,473,894	$2,473,940	$2,474,047	$2,473,950	$2,474,074	$2,473,993
Total Social Value	$4,931,045	$4,918,419	$4,920,534	$4,920,798	$4,920,480	$4,921,394	$4,921,017
Friant Division							
Irrigated Acres	753	750	749	750	750	750	750
Gross Revenue	$2,563,115	$2,558,851	$2,558,706	$2,559,822	$2,558,893	$2,405,788	$2,404,995
Gross Revenue/Acre	$3,405	$3,414	$3,414	$3,412	$3,414	$3,206	$3,208
Net Revenue	$398,171	$384,779	$384,686	$387,349	$384,945	$364,555	$362,460
Net Revenue/Acre	$529	$513	$513	$516	$514	$486	$483

Key:
AF = acre-feet
Alt. = Alternative
CVPM = Central Valley Production Model

Table 6-9.
Long-Term Average Water Supply Impacts Future Level

All CVPM Regions							
	No-Action	Future Alt A		Future Alt B		Future Alt C	
		Low	High	Low	High	Low	High
Irrigated Acres (Acres)	7,210	7,210	7,210	7,210	7,210	7,210	7,210
Surface Water Use (AF)	11,942	11,866	11,872	11,865	11,863	11,870	11,870
Ground Water Use (AF)	9,137	9,206	9,201	9,206	9,207	9,202	9,202
Total Water Use (AF)	21,079	21,071	21,073	21,071	21,070	21,072	21,072
Water/Acre (AF/Acre)	2.92	2.92	2.92	2.92	2.92	2.92	2.92
Gross Revenue	$19,784,844	$19,784,717	$19,785,440	$19,784,674	$19,785,164	$19,784,727	$19,785,206
Gross Revenue/Acre	$2,744	$2,744	$2,744	$2,744	$2,744	$2,744	$2,744
Net Revenue	$3,112,987	$3,101,136	$3,098,334	$3,100,983	$3,098,224	$3,102,560	$3,099,946
Net Revenue/Acre	$432	$430	$430	$430	$430	$430	$430
Consumer Surplus	$3,079,354	$3,079,195	$3,079,166	$3,079,184	$3,079,148	$3,079,224	$3,079,186
Total Social Value	$6,192,341	$6,180,331	$6,177,500	$6,180,168	$6,177,372	$6,181,784	$6,179,133
Friant Division							
Irrigated Acres	854	854	854	854	854	854	854
Gross Revenue	$3,536,421	$3,536,075	$3,535,871	$3,536,060	$3,535,901	$3,536,134	$3,535,974
Gross Revenue/Acre	$4,142	$4,141	$4,141	$4,141	$4,141	$4,142	$4,141
Net Revenue	$597,390	$584,594	$578,736	$584,451	$579,415	$586,186	$581,313
Net Revenue/Acre	$700	$685	$678	$685	$679	$687	$681

Key:
AF = acre-feet
Alt. = Alternative
CVPM = Central Valley Production Model

6.2 Municipal Water Supply Impacts

The Alternatives increase water supplies to M&I water users. The M&I water supply benefits largely accrue to SWP contract holders located south of the Delta. Estimates for change in deliveries to M&I water users by year type for the Alternatives are shown in Table 6-10. As shown, water deliveries are increased primarily in drier years.

Table 6-10.
Changes in M&I Deliveries (TAF)

	Existing Conditions (2005)			Future Conditions (2030)		
	A	B	C	A	B	C
Wet	3.99	3.99	3.65	4.74	2.58	1.87
Above Normal	2.67	2.67	2.60	10.60	10.05	9.89
Below Normal	26.11	26.11	24.00	31.45	31.58	27.11
Dry	28.98	28.98	25.47	20.56	21.48	17.50
Critical	12.15	12.15	9.63	17.31	20.28	16.26
Average All	14.11	14.11	12.52	15.41	15.30	12.85

Key:
M&I = municipal and industrial
TAF = thousand acre-feet

M&I water users have increasingly relied on the water transfer market to augment existing supplies and avoid shortages. This analysis relies in part on market prices paid to purchase water on an annual basis from willing sellers. The market prices are reported according to the payments made directly to the sellers. The buyers incur additional costs to convey the water to their M&I service areas. These costs include both conveyance losses, which diminish the volume of water delivered to end users, as well as wheeling and power charges. The conveyance costs are estimated for M&I water users benefiting from the Alternatives, and added to the estimated market prices to acquire the water to develop an estimate of the full cost associated with additional water supply obtained in the transfer market. Figure 6-3 illustrates the information used to estimate the value of M&I water supplies.

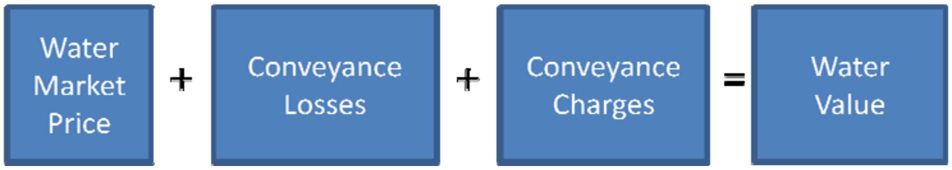


Figure 6-3.
General M&I Water Value Estimation Procedures

Data and estimation methods are described below.

6.2.1 Water Market Prices

A database of California water market sales was developed for use in this analysis. Information for each transaction was researched and recorded to allow statistical analysis of a variety of factors influencing water trading activity and prices. During the research, transactions occurring from 1990 through 2008 were documented. The transactions were filtered for this analysis according to the following criteria:

- Water sales originating outside the operating region of the SWP facilities were excluded. These regions include the north coast, north Lahontan, and south Lahontan regions.
- Permanent water sales were excluded.
- "Within-project" transfers were removed from the analysis because they do not reflect "arms-length" transactions.
- Transactions associated with SWP Turnback Pool supplies were excluded because they are associated with rules that limit market participation.
- Purchases of "flood" supplies were excluded.
- Reclaimed and desalination water sales were removed from the analysis.
- Water sales with incomplete or inadequate information were excluded.

Following application of the above criteria, 472 long-term and short-term transfers remained to support the statistical analysis. All prices are adjusted to 2008 dollars using the U.S._Consumer Price Index. Prices and volumes are presented from the seller's perspective and do not include conveyance charges or losses.

6.2.2 Estimation Procedures

This study builds on previous analyses of the California water market by applying an expanded data set and considering additional factors that may describe water market trading activity and prices. The water transfer pricing regression applied in this study is estimated using a recursive specification. The first regression estimates the unit price for water trades and the second estimates the level of water trading activity. The coefficients from the models are used to forecast water prices to represent future conditions.

The model theorizes that prices and volume of water traded can be estimated through consideration of the following market factors: water supply, geographic location, real water price escalation, buyer type, water type/source, contract terms, and state water banking programs. Additional demand and supply factors were tested in the model but did not result in an improvement in overall explanatory power. These factors are described below.

Water Supply

As previously described, hydrologic conditions are a primary driver of water transfer market activity and prices. Therefore, it is important to include a variable that appropriately captures water supply conditions to describe water trading activity. In this analysis, water supply conditions are measured using the Sacramento Valley Water Year Hydrologic Classification Indices (DWR 2007c).

Geographic Location

Water acquisitions vary by location according to water year type. Consequently, the origin of the water source for each transaction is used to determine geographic differences in water prices. These differences reflect regional water conveyance constraints as well as the costs of accessing alternative water supplies. In addition, the geographic locations account for local political restrictions that limit the supply of water that can be marketed. Water sales applied in the regression analysis were allocated among the Water Transfer Analysis Regions identified by the Common Assumptions Economic Workgroup (DWR and Reclamation 2006). Binary variables are used to denote the different geographic regions.

Real Water Price Escalation

Due to the growing urban water demand in the State, population is considered to have a strong influence on past and future water transfer prices. The water trading activity equation uses population within the SOD regions to isolate the impact of population growth on water transfer demand and water right prices. Population forecasts prepared by California Department of Finance are then used to estimate future changes in water transfer demand and prices over the 100-year period of analysis.

Buyer Type

Previous economic analyses of water prices have concluded that the type of buyer (e.g., M&I, agricultural, and environmental) can influence water prices. The regression water pricing model tests the influence of buyer type on water price. In this analysis, binary variables are used to estimate price differences between environmental, urban, and agricultural buyers.

Water Type/Source

The regression water pricing model tests for differences in water type to in turn test for price effects associated with differences in reliability, if any. For example, it may be important to distinguish CVP and SWP water from other water sources. In addition, the model includes a binary variable to estimate price differences between groundwater and surface water sources.

Contract Terms

The terms of the contract between buyer and seller often influence water prices. This is particularly true in California, where environmental documentation is required for some types of long-term and permanent transfers. Consequently, this analysis distinguishes between transactions with short- and long-term (more than 1 year) contracts. Short-term contracts were used to measure spot-market prices. These contracts best represent current prices because they are negotiated annually. Both long-term and short-term contracts were used to estimate the annual volume of water traded. Long-term contracts were included only if the water had actually been traded during the year. The volume of water traded through both short-term and long-term trades represents the amount of water being moved throughout the market region to meet annual water demands. This volume is expected to affect spot-market prices because it represents annual water demand.

State Water Bank

The State has participated in the water market to help facilitate trades. This activity occurred as part of the Drought Year Program of 1991, 1992, and 1994 and the Dry Year Program of 2001, 2002, 2003 and 2004. The programs are similar in that the DWR sets up a state water bank to buy water primarily NOD and sell the water to agricultural and urban water users facing shortages. To account for the market conditions that existed during operation of the state water bank, a binary variable is included in the model to isolate the transactions from other observations included in the regression analysis.

6.2.3 Model Results

Two equations were applied to estimate the economic benefits of increased M&I water supplies. The first equation was used to forecast prices when volume of water traded is an explanatory variable. Price was estimated based on 294 short-term water right transactions in order to represent spot-market prices. The second equation was used to estimate the volume of water traded in the market. Volume was estimated based on 472 short-term and long-term transactions in order to represent the volume of water traded throughout the region of analysis. The estimation results of the two equations are provided below.

Equation 1

$$P=constant+TAFT_t+Enviro_{i,t}+Urban_{i,t}+SWB_{i,t}+GW_{i,t}+SC_{i,t}+SODO_{i,t}$$

P=Price per Acre-Foot

TAFT=Total Acre Feet Traded (thousands)

Environ=Environmental Water End Use (binary)

Urban=Urban Water End Use (binary)

SWB=State Water Bank/ Dry Year Water Acquisitions (binary)

GW=Groundwater (binary)

SC=South Coast Region Water Supplier (binary)

SODO=SOD Water Supplier Outside South Coast Region (binary)

Results for Equation 1 are provided in Table 6-11. The model’s Adjusted R-squared is 0.45.

Table 6-11.
Equation 1 Results

Variable	Description	Coefficient	Standard Error	t-stat
TAFT	Annual Volume Traded (TAF)	0.09	0.02	5.37
Environ	Buyer Type Environmental (binary)	23.43	8.91	2.63
Urban	Buyer Type Urban (binary)	59.48	8.69	6.84
SWB	State Water Bank (binary)	22.58	8.35	2.7
GW	Groundwater (binary)	31.98	25.26	1.27
SC	Supplier Region South Coast (binary)	88.68	29.44	3.01
SODO	Supplier Region South of the Delta Outside South Coast (binary)	23.95	8.43	2.84
Constant	Equation Constant	6.39	13.22	0.48

Key:
GW = groundwater
SC = South Coast
SODO = South of the Delta
SWB = State Water Bank
TAF = thousand acre-feet
TAFT = total acre feet traded

TAFT was measured as the total annual volume of water traded in regions within the SWP service area through the recorded short-term and long-term lease agreements since 1990. As shown, the level of market activity was positively related to water prices. The results show that for each 100,000 acre-feet traded in the region, the spot-market price increased by approximately $9.49 per acre-foot. A linear model was chosen to show the linear relationship between *P* and *TAFT*. A nonlinear relationship was tested but did not improve the model.

The binary variables describe conditions that influence prices but are qualitative in nature. The coefficients for *Environ* and *Urban* represent the influence that end-water use has on price. When these variables are zero, the model estimates prices to agricultural water users. Urban and environmental water users generally paid more for water than agricultural users, as indicated by the positive coefficients on the two variables. The results show municipal water buyers pay $59.48 per acre-foot more than agricultural buyers in the market. In addition, water leases for urban use were priced $36.05 per acre-foot more than environmental water leases, on average.

SWB is an indicator of State water right purchases through the Drought Year Program of 1991, 1992, and 1994 and the Dry Year Program of 2001, 2002, 2003 and 2004. The programs are similar in that DWR acts as a broker, and the Dry Year Program is essentially a replacement of the earlier program. The binary variable is used to account for the price discovery that occurred during operation of the bank. The coefficient value indicates that water leased under the State Water Bank was priced $22.58 per acre-foot higher than other transactions. *GW* measures the difference in price between groundwater and surface water sources. The results indicate that groundwater was priced $31.98 per acre-foot more than surface water sources.

SC and *SODO* are binary variables intended to measure the difference between NOD and SOD water prices. SOD was separated into two regions because of differences in market conditions and conveyance infrastructure. Water transactions involving sellers in the south coast region were priced nearly $88.69 per acre-foot higher than NOD transactions, and $64.73 per acre-foot more than transactions elsewhere in the SOD region.

Equation 2 estimates the annual water market activity according to hydrologic conditions and the population using both long-term and short-term transactions. The coefficients are used to project the volume of water traded over the analysis period. The model's Adjusted R-squared is 0.74.

Equation 2

$$TAFT_t = -Constant_t + WY_t + Pop_t + e$$

TAFT=Total Acre-Feet Traded (thousands)

Pop=Population SOD (thousands)

WY= Water Year (1-5, with 1 being the driest and 5 being the wettest)

e = Model Error

Equation 2 was estimated using observations from 1990 to 2008.

- *Pop* was based on the total population located SOD (CDF 2007). The California Department of Finance only calculates projections by county. The projections displayed are based on counties with a majority of their population residing south-of-Delta using the California Department of Water Resources California Interagency Watershed Map of 1999.

- The water year-types are from the Water Year Index for the Sacramento Region from 1990-2006 (DWR 2007c). The index is based on measured unimpaired runoff and can be group into critical, dry, below-normal, above-normal, and wet water years. The State assigns an index number based on water runoff and the previous year's water index, and is calculated as shown in Equation 3:

Equation 3

*Sacramento Valley Water Year Index = 0.4 * Current Apr-Jul Runoff Forecast (in maf)+ 0.3 * Current Oct-Mar Runoff in (maf) + 0.3 * Previous Water Year's Index (if the Previous Water Year's Index exceeds 10.0, then 10.0 is used)*

The coefficients for water year (*WY)* and population (*Pop)* both were significant at the 95 percent confidence level, as Table 6-12 shows. The coefficient for *WY* suggests that water market trading activity decreases by 115,000 acre-feet for each unit increase in the water year index. The coefficient for *Pop* indicates that a population increase SOD of 67,000 people increases trading by 1,000 acre-feet.

Table 6-12.
Equation 2 Results

TAFT	Description	Coefficient	Standard Error	t-stat
WY	Water Year (index where 1=critical and 5=Wet)	-115.01	21.06	-5.46
Pop	Population SOD (thousands)	0.07	0.02	4.28
Constant	Equation Constant	-1,074.28	465.58	-2.31

Key:
SOD = south of Delta
TAFT = total acre feet traded
WY = water year

Water Conveyance Costs

The cost to convey water to M&I users is estimated according to the cost to move water through SWP facilities. Conveyance cost varies by location and user type. For example, SWP contractors pay a unit variable cost to move water based on a melded power rate. In comparison, non-SWP contractors pay a wheeling charge for access to SWP facilities in addition to a market rate for the power required to pump the water. As a result, non-SWP contractors incur significantly higher conveyance costs.

Non SWP Contractors. Non-SWP contractors pay a different rate to move water through the SWP facilities. The primary difference is the cost of power. SWP contractors pay a melded rate for power that is below the market rate while non-SWP contractors pay the market rate for power. In addition, non-SWP contractors pay a different wheeling rate for access to SWP facilities. This analysis applies the non-SWP conveyance costs to estimate willingness to pay because they are considered to be more reflective of the opportunity cost for use of the resource.

The following factors are used to estimate conveyance costs:

- **SWP wheeling rate** – The non-SWP contractor wheeling rate includes the O&M and capital costs for transportation and conservation facilities, and a cost for direct fish losses (Jones 2006). Wheeling rates were derived for each region by taking the volume-weighted average of annual quantities delivered from each canal (DWR 2006). The SWP wheeling rate is listed by region in Table 3-5. The rate ranges from $15 per acre-foot for San Luis Division buyers to $689 per acre-foot for buyers in the Coastal Branch of the California Aqueduct. The wheeling rate is provided separately for the Metropolitan Water District of Southern California because the district receives its water from two different regions where rates vary significantly.

- **Power Costs** – In addition to the SWP wheeling rate, non-SWP contractors pay for power used at the pumping facilities. Power costs are available from the Dow Jones SP15 Index (Dow Jones 2009). Path 15 is an 84-mile power transmission corridor running north and south through California's Central Valley. SP15 connects Southern California with the northern part of the state. The index provides the volume-weighted averages of wholesale day-ahead firm physical electricity transactions for SP15. This study uses the index's weighted average off-peak and peak annual price from 2002 to 2006 to estimate power costs.

- **Cumulative Power Demand** – The amount of power required is based on DWR's estimations of power use per acre-foot for SWP power facilities (DWR 2006). A pumping plant facility is selected as a reference delivery point for each region. For example, the Cordelia Pumping Plant is chosen as the plant used for buyers wheeling water to the North Bay Aqueduct. Table 6-13 lists the point of reference for each buyer region and the associated cumulative power demand.

Table 6-13.
Estimated M&I Conveyance Costs by Region

Contractor Region	Reach	Pumping Plant	Cumulative Power Demand from the Delta (kWh/acre-foot)	Power Rate ($/kWh)	SWP Wheeling Rate ($/acre-foot)	Total Conveyance Cost ($/acre-foot)
North Bay Aqueduct	1, 3a, 3b	Cordelia-Napa	786	$0.049	$152	$191
South Bay Aqueduct	1, 2, 4-9	South Bay and Del Valle	1,165	$0.049	$61	$119
North San Joaquin Division	1	Banks	296	$0.049	$15	$30
San Luis Division	4	Dos Amigos	434	$0.049	$28	$49
South San Joaquin Division	10s, 12e, 12a, 11b, 13b, 16a	Teerink	971	$0.049	$37	$85
Mojave Division	19, 20a, 20b, 21, 22a, 22b, 24	Pearblossom to West Fork Mojave River	4,549	$0.049	$175	$389
Santa Ana Division	22b, 22a	Crafton Hills	6,507	$0.049	$164	$485
West Branch	30	Oso	4,126	$0.049	$175	$378
Coastal Branch	35	Devil's Den through Tank I	1,416	$0.049	$689	$759
Metropolitan Water District	36a, 28h, 28j, 30	Oso; Cherry Valley	4,126; 6,731	$0.049	$117	$446

Sources: California Department of Water Resources, Management of the California State Water Project: Bulletin 132-05. Table B-17 Unit Variable OMP&R Component of Transportation Charge, December 2006.

California Department of Water Resources, Management of the California State Water Project: Bulletin 132-05. Table 7. Kilowatt-Hour Per Acre-Foot Factors for Allocating Off-Aqueduct Power Facility Costs, December 2006.

Dow Jones (DJ). 2002-2006. Dow Jones U.S. Daily Electricity Price Indexes: DJ South Path 15.

Jones, Jon. 2008 Charges for Wheeling Non-State Water Project Water Through State Water Project Facilities, State Water Project Analysis Office Division of Operations and Maintenance, Sep. 19, 2006.

Key:
kWh=kilowatt hour
SWP=State Water Project

6.2.4 Estimated Conveyance Losses

Water delivery results from the CALSIM model incorporate conveyance losses. Consequently, it is necessary to estimate conveyance losses to adjust estimated water market prices according to the geographic source of the supply. For example, an estimated delivery from CALSIM of 1,000 acre-feet to an M&I user may require the purchase of 1,100 acre-feet at the source if 10 percent conveyance losses apply. Due to limited information regarding convey losses and specific sources of the transfer water, this analysis applies a 20 percent conveyance loss to water originating NOD. Conveyance losses for water supplies originating SOD were not considered.

Table 6-14 reports the estimated annual M&I water supply benefits for each of the Alternatives. As shown, the Alternatives provide an average annual benefit of $6.9 to $7.8 million under Existing Conditions and $9.1 to $10.8 million under Future Conditions.

Table 6-14.
Estimated Annual Benefits by Alternative and Water Year Type

	Existing Conditions (2005)			Future Conditions (2030)		
	A	B	C	A	B	C
Wet	$2,276,282	$2,276,282	$2,095,793	$3,076,334	$1,572,147	$1,092,286
Above Normal	$1,086,715	$1,086,715	$1,070,891	$8,769,675	$8,410,405	$8,368,654
Below Normal	$13,716,638	$13,716,638	$12,659,798	$21,450,781	$21,618,942	$18,582,432
Dry	$17,066,886	$17,066,886	$14,965,099	$13,889,107	$14,748,477	$11,968,260
Critical	$6,349,982	$6,349,982	$4,764,822	$12,406,135	$14,534,355	$11,604,747
Average All	$7,816,232	$7,816,232	$6,893,964	$10,761,192	$10,756,158	$9,060,622

6.3 Recreation

This section addresses the effects of the Alternatives on recreation activities on Millerton Lake. In general, changes to recreation participation can generate positive economic impacts if recreation visitation increases as a result of reservoir operations, or if the quality of existing activities is improved or enhanced. Changes to recreation can result in economic losses if visitation is curtailed or reduced due to reservoir operations.

Millerton Lake was formed by Friant Dam, and represents a regionally important recreation site for water sport enthusiasts (motor boating and water skiing), other day use recreationists, and campers. Recreation activities at Millerton Lake may be affected by the storage alternatives through changes in water management methods that would affect lake levels and releases. Changes in lake levels would affect recreation activities primarily by reducing access to boat ramps, marinas, and boat-in campgrounds; reducing water surface area for boaters; and exposing large areas of shoreline, negatively affecting aesthetic quality and access for picnickers, swimmers, and shoreside fishing areas.

Several forms of recreation often take place within a visit, and the mix of activities can affect the value placed on (and benefit from) a site visit by a recreationist.

Elevations of Millerton Lake are uniformly lower for the Alternatives as compared to the No Action, ranging from 5 feet (in September) to 28 feet (in April) lower when averaging all simulation years. A similar relationship applies to storage volume in Millerton Lake. The period with the greatest difference in storage and elevation is the typically higher volume months of April and May. To the extent that recreation visitation at Millerton Lake is correlated with lake elevations or to storage volume, and there is a potentially estimable change in recreation visits to Millerton Lake.

The quantification presented in this section relies on historic information, recreation opportunities assessment performed during plan formulation, personal interviews with knowledgeable staff at Millerton Lake, and a qualitative estimate of the effects of the Alternatives on recreation activities and associated visitation. The change in recreation participation and economic value (willingness-to-pay) that potential visitors would attribute for enhanced recreation opportunities at Millerton Lake were not evaluated. Similarly, there has been no effort to collect new or additional information.

6.3.1 Model Description

A recreation use model of Millerton Lake was developed for a separate storage investigation, and was applied to analyze the effects of the Alternatives in the SJRRP. The model uses historic visitation and related information to develop a profile of recreation. A “recreation profile” refers to a characterization of the types and quantity of recreation activities engaged in by visitors to the site. This can include a single activity (e.g., picnicking) or a combination of several activities for a single visit (e.g., waterskiing, swimming, and camping). The value attributed to visits to Millerton Lake should account for the full profile of recreation activities.

Changes in reservoir operations and other attributes (such as angler success rates) are applied as inputs to the model in order to estimate changes in visitation. The results of the qualitative recreation assessment were also reviewed and their findings incorporated into the visitation model according to the degree of change anticipated. The model then provided an estimate of the change in recreation by activity type on an annual basis.

Historic visitation information was available from the California Department of Parks and Recreation, Millerton Lake State Recreation Area (SRA). This included monthly visits from July 2001 through February 2007, and annual visits from 1996 through 2006. Visits were categorized as “Paid Day Use,” “Free Day Use,” and “Paid Camping.” These were summed to be “Total Attendance.” A separate tally tracked “Boat Launches.” No additional records are available indicating the specific recreation activities of “day use” visitors.

Recreation visits increased significantly from previous years beginning in 2001; also, in 2002, “Free Day Use” was virtually eliminated due to changes in admittance structures and parking at the entrance to the Millerton Lake SRA. Finally, records for 2006 were thought to be understated and in need of further review, and were omitted from the model.

Table 6-15 displays average visitation to Millerton Lake based on attendance records from 2001 through 2005. Visitation was grouped into categories representing the primary purpose for visits, based on estimates provided by the park superintendent (see Table 6-16). It is acknowledged that recreationists often participate in more than one activity during a visit; however, the economic literature on recreation largely supports the concept that most of the consumer surplus associated with a visit can be attributed to the primary purpose.

Table 6-15.
Calendar Year Attendance to Millerton Lake State Recreation Area

Visitor Type	Average Annual Visits[1]
Day Use (fee & paid)	477,419
Boat Launches	33,318
Camping	52,932

Source: California Department of Parks and Recreation, Millerton Lake SRA, Calendar Year Attendance, 1996-2006.
Note:
[1] Average of 2001 through 2005.

Attendance records during the spring and summer months of April through September were compiled for the period of 2001 through 2005, in order to derive the share of annual visits that take place during each month (see Table 6-17). As the shares indicate, there is a peak in total visitation, camping, and boat launches during June and July, followed by a decline in August. Lowering lake water levels in August are one of the reasons attributed to this decline. School starting in August and persistent hot weather may also be factors (Cooper 2008).

Table 6-16.
Estimate of Annual Visitors by Primary Recreation Type for Millerton Lake State Recreation Area

Recreation Activity	Percent of Day Use[1]	Estimated Users[2]
Boating	58%	266,544[3]
Picnicking	30%	143,266
Swimming	8%	38,194
Fishing	3%	23,871
Other	1%	5,585
Camping	N/A	52,932

Notes:
[1] Percentages provided by Jess Cooper, Millerton Park Superintendent, personal communication with Michael Taylor, Cascade Economics LLC, 26 February 2008. The percentages generally reflect summer visitors (May-September).
[2] Estimates of annual users (visits) by activity were adjusted slightly to reflect differences in the weighting of recreation activities during off-peak times of the year.
[3] Boating visits (including motor boating and water skiing) were linked to "boat launches" by assuming 8.0 visitors per boat launch.
Key:
N/A = not available

Table 6-17.
Derived Share of Annual Visitation, by Month for Millerton Lake State Recreation Area

Month	Total Attendance	Camping	Boat Launches
April	10%	8%	6%
May	14%	14%	15%
June	15%	16%	19%
July	16%	19%	19%
August	12%	15%	16%
September	9%	7%	7%

Source: California Department of Parks and Recreation, Millerton Lake SRA, Calendar Year Attendance, 1996-2006.
Note:
[1] Average of 2001 through 2005.

6.3.2 Modeling Assumptions

The recreation opportunities assessment contained in the Appendix presents a qualitative evaluation of the overall impact of the Alternatives on Millerton Lake recreation. These evaluations indicate a generally "less than significant" effect on recreation opportunities in Millerton Lake associated with the Alternatives; however, it also notes that opportunities involve some tradeoffs where high water levels could be detrimental to some shoreline uses. Nevertheless, high lake water levels are unconditionally better, and lower lake levels worse, for boating-related activities, which also represent the largest amount of visitor participation.

Lower storage volumes and associated surface area in Millerton Lake overlap with peak boating use during April through September. However, limits due to congestion among boaters are anticipated only May through August, which represents some 69 percent of all boat launches. For this analysis, it is assumed that boating visits under With Project conditions decrease by 10 percent during this period.

Under current operations, Millerton Lake experiences substantial fluctuations in elevation, typically 75 to 100 feet within the year from the peak in April or May, to the low water level in September. When considered on a seasonal basis, the Alternatives have the effect of lessening the fluctuation to 45 feet on average, as the reservoir drawdown is spread over a greater part of the year. Although the average elevations will be lower during the peak recreation season than existing conditions, the operating plan under Alternatives could lead to a permanent relocation of park facilities (picnic and camping sites, parking lots, restrooms) closer to the new mean water levels in order to enhance their aesthetics and usability. Were that the case, the predominant shoreline activities would not be negatively affected by the lower water elevations in the Alternatives.

Fish productivity models of black bass (largemouth and spotted) in Millerton Lake were used to analyze the biological effects of the Alternatives on these species. Black bass is a highly targeted species by anglers who visit Millerton Lake. The fishery models indicate that the Alternatives will result in an increase in the productivity (spawning index) of both species: largemouth bass would increase by 3.2 percent, and spotted bass by 23.5 percent. To the extent that a higher spawning index results in larger number of fish in Millerton Lake for anglers to target, the effect on recreational angling could be an increase in success rate (e.g., fish caught per day), or an increase in angler visits per year (as greater fishing success encourages more participants or more frequent visits). For this analysis, it is assumed that the change in spawning index results in a change of 10 to 15 percent in angler visits.

Finally, in order to model the effects of conditions in 2030, county level population forecasts from the California Department of Finance are used. They indicate that the population in the six-county area (Fresno, Kings, Kern, Madera, Merced, and Tulare) would increase approximately 70.1 percent from 2006 to 2030. It is assumed that recreation visitation to Millerton Lake, which draws almost entirely from this region, would increase in the same proportions. This means that boating visits are projected to be 453,388 annually, and fishing visits will be 40,604 per year under the No Action Alternative. There is no indication, however, from the recent Millerton Lake Resource Management Plan that capacity limits among recreation visitors is a concern for future planning.

6.3.3 Modeling Output

The Alternatives will result in a net decrease in the number of boat launches and boating visits of approximately 31,300 per year as compared to the No Action Alternative. This will occur during the peak boating season of May through August. The Alternatives will result in a net increase in angler visits to Millerton Lake, as compared to the No Action Alternative. If angler visits increase by 10 percent, the net change would be approximately 4,060 visits per year. If the angler visits increase by 15 percent, the net change would be approximately 6,090 visits per year.

6.4 Regional Economics (IMPLAN)

This section addresses the interim findings of a regional economic analysis of the direct project effects, and to satisfy the requirements of the Regional Economic Development (RED) account of the Principles and Guidelines (P&G). The preliminary findings incorporate changes in agricultural output for the restoration alternative plans, as well as recreation impacts on the San Joaquin River and on Millerton Lake. The changes in hydroelectric power generation would affect statewide residents as a whole in terms of electricity rates; however, preliminary results indicate the changes would be virtually imperceptible at the statewide level, and were not included in the analysis. A regional analysis has not been conducted incorporating other potential direct effects, including changes in M&I water quality, flood management, or other areas potentially affected by the alternatives.

Two I/O regional economic models were developed for regional economic analyses specific to the Investigation. The first incorporated economic activity in the six-county region surrounding the Friant Division. The six counties include Fresno, Kern, Kings, Madera, Merced, and Tulare.

A second regional economic impacts model was developed to address effects at the California statewide level. This model is intended to capture effects of the alternative plans that transcend beyond the Friant Division, affecting residents and businesses throughout the State. In general, even when a project is concentrated in a particular region and sector, economic activity (sales and purchases) typically extend beyond that area both directly and indirectly. For example, agricultural inputs such as seed, fertilizer, insurance services, and fuel and transportation, often originate outside the region of emphasis. After accounting for direct sales and purchases, the indirect and induced transactions that result from income changes and secondary effects broaden the boundaries of the originally affected area.

Furthermore, the multidisciplinary nature of the proposed alternative plans will result in categories of effects that are more likely to accrue outside the six-county Friant Division. These include M&I water quality benefits, M&I water supply, emergency water supply reliability, and ecosystem benefits. For this reason, a statewide model is best able to capture the economic impacts on the larger scale.

The two models will heretofore be referred to as the “Friant Division” and “Statewide” models.

6.4.1 Model Description

The regional economic models are based on IMPLAN software. The models are used to measure the indirect effect that changes in crop production and recreation-related expenditures (or other direct effects) may have on the regional economy, in terms of changes in industry output, employment, and income. The models are based on 2007 data, the most current data that are available.

In general terms, an I-O model is used to estimate the effects of changes in final demand on the regional economy. The direct effect is the change (or increase) in overall agricultural output determined from the agricultural economics optimization model described previously. Because the businesses within a local economy are linked together through the purchase and sales patterns of goods and services produced in the region, an action that has a direct effect on one industry is likely to have an indirect effect for firms providing production inputs and support services, as the demand for their products also increases. As household income is affected by the increases in regional economic activity, additional induced benefits are generated by increased household spending.

Three different economic measures are typically presented when discussing regional impacts. “Output” (also known as total industry output) represents the value of production of goods and services by businesses in the regional economy. This can serve as an overall measure of the local economy, and is useful for comparing regions and considering impacts. The second measure is “Personal Income,” which is the sum of employee compensation and proprietor income. Employee compensation represents total payroll costs, including wages and salaries paid to workers plus benefits such as health insurance, as well as retirement payments and noncash compensation. Proprietor income includes payments received by self-employed individuals as income, such as income received by private business owners, doctors, or lawyers. This measure is useful to show how the employees and proprietors of businesses producing the output share in the fortunes of those businesses. The third measure is “Employment.” This represents the annual average number of employees, whether full- or part-time, of the businesses producing the output.

The link from regional analysis to the RED account specified in the P&G is straightforward. The RED account considers changes in the distribution of regional economic activity through two measures:

- Regional income
- Regional employment

From the regional impact analysis, regional income is derived directly from the measure of “Personal Income.” Regional employment is associated with the measure of “Employment” from the regional impact analysis.

6.4.2 Modeling Assumptions

Agricultural commissioner crop reports were used to revise and update the commodity categories within the Friant Division model to improve the precision of estimates. This is typically a necessary order to “fine tune” the model to reflect unique regional conditions involving agricultural production. Such adjustments to the model were not necessary for the Statewide model because commodity-based data on employment and income are generally reliable at a State level.

Agricultural direct effects by crop and region were obtained from output of the agricultural economics model. The output data were organized and entered as inputs to appropriate agricultural sectors within the Statewide and Friant Division regional impacts models. In the latter case, only the portion of CVPM applied to the Friant Division was included in the Friant Division model.

For each of the scenarios, the procedure was similar for estimating regional economic impacts. After agricultural direct effects were applied, the models then calculated the indirect, induced, and total effects of the increase in agricultural production on the regional economy. This process was repeated for each of two scenarios, one involving the existing base and Alternative A, and the other involving the future base with Alternative A. The two scenarios were selected because they represent the highest level of change in agricultural economic activity, in terms of gross output, for the two bases, respectively. The results can be considered an upper limit on the regional economic impacts and RED benefits of all the remaining scenarios.

The economic base for California as a whole is shown in Table 6-18. More than $3.2 trillion in goods and services are produced within the state. The largest sector in terms of industry output is manufacturing, at $609 billion annually. Other important sectors include real estate; professional and technical services; information; and finance and insurance, all exceeding $200 billion per year. Agriculture, forestry, and fishing contribute some $48 billion annually.

More than 20.3 million jobs are present in the state, with associated personal income (from all sources) of about $1.2 trillion. Government, transportation, and warehousing generate the largest number of jobs in the state, at more than two million each. Agriculture is responsible for about 468 thousand jobs, and more than $14 million in personal income. Table 6-19 provides the economic base data for the Friant Division six-county region. More than $158 billion in goods and services are produced within the region, including just under $19 billion from agriculture, forestry, and fishing. Local industry supports nearly 1,187,000 jobs and earnings of more than $52 billion. In terms of output, manufacturing is the largest industry, contributing over $35.3 billion of the county’s total industry output. However, agriculture is the second largest in output but the highest (after government) in terms of employment.

Table 6-18.
California State Model 2007 Economic Base

Industry	Industry Output ($ millions)	Employment (No. of jobs)	Personal Income ($ millions)
Agriculture, Forestry, Fish, and Hunting	48,481.8	468,491	14,242.7
Mining	19,701.1	37,351	4,848.3
Utilities	66,455.7	58,518	11,920.3
Construction	201,266.9	1,198,694	81,599.6
Manufacturing	609,921.4	1,471,506	130,176.9
Wholesale Trade	149,065.4	771,828	57,662.8
Transportation and Warehousing	168,788.5	2,061,001	74,616.4
Retail Trade	77,593.0	531,712	31,252.8
Information	233,584.2	580,317	64,880.2
Finance and Insurance	226,888.9	899,198	80,229.2
Real Estate and Rental	362,245.0	1,146,502	36,814.9
Professional, Scientific, and Tech Services	250,830.9	1,737,818	140,778.2
Management of Companies	47,384.8	208,946	22,003.4
Administrative and Waste Services	90,265.1	1,212,008	44,812.0
Educational Services	23,723.7	378,704	12,602.7
Health and Social Services	166,791.8	1,672,460	93,234.9
Arts, Entertainment, and Recreation	40,762.0	486,842	18,422.4
Accommodation and Food Services	89,814.5	1,379,454	32,384.6
Other Services	80,672.1	1,208,414	32,340.2
Government and Non-NAICS	248,642.6	2,865,748	197,309.0
Totals	**3,202,879.2**	**20,375,511**	**1,182,131.5**

Source: 2007 IMPLAN data from Minnesota IMPLAN Group, Inc., with modifications made by Cascade Economics LLC.

Key:
NAICS = North American Industry Classification System

Table 6-19.
Friant Division Model Six-County Region 2004 Economic Base

Industry	Industry Output ($ millions)	Employment (No. of jobs)	Personal Income ($ millions)
Agriculture, Forestry, Fish, and Hunting	18,824.6	192,967	5,131.5
Mining	5,920.9	11,699	1,349.2
Utilities	4,448.0	4,916	652.6
Construction	11,066.2	71,579	4,239.6
Manufacturing	35,344.4	71,500	4,216.8
Wholesale Trade	5,116.7	32,901	1,947.0
Transportation and Warehousing	8,458.2	116,277	3,729.8
Retail Trade	4,684.4	32,759	1,807.7
Information	3,562.2	10,916	678.8
Finance and Insurance	5,738.4	30,001	1,645.7
Real Estate and Rental	11,030.3	27,824	795.2
Professional, Scientific, and Tech Services	4,887.3	43,049	2,379.1
Management of Companies	1,292.9	7,881	476.8
Administrative and Waste Services	3,080.6	50,877	1,468.6
Educational Services	481.5	9,740	203.8
Health and Social Services	8,960.4	105,202	4,875.5
Arts, Entertainment, and Recreation	544.9	11,406	210.5
Accommodation and Food Services	3,474.1	63,917	1,154.2
Other Services	4,003.7	66,610	1,605.0
Government and Non-NAICS	17,339.7	224,543	13,920.6
Totals	**158,259.3**	**1,186,563**	**52,487.9**

Source: 2007 IMPLAN data from Minnesota IMPLAN Group, Inc., with modifications made by Cascade Economics LLC.
Key:
NAICS = North American Industry Classification System

6.4.3 Output Description

The following section provides results of regional impact analysis conducted during plan formulation for the Investigation.

Total Industry Output

Table 6-20 presents the results of the Friant Division and Statewide regional economic models by alternative. Under the existing base with Alternative 1, the direct impact to agricultural producers industries would be -$5.0 million within counties in the Friant Division, and about -$3.4 million within the State. These direct impacts would yield indirect impacts, largely to input supply and agricultural support industries, and induced impacts, or the change in overall output throughout the region as a result of greater household spending. Indirect and induced impacts would be $2.3 million in the Friant

Division and -$52.6 million statewide. The combined total of direct, indirect, and induced impacts will result in a total economic impact of -$2.7 million annually in the Friant Division and -$56.0 million statewide.

Table 6-20.
Regional Economic Impacts on Total Industry Output, By Scenario

Scenario and Impact Area	Direct ($)	Indirect and Induced ($)	Total ($)
Existing Base and Alternative 1			
Friant Division	-4,975,200	2,281,100	-2,694,100
Statewide	-3,435,400	-52,586,100	-56,021,500
Future Base and Alternative 1			
Friant Division	-3,061,100	-4,889,500	-7,950,652
Statewide	-1,660,700	-51,321,200	-52,981,929

A similar outcome applies to the future base with Alternative 1. The direct impact to agricultural producers and support industries would be -$3.1 million within the Friant Division counties, and -$1.7 million in the State. The direct impacts would yield indirect and induced impacts of -$4.9 million in the Friant Division and -$51.3 million annually statewide. The combined total of direct, indirect, and induced impacts would be -$8.0 million annually in the Friant Division and -$53.0 million statewide.

Personal Income

The second measure of regional impacts is “Personal Income,” the sum of employee compensation and proprietor income, and a measure of benefit for the RED account. Results for this category are shown in Table 6-21.

Table 6-21.
Regional Economic Impacts on Personal Income, By Scenario

Scenario and Impact Area	Direct	Indirect and Induced	Total
Existing Base and Alternative 1			
Friant Division	-$11,678,100	-$9,560,700	-$21,238,856
Statewide	-$179,317,400	-$94,226,600	-$273,543,968
Future Base and Alternative 1			
Friant Division	-$11,170,700	-$9,186,000	-$20,356,620
Statewide	-$178,801,600	-$93,794,800	-$272,596,423

Crop production increases and expenditures by recreation visitors would lead to direct impacts on personal income in the Friant Division -$11.7 million under the existing base with Alternative 1. A total -$179.3 million impact is reflected annually statewide. This change in personal income would lead to indirect and induced impacts in the Friant Division of -$9.6 million. At the State level, the indirect and induced impacts would be

-$94.2 million. The total impact on personal income in the Friant Division counties is about -$21.2 million annually. In California, the total impact is -$273.5 million.

The future base with Alternative 1 would have an effect on personal income comparable to that for total industry output. Direct impacts would be -$11.1 million for Friant Division (-$179.3 million statewide), and indirect and induced impacts would be -$9.2 million (-$93.8 million statewide). Total impacts to personal income would be -$20.4 million annually in the Friant Division, and -$272.6 million statewide.

Employment

Employment impacts are measured in total jobs, whether full- or part-time, in the businesses producing the output. Direct impacts are those related to crop production, and establishments that sell goods and services to recreation visitors. Employment is included in the RED account. Table 6-22 summarizes regional employment impacts from the project based on changes in agricultural production.

Table 6-22.
Regional Economic Impacts on Employment (Jobs), by Scenario for Alternative Plans

Scenario and Impact Area	Direct	Indirect	Total
Existing Base and Alternative 1			
Friant Division	300	-400	-100
Statewide	2,700	-2,900	-200
Future Base and Alternative 1			
Friant Division	300	-400	-100
Statewide	2,700	-2,800	-100

Approximately 300 additional agricultural and service sector jobs in the Friant Division (2,700 statewide) would be a direct result of implementing Alternative 1 with the existing base. Approximately 400 jobs in the Friant Division (2,900 statewide) would be lost in support and input industries, and as a result of increased household spending. In total, approximately 100 jobs in the Friant Division (200 statewide) would be lost.

For the future base and Alternative 1, approximately 300 agricultural and service sector jobs would be generated in the Friant Division (2,700 statewide). This would result in 400 jobs lost in the support and input industries in the Friant Division (2,800 lost statewide), and from increased regional spending. A total of 100 jobs in the Friant Division (100 statewide) would be lost in the region.

6.5 Flood Damages (FDA)

This FDA uses the Flood Damage Analysis model (HEC-FDA) developed by the USACE, Hydrologic Engineering Center. The model input files and methodology used were developed by the Comprehensive Study, updated as required.

FDA requires the integration of hydrologic, hydraulic, geotechnical, and economic data. A brief overview of these data and their integration are given below. Additional data and details can be found in the USACE Technical Studies Documentation (USACE 2002).

The flood damage reduction analysis was done using HEC-FDA, which integrates hydrologic, hydraulic and geotechnical engineering and economic data. HEC-FDA incorporates uncertainty and risk analysis using a Monte-Carlo simulation procedure. The primary outputs of the HEC-FDA are expected annual damages (EAD). Secondary outputs are the project reliability and flood risk statistics.

Modeling Assumptions

The Comprehensive Study performed basin-wide risk-based economic analysis using the HEC-FDA model. The results of the risk-based analysis express economic impact in terms of EAD. A complete description of the economic studies performed during the Comprehensive Study is included in Appendix F of the USACE Technical Studies Documentation (USACE 2002). The portion of the Comprehensive Study that covered the San Joaquin River from Millerton Lake to the Merced River forms the basis for this modeling effort.

The Comprehensive Study economic analysis was based on the P&G published in 1983 by the U.S. Water Resources Council (1983). A primary objective in the study was to determine the expected annual damage along a river reach, taking into account all possible flood scenarios, and to compare changes in the damage resulting from various alternative plans. The determination of EAD in a flood management study must take into account interrelated hydrologic, hydraulic, geotechnical and economic information and their associated uncertainties. The EAD is the economic outcome of the flood risk. Specifically, EAD is determined by combining stage-frequency and stage-damage functions and integrating the resulting damage-frequency function. Uncertainties are present for each of these functions and are carried forth into the EAD computation. The interrelated hydrologic, hydraulic, geotechnical and economic information and their associated uncertainties are summarized in the project reliability and flood risk statistics. For the Comprehensive Study, most of the rivers being studied have levees on one or both sides for part or all of their studied length. Levees prevent water from breaking out into adjacent floodplain areas. As river stage increases, the probability of levee failure also increases.

The results of the flood risk analysis are affected by technical considerations and assumptions regarding the input to HEC-FDA. For example, the Comprehensive Study geotechnical studies developed relationships that characterized the reliability of the levees, which were utilized to trigger levee failures in the hydraulic models, which ultimately affected the stage-frequency curves used in the risk analysis (USACE 2002).

Perhaps the most significant assumption is the failure methodology, which can significantly influence simulated flood flows. The methodology was chosen to provide a reproducible and consistent simulation of potential flooding extent for system-wide hydraulic and economic evaluations. It does not represent conditions that would occur during an actual flood event, when flood fighting and other emergency actions are likely to take place, and fewer failures are likely to occur. In some cases, the cumulative effect of multiple upstream failures can reduce the volume of flow in downstream reaches, or large breaches can produce pronounced reductions in stage. These effects are less pronounced in the San Joaquin River basin where flood volumes are relatively smaller, levees tend to be shorter, and overbank flooding occurs more frequently than in the Sacramento River basin. While this levee failure methodology is sufficient for the basin-wide risk analyses, it should be considered when interpreting model results.

The HEC-FDA Comprehensive Study model used October 2001 price levels. In order to get an accurate and updated portrayal of any induced flooding, the stage-damage curves were indexed to October 2008 price levels. The NRCS Economics Normalized Market-Clearing Price Estimates, National-Level Indices prices received by farmers for all crops, were used to update the agricultural price levels. For all other damage categories Marshall & Swift (M&S) Comparative Cost Multipliers were used (Marshall and Swift 2007). In Table 6-23 below, all of the update factors for the different damage categories are listed. The FDA Update Factors listed below were each used to adjust the Stage-Damage curve data in the models. This was the only change to the economic inputs into HEC-FDA.

Table 6-23.
Price Level Updates October 2001 to October 2008

M&S Construction Class	M&S Update Factor
A	1.43
B	1.44
C	1.40
D	1.32
S	1.43

Damage Category	Combination	FDA Update Factor
Commercial	0.2*(A+B+C+D+S)	1.41
Farmstead	(D*0.5)+(S*0.5)	1.38
Industrial	(B*0.25)+(S*0.25)+0.5*(A+C+D)	2.80
Multifamily Residential	(D*0.75)+(B*0.25)	1.35
Mobile Home	D	1.32
Public	0.2*(A+B+C+D+S)	1.41
Single Family Residential	D	1.32
Agriculture	252/230.30	1.09

Key:
M&S = Marshall and Swift

To analyze the flood impacts new hybrid stage-frequency curve as discussed in the UNET section were used in HEC-FDA. No other changes were made to HEC-FDA.

All changes in expected annual flood damages from the No-Action condition to either Phase 1 or Phase 2 are attributable to changes in the stage-frequency curves. Each curve constrains water surface elevations for the nondamaging frequency, each flood flow that was modeled and the Likely Failure Point (LFP) translated from the Breakout Point to the Index Point. The No-Action data is almost identical to the Comprehensive Study analysis. Phase 1 and 2 water surface elevation in the stage-frequency curves experienced both increases and decreases from the No-Action depending on the HEC-FDA model reach. Increases in the stages leads to induced flooding (an increase in EAD). Please note that the HEC-FDA model reaches are the same as the Comprehensive Study and do not match up with the restoration program’s reaches.

Determination of Expected Annual Damages

The determination of EAD for a flood reduction study must take into account complex and uncertain hydrologic, hydraulic, geotechnical, and economic information:

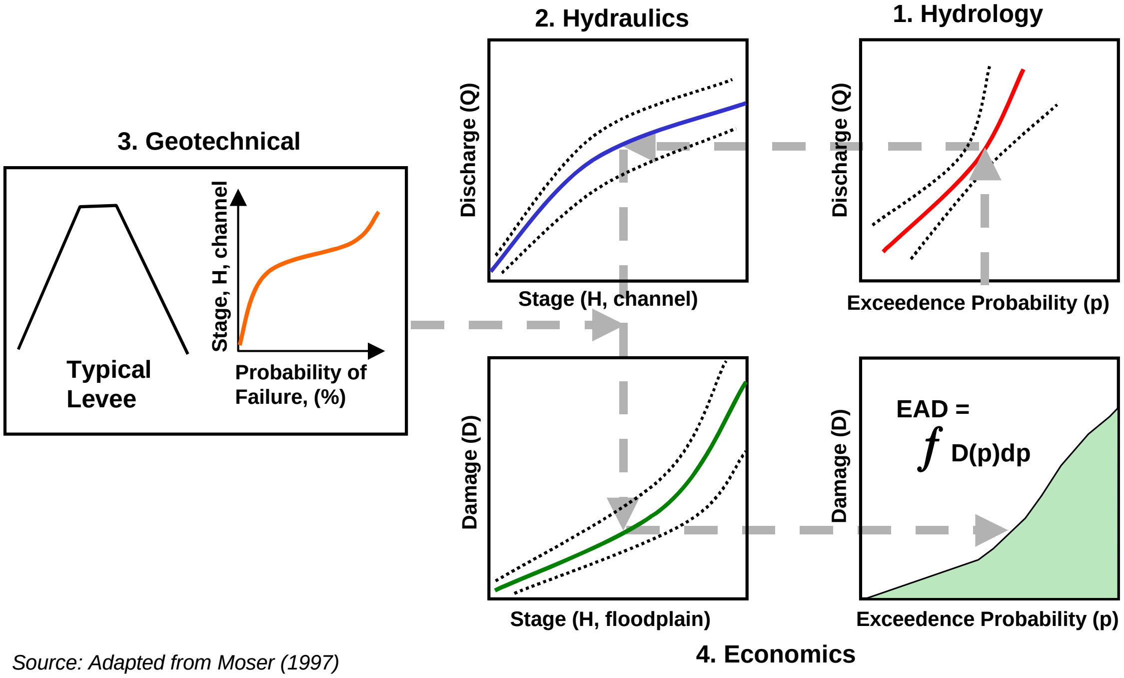
- **Hydrologic –** The discharge-frequency function describes the probability of floods equal to or greater than some discharge Q
- **Hydraulics –** The stage-discharge function describes how high (stage) the flow of water in a river channel might be for given volumes of flow discharge
- **Geotechnical –** The geotechnical levee failure function describes the levee failure probabilities vs. stages in channel with resultant stages in the floodplain
- **Economics –** The stage-damage function describes the amount of damage that might occur given certain floodplain stages

Figure 6-4 illustrates the conceptual risk approach for USACE flood damage analyses. To find the damage for any given flood frequency:

1. The discharge for that frequency is first located in the discharge-frequency panel (panel No. 1).
2. Then the river channel stage associated with that discharge value is determined in the stage-discharge panel (panel No. 2).
3. Most of the rivers being studied have either project or non-project levees which may fail before the water reaches the top (panel No. 3).
4. Once levees have failed and water enters the floodplain, then stages (water depths) in the floodplain inundate structures and crops and cause damage (panel No. 4, left side).
5. By plotting this damage and repeating for process many times, the damage-frequency curve is determined (panel No. 4, right side). EAD is then computed by

finding the area under the flood damage-frequency curve by integration for both without and with project conditions independently. Reductions in EAD attributable to projects are flood reduction benefits.

Appendix E and Appendix F of the Technical Studies Documentation (USACE 2002) provides a more detailed description of the USACE risk and economics analysis for the Comprehensive Study.



Source: Adapted from Moser (1997)

Figure 6-4.
Conceptual Risk Approach for Estimating Flood Damage

Project Reliability and Flood Risk Computations

Reliability is computed as the exceedence probability (EP) for a target stage or the likelihood of levee failure. Flood risk is defined as the probability of one or more exceedences of the target stage or levee failures in a specified number of years. For the Expected Annual Exceedence Probability (AEP) the number of years is 1, the model also computes the exceedence probabilities for 10, 30 and 50 years. The expected (mean) exceedence probability for the stage or the levee failure probability is obtained by averaging the target stage or levee failure probability over all the Monte Carlo simulations.

The risk of flooding one or more times in N_R years is computed as:

$$R = 1 - (1 - p)^{N_R}$$

Where p is either the probability of exceeding the target stage or levee failure. An expected value of R is reported as the average over all Monte Carlo simulations.

For the conditional non-exceedence probability (CNP) a specific flood event is assumed (the model produces results for the 10 percent, 4 percent, 2 percent, 1 percent, 0.4 percent, and 0.2 percent floods), and given that flood, how likely the stage will not be exceeded (levee is not overtopped or breached). For a given hydrologic event the mean flow and uncertainty around it are sampled from in the Monte Carlo simulation and the number of times exceedence is not experienced is recorded. Table 6-24 is an example of all possible flows that may occur for the 1 percent occurrence flood. The CNP for the 1 percent event would be 0.9696. In other words there is a high level of confidence (over 90 percent) that if a 100 year flow occurred that the flood management system would not be exceeded.

Table 6-24.
Computing Conditional Non-Exceedence Probability

1 Percent Flood Flows (cfs)	Frequency	Occurrences of Exceedence	Cumulative Occurrences	Cumulative Frequency	Exceedence Probability	Non-Exceedence Probability
900	200	0	0	200	0.0000	1.0000
990	5000	5	5	5,200	0.0010	0.9990
1,000	10,000	20	25	15,200	0.0016	0.9984
1,010	5,000	500	525	20,200	0.0260	0.9740
1,100	100	90	615	20,300	0.0303	0.9697
1,200	5	2	617	20,305	0.0304	0.9696[1]

Note:
[1] The conditional non-exceedence probability is the non-exceedence probability after all possible flows have been simulated the process takes into account all hydrologic, hydraulic, and geotechnical uncertainties.
Key:
cfs = cubic feet per second

Output Description

The study's economic flood damages for each separable hydraulic area and for the study area as a whole are displayed. The project (may be No-Action or Without-Project) reliability and flood risk is reported by separable hydraulic area only. These statistics are the AEP and the suite of EPs and CNPs. The results in the attachment are totals not by category.

6.6 Hydropower Modeling

SJRRP alternatives would affect the operations, energy use, and generation of existing hydropower facilities, and could also provide new opportunities for hydroelectric energy generation. The Long_Term_Gen and SWP_Power models were used to simulate energy generation and consumption for CVP and SWP facilities, respectively. The Friant Dam Hydropower Generation Model (FDHGM) was used to compute generation from the three power plants at Millerton Lake. This Section provides an overview of modeling methodology used in Long_Term_Gen, SWP_Power, and FDHGM.

6.6.1 Model Description

Long_Term_Gen and SWP_Power were developed as part of the CALFED Common Assumptions process using standard generating and pumping equations, and physical characteristics of the various plants provided by the Central Valley Operations (CVO) or SWP Operations Control Office (OCO).

FDHGM was developed in support of the USJRBSI and includes the power facilities local to Millerton Lake.

All three models are Microsoft Excel spreadsheet based. The spreadsheets use CalSim simulation reservoir storage and flow output as an input, and flow, head, and turbine or pump characteristics to compute hydropower generation or consumption. The models cover the same simulation period as CalSim, October 1921 to September 2003.

Energy generation is a function of reservoir release, net head, and duration of generation. Net head is the actual head available for power generation; it is reservoir water surface elevation (a function of storage) minus tail race elevation (a function of release). Energy generation is also subjected to facility capacities. Similarly, the calculation of energy required for pumping in both models is a function of pumping rate, pumping head (i.e., net head with hydraulic losses), and duration of pumping. The following section describes the relationships between water and power.

Water – Power Relation

Primary variables that affect energy generation are flow rate and head (the elevation difference between the upstream reservoir and the water level below the powerhouse). Energy generated by a hydroelectric project is a function of net head available (gross head less hydraulic losses), water flows available from storage reservoirs, and generation efficiency of the turbine equipment. Similarly, energy required for pumping is a function of the pumping head (gross head, plus hydraulic losses, plus requirements for submergence), water flow rate, and efficiency of the pump. The water-power equation is defined by the following formula:

$$\mathrm{kW} = \frac{Q \times H \times e}{11.81} \quad (1)$$

Where:

kW = power (kilowatt)
H = net head (feet)
Q = flow rate through turbine (cubic feet per second)
e = efficiency of the turbine
11.81 = unit conversion factor

To convert the power output kW to energy kilowatt-hour (kWh), the water power generation equation must be integrated over time. The time step used in the model is monthly.

Power Generation Assumptions

Power generation assumptions are described below for the variables listed above (Net Available Head (H), Flow Rate (Q), Generation Efficiency (e)), turbine specifications, model description, hydropower prices, and pumped-storage modeling.

Net Available Head (H). Net available head (H) is the actual head available for power generation, and is used for computing the energy generated. The net available head is the gross head, minus head losses through intake structures, penstocks, and outlet works. The gross or static head is determined by subtracting the tailwater elevation from the forebay water surface elevation. Head losses are assumed to be 2 to 7 percent of the gross head, depending on the configuration of the powerhouse structure.

Flow Rate (Q). Flow rate (Q) used for energy calculations is the rate of usable flow available for power generation. Usable flow is the flow passing through the powerhouse, and does not include spillway releases.

Generation Efficiency (e). Efficiency (e) is the overall efficiency of the turbine and the generator. For preliminary studies, a turbine and generator efficiency of 80 to 85 percent is typically used. Generation efficiencies in the models are determined according to the configuration of the generators and turbines.

Turbine Specifications. For multiple turbine applications, it is assumed that all turbines are identical, and that a single turbine will be used up to its maximum flow rate capacity; then, flow would be divided equally between two turbines up to the maximum number of turbines selected. When flow through the powerhouse is less than the minimum turbine flow rate, the unit will shut off.

LongTermGen for CVP Energy Simulation

Long_Term_Gen is a monthly model that simulates both power generation and consumption in the CVP system. The simulated powerplants include Trinity, Lewiston, Carr, Spring Creek, Shasta, Keswick, Folsom, Nimbus, and New Melones powerplants, and O'Neill and the CVP portion of Gianelli pumping-generating plants. Simulated pumping plants include C. W. “Bill” Jones, the CVP portion of Banks, Contra Costa, Pacheco, the CVP portion of Dos Amigos, Folsom, Corning, and Red Bluff pumping plants; San Luis, Delta-Mendota Canal, and Tehama-Colusa relift pumping plants; O'Neill and the CVP portion of Gianelli pumping-generating plants. Table 6-25 summarizes Long_Term_Gen simulated CVP energy facilities and their corresponding CalSim inputs.

Table 6-25.
CVP Facilities Simulated in LongTermGen and Corresponding CalSim Variables

CVP Facilities	CalSim Variables for Storage	CalSim Variables for Conveyance
Powerplants		
Trinity	S1	C1
Lewiston[1]	N/A	C100
Judge Francis Carr	S3	D100
Spring Creek	S3	D3
Shasta	S4	D4
Keswick	S5	C5
Folsom	S8	C8
Nimbus	S9	C9
New Melones	S10	C10
O'Neill	N/A	C702 minus C705
CVP portion of Gianelli	S11+S12+S13	D703
Pumping Plants		
C. W. “Bill” Jones	N/A	D418
CVP portion of Banks	N/A	D419_CVP
Contra Costa	N/A	D408
O'Neill	N/A	C702 minus C705
CVP portion of Gianelli	N/A	D703 minus C11
Pacheco	N/A	D11
CVP portion of Dos Amigos	N/A	C834 + D419_CVC
Folsom	N/A	D8
Corning	N/A	D419
Red Bluff	N/A	D419 + C171
Delta-Mendota Canal-California Aqueduct Intertie	N/A	C700A
San Luis Relift	N/A	C832
Delta-Mendota Canal Relift	N/A	C705
Tehama-Colusa Relift	N/A	C171

Note:

[1] It is assumed that no energy is generated at Lewiston Powerplant.

Key:
CVP = Central Valley Project
N/A = not applicable

Functions and parameters assumed in Long_Term_Gen were mostly provided by the Western Area Power Authority (Western) of the U.S. Department of the Interior, which is responsible for managing energy generated from the CVP system.

Energy Generation. Using CalSim outputs as Long_Term_Gen input, general modeling procedures and assumptions for monthly energy generation calculation in Long_Term_Gen are as follows:

- Convert CalSim storage (TAF) to reservoir water surface elevation (feet) and CalSim release (cfs) to tail race elevation (unit in feet) using predefined correlation equations. Each reservoir has its own specific equations. The gross head of release available for power generation is equal to the elevation difference of reservoir water surface and tailrace. Long_Term_Gen uses the average monthly storage for energy calculation.

- Calculate the energy factor (the amount of energy can be generated from each acre-foot of release kilowatt-hour per acre-foot (kWh/acre-foot)), as a function of the gross head. Each reservoir has its own specific energy factor equation.

The total energy production at the powerplant (kWh) is the product of energy factor and releases through the turbine (acre-feet). In the model, the amount of releases that could go through the generator turbines is constrained by the assumed total turbine capacity. The difference between the CalSim release and the amount of release through the turbines is defined as spill. Energy foregone through spilling is the product of energy factor and spill.

The amount of energy available at the load center is equal to the total generated energy from the powerplant minus assumed transmission losses.

Since power generated from the Lewiston Powerplant is not currently marketed through Western, Long_Term_Gen assumed zero generation from the plant.

Energy Consumption. The general modeling procedures and assumptions for the monthly calculation of CVP energy consumption in Long_Term_Gen are as follows:

- Convert the CalSim pumping rate (cfs) into a monthly volume (TAF).
- Calculate the total required pumping energy at the pumping plant by multiplying the energy factor and the monthly volume of pumping. The energy factors, either defined by Western or calculated from a function of gross head, represent the amount of energy required to pump 1 acre-foot of water (kWh/acre-foot).
- Calculate the total required pumping energy at each pumping plant by adding estimated energy loss at the plant. Such losses are predefined in Long_Term_Gen.
- Differentiate the pumping energy required during off-peak and on-peak hours. The goal is to maximize off-peak pumping first to minimize pumping costs. There are two sets of off-peak hour percentage assumptions. The first is a user-defined percentage. The second assumes that Sunday and holidays have zero on-peak hours while there are 16 on-peak hours and 8 off-peak hours for the remaining days.

San Luis Reservoir is a pump-storage reservoir that generates energy with releases and consumes energy during pumping. It is assumed that months with reservoir releases would have zero pumping. Since CalSim does not explicitly simulate the operations of O’Neill Forebay, the amount of O’Neill Pumping Plant is assumed to be the difference between CalSim arcs C702 and C705.

SWP Power California for SWP Energy Simulation

SWP_Power is a monthly model used to simulate both power generation and consumption in the SWP system. Simulated SWP powerplants include Oroville, the Thermalito Complex, Alamo, Mojave, Devil Canyon, Warne, and Castaic powerplants, and the SWP portion of Gianelli Pumping-Generating Plant. Simulated SWP pumping plants are the SWP portion of Banks, SWP portion of Dos Amigos, Buena Vista, Teerink, Chrisman, Edmonston, Pearblossom, Oso, South Bay Aqueduct, Del Valle, Las Perillas, and Badger Hill pumping plants, and the SWP portion of Gianelli pumping-generating Plant. Table 6-26 summarizes SWP_Power simulated SWP energy facilities and their corresponding CalSim inputs.

SWP_Power uses a methodology to calculate SWP energy generation and consumption that is very similar to LTG's. Functions and parameters in SWP_Power were provided by the State OCO.

Friant Dam Hydropower Generation Model (FDHGM)

FDHGM is a monthly model used to simulate power production at Millerton Lake (see Table 6-27). Simulated powerplants include plants on the Friant-Kern and Madera Canals and on the outlet to the San Joaquin River.

FDHGM uses a methodology to calculate SWP energy generation and consumption that is very similar to Long_Term_Gen's. The head for each of the facilities was based on the difference between the facility's normal tailwater elevations and Millerton Lake levels. Normal tailwater elevations are based on bathymetric data for the study area. Flow data for each of the canals, and Millerton Lake levels, were taken from CalSim. Rated capacities of the hydropower facilities and canals were used to determine flow and head ranges for generation. The Friant-Kern Canal capacity was assumed to be 3,600 cfs and Madera Canal capacity was assumed to be 1,300 cfs.

Table 6-26. SWP Facilities Simulated in SWP_Power and Corresponding CalSim Variables

SWP Facilities	CalSim Variables for Storage	CalSim Variables for Conveyance
Powerplants		
Oroville	S6	C6
Thermalito Complex	S7	C7 + C200A
SWP portion of Gianelli	S11 + S12 + S13	D805 minus C12
Alamo	N/A	C876
Mojave	N/A	C882
Devil Canyon	S25	C25
Warne	S28[1]	C892
Castaic	S28 and S29[1]	C893
Pumping Plants		
SWP portion of Banks	N/A	D419_SWP
SWP portion of Gianelli	N/A	D805 minus C12
SWP portion of Dos Amigos	N/A	C825
Buena Vista	N/A	C860
Teerink	N/A	C862
Chrisman	N/A	C864
Edmonston	N/A	C865
Pearblossom	N/A	C880
Oso	N/A	C890
South Bay	N/A	D801
Del Valle	N/A	D811
Las Perillas	N/A	D850
Badger Hill	N/A	C866

Note:
[1] CalSim storage numbers are used in the calculation of tailrace elevation.
Key:
N/A = Not applicable
SWP – State Water Project

Table 6-27. Millerton Lake Facilities Simulated in FDHGM and Corresponding CalSim Variables

Facility	CalSim Variable
Millerton Storage	S18
Friant-Kern Canal Diversion	D18A
Madera Canal Diversion	D18B
San Joaquin River Release	C18

6.6.2 Modeling Assumptions

For each SJRR alternative, outputs from CalSim simulations were inputs to Long_Term_Gen, SWP_Power, and FDHGM to simulate power generation and consumption throughout the CVP, SWP, and Friant systems, respectively. These CalSim outputs include reservoir releases, conveyance flow rates, and end-of-month reservoir storages.

The models computer power generation and pumping usage on a plant by plant basis, and combine them into system-wide power summaries. For the PEIS/R the results of the power modeling was summarized into three parameters:

- **CVP/SWP Generation** – the total CVP and SWP system generation computed by Long_Term_Gen and SWP_Power. The values include North of Delta, In-Delta, and South of Delta facilities.
- **CVP/SWP Pumping** – the total CVP and SWP pumping energy used system systemwide computed by Long_Term_Gen and SWP_Power. The values include North of Delta, In-Delta, and South of Delta facilities.
- **Millerton Generation** – the total generation of the three powerplants at Millerton Lake computed by FDHGM.

6.6.3 Output Description

Output from the hydropower modeling is presented on an annual average basis in Table 6-28. The data is not presented as an annual time series, or on a monthly time step because of the assumptions involved in the modeling.

Table 6-28.
Comparison of Hydropower Table of Values Used it the PEIS/R

		CVP/SWP Generation		CVP/SWP Pumping		Millerton Generation	
		(GWh)	% Change	(GWh)	% Change	(GWh)	% Change
Existing Conditions	Existing Condition	9,855		10,547		89	
	Alternative A	9,884	0%	10,648	1%	74	-17%
	Alternative B	9,885	0%	10,653	1%	74	-17%
	Alternative C	9,882	0%	10,646	1%	74	-17%
Future	No Action	9,915	1%	11,086	5%	89	0%
	Alternative A	9,935	0%	11,165	1%	74	-17%
	Alternative B	9,935	0%	11,165	1%	74	-17%
	Alternative C	9,931	0%	11,163	1%	74	-17%

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7.0 Hydraulic Modeling

Hydraulic modeling performed for the Public Draft PEIS/R included modeling of river hydraulics and flood hydraulics, as described in the following sections.

7.1 River Hydraulics (HEC-RAS)

A one-dimensional steady-flow (HEC-RAS) model of the 150-mile reach of the San Joaquin River between Friant Dam and the confluence with the Merced River was developed for evaluating the hydraulic impacts of restoration actions. The model can be modified to represent a variety of potential restoration conditions. This provides tools that will be used to allow the evaluation of channel capacity, fish passage in channels and at structures, spawning and rearing habitat for fisheries, growth and mortality of riparian vegetation, and sediment transport. The model results may also be used to aid in evaluating temperature effects and surface water/groundwater linkages. This Section provides a description, assumptions, and outputs of the HEC-RAS model.

7.1.1 Model Description

The initial model was developed by MEI using the USACE HEC-2 computer software. The original model was very complex and challenging to execute, and the output files required significant effort to compile into a reasonable summary format. Recent enhancements to the USACE HEC-RAS software eliminate many of the problems that led to the original modeling approach. As a result, the HEC-2 model was converted into HEC-RAS format. MEI has continued to refine the model to correct issues caused by the automated conversion process (MEI 2008a).

The original HEC-2 model consisted of four different models: Merced River (River Mile (RM) 188) to the San Joaquin River and Sand Slough Control Structures (RM 168.5), Sand Slough Control Structure to Mendota Dam (RM 204.8), Mendota Dam to Chowchilla Bypass Bifurcation Structure (RM 216), and Chowchilla Bypass Bifurcation Structure to Friant Dam (RM 267.5). During the model conversion from HEC-2 to HEC-RAS, the four models were combined into a single continuous model.

Topography

Topographic data for the model were derived from topographic and bathymetric surveys conducted in 1998 and1999, supplemented with limited amounts of newer topography in specific areas. Elevations were subsequently corrected to account for subsidence that occurred in the Mendota Pool area since the survey control on which the mapping was based. All elevations in both the original HEC-2 model and the converted HEC-RAS model are based on the National Geodetic Vertical Datum of 1929, and all cross section alignments were geo-rectified into the California State Plane (Zone 3) 1983 North American. DWR intends to update the models with the new 1-foot contour interval mapping in North American Vertical Datum 1988 that is currently in preparation for use with the next phase of planning and design (MEI 2008b).

Cross Sections

The HEC-RAS model contains approximately 2,160 cross sections for the 150-mile-long reach from Friant Dam to the Merced River. This includes 28 cross sections extending 2.4 miles into the Eastside Bypass downstream from the Sand Slough Control Structure (RM 168.4), and 142 cross sections that extend about 15.8 miles into the Chowchilla Bypass downstream from the Bifurcation Structure (MEI 2008b).

Bridges and Structures

Geometric data for bridges and other hydraulic structures were obtained from a variety of sources, including CALTRANS, CDWR, the Merced County Road Department, the Southern Pacific Railroad, the Atchison Topeka Santa Fe Railroad, previously developed hydraulic models, and field surveys. Most of the data for bridges and structures were assembled in 1999 as part of the original HEC-2 model development. The hydraulic structures incorporated into the model include the Chowchilla Bypass Bifurcation Structure, the Sand Slough Control Structure, and Sack Dam (MEI 2008b).

Flow Paths

Flow conditions in the reach are very complex, with islands, multiple flow paths, and locations with flow breakouts during high flows. In areas where well-defined flow paths occur, separate flow paths were incorporated into the model. A total of 26 splits of multiple flow paths were included in the HEC-RAS model, nine split flows in the reaches downstream from Mendota Dam and 17 upstream from Mendota Dam.

Roughness

To account for varying roughness across the channel and floodplain, zones within which the hydraulic roughness characteristics are expected to be similar were delineated on the 1998 aerial photography based on the physical appearance of the vegetation and the ground surface. A total of seven distinct zone types were identified, with roughness values ranging from 0.035 for channel bed and open water to 0.1 for dense trees and brush.

7.1.2 Modeling Assumptions

In addition to the physical boundary conditions provided by structures in the system, assumptions regarding the probable flows and operating rules at various locations significantly affect the model results.

Boundary Conditions

In the conversion from HEC-2 to HEC-RAS, the downstream and internal boundary conditions were updated. The model includes boundary conditions at the downstream ends of Reach 5 using the rating curve for the Newman gage and the Eastside and Chowchilla Bypasses using normal depth. There are internal boundary conditions that are dependent on the operating rules of specific structures, as well as the assumed hydrology at that location. For example, the internal boundary condition at the Mendota Pool is controlled by the operation of Mendota Dam and the other inflows and outflows within the pool.

Flow Losses

Due to the effects of channel percolation losses and diversions, the flow varies significantly along the reach between Friant Dam and the Bifurcation Structure, particularly in the range of flows below about 500 cfs. To quantify these effects, estimated flow-loss relations were developed for the reach and applied to the Friant Dam releases (MEI 2008b).

Model Validation

The model was validated, to the extent possible, using a set of surveyed water-surface elevations and the rating curves for stream gages located along the project reach. As additional data become available, appropriate adjustments should be made to the model to improve the calibration.

7.1.3 Output Description

The model can be used to estimate steady-state water-surface profiles and provide output for various hydraulic parameters, such as water depth, channel and floodplain velocities, and inundation areas. These outputs were used as a tool to identify existing reach capacities, and ranges of potential channel cross-section widths corresponding to different Restoration Flows, water depth, and channel roughness. The following is a general description of what modeling has been completed, and the typical output results.

Flow Capacity Analysis

The model was used to determine the non-damaging flow capacities in Reaches 2A, 2B, 3, 4A, and 4B in an effort to define the capability of existing channels to carry Restoration Flows. The existing channels are contained in various segments by dominant project and non-project levees, minor interior levees/berms, and high terraces that often support agriculture. The non-damaging flow capacity is defined as the flow that remains within the river corridor at an elevation of at least 3 feet below the crest of the relevant dominant or interior levee (i.e., 3-foot freeboard elevation) and does not flood adjacent agriculture or urban land (MEI 2008c).

The HEC-RAS hydraulic model of the study reach was used to estimate water-surface elevations over a range of discharges up to 16,400 cfs, the approximate capacity of the low-level outlets from Friant Dam. The range of modeled discharges varies by reach due to the limited capacity of particular segments of the river. The elevations of a variety of features, including dominant project and non-project levees, minor interior levees/berms, and high terraces that often support agriculture were identified and compared with computed water-surface profiles to identify the capacity-limiting feature in each reach. Table 7-1 summarizes the approximate non-damaging flow in each reach and shows an example of how the HEC-RAS output with analysis may be used.

Table 7-1.
Summary of Estimated Flow Capacities in Reaches 2A, 2B, 3, 4A, and 4B of the San Joaquin River

Reach	Dominant Levee Freeboard Capacity (cfs)	Interior Levee Freeboard Capacity (cfs)	Approximate Non-Damaging Flow Capacity (cfs)
2A	9,000	8,700	8,700
2B[1]	1,500	3,300	1,500
3	3,400	1,300[2]	1,300[2]
4A	3,900	3,300	3,300
4B	100[3]	<100[3]	<100[3]

Notes:
[1] Freeboard elevations within Mendota Pool are encroached at all flows based on the assumed normal pool elevation. Estimated levee freeboard capacity does not reflect this condition. Additional analysis should be conducted to assess the levee freeboard for the pool.
[2] Levee freeboard capacity excludes a small area of land that may be defined as a damageable surface.
[3] Primarily reflect limited channel capacity of upper portion of reach.
Key:
cfs = cubic feet per second

Floodplain Sensitivity

The HEC-RAS model was used to perform a sensitivity analysis of potential levee setback alignments over a range of floodplain roughness conditions. This information was provided to the Alternatives Formulation Group to determine potential ranges of floodplain and levee setback plans for Reach 2B and Reach 4B. A supplemental analysis was conducted to determine levee setback widths that provide a hypothetical average floodplain depth of 18 inches at various flows and roughness.

These analyses were performed using the base conditions HEC-RAS model that was modified to include levees along alignments that represent varying setback distances from the main channel. A series of model runs were made for flows of 2,000, 3,000, 4,000 and 4,500 cfs. For each of these flows, the model was run for a range of Manning’s roughness values for a range of possible floodplain vegetated conditions from minimal woody vegetation to a riparian forest. Output results included the minimum and maximum floodplain widths and water depths at full restoration flow (4,500 cfs), and at flows ranging from 2,000 to 4,000 cfs for the 18 inches floodplain criteria.

The model output consists of typical cross sections for each levee alignment that include a range of water surface elevations corresponding to each roughness value, the average flood plain width, and channel and floodplain depths. Model output also consists of summary tables that contain the above information, and other hydraulic parameters (e.g., velocity, etc.).

7.2 Flood Hydraulics

The SJRRP will increase the minimum flows and the duration and frequency of higher flows in the San Joaquin River up to the flow schedule defined in Exhibit B of the Settlement, as limited by then-current channel capacity. Certain modifications stipulated in the Settlement would increase channel capacity. These modifications include levee setbacks in Reach 2B to safely pass at least 4,500 cfs, modifications to provide a conveyance capacity of at least 475 cfs in Reach 4B1, and modifications in Reach 4B1 to convey flows of at least 4,500 cfs. In the event that release of water from Friant Dam is required for flood control purposes, concurrent Interim and Restoration flows would be reduced by an amount equivalent to the required flood control release. If flood control releases from Friant exceed the concurrent scheduled Interim and Restoration flows, no additional releases above that required for flood control releases would be made for SJRRP purposes. However, changes to the operational criteria at the bifurcation structures and improvements to the levee system within the Restoration Area could affect downstream flood potential. FDA modeling is being conducted to quantify these potential effects under different physical and operating scenarios. To support FDA modeling, Tetra Tech performed unsteady hydraulic modeling using the UNET unsteady-flow model that was originally developed for the Sacramento and San Joaquin River Basins Comprehensive Study (USACE, 2001).

For this study, Tetra Tech modified the Sacramento and San Joaquin River Basins Comprehensive Study UNET model as appropriate to represent a range of potential project conditions with various operational criteria. The following sections summarize the modeling procedures; specific details are discussed in Tetra Tech 2009.

7.2.1 Model Description

The UNET computer software is designed to simulate unsteady flow through a full network of open channels and storage areas. The flood routing in UNET uses the unsteady flow equations to compute the progression of flood waves through the system. In performing the flood routing, the UNET program considers overbank storage, levee breaches, diversions, and other internal boundary conditions. An April 2000 modification of UNET Version 4.0 program that was developed specifically for the Comprehensive Study was used for this study. The original Sacramento and San Joaquin River Basins Comprehensive Study UNET model was developed to evaluate the hydraulic conditions (e.g., discharge, velocity, depth, etc.) and levee performance in the Sacramento and San Joaquin River systems under normal and flood flow conditions (USACE 2002).

Model Development, Assumptions and Limitations

The following sections describe the development and limitations of the original Sacramento and San Joaquin River Basins Comprehensive Study UNET model, and the modifications to that model that were necessary to facilitate the FDA modeling.

Sacramento and San Joaquin River Basins Comprehensive Study UNET Model Development. In general, the development of the UNET model for the Sacramento and San Joaquin River Basins Comprehensive Study involved collecting and processing topographic data, developing river channel alignments and cross-sectional geometry from the available topographic and hydrographic data, and testing/modifying the model to reproduce observed conditions.

Extensive topographic data were collected for the San Joaquin River Basin as part of the Sacramento and San Joaquin River Basins Comprehensive Study. Digital river channel alignments depicting the centerline of the low-flow channel were developed based on topographic and hydrographic information. Cross section profiles were then extracted from the topographic data along the channel alignments. Additional model input included definition of bridge structures, diversion structures, storage areas, levee failure points, model connectivity elements, and boundary conditions. The UNET model requires four primary types of boundary conditions. Upstream boundary conditions, or inflow hydrographs of discharge versus time for particular flood events, are required for all reaches that are not connected to another reach at their upstream end. Downstream boundary conditions, such as stage hydrographs from tide gages in the Delta, are required at the downstream end of all river systems not connected to another reach or river. Interior boundary conditions define reach connections and ensure continuity of flow. Internal boundary conditions represent storage interactions, spillways or diversion structures, bridge or culvert hydraulics and points of levee failure.

Levee Failure Methodology. Levee failure is simulated by UNET as a levee breach that sends water into the overbank storage areas. A methodology was developed to determine the water-surface elevation that would likely result in levee failure within each section of levee. The likely failure point (LFP) is defined as the point at which there is a 50-percent probability of failure if the water-surface reaches this level. LFPs were determined for each section of levee based on available geotechnical data, extensive interviews with levee district personnel, and best engineering judgment. The LFPs were incorporated into the UNET model that simulates a levee breach (the elevation of the breach is generally lower than the LFP elevation) when the water-surface reaches the specified elevation of the LFP, and delivers flow to overbank storage areas.

Upstream Boundary Flow Hydrographs. The model was executed over a range of flood events including the 10-, 25-, 50-, 100-, 200-, and 500-year return frequency floods. The hydrographs used for the upstream boundary conditions were derived from hydrologic (HEC-5) modeling, as discussed in Appendices B and C of the Sacramento and San Joaquin River Basins Comprehensive Study Technical Studies Documentation (USACE 2002). Eight storm centerings were considered to evaluate the effects of floods originating from different locations in the basin, including:

- El Nido (Mainstem San Joaquin River)
- Newman (Mainstem San Joaquin River)
- Vernalis (Mainstem San Joaquin River)
- Friant Dam (Tributary)
- Fresno Slough (Tributary)
- Merced River (Tributary)
- Tuolumne River (Tributary)
- Stanislaus River (Tributary)
- Modeling Procedure

Sacramento and San Joaquin River Basins Comprehensive Study UNET Model Limitations. The UNET model developed for the Sacramento and San Joaquin River

Basins Comprehensive Study analysis was created with the following assumptions and limitations:

- The level of detail was limited by the availability of geometric and topographic data that is represented in the model with cross sections. The spacing of the cross sections is as high as ¼-mile, and the model only computes hydraulic conditions at cross section locations.
- The various return frequency floods were modeled using synthetic hydrology output from the HEC-5 models discussed above. Although the HEC-5 models were verified to the extent possible, the availability of measured data with which the models could be calibrated is somewhat limited.
- Because the levee failures in some cases deliver flow to offline storage areas, actual flooding conditions in the storage areas is not directly modeled.
- UNET does not account for sediment movement and the associated aggradation or degradation.
- The model assumes no exchange with groundwater.
- The model is a comprehensive representation of the entire San Joaquin River Basin, capable of simulating the complex interaction of multiple stream systems and waterways.
- The model used for this study simulates one-dimensional, fully unsteady flow, and is of sufficient detail to provide appropriate results for a systematic flood damage analysis of the basin.

Modifications to Sacramento and San Joaquin River Basins Comprehensive Study UNET Model for the SJRRP FDA Analysis. The UNET model developed for the Sacramento and San Joaquin River Basins Comprehensive Study was modified to evaluate the effects of improvements associated with the SJRRP. Flood control operating criteria are described in the Friant Dam Flood Control Manual, however under real-time conditions, flood control operations have historically been adapted to minimize flood risk. Therefore, the without-project conditions were modeled under both Flood Control Manual operating criteria, and under historical operating practices. Because these historical practices are expected to continue in the foreseeable future, the program alternatives are also modeled under both operating criteria as described in the Flood Control Manual, and under adaptive operating practices. To address the two different conveyance capacities in Reach 4B1 included in the program alternatives, and because the operating criteria for the diversion structures may be modified to reduce flood impacts, a total of six model scenarios were considered, including:

- Scenario 1. No-Action Alternative, Flood Control Manual Operating Criteria.
- Scenario 2. No-Action Alternative, Historical Practice Operating Criteria.

- Scenario 3. Alternatives A1, B1, and C1 (475 cfs in Reach 4B1), Flood Control Manual Operating Criteria.
- Scenario 4. Alternatives A1, B1, and C1 (475 cfs in Reach 4B1), Adaptive Practice Operating Criteria.
- Scenario 5. Alternatives A2, B2, and C2 (4,500 cfs in Reach 4B1), Flood Control Manual Operating Criteria.
- Scenario 6. Alternatives A2, B2, and C2 (4,500 cfs in Reach 4B1), Adaptive Practice Operating Criteria.

Modifications to Model Geometry. The channel modifications to Reaches 2B and 4B1, as stipulated in the Settlement, were incorporated into the UNET model by modifying the cross-sectional geometry. The No-Action Alternative scenarios (Scenarios 1 and 2) were developed to provide a baseline with which to compare the with-project scenarios. For the No-Action Alternative scenarios, the geometry in the UNET model was not modified, since this geometry represents existing conditions without any SJRRP-related improvements. The model geometry for Alternatives A1, B1, and C1 (Scenarios 3 and 4) was modified to include setback levees in Reach 2B to provide 4,500 cfs capacity (Figure 7-1), and in-channel modification in Reach 4B1 to provide channel capacity of 475 cfs. Under Alternatives A2, B2, and C2 (Scenarios 5 and 6), the chanel geometry was modified to include setback levees in Reach 2B to provide 4,500 cfs capacity (Figure 7-1), and in-channel modification in Reach 4B1 to provide channel capacity of 4,500 cfs capacity (Figure 7-2). It should be noted that the proposed Mendota Pool Bypass was not incorporated in the UNET model geometry, since this channel will not be operated for flood flow conveyance.

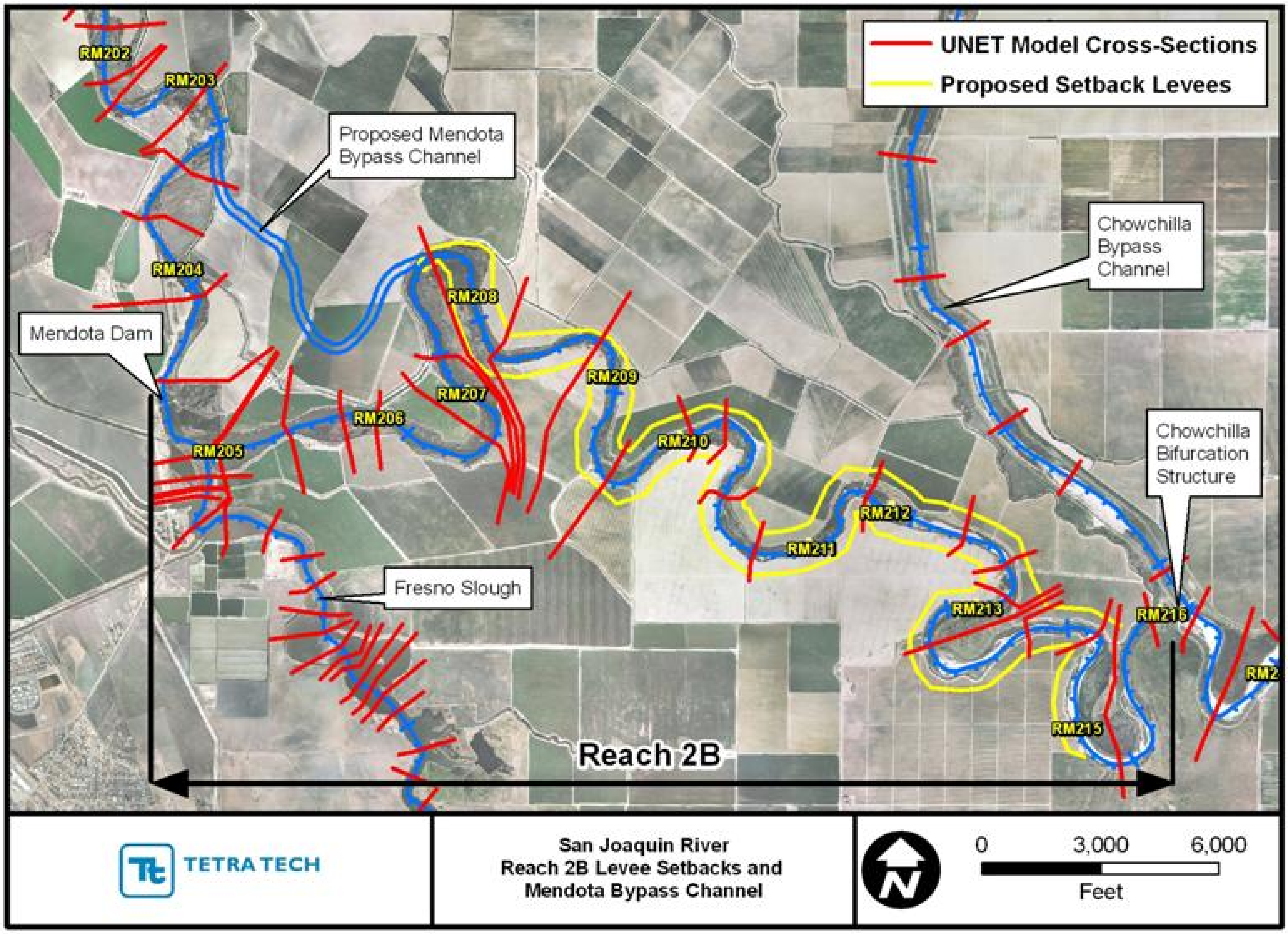


Figure 7-1.
Modeled Levee Setbacks in Reach 2B

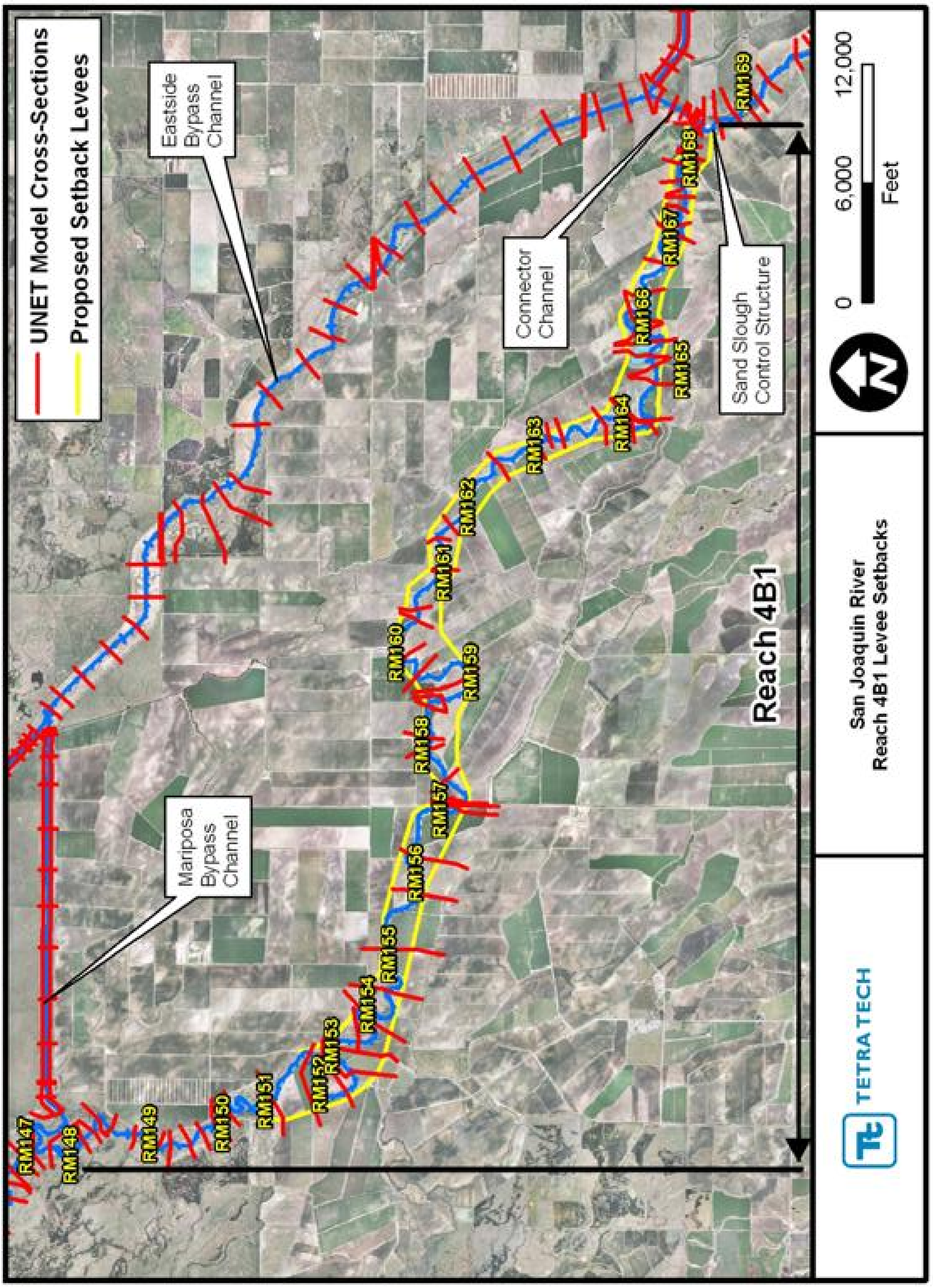


Figure 7-2.
Modeled Levee Setbacks in Reach 4B1.

Modifications for Diversion Structure Operating Criteria. The operations of the Chowchilla Bypass Bifurcation Structure and at the Sand Slough Control Structure directly affect flooding conditions in the reaches below the structures. For the purposes of modeling flood hydraulics, three operating criteria were incorporated, including the Flood Control Manual operating criteria (Scenarios 1, 3, and 5), the Historical Practice operating criteria (Scenario 2), and the Adaptive Practice operating criteria (Scenarios 4 and 6), as described below. These operating criteria were incorporated into the model using either a split flow rating curve or by directly entering the split flow hydrograph as internal boundary conditions. Additional details regarding the modeling of the various operational criteria are presented in Tt-MEI (2009).

The Flood Control Manual operating criteria at the Chowchilla Bypass Bifurcation Structure specifies that all flow up to 2,500 cfs is delivered to Reach 2B, and all additional flow for upstream discharges between 2,500 cfs and 8,000 cfs is diverted to the Chowchilla Bypass subject to the limitation that flows in Reach 3, including inflows from the James Bypass and Fresno Slough, cannot exceed 4,500 cfs (The Reclamation Board, 1969). Under extreme flow conditions, the portion of the flow that exceeds 8,000 cfs is split evenly between the river and the Chowchilla Bypass. At the Sand Slough Control Structure, the upstream discharge is split evenly between Reach 4B1 and Sand Slough up to 3,000 cfs, and all flows above 3,000 cfs are delivered to Sand Slough (i.e., a maximum of 1,500 cfs is delivered to Reach 4B1).

In practice, only the first 1,300 cfs is delivered to Reach 2B due to seepage impacts in this part of the reach. Similar to the Flood Control Manual operating criteria, under extreme flow conditions, the portion of flow that exceeds 8,000 cfs is split evenly between Reach 2B and the Bypass Channel. At the Sand Slough Control Structure, all flow is delivered to Sand Slough, resulting in no flow in Reach 4B1. These operations are reflected in the Historical Practice operating criteria (Scenario 2).

At the Chowchilla Bypass Bifurcation Structure, the Adaptive Practice operating criteria are identical to the Historical Practice operating criteria. Under Alternatives A1, B1, and C1 (Scenario 4), the Adaptive Practice operating criteria at the Sand Slough Control Structure flow is split evenly between Reach 4B1 and Sand Slough up to 950 cfs, and all flows above 900 cfs are delivered to Sand Slough (i.e., a maximum of 475 cfs is delivered to Reach 4B1). Under Alternatives A2, B2, and C2 (Scenario 6), the Adaptive Practice operating criteria at the Sand Slough Control Structure flow at the Sand Slough Control Structure is split evenly between Reach 4B1 and Sand Slough up to 3,000 cfs, and all flows above 3,000 cfs are delivered to the Connector Channel (i.e., a maximum of 1,500 cfs is delivered to Reach 4B1).

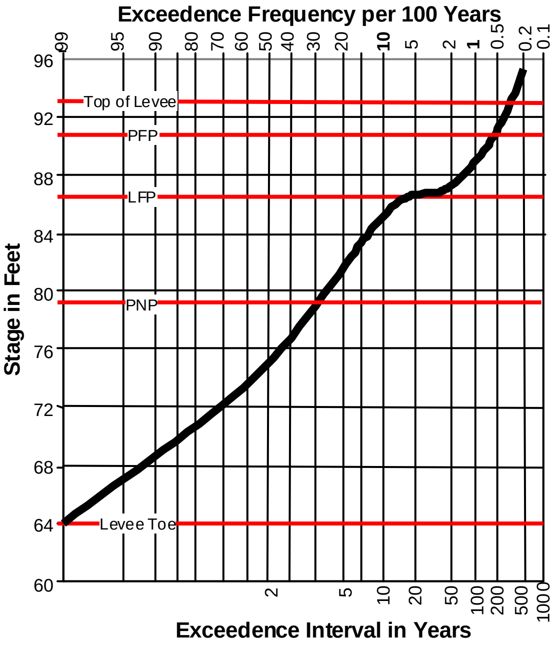
Upstream Boundary Flow Hydrographs. The model was executed over a range of flood events including the 10-, 25-, 50-, 100-, 200-, and 500-year return frequency floods. A total of five storm centerings were selected for evaluation based an initial determination of the centerings that result in the most significant damages (see Section 6.5 of this appendix). These storm centerings were:

- El Nido (Mainstem San Joaquin River)

- Newman (Mainstem San Joaquin River)
- Vernalis (Mainstem San Joaquin River)
- Friant Dam (Tributary)
- Kings River (Tributary)

7.2.2 Output Description

Output from the model runs were used to develop stage versus frequency curves (Figure 7-3) for each of the model scenarios and storm centerings at 42 index points corresponding to the damage areas to be used in the FDA modeling. In most of the reaches where levee failures are indicated, once a breach occurs, the water-surface elevation does not significantly increase (and in some cases, decreases) with increasing discharge since a large volume of flow escapes through the breach. Because the FDA modeling requires a stage-frequency curve that increases with increasing flow magnitude, it was necessary to adjust the curve for stages that exceed the elevation of the LFP. The adjusted portion of the curve was developed by first re-running a modified version of the models that did not include levee failures. This version of the models forces all flow to be conveyed between the levees and results in stage-frequency curves that always increase with increasing discharge. Since the output from this version of the models show unrealistically high stages, the resulting stage-frequency curves were adjusted downward to match the curve based on the with-failure simulations at a stage equal to the elevation of the LFP. The final curve was then created by merging the with-failure curve below the LFP and the adjusted without-failure curve above the LFP, resulting in a smooth and continuously increasing stage frequency curve.



Key:
LFP = Likely Failure Point
PFP = Probably Failure Point
PNP = Probably Non-failure Point

Figure 7-3.
Typical Stage-Frequency Curve

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8.0 Other Modeling

8.1 Sediment Modeling

The sediment model was developed and documented by Reclamation. The documentation is provided in its entirety in Appendix N, “Geomorphology, Sediment, and Vegetation Assessment” in its attachments.

8.2 Vegetation Modeling

Vegetation modeling uses the sediment modeling platform with additional algorithms for both native and invasive vegetation growth and mortality. Documentation on the vegetation model, developed by Reclamation, including results from an initial analysis are reported in Appendix N, “Geomorphology, Sediment, and Vegetation Assessment” in Attachment, “SRH-1DV Vegetation Modeling of the San Joaquin River, Friant Dam to Merced River Confluence, California.” A summary of vegetation modeling results is also incorporated in Appendix N, “Geomorphology, Sediment Transport, and Vegetation Assessment.”

8.3 Air Quality Modeling – Program Level Air Pollutant Emissions Modeling

The restoration project includes increased minimum flow requirements in the San Joaquin River. These requirements will result in potential changes to the flood protection levees and canals along Reaches 2B and 4B of the restoration area. Construction of additional levee and canal infrastructure could result in adverse emissions of criteria air pollutants and precursors from land disturbance, material transport, equipment exhaust, and employee commute trips.

8.3.1 Model Description

Emission factors and equipment assumptions from four different models were combined into one project-specific calculation table.

Emission factors for construction equipment were taken from the California Environmental Protection Agency Air Resources Board’s (ARB) OFFROAD2007 model (ARB 2008). The off-road emissions inventory from OFFROAD2007 is an estimate of the population, activity, and emissions estimate of the varied types of off-road equipment. The major categories of engines and vehicles include agricultural, construction, lawn and garden, and recreational offroad, and include equipment from hedge trimmers to cranes. The OFFROAD2007 model estimates the relative contribution of gasoline, diesel, compressed natural gas, and liquefied petroleum gas-powered vehicles to the overall emissions inventory of the state.

Equipment populations were based on default settings from ARB-approved URBEMIS2007 v9.2.4 and levee work conducted under the Sacramento Area Flood Control Agency Natomas Levee Improvement Program. URBEMIS is a computer program that can be used to estimate emissions associated with land development projects in California such as residential neighborhoods, shopping centers, and office buildings; area sources such as gas appliances, wood stoves, fireplaces, and landscape maintenance equipment; and construction projects. URBEMIS stands for "Urban Emissions Model."

Emission factors for on-road vehicles were taken from Sacramento Metropolitan Air Quality Management District's Roadway Construction Emissions (RCE) Model v6.3. RCE calculates a project's emissions in pounds per day by project phase, and tons over the entire construction period. RCE can be used to estimate emissions for both vehicle exhaust and fugitive dust. Emission factors from RCE are based on ARB's EMFAC2007. EMFAC2007 is used to calculate emission rates from all motor vehicles, such as passenger cars to heavy-duty trucks, operating on highways, freeways and local roads in California.

Emission factors for material hauling and ground disturbance are from the U.S. Environmental Protection Agency's AP-42 emission factors database. The Emission Factor and Inventory Group, in the U. S. Environmental Protection Agency's Office of Air Quality Planning and Standards, develops and maintains emission estimating tools to support the activities mentioned above. The AP-42 series is the principal means by which the Emission Factor and Inventory Group documents emission factors.

8.3.2 Modeling Approach and Assumptions

Using the four models described above, a comprehensive calculation table was created to combine all major emissions sources related to the potential construction of additional levees and canals. Emission sources include material hauling, ground disturbance, heavy duty equipment operations, and passenger vehicles. The following assumptions were used in the model and are based on default URBEMIS settings and projects of similar magnitude.

- Haul Trucks would carry approximately 14 cubic yards per load
- Haul Trucks would travel 10 miles per round trip from borrow site locations to levee construction areas
- Haul Trucks would travel 50 percent on paved roads and 50% on unpaved roads
- 75 employees per project phase
- 5 Water Trucks, 10 Scrapers, 10 Loaders, 20 Bulldozers, 5 Compactors, 5 Graders, and 10 Excavators per project phase
- Emissions are modeled for the 2010 construction season (emissions for subsequent years would be less because of stricter emissions standards)

- Levee construction would occur for 220 days per year for 3 years
- Annual Emissions assume 50 percent of 2B and 50 percent of 4B construction occur in the same year
- Equipment and Employee Numbers are based on default URBEMIS2007 settings, default SMAQMD Road Construction v6.3 Model settings, and SAFCA
- Natomas Levee Improvement Program actions that are similar in magnitude to the San Joaquin River Restoration actions

8.3.3 Output Description

The air quality emissions model simulates an approximate amount of emissions that could be associated with implementation of the larger levee and canal construction actions of the SJRRP.

Output data for Alternative A was calculated. Borrow material estimates were not available for Alternatives B and C; they would likely be similar to Alternative A.

The outputs included are:

- Unmitigated and Mitigated Daily and Annual Emissions of reactive organic gas (ROG)
- Unmitigated and Mitigated Daily and Annual Emissions of nitrous oxide (NO_X)
- Unmitigated and Mitigated Daily and Annual Emissions of particles of 10 micrometers or less (PM_{10}) Unmitigated and Mitigated Daily and Annual Emissions of carbon dioxide (CO_2)

Modeling output is listed in the Air Quality Modeling Output Attachment. The results have been summarized for worst-case emissions in pounds per day and tons per year in Table 8-1.

Table 8-1.
San Joaquin River Reaches 2B and 4B Summary

Emissions	ROG	NO_X	PM_{10}	CO_2	Units
Daily Emissions					
Unmitigated Worst-Case Daily Emissions	5.8	42.6	1,533.2	4,785.8	lb/day
Standard Mitigation Reductions	5%	20%	75%	0%	percentage reduction
Mitigated Worst-Case Daily Emissions	**5.5**	**34.1**	**383.3**	**4,785.8**	lb/day
Annual Emissions					
Unmitigated Worst-Case Annual Emissions	5.3	39.9	1,313.6	4,452.9	tons per year
Standard Mitigation Reductions	5%	20%	75%	0%	percentage reduction
Mitigated Worst-Case Annual Emissions	**5.1**	**31.9**	**328.4**	**4,452.9**	tons per year

Source: EDAW 2009

Key:
CO_2 = carbon dioxide
NO_x = nitrous oxide
PM_{10} = particles of 10 micrometers or less
ROG = reactive organic gas

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