Final

DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal Phase 2 Analysis

Prepared for

State Water Contractors and Department of Water Resources' Municipal Water Quality Investigation Program

June 2008

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Submitted to

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Abbreviations and Acronyms

Aqueduct	California Aqueduct
CDEC	California Data Exchange Center
cfs	cubic feet per second
CVO	CVP Operations Office
CVP	Central Valley Project
DMC	Delta-Mendota Canal
DSM2	Delta Salinity Model 2
DSM2 Aqueduct Model	DSM2 California Aqueduct Extension Model
DSS	data storage system
EC	electrical conductivity
IEP	Interagency Ecological Program
MWQI	Municipal Water Quality Investigation
RMS	root mean square
RTDF	real-time data and forecasting
SWP	State Water Project
SWP OCO	DWR SWP Operations Control Office
TDS	total dissolved solids

SECTION 1

Introduction

In view of their increased reliance on the State Water Project (SWP), the State Water Contractors realize the importance of developing water quality planning and forecasting simulation capabilities for the California Aqueduct (Aqueduct). This report summarizes the work conducted under the Phase 2 analysis of the Delta Simulation Model 2 (DSM2) Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal (DMC) systems. This report contains a brief review of work conducted under Phase 1 and summaries for each of the four tasks conducted under Phase 2. The individual technical memorandums prepared for each of the four Phase 2 tasks are included in Appendices A through D. A schematic of the DSM2 California Aqueduct Extension Model (DSM2 Aqueduct Model) is included as Appendix E. Maps of the overall SWP and detailed maps of relevant divisions are provided as Appendix F.

The Department of Water Resources' (DWR) Municipal Water Quality Investigation (MWQI) program is interested in developing the capability to do real-time data and forecasting (RTDF) of short- and long-term water quality. The objective is to develop water quality planning and forecasting simulation capabilities, which are currently only available for the Delta. Possible future applications of this model could also include DMC recirculation studies, where this model would be connected with the Delta and San Joaquin DSM2 modules.

Background

The Phase 1 model was constructed and calibrated for flow and water quality for a 3-year period (January 1, 2000 through December 31, 2003).[1] The model includes the main branch of the Aqueduct, the East Branch through Silverwood Lake, the West Branch through Pyramid Lake, the South Bay Aqueduct through the Santa Clara Tank, and the DMC to the Mendota Pool. The Coastal Branch is treated as a diversion in the model; it is not specifically modeled.

The model performs well for a wide range of expected flows and salinity conditions. Calibration showed acceptable reproduction of flows, water surface elevations, and salinity transport. The difficulties with calibration are predominantly associated with the quality of the supporting data used for the boundary conditions, the lack of data for stormwater and other episodic inflows to the system, and the representation of San Luis Reservoir as a completely mixed water body. The Phase 1 report included several recommendations for further improvement and application of the DSM2 Extension for the California Aqueduct.

[1] CH2M HILL. 2005. *DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal*. Sacramento, CA. June.

Purpose of Phase 2 work

The second phase of development and analysis with the DSM2 Aqueduct Model included four tasks developed upon the results and recommendations of the Phase 1 analysis. The purpose of Phase 2 was to investigate ways to improve the DSM2 Aqueduct Model developed in Phase 1 and then extend the usefulness of the tool through development of a planning mode and a forecasting mode application. These four tasks were conducted in Phase 2:

- Task 1: Tracer tests for determination of travel time
- Task 2: Analysis of San Luis Reservoir and O'Neill Forebay
- Task 3: Development of planning simulation mode
- Task 4: Development of forecast mode implementation plan

The following four sections of this report provide an overview of each Phase 2 task that includes a general discussion of the approach and a summary of results.

SECTION 2

Task 1: Tracer Tests for Determination of Travel Time

This task investigated the travel time of a numerical tracer slug through the system for 10 specific flow conditions expected to represent the full range of possible flow conditions in the California Aqueduct. The model developed under Phase I of this project was used to complete this task. The purpose was to determine the travel time through the aqueduct for the full range of operational flows for use in water quality planning and/or emergency response coordination.

Approach

The calibrated Phase 1 DSM2 Aqueduct Model was used to estimate travel times of a numerical tracer slug through the aqueduct system. Historical flow records at various locations along the aqueduct were analyzed to determine appropriate flows for use in the tracer simulations. Two sets of five model runs were made representing the full range in expected flow conditions through the system; the first set was based on flows through Dos Amigos Pumping Plant, and the second set was based on flows through Banks Pumping Plant. Together, the 10 simulations identify the travel time from the Banks Pumping Plant to the terminal reservoirs. Results of the model simulations were presented in tabular and graphical format. Summary tables indicate the travel time to each major system component (check structures, reservoirs, and pumping plants).

Travel time through the aqueduct system is primarily a function of flow rate, considering the constant-volume method in which the system is operated. Channel flow rates depend on the pumping flows and the channel diversions. Flow rates at Banks Pumping Plant and Dos Amigos Pumping Plant are the primary controlling influences for the majority of the system. The filling and release operations of San Luis Reservoir can influence the travel time and the concentration of a conservative constituent moving through the aqueduct by affecting the residence time of the tracer in O'Neill Forebay and the downstream flow rate. For this reason the analysis presents travel times through several individual sections of the system, including the section from Banks Pumping Plant to O'Neill Forebay and the section from O'Neill Forebay to the terminal reservoirs. The 4-year flow and diversion dataset (January 2000 through December 2003) compiled during the Phase 1 investigation was analyzed to select a range of boundary flows to be used during the travel time investigations.

Two pumping rates bracketing the range of monthly average flows over the 4-year dataset (1,901 cfs and 10,491 cfs) were chosen as the minimum and maximum boundary flows at Dos Amigos Pumping Plant. Three more values were selected at intervals approximately equally spaced between the maximum and minimum values. These five target flows capture the range of expected flows below O'Neill Forebay and will provide enough data points to determine travel time curves for the full range of flow conditions.

A post-processing tool was developed using Microsoft Excel to calculate the time at which the tracer concentration peaked at each location and to calculate the travel time through several sections of the aqueduct. The results presented in this section include the analysis of the EC output from the 10 tracer simulations.

Summary of Task 1 Results

The travel times from Banks Pumping Plant to Check 67 and from O'Neill Forebay (Check 13) to Check 67 ranged from 12.42 days to 31.33 days, generally varying inversely with the amount of pumping at Dos Amigos Pumping Plant. Travel times from Banks Pumping Plant to O'Neill Forebay for the five simulations TRCR6 to TRCR10 range from 21 days at low flow to less than 2 days at high flow.

A series of plots were generated to summarize the results of the travel time simulations conducted in this task. The plots demonstrate the relationship between flow and travel time through various portions of the system. The aqueduct is managed to maintain a constant volume, and thus the flow through the system is proportional to the velocity. The travel time, however, is inversely proportional to the velocity (velocity = distance / time), hence the relationships are not linear.

Diversions from the aqueduct can be considerable when expressed as the fraction of the flow through a given reach. For example, 27 percent of the flow through Dos Amigos is diverted before Check 21, and 36 percent of the flow through Check 21 is diverted before Check 42 for the time periods used in the tracer simulations. The diversion locations, whether at the beginning or end of a given pool, will influence the travel time through that pool. In the model application, all diversions were aggregated and applied on the end of each individual pool. This feature imparts a bias on the predicted travel times; actual times will be slightly higher because the deliveries are actually not grouped at the end of each pool. The travel time through a reach is more strongly correlated with the net flow through the reach than the inflow to the reach, considering the diversions along the reach.

SECTION 3

Task 2: Analysis of San Luis Reservoir and O'Neill Forebay

The purpose of Task 2 was to determine if a more complex representation of San Luis Reservoir would improve the calibration and predictive ability of the model compared to the Phase 1 calibration simulation. Phase 1 results indicate that EC predictions from the calibration simulation are reasonably accurate for the first 16 months of the simulation, but then begin to deviate from the measured data on June 2002. Analysis was focused on time periods in which errors in the Phase 1 calibration effort were largest.

Approach

Task 2 began with a review of the Phase 1 calibration results to identify specific time periods where model refinements would most likely lead to improvements in performance. The boundary conditions applied in Phase 1 were identified as an area for potential improvement. A range of physical changes to the representation of San Luis Reservoir in the DSM2 model were evaluated and potential improvements in the predictive capability of the model were quantified. Field data, obtained subsequent to the Task 2 modeling evaluation, were reviewed to assess if the dataset provided useful information on the vertical structure of the reservoir. Finally, DSM2 results and historical field data were analyzed to investigate alternative operations to reduce average annual salinity levels in San Luis Reservoir.

Review of Phase 1 Model Results

Beginning in September 2002 the predicted EC in San Luis Reservoir shows a somewhat constant offset from the measured data. Review efforts were thus focused on the 2-month period beginning June 1, 2002, when deviations from measured values were most severe. Measured EC in San Luis Reservoir increased by over 15 percent during the two months of June and July, 2002. According to flow records, this increase in EC occurred while water was being released from the reservoir, and is thus considered suspect. The EC increase is likely not related to the transport of salt into the reservoir from O'Neill Forebay.

Boundary Condition Refinements

Boundary condition refinements led to minor improvements in the model-predicted EC at O'Neill Forebay, particularly during times when flows from the DMC are being diverted into O'Neill Forebay and then San Luis Reservoir. Improvements were not consistent, and did not demonstrate any seasonal patterns. The month with the highest RMS error in the Phase 1 calibration simulation (September 2001) shows a significant improvement as a result of the Banks EC refinement included in the Test 4 simulation. The month with the second-highest RMS error (December 2002) shows a considerable improvement as a result of specifying the historical measured DMC EC at Check 12 as the EC for the DMC inflow to O'Neill Forebay.

Representation of San Luis Reservoir

The Phase 1 report noted that further investigation was needed to assess how best to simulate San Luis Reservoir and its operations. One suggestion was the use of a two-reservoir model instead of the single-reservoir model used in the Phase 1 analysis. The first reservoir would represent the smaller effective mixing volume near the dam, and a second larger reservoir would represent the remaining lake volume. As part of Task 2, an extensive series of DSM2 simulations were run to determine if changes in the representation of the reservoir would improve the model's ability to reproduce measured EC concentrations in San Luis Reservoir. Numerous variations of the two-reservoir concept were investigated.

Review of Field Data

Subsequent to the completion of the DSM2 modeling effort conducted in this task, Robert Duvall (Water Quality Section, California Department of Water Resources) provided vertical profile data for San Luis Reservoir covering the period 2001 through 2003. The profile data demonstrate that the reservoir is well mixed vertically, at least near the Pacheco Pumping Plant Intake.

Analysis of Opportunities to Reduce Average Annual Salinity Levels in San Luis Reservoir

Project staff investigated opportunities to lower the average annual EC concentration in San Luis Reservoir through alternative operations strategies. Two methods of lowering the average annual EC concentration in San Luis Reservoir were investigated. The first method involved shifting inflows to San Luis Reservoir from periods of higher-than-average EC at Banks and Jones Pumping Plants to periods with lower-than-average EC at these boundaries. The second method involved operating Banks Pumping Plant around the spring/neap tidal cycle.

Summary of Task 2 Results

Attempts to improve the predictive capacity of the DSM2 model resulted in reductions in RMS errors of approximately 9 percent from the Phase 1 calibration simulation as measured at Check 13 on the Aqueduct downstream of O'Neill Forebay. The majority of this error reduction was the result of refinements in the boundary EC applied at Banks Pumping Plant. Changes to the model representation of San Luis Reservoir and its connection with O'Neill Forebay resulted in only minor reductions in RMS errors. The small reduction in RMS error does not justify the added model complexity associated with this alternative representation of San Luis Reservoir.

Refinements in the representation of the EC boundary conditions demonstrated the potential to reduce the calculated RMS error in EC by up to 15 percent at Check 13. A refinement in the treatment of data gaps in the Banks EC boundary conditions yielded an improvement of 8 percent as compared to the Phase 1 simulation.

Groundwater pump-ins and other local inflows may be responsible for the differences between measured EC at Jones Pumping Plant and Check 12 on the DMC. Quantification of the volume and water quality associated with these inflows will improve the model's predictive capacity.

Field data indicate generally very little variation in EC throughout the water column, and thus it may be unnecessary to model San Luis Reservoir with distinct upper and lower layers. Additional data collection (profiles of EC near the dam) would provide valuable information on whether the entire reservoir shows the same vertical structure as the profiles collected near the Pacheco Pumping Plant Intake.

Adjustments to the annual filling pattern of San Luis Reservoir could result in minor reductions in San Luis Reservoir EC on an annual basis. Shifts in flow from October and November to February and March could lower annual average EC in San Luis Reservoir by a few percentage points. However, there are water supply concerns associated with such moves.

Spring/neap variations do not seem to have a discernable influence on short-term variations in EC near Clifton Court Forebay. Other factors (including pumping rates through Banks Pumping Plant, San Joaquin River flows and EC, and agricultural return flows) seem to exert more influence on EC near Clifton Court Forebay. Thus, variations in operations at Clifton Court Forebay on a fortnightly basis are not likely to cause significant changes in EC concentrations in Clifton Court Forebay or San Luis Reservoir.

SECTION 4

Task 3: Planning Simulation Mode

The purpose of Task 3 was to develop the capability to run the DSM2 Aqueduct Model in planning mode in support of the MWQI program's desire to conduct DSM2 simulations for water quality planning and forecasting based on the use of CALSIM2 Model results.

CALSIM2 and the extended DSM2 model overlap and simulate south-of-Delta SWP and CVP operations. Both model grids include the Aqueduct and the DMC, and include Delta exports at Banks and Jones Pumping Plants, San Luis Reservoir operations, and diversions to contractors or other aqueduct segments (South Bay Aqueduct, Coastal Branch, and West Branch). CALSIM2 is used to make monthly decisions about water supply distribution and allocation based on storage and forecasted inflows over a broad hydrologic range. DSM2 is used to understand the hydrodynamics and water quality at any point in the system. By utilizing both models, DSM2 can be run in planning mode, enabling agencies to assess the impacts of water quality and supply along the Aqueduct and DMC.

Approach

To allow use of CALSIM2 model results with DSM2, a processor was developed to disaggregate CALSIM2 model results for South Delta pumping and diversions along the Aqueduct and DMC and assign them to appropriate nodes in DSM2. The preprocessor was developed in Excel to take advantage of publicly available tools that allow for import and export of DSS data into and out of Excel. When used in planning simulation mode, the DSM2 Aqueduct Model allows simulation of the full 82-year CALSIM2 simulation period of water years 1922 through 2003.

It was necessary to disaggregate CALSIM's representation of diversions from the California Aqueduct and DMC and assign them to appropriate nodes in DSM2. CALSIM2 delivery arcs are mapped to DSM2 model segments (several pools grouped together between major facilities, such as pumping plants) so that the CALSIM2 deliveries are aligned with the correct reaches of the DSM2 system.

During the development of the DSM2 Aqueduct Model, contractor diversions pulling water within the same pool (Aqueduct or DMC) were aggregated into a single diversion for that pool at the downstream node. In some instances, a contractor diverts water from several pools in the DSM2 model, whereas in CALSIM2 the contractor is represented with a single delivery arc. In these situations, the single CALSIM2 delivery arc is split between the DSM2 nodes with this contractor, using historical average monthly flow data to determine the percentage of the delivery that goes to each node.

Summary of Task 3 Results

The DSM2 Aqueduct HYDRO model was run in planning mode for a 73-year period using CALSIM2 model results as boundary conditions. An Excel-based tool was developed to apply flows from CALSIM2 as boundary data for use with DSM2. The tool generates time-series data that is exportable into DSS format for the following:

- Flows at Banks and Jones
- San Luis Reservoir and O'Neill Forebay operations
- Contractor deliveries from the Aqueduct
- Diversions for the South Bay Aqueduct, the Coastal Branch, and the West Branch, and Kern River Intertie

CALSIM2 results were also used to specify boundary EC concentrations at Banks and Jones Pumping Plants for use in the simulations. Full-period runs with QUAL were conducted for the 73-year period of water years 1922 to 1994. Results demonstrate the damping capacity of San Luis Reservoir on annual EC fluctuations in the Aqueduct.

The planning mode version of the DSM2 Aqueduct Model can be used to ascertain changes to the Aqueduct system (flow and water quality) associated with significant changes in flow or water quality conditions at Banks Pumping Plant and/or Jones Pumping Plant. Several potential actions under review in the Delta, including pumping curtailments associated with the decline of pelagic organisms and also the re-plumbing of the system (Through-Delta Facilities, Franks Tract, and other projects concepts), could be studied with the planning mode version of the DSM2 Aqueduct Model to determine the impacts of these potential Delta actions on Aqueduct water quality.

SECTION 5

Task 4: Forecast Mode Implementation Plan

Task 4 outlined a plan to implement the DSM2 Aqueduct Model in forecast mode. The following discussion includes a brief review of ongoing forecasting activities, discusses the data needs for running the DSM2 Aqueduct Model, provides sources for the required data, and outlines an implementation plan to run the model in forecasting mode.

Review of Current Forecasting Activities

The Task 4 memorandum provides a review of forecasting activities related to the SWP and CVP being conducted by DWR SWP Operations Control Office (SWP OCO), CVP Operations Office (CVO), and DWR Operations and Maintenance and DWR Power Forecasting and Scheduling. These forecasting activities will provide model input for Aqueduct forecasts. Task 4 also included the description of all data required to run the DSM2 Aqueduct Model in forecast mode:

- Current conditions required to initialize the model
- Boundary flows and water quality at Banks and Jones Pumping Plants
- Deliveries and diversions from the aqueduct and DMC
- San Luis Reservoir and Gianelli Pumping-Generating Plant operations
- O'Neill Pumping-Generating Plant operations
- Groundwater pump-ins and stormwater inflows

Summary of Implementation Plan

A detailed implementation plan is provided in the Task 4 technical memorandum, following discussions of the goals of forecasting activities, model accuracy, and assumptions involved in the development of the implementation plan. The implementation plan was developed to maintain consistency with current DSM2 Delta forecasting activities. The five-step plan includes discussion of data sources and retrieval, data formatting, modeling simulations, and processing and distribution of model results. The tasks required to implement the DSM2 Aqueduct Model in forecasting mode are summarized below.

Step 1: Data Retrieval

The primary sources of boundary condition data are DWR's Delta forecasts and Allocation Model. The Delta forecasts, whether short term or long term, will provide flow and water quality time series data for Banks and Jones Pumping Plants. The Allocation Model will provide the basis for specifying diversions along the Aqueduct and San Luis Reservoir operations. Tables 1 through 3 provide detailed listings of (1) the data source and contacts, (2) data collection issues, and (3) required pre-processing tools.

TABLE 1
Contacts for Required Data
DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal Phase 2 Analysis

Name	Agency	Department	Phone and e-mail
Tracy Hinojosa Operations Control Office	DWR	Delta Compliance and Modeling	tracyh@water.ca.gov 916-574-2655
Abdul Khan	DWR	Delta Compliance and Modeling	akhan@water.ca.gov
Tracy Pettit	DWR	Water forecasts and scheduling	pettit@water.ca.gov (916) 574-2662
Molly White	DWR	Water forecasts and scheduling	mwhite@water.ca.gov 916-574-2651
Tuan Bui Senior Engineer	DWR	Power forecasts and scheduling	tbui@water.ca.gov 916-574-2663
Ted Swift Municipal Water Quality Investigations	DWR	Office of Water Quality, Real Time Data and Forecasting Project	tswift@water.ca.gov 916-651-9694
Paul Fujitani Chief, Water Operations Division	Reclamation	CVO Forecasts	pfujitani@mp.usbr.gov 916-979-2197

TABLE 2
Summary of Data Requirements for Aqueduct Forecasting Model
DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal Phase 2 Analysis

DATA ISSUES										
DSM2 Aqueduct Data File Name	Description	Physical Location	Model ID/Node # (If Applicable)	Period		Temporal Resolution	Potential Data Source	Pre-processing Tool Reference	Major Issues (If Any)	Comments
				From	To			Pre-processing Tool Name		
Boundary_daily.dss	Banks Flow	Banks Pumping Plant	Node 400	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "HRO" has daily flow
Boundary_daily.dss	Jones Flow	Jones Pumping Plant	Node 100	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "TRP" has daily flow
Balance_final.dss	Contractor Diversions/Deliveries	Turnouts in Aqueduct and DMC	Various	Start of simulation	End of simulation	Monthly or daily	SWP/CVP Allocation and Contractor requested deliveries	Contractor Deliveries Mapping Tool	Critical item; will require significant effort both in terms of conceptualization and implementation.	Obtaining contractor delivery requests could be an issue. EXCEL tool will disagregate SWP and CVP Allocations to appropriate DSM2 nodes.
Boundary_daily.dss	Gianelli Pumping/Generating Plant Operations	Gianelli Pumping - Generating Plant	Reservoirs "SANLUISR" and "ONEILLR"	Start of simulation	End of simulation	Daily or hourly	DWR Power Operations Forecasts and historic hourly flow data	Reservoir Operations Tool	Some issues, but can be addressed with some effort.	Substantial work required; DWR forecasts are done monthly with shorter term forecasts available for 1 week.
Boundary_daily.dss	O'Neill Pumping/Generating Plant Operations	O'Neill Pumping - Generating Plant	Reservoir "ONEILLR" and DMC Node 280	Start of simulation	End of simulation	Daily or hourly	DWR Power Operations Forecasts and historic hourly flow data	Reservoir Operations Tool	Some issues, but can be addressed with some effort.	Substantial work required; DWR forecasts are done monthly with shorter term forecasts available for 1 week.
Balance_final.dss	Stormwater Inflow rates	Various	Various	Start of simulation	End of simulation	Event	Historic inflow data and precipitation forecasts	Stormwater Inflows	Some issues, but can be addressed with some effort.	Stormwater inflows are expected to be negligible except during extreme rainfall events.
Balance_final.dss	Kern River Intertie Inflow	Kern River Intertie	Node 431	Start of simulation	End of simulation	Event	Realtime Kern River Flow and flow forecasts	Kern River Intertie Flows	Some issues, but can be addressed with some effort.	Kern River flow forecasts (at Lake Isabella) available from California/Nevada River Forecast Center (www.cnrfc.noaa.gov)
Balance_final.dss	Groundwater Inflow rates	Various	Various	Start of simulation	End of simulation	Event	Water agency estimates; historical daily pump-in records		Some issues, but can be addressed with some effort.	Substantial work required; availability of forecasts unknown. Could estimate monthly inflows based on recent historical data.
All_EC_daily.dss	Banks EC	Banks Pumping Plant	Node 400	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "HBP" has hourly EC
All_EC_daily.dss	Jones EC	Jones Pumping Plant	Node 100	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "DMC" has hourly EC
All_EC_daily.dss	Inflow (stormwater, groundwater) EC	Various	Various	Start of simulation	End of simulation	Event	Historic groundwater water quality records (MWQI program)		Some issues, but can be addressed with some effort.	Substantial work required; survey of historic SW and GW EC could provide range of estimates; without real time monitoring assumptions will be required
*.hrf restart file	Initial Stage	Entire Model Grid	All	Start of simulation	N/A	Real Time	Realtime data (CDEC)	(input formatting only)	No major issues.	CDEC stations with hourly stage: SNL and ONF; channel stages from historical simulation
reservoirs.inp	Initial Reservoir Elevations	San Luis Reservoir, O'Neill Forebay	SANLUISR and ONEILLR	Start of simulation	N/A	Real Time	Realtime data (CDEC)	(input formatting only)	No major issues.	CDEC Stations ONF and SNL have hourly reservoir elevations
*.qrf restart file	Initial EC	Entire Model Grid	All	Start of simulation	N/A	Real Time	Realtime data (CDEC)	EC Interpolator	No major issues.	CDEC Stations ONF and SNL have hourly reservoir elevations

TABLE 3
Summary of Suggested Pre-processing Tools
DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal Phase 2 Analysis

PRE-PROCESSING TOOLS ISSUES

DSM2 Aqueduct Data File Name	Pre-processing Tool Name	Pre-processing Tool Function	Model ID/Node # (If Applicable)	Pre-processing Input/Output		Recommended Platform	Major Issues (If Any)	Comments	LOE Estimate for Tool Development (Person Days)
				Input	Output				
Balance_final.dss	Contractor Deliveries Mapping Tool	Map proposed contractor deliveries to DSM2 nodes in the Aqueduct and DMC	Various	SWP Allocation and contractor delivery requests	Time series of diversions and deliveries	Excel/VB	Critical item; will require significant effort both in terms of conceptualization and implementation.	Obtaining contractor delivery requests could be an issue. EXCEL tool will disagregate SWP and CVP Allocations to appropriate DSM2 nodes.	10
Boundary_daily.dss	Reservoir Operations Tool	Develop Time series for flows into and out of San Luis Reservoir and O'Neill Forebay through Gianelli and O'Neill Pumping-Generating Plants	Reservoirs "SANLUISR" and "ONEILLR"	DWR Power Operations Forecasts and historic hourly flow data	Time series of flows through Gianelli and O'Neill P/G plants	Excel/VB	Some issues, but can be addressed with some effort.	Review of historic data indicates significant variations in intraday operations, such that use of daily average flows could mischaracterize salinity transport into and out of San Luis Reservoir.	5
Balance_final.dss	Stormwater Inflows	Develop tool to assign predicted stormwater inflows to appropriate DSM2 nodes	Various	Historic inflow data and precipitation forecasts	Stormwater inflows for DSM2 nodes	Excel/VB	Some issues, but can be addressed with some effort.	OCO reports list inflows into pools 17, 18, 19, and 21 (Nodes 419, 420, 421, and 423)	4
Balance_final.dss	Groundwater Pump-ins	Develop tool to assign predicted groundwater pump-ins to appropriate DSM2 nodes	Various	Historic inflow data and forecasts	Groundwater pump-ins for DSM2 nodes	Excel/VB	Some issues, but can be addressed with some effort.	Will require coordination with individual water agencies, predictive capability is unknown	4
Balance_final.dss	Kern River Intertie Flows	Develop tool to predict Kern River Intertie flows into California Aqueduct	Node 431	Kern River real time flows (CDEC Station "ISB" and Kern River flow forecasts	Kern River Intertie Inflow to Aqueduct	Excel/VB	Some issues, but can be addressed with some effort.	Kern River flow forecasts (at Lake Isabella) available from California/Nevada River Forecast Center (www.cnrfc.noaa.gov)	3
*.qrf restart file	EC Interpolator	Interpolate real time EC at select locations for specification of initial EC conditions throughout DSM2 model grid	All Nodes	Real Time EC from CDEC	Initial EC values for every node/reservoir	Excel/VB	Some issues, but can be addressed with some effort.	CDEC Stations with real time (hourly) EC: Aqueduct Checks 13, 21, 29, 41, and 66; Jones PP (DMC), Banks (HBP), San Luis Res (PPP), and O'Neill Intake (ONI). Real time EC data is no longer available at Checks 12 and 18.	3

Step 2: Data Processing and Quality Review

The retrieved data must be reviewed for quality and formatted for use in the DSM2 Aqueduct Model. To develop and format data to address required inputs, several tools with the following functions must be created:

- Map proposed contractor deliveries from DWR's Allocation Model and CVP's Allocation Model to DSM2
- Develop flow time series for exchanges between O'Neill Forebay, San Luis Reservoir, and DMC.
- Predict Kern River Intertie flows (correlate real-time flow measurements on the Kern River to flows into the aqueduct)
- Predict stormwater inflows (relate real-time rainfall data to projected storm water inflows to the aqueduct)
- Predict groundwater pump-ins and assign to appropriate nodes
- Interpolate between real-time EC check measurements to generate EC values for all DSM2 grid nodes to specify initial water quality conditions in the aqueduct

Step 3: Model Simulations

Model simulations should be conducted on a weekly basis following the release of Delta forecasts by DWR staff.

Step 4: Processing and Review of Model Results

After model simulations are completed, the results must be carefully processed and reviewed for reasonableness. A standard set of figures and tables should be developed at select locations in the system.

Step 5: Distribution of Model Results

Model results can be disseminated to interested stakeholders following the weekly model simulation and analysis of results. A weekly report could provide a summary of near-term forecast conditions and real-time conditions in the aqueduct.

Limitations of Forecasting Model

It is important to understand the potential limitations associated with the DSM2 Aqueduct Model for application to short-term and long-term forecasts. These limitations were described in the Phase 1 report (CH2M HILL, 2005) and include proper specification of flows that achieve a mass balance, the variability in actual daily diversion and the compromise of using monthly averaged diversions, the treatment of reservoirs as completely and instantaneously mixed, and the representation of gate structures and their influence on average flow in the Aqueduct. Potential limitations associated with the forecast application follow:

- For short-term forecasts, the ability to adequately forecast boundary flows, including inflows and diversions, influences the quality of the forecasts. Contractors' diversions are not easily forecasted; daily diversions from the aqueduct may be considerably higher or lower than requests by individual contractors. Currently, there is no short-term (weeks to months) forecast of contractors' diversions aside from the Allocation Model. The Power Forecasting and Scheduling group makes short-term (1 week) estimates for contractors' diversions; these estimates rely heavily on recent contractor diversion patterns. These data, however, are often forecasted for only a week in the future.
- For short-duration forecasts, recent observed data specifying flow and water quality conditions at Banks and Jones Pumping Plants could be used for boundary conditions. In particular, if short-duration forecasts of conditions in the southern portion of the Aqueduct are desired, conditions in the Aqueduct may be controlled by antecedent conditions at Banks and Jones Pumping Plants rather than future forecasted conditions.
- As discussed above, the primary limitation on the long-term predictive capability of the DSM2 Aqueduct Model is the accuracy of forecasts from the Delta model. The DSM2 Delta model, in turn, is limited by the accuracy in simulating hydrodynamics and water quality in the Delta, as well as the accuracy of predicted hydrology used in the Delta model. The Aqueduct is primarily a conveyance system, and thus conveys EC from Banks and Jones Pumping Plants to the terminal reservoirs, with offstream storage in San Luis Reservoir offering minor complications. Compared to the potential variation in EC at the Banks and Jones Pumping Plants, boundary conditions (diversions) in the Aqueduct have a relatively minor influence on the water quality at the aqueduct terminus; misrepresentations of diversions may introduce errors in predicted travel time through the system, but in simple terms, the EC at the upstream end will be conveyed to the downstream end of the system, so proper specification of EC at the upstream boundaries is critically important.
- Improvements in forecasting accuracy may be possible with the installation of an additional water quality monitoring station in San Luis Reservoir adjacent to the inlet/outlet works. Real-time EC data could be used for specification of initial conditions and even as a boundary condition for short-period simulations.

SECTION 6

Conclusions and Recommendations

Task 1 Conclusions and Recommendations

- The DSM2 Aqueduct Model was used to determine travel time through the aqueduct system for the full range of expected flows in the Aqueduct. As expected, travel times decrease with increasing upstream flow. This inverse relationship is generally true between the travel times and flow through Dos Amigos Pumping Plant, since this flow serves as the primary flow boundary condition for the aqueduct below O'Neill Forebay. Travel times between Banks and O'Neill Forebay are not necessarily related to flow at Dos Amigos, but are correlated to flows at Banks Pumping Plant. Flows at Banks and at Dos Amigos are not expected to be related because of draining and filling patterns associated with San Luis Reservoir.
- The complexity of the operations of the aqueduct system is such that simplistic relationships between travel time and upstream flow are not adequate to assess travel time through the system. Model results show the dynamic nature of the operations of the aqueduct and the effect that the location and timing of the diversions have on the travel time through the system. Deviations from the expected inverse relationship between upstream flow and travel time through a given reach are associated with diversions from the aqueduct system. Travel times show a better correlation to the net flows through a reach than they do to the upstream inflow to a reach.
- Aqueduct modeling for emergency response planning, near-term planning, or real-time forecasting analyses needs to include the use of real-time, or best estimates of, boundary condition flows (Banks and Jones Pumping Plants) and system diversions to provide a reasonable basis for simulating the dynamics of aqueduct operations and developing estimates of system travel times. Data quantifying the volume and water quality of turn-ins in the southern portion of the aqueduct system would improve model results.

Task 2 Conclusions and Recommendations

- Changes in the geometric representation of San Luis Reservoir were implemented with the goal of reducing errors between predicted and measured EC in San Luis Reservoir and points downstream. The flow and EC boundary conditions, specifically the method used to fill gaps in historic data, were also investigated in order to improve predictive performance. Results indicate that while the model results were not appreciably improved with alternative geometric representations of San Luis Reservoir, the improvement in applying boundary conditions yielded reductions in RMS error in measured EC at Check 12 on the order of 9 percent from the Phase 1 calibration simulation.

- Groundwater pump-ins and other local inflows may contribute for a portion of the differences between measured EC at Jones Pumping Plant and Check 12 on the DMC. Quantification of the volume and water quality associated with these inflows will improve the predictive capacity of the model.
- Field data indicate that there is generally very little variation in EC throughout the water column in San Luis Reservoir, and thus it may be unnecessary to model San Luis Reservoir with distinct upper and lower layers. Additional data collection (profiles of EC near the dam) would provide valuable information on whether the entire reservoir shows the same vertical structure as the profiles collected near the Pacheco Pumping Plant Intake.
- There is potential for minor improvements in the annual average EC in San Luis Reservoir through adjustments in standard operations. Adjustments to the annual filling pattern of San Luis Reservoir could result in minor reductions in San Luis Reservoir EC. Shifts in flow from October and November to February and March could lower annual average EC in San Luis Reservoir by a few percentage points. Water supply considerations must be taken into account when proposing changes to the annual filling cycle of San Luis Reservoir.
- Spring/neap variations do not seem to have a discernable influence on short term variations in EC in the vicinity of Clifton Court Forebay. Variations in operations at Clifton Court Forebay on a fortnightly basis are not likely to cause significant changes in EC concentrations in Clifton Court Forebay or San Luis Reservoir.

Task 3 Conclusions and Recommendations

- Planning mode applications were successfully implemented. The DSM2 Aqueduct Model was run in planning mode for a 73-year period using CALSIM2 model results as boundary conditions. An Excel-based tool was developed to apply flows from CALSIM2 as boundary data for use with DSM2. CALSIM2 results were also used to specify boundary EC concentrations at Banks and Jones Pumping Plants for use in the simulations. Full-period runs with QUAL were conducted for the 73-year period of water years 1922 to 1994. Results demonstrate the damping capacity of San Luis Reservoir on annual EC fluctuations in the Aqueduct.
- The planning mode version of the DSM2 Aqueduct Model can be used to ascertain changes to the Aqueduct system associated with significant changes in flow or water quality conditions at south-of-Delta export facilities. Several potential actions under review in the Delta, including pumping curtailments associated with pelagic organism decline, and physical and operational changes to the system, could be studied with the planning mode version of the DSM2 Aqueduct Model.

Task 4 Conclusions and Recommendations

- Forecast simulations for Aqueduct water quality and hydraulics will complement current Delta forecast simulations conducted by DWR. Some data required to run short-term forecasts with the aqueduct model are not readily available. For certain data, assumptions will have to be made to develop daily patterns from monthly forecasts.

- Initialization of the DSM2 Aqueduct Model should be feasible by obtaining observed data from the IEP and CDEC Web sites. A script similar to that developed by DWR for initialization of the Delta model should be developed. The script should be written to interpolate values between locations with available EC data to provide initial condition data for all nodes in the aqueduct model grid.
- The tabulation of required data will require assistance from several agencies who have developed forecasting models of their own (DWR, Bureau of Reclamation). Reclamation, for example, has developed estimates of monthly delivery patterns to CVP contractors on the DMC based on historical data. These estimates vary with the annual allocation level. This work could be adopted for use in forecasting studies with approval from Reclamation.
- The quality of the forecast simulations will be heavily influenced by boundary conditions at Banks and Jones Pumping Plants. DWR's forecasting simulations should be analyzed to estimate the magnitude of average errors between DWR Delta forecasts (water quality at export locations) and actual field measurements. This will allow for a description of the potential errors introduced into the DSM2 Aqueduct Model at the boundaries.
- The current real-time data-collection system is adequate for running the model in forecast mode for the prediction of salinity. Improvements in forecasting accuracy may be possible if an additional water quality monitoring station is installed in San Luis Reservoir adjacent to the inlet/outlet works. Accurate simulation of other constituents of concern (such as organic carbon) will require deployment of additional data-collection instrumentation throughout the system.
- Finally, it is suggested that an up-to-date historical simulation of the aqueduct and DMC be maintained. This would involve appending the time series files prescribing all boundary conditions on a weekly basis with recent in-Delta and aqueduct flow and EC measurements.

Appendix A:
Task 1 Technical Memorandum

Phase II DSM2 Extension for the California Aqueduct: Task 1 - Tracer Tests for Determination of Travel Time

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DATE: June 12, 2007

Introduction

This Technical Memorandum is the first of four detailing tasks completed under Phase II of the DSM2 Extension for the California Aqueduct Project. This Task investigated the travel time of a numerical tracer slug through the system for ten specific flow conditions expected to represent the full range of possible flow conditions in the California Aqueduct. Work completed under this task made use of the model developed under Phase I of this project.

The Phase 1 model was constructed and calibrated for both flow and water quality for a three year period (1/1/2001 to 12/31/2003). The model includes the main branch of the California Aqueduct, the East Branch through Silverwood Lake, the West Branch through Pyramid Lake, the South Bay Aqueduct through the Santa Clara Tank, and the Delta Mendota Canal to the Mendota Pool. The Coastal Branch is treated as a diversion in the model; it is not specifically modeled.

The purpose of this task is to determine the travel time through the aqueduct for the full range of operational flows for use in water quality planning and/or emergency response coordination.

Approach

The calibrated Phase 1 DSM2 Aqueduct model was used to estimate travel times of a numerical tracer slug through the aqueduct system. Historical flow records at various locations along the aqueduct were analyzed to determine appropriate flows for use in the tracer simulations. Two sets of five model runs were made representing the full range in expected flow conditions through the system; the first set (TRCR1 through TRCR5) was based on flows through Dos Amigos Pumping Plant, and the second set (TRCR6 through TRCR10) was based on flows through Banks Pumping Plant. Together, the ten simulations identify the travel time from the Banks Pumping Plant to the terminal reservoirs. Results of the model simulations are presented in both tabular and graphical format. Summary tables indicate the travel time to each major system component (check structures, reservoirs, and pumping plants).

Assumptions/Definitions

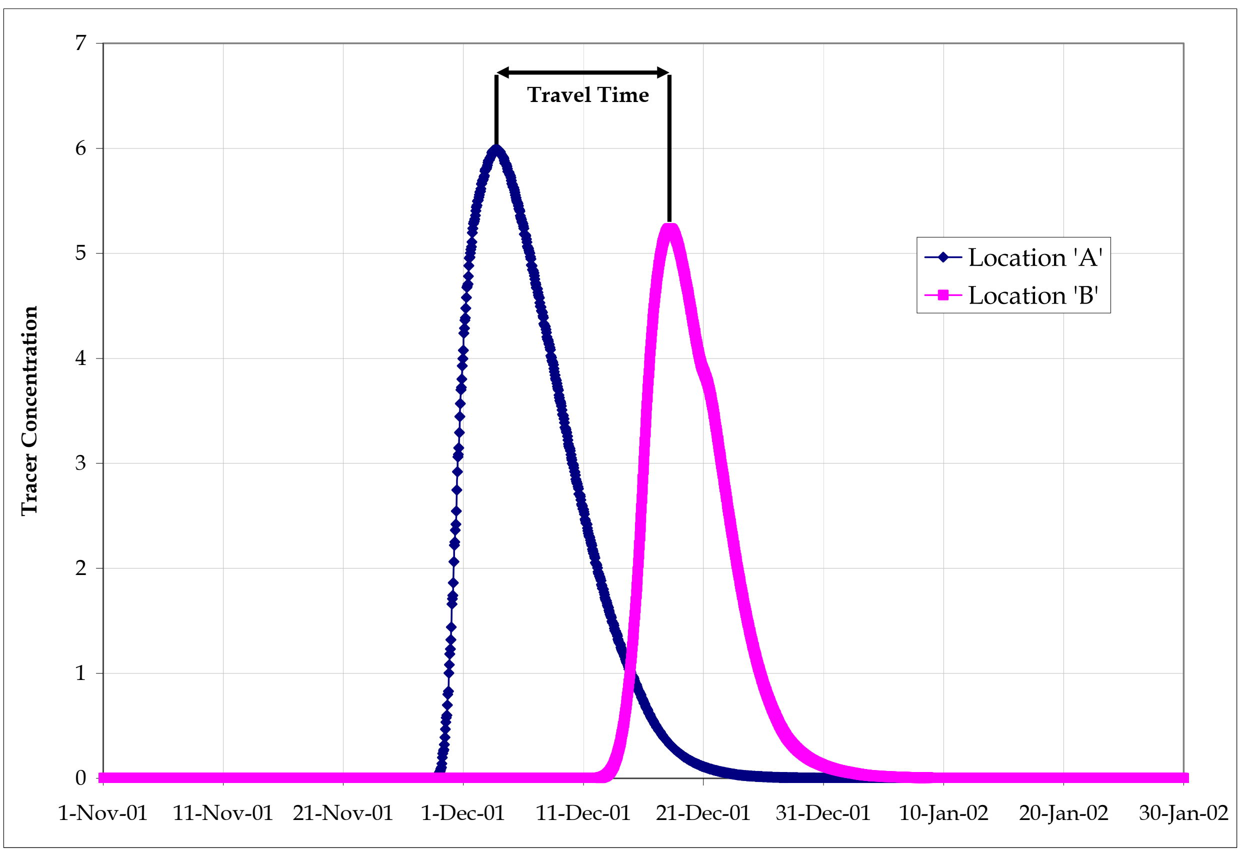
Tracer

Electrical Conductivity (EC), which was used to calibrate water quality component of the DSM2 Aqueduct Model during the calibration process, was chosen as the conservative tracer to estimate the travel times through the California Aqueduct in this task. The tracer slug was applied as a constant EC concentration of 100 µmhos/cm for a 24-hour period at Banks Pumping Plant.

Travel Time

The time for a tracer concentration to peak at any given location 'B' along the Aqueduct relative to the peaking time at an upstream location 'A' was assumed as the travel time between locations 'A' and 'B' in this task (Figure 1). As noted above, the tracer application at Banks was uniform over a 24-hr period. Therefore, travel time from Banks was calculated from the middle of the 24-hr period of the tracer application (hour 12 of the 24-hour application).

Figure 1. Definition of Travel Time



Methodology

Selection of Flows

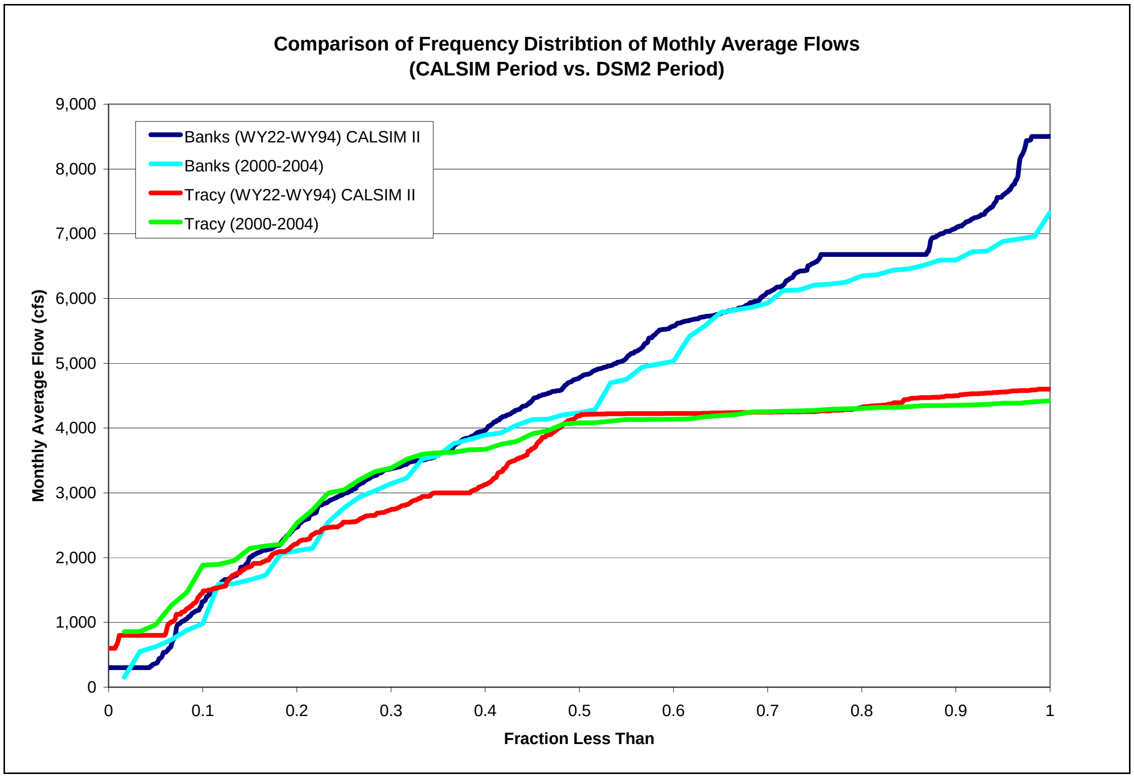
Travel time through the aqueduct system is primarily a function of flow rate, considering the constant-volume method in which the system is operated. Channel flow rates depend on the pumping flows and the channel diversions. Flow rates at Banks Pumping Plant and Dos Amigos Pumping Plant are the primary controlling influences for the majority of the system. The filling and release operations of San Luis Reservoir can influence the travel time as well as the concentration of a conservative constituent moving through the aqueduct by affecting the residence time of the tracer in O'Neill Forebay and the downstream flow rate. For this reason the analysis presents travel times through several individual sections of the system, including the section from Banks Pumping Plant to O'Neill Forebay and the section from O'Neill Forebay to the Terminal Reservoirs.

Flow through Banks Pumping Plant establishes the travel time to O'Neill Forebay. The amount of pumping at Dos Amigos Pumping Plant controls the travel time through the majority of the California Aqueduct since it is located at Milepost 86.73 of the 400-mile long system. For this reason, the selection of flows for the first five travel time simulations focused on flow pumped through Dos Amigos.

The four-year flow and diversion dataset (January 2000 through December 2003) compiled during the Phase 1 investigation was analyzed to select a range of boundary flows to be used during the travel time investigations. Frequency distributions for all major boundary conditions were generated and used to select flows for use in the model simulations. Figure 2 presents these frequency distributions for flows at Banks, Tracy, Dos Amigos, and the accumulated diversions for the portion of the system represented in the Phase 1 model. Percentiles were calculated for the monthly averaged flow through Dos Amigos Pumping Plant.

Figure 2 demonstrates the similarities between the monthly average flow at Banks and Tracy for the full period used in the CALSIM II model (WY1922 to WY1994) and the 2000-2003 period used in the DSM2 Aqueduct model. The frequency distributions indicate that the CALSIM II model has slightly higher flows at Banks, on average, than the 4 year time period used in the DSM2 model development. Overall, the range of flows used to develop the tracer simulations is considered appropriate based on the comparison of the frequency distribution from the 72-years of CALSIM II simulation results. Two pumping rates bracketing the range of monthly average flows over the four year dataset (1901 cfs and 10,491 cfs) were chosen as the minimum and maximum boundary flows at Dos Amigos Pumping Plant. Three more values were selected such that they were approximately equally spaced between the maximum and minimum values. These five target flows capture the range of expected flows below O'Neill Forebay, and will provide enough data points to determine travel time curves for the full range of flow conditions.

Figure 2. Comparison of Flow Ranges as Tracy and Banks for Two Periods



Selection of Tracer Release Time

The calibration simulation inputs from Phase 1, including Dos Amigos and Banks pumping rates, were used to estimate the travel times in the ten scenarios. The original scope called for constant boundary conditions during the model simulations, but based on discussions with MWQI staff it was decided that this approach was not reflective of actual conditions, primarily because of the time required to traverse the system at the lowest flows, and indications in the historical flow record that low flows are short in duration. This setup takes into account the historical variability in the pumping rates, diversions, and other boundary conditions while estimating the travel times.

The tracer release dates for the first five simulations (TRCR1 through TRCR5), presented in Table 1, were chosen such that the average flow rate at Dos Amigos Pumping Plant was approximately equal to the target flows determined from the frequency analysis discussed above. The target flows were averaged over the approximate travel time for each flow, based on results of preliminary simulations.

Table 1: Summary of the target Dos Amigos pumping rates and the tracer release dates for the five Simulations

Simulation	Target Dos Amigos Pumping Rate (cfs)	Tracer Release Date
TRCR1	1901	11/24/2001
TRCR2	4048	1/26/2002
TRCR3	6196	8/13/2002
TRCR4	8343	7/15/2002
TRCR5	10491	7/5/2003

The five simulations, TRCR6 through TRCR10 were conducted to capture the range of flows through Banks Pumping Plant and thus the range of travel times through the upper portion of the California Aqueduct. The flows at Banks Pumping Plant in the first five simulations ranged from 5227 cfs to 6843 cfs, which is not representative of the possible range of flows.

In order to characterize the travel times from Banks Pumping plant to the entrance of O'Neill Forebay (Check 12) for the range of pumping rates expected at Banks, five target flows were selected for the TRCR6 to TRCR10 simulations based on the frequency analysis of the historical Banks pumping data. In the calibration simulation from Phase 1, five dates were identified with flows corresponding closely to five selected target flows to initiate the tracer release at Banks Pumping Plant. The flows and the dates for these five simulations are shown in Table 2.

Table 2. Summary of the target Banks pumping rates and the tracer release dates for the five simulations.

Simulation	Target Banks Pumping Rate (cfs)	Tracer Release Date
TRCR6	449	04/26/2003
TRCR7	2267	11/22/2003
TRCR8	4084	08/04/2001
TRCR9	5902	06/28/2003
TRCR10	7719	01/01/2002

Simulation Process

Results from the DSM2 HYDRO simulation from the final Phase 1 calibration run were used in the tracer (QUAL) simulations. EC concentrations were initialized at zero throughout the system at the start of each tracer simulation. The EC at Banks was prescribed as 100 μmhos/cm for a 24 hour period on the dates summarized in Tables 1 and 2. All other inflow boundary conditions were assigned a zero concentration. Model results in the form of hourly EC predictions were analyzed to determine the travel time of the tracer slug through the system.

Results

A post-processing tool was developed using MS-EXCEL to calculate the time at which the tracer concentration peaked at each location and to calculate the travel time through several sections of the aqueduct. The results presented in this section include the analysis of the EC output from the ten tracer simulations.

The tracer release dates were chosen so that the flows, averaged over an approximation of the travel time through the system for that flow, would evenly span the range of flows shown in Figure 2. Average flows were calculated using the actual travel time as determined in the study to check the assumption and ensure the flows used in the analysis were still adequately distributed through the full range of flows. The results of these calculations are summarized in Tables 3 and 4. Table 3 shows simulated flows at Dos Amigos averaged over the resulting travel time from Banks to Check 67; Table 4 lists Banks pumping rates averaged over the travel time from Banks to O'Neill Forebay.

Table 3. Check of Actual Dos Amigos Flows Averaged over Tracer Travel Time.

Simulation	Target Dos Amigos Pumping Rate (cfs)	Dos Amigos Pumping Rate Averaged Over Simulated Travel Time (cfs)
TRCR1	1901	1896
TRCR2	4048	3946
TRCR3	6196	7027
TRCR4	8343	8971
TRCR5	10491	10718

Table 4. Check of Actual Banks Flows Averaged over Tracer Travel Time.

Simulation	Target Bank Pumping Rate (cfs)	Banks Pumping Rate Averaged Over Simulated Travel Time (cfs)
TRCR6	449	561
TRCR7	2267	2267
TRCR8	4084	4017
TRCR9	5902	5841
TRCR10	7719	7719

The travel times from Banks Pumping Plant to Check 67 and O'Neill Forebay (Check 13) to Check 67 are presented in Table 5 for the first five simulations. The flows through the Dos Amigos Pumping Plant, averaged over the run-specific travel time, are presented as well. The travel time for the tracer slug from Banks Pumping Plant to Check 67 ranged from 12.42 days to 31.33 days, generally varying inversely with the amount of pumping at Dos Amigos Pumping Plant. The lack of consistent decrease in travel time with increase in flow at Dos Amigos (i.e. runs TRCR 4 and TRCR 5) can be explained by the level of diversions applied during each simulation, for it is the net flow in the system that is highly correlated to travel time, and not necessarily the flow at Dos Amigos. This is explained in more detail below.

Travel times from Banks Pumping Plant to O'Neill Forebay for the five simulations TRCR6 to TRCR10 are presented in Table 6. Travel times range from 21 days at low flow to less than 2 days at high flow.

Table 5. Summary of Travel Times from O'Neill Forebay Outlet (Check 13) to Check 67 (Inlet to Silverwood Lake) and Banks PP to Check 67

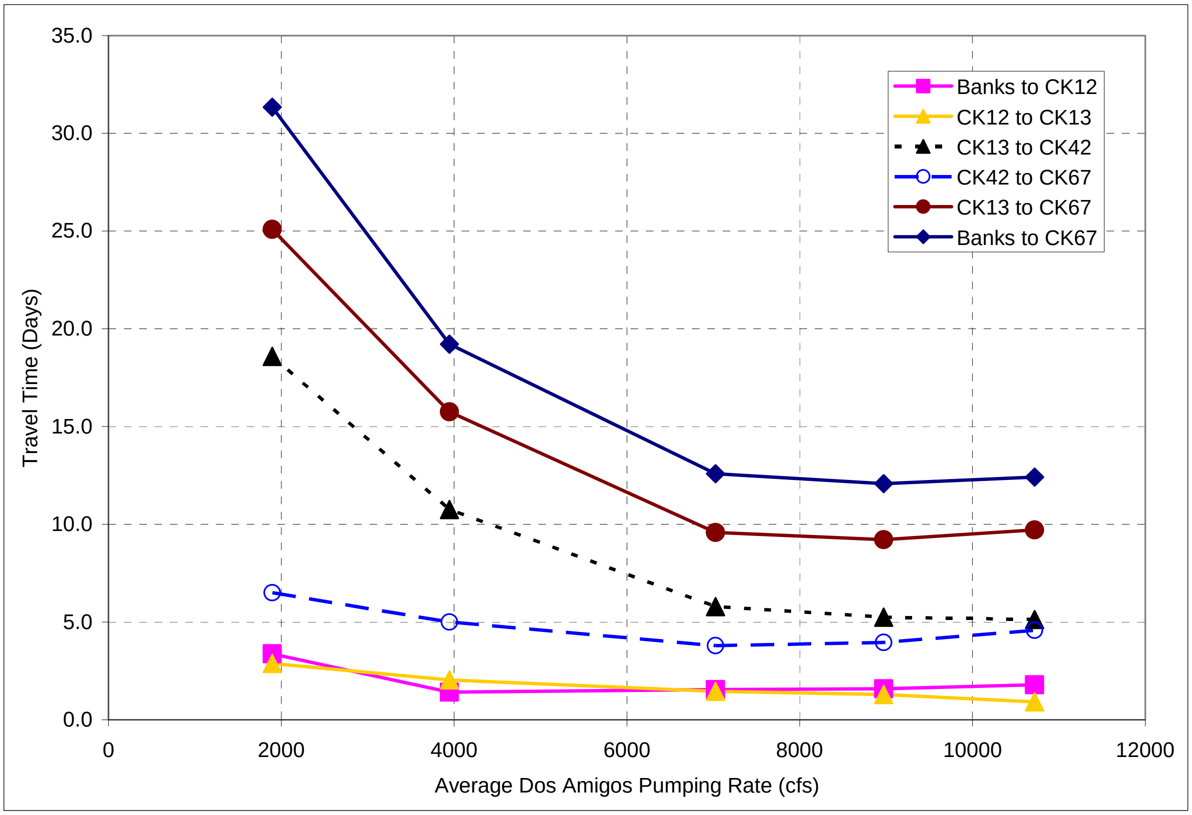
Simulation	Pumping Rate Averaged Over Travel Time (cfs)		Travel Time			
			CK13 to Check 67		Banks to Check 67	
	Banks	Dos Amigos	Days	Weeks	Days	Weeks
TRCR1	5227	1896	25.08	3.58	31.33	4.48
TRCR2	5893	3946	15.75	2.25	19.21	2.74
TRCR3	6836	7027	9.58	1.37	12.58	1.80
TRCR4	6744	8971	9.21	1.32	12.08	1.73
TRCR5	6843	10718	9.71	1.39	12.42	1.77

A series of plots have been generated to summarize the results of the travel time simulations conducted in this task. The plots demonstrate the relationship between flow and travel time through various portions of the system. Plots use both average flow at the upstream end of a particular reach (i.e. Dos Amigos flow), as well as average net flow through a reach, which takes into account channel diversions and deliveries. The net flows are calculated as the average of the simulated flow at every check structure on a given day. The aqueduct is managed to maintain a constant volume, and thus the flow through the system is proportional to the velocity. The travel time, however, is inversely proportional to the velocity (velocity = distance / time), hence the shape of the curves.

Table 6. Summary of travel time to O'Neill Forebay.

Simulation	Banks Pumping Rate Averaged Over Travel Time to Check 12 (cfs)	Travel Time from Banks to Check 12 (Days)
TRCR6	561	20.88
TRCR7	2267	4.75
TRCR8	4017	3.17
TRCR9	5841	2.13
TRCR10	7719	1.83

Figure 3. Travel Time vs. Average Flow through Dos Amigos (TRCR 1 through TRCR 5) (note: Refer to Table 5 for the Banks pumping associated with the Dos Amigos pumping)



The general inverse correlation between the average Dos Amigos pumping rate and the corresponding travel time through the aqueduct is shown in Figure 3. Results are presented for the full modeled system (Banks to Check 67, as well as the following sub-sections of the aqueduct in relation to Dos Amigos pumping rate:

- Banks Pumping Plant to O'Neill Inlet (Check 12; MP 66.71),
- O'Neill Inlet to O'Neill Outlet (Check 13; MP 70.88),
- O'Neill Outlet to West Branch diversion (Check 42; MP 305.0),
- O'Neill Outlet to entrance of Silverwood Lake (Check 67; MP 405.94), and
- West Branch Diversion to entrance of Silverwood Lake.

Figure 3 demonstrates that the travel time between Banks Pumping Plant and Check 12 is independent of flow through Dos Amigos Pumping Plant; this is expected considering the influence of San Luis Reservoir operations on flows at Dos Amigos.

Table 7 lists the computed travel times for the five scenarios representing the range of flows at Dos Amigos. Results are presented for four sub-sections of the aqueduct. Results presented in Table 7 do not always demonstrate decreased travel times with increased flow at Dos Amigos. The travel time from Banks to O'Neill Forebay is a function of flow at Banks, not Dos Amigos, so the results for Banks to Check 12 are indeed correct.

The pool diversions and deliveries along the aqueduct explain the counter-intuitive results demonstrating slight increases in travel time with increases in flow through Dos Amigos. The net flow results show the expected inverse relationship between travel time and flow through the system.

Table 7. Breakdown of Travel Time through California Aqueduct

	Travel Time (Days)			
Simulation	Banks to CK 12	CK 12 to CK 13	CK 13 to CK42	CK 42 to CK 67
TRCR1	3.38	2.88	18.58	6.50
TRCR2	1.42	2.04	10.75	5.00
TRCR3	1.54	1.46	5.79	3.79
TRCR4	1.58	1.29	5.25	3.96
TRCR5	1.79	0.92	5.13	4.58

Diversions from the aqueduct can be considerable when expressed as the fraction of the flow through a given reach. For example, 27% of the flow through Dos Amigos is diverted before Check 21, and 36% of the flow through Check 21 is diverted before Check 42 for the time periods used in the tracer simulations. The locations of the diversions, whether at the beginning or end of a given pool, will influence the travel time through that pool. In the model application, all diversions were aggregated and applied at the end of each individual pool. This may impart a bias on the predicted travel times, as the simulated travel times will be slightly higher than under actual conditions because a larger volume of flow is traveling through the entire length of the pool.

The travel time through a reach may be more strongly correlated with the net flow through the reach than the inflow to the reach depending on the magnitude of the diversions along the reach. Table 8 presents the net flows through the four sections of the aqueduct for which travel times are presented in Table 7. The net flows have been averaged over the individual travel time through each section for the simulation. Since the diversions have been accounted for, the net flows do not necessarily increase as a result of an increase in Dos Amigos flow. Even though the flow through Dos Amigos is 8971 cfs in “TRCR 4” and 7027 cfs in “TRCR 3”, the location and magnitude of the diversions and closure flows yield net flows that are slightly higher in “TRCR 3” between Check 42 and Check 67.

Table 8. Summary of Net Flows through Aqueduct Sections

	Average Pumping Rate (cfs)		**Average Net Flow Over Travel Time in each section (cfs)**			
Simulation	**Banks**	**Dos Amigos**	**Banks to O’Neill**	**Dos Amigos to Check 42**	**Check 42 to Check 67**	**Dos Amigos to Check 67**
TRCR1	5227	1896	5226	1680	945	1333
TRCR2	5893	3946	6092	2531	1033	1823
TRCR3	6836	7027	6504	4471	1575	3102
TRCR4	6744	8971	6456	5248	1484	3469
TRCR5	6843	10718	6595	5796	1406	3721

Figure 4 shows the travel times in the individual sections plotted against the average net flow between Dos Amigos Pumping Plant and the entrance to Silverwood Lake (Check 67).

Figure 4. Travel Times in Aqueduct Sections plotted against Average Net flow between Dos Amigos Pumping Plant and Silverwood Lake (note: Refer to Table 8 for the Banks pumping associated with the Dos Amigos pumping)

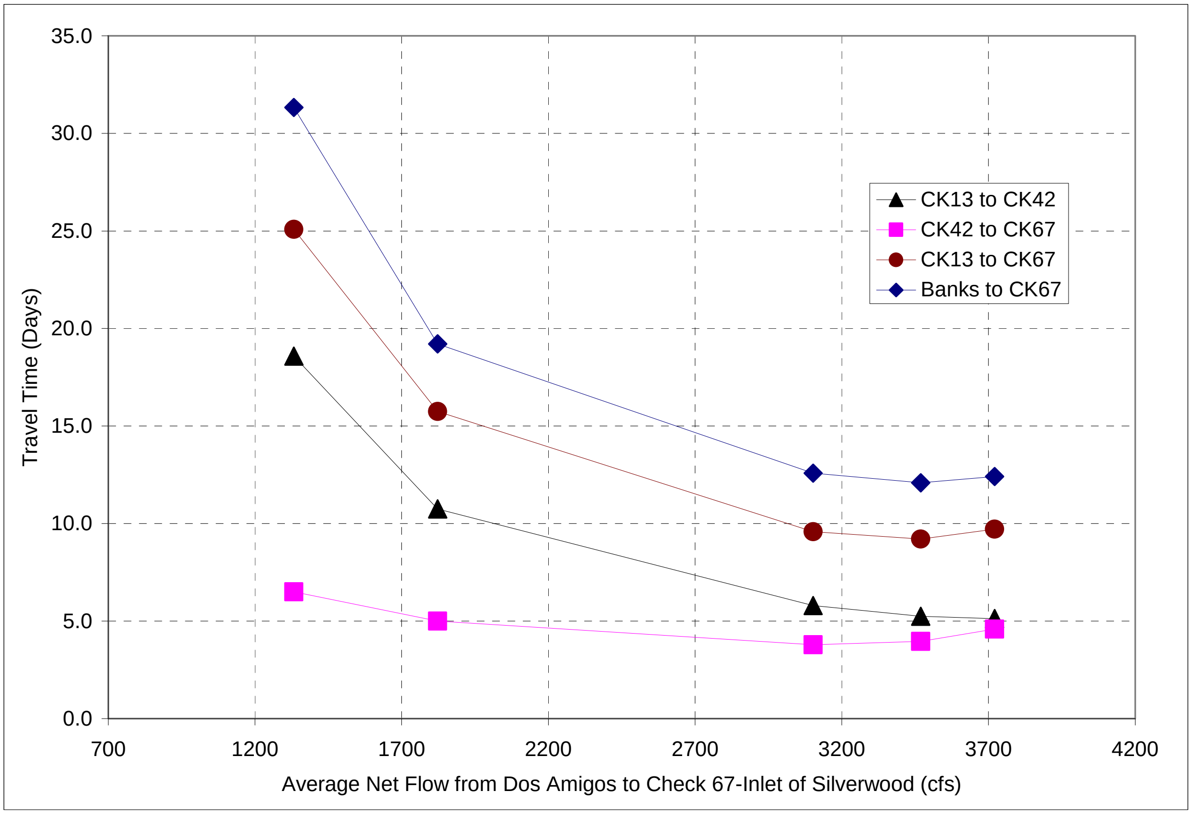


Figure 5. Travel Time from Check 13 to Check 42 and from Check 42 to Check 67

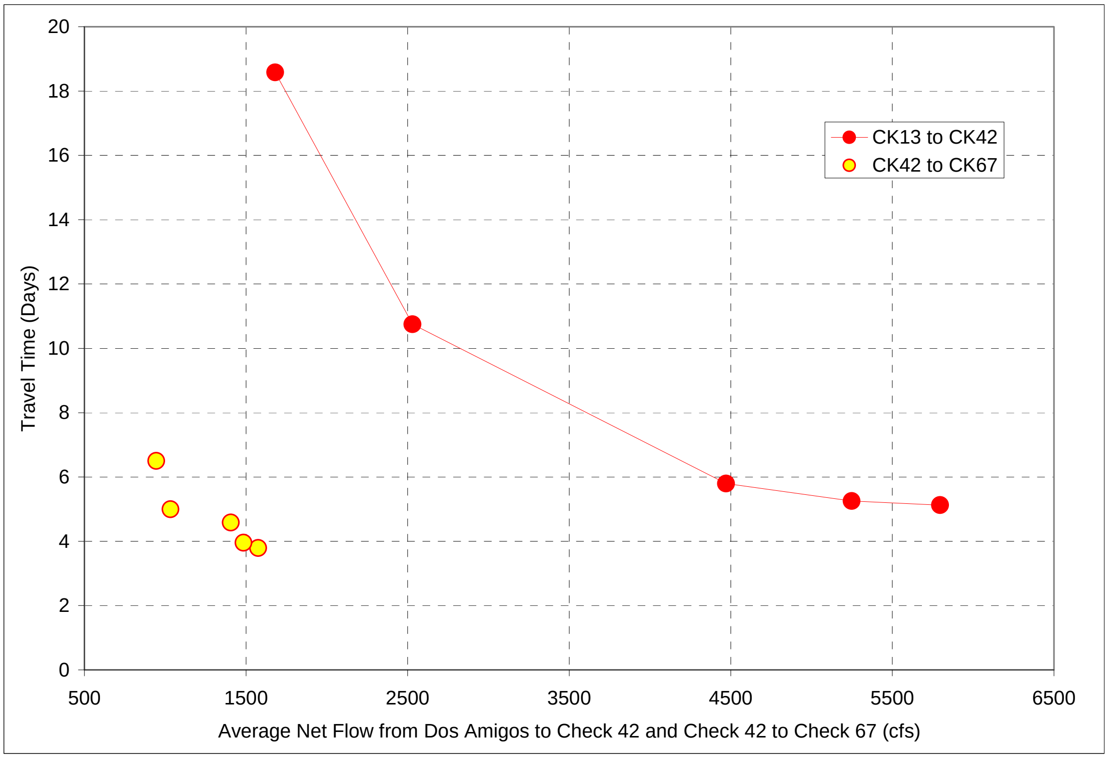
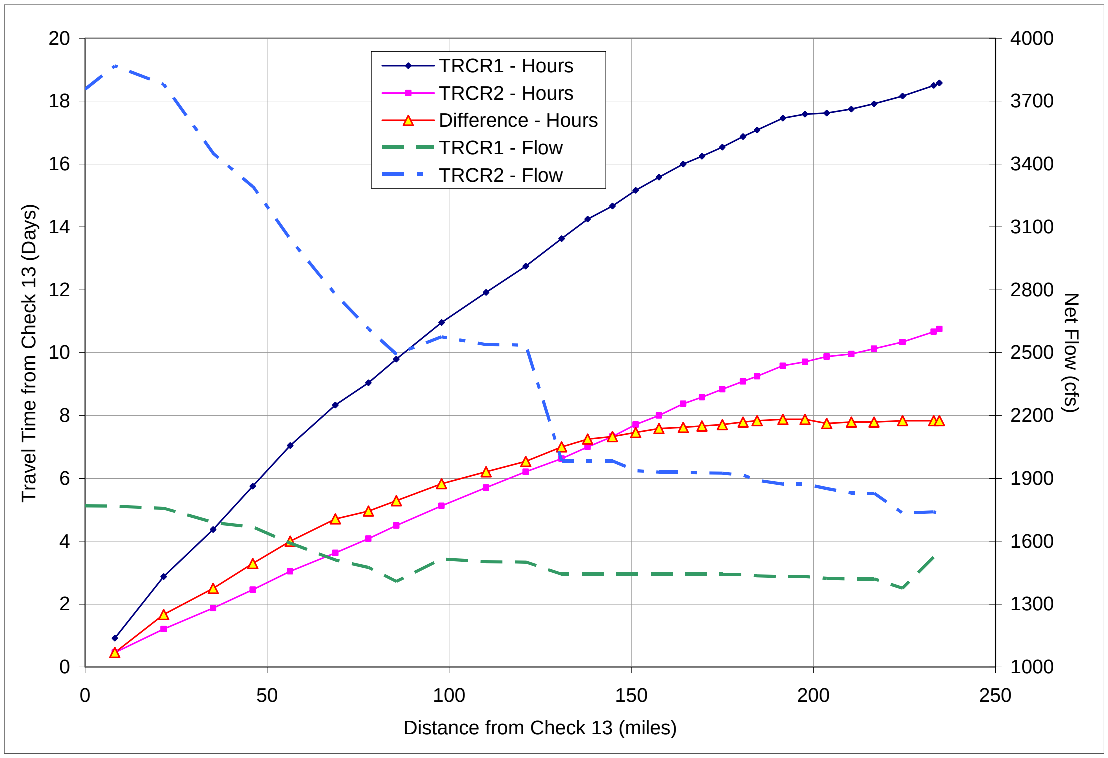


Figure 5 shows the variation in travel time as a function of net flow for the reaches from Check 13 to Check 42 and from Check 42 to Silverwood. The travel time shows an expected inverse correlation to the average net flow for both reaches. One important observation that can be made from this figure is the lack of variation in the flows and the travel times below Check 42. Despite the range in flows at Dos Amigos (1896 to 10718 cfs), the flow below Check 42 only varies from 945 cfs to 1575 cfs.

The influence of the spatial and temporal variability in the diversions and closure flows applied during the model calibration on the travel is demonstrated in Figure 6. In Figure 6, the travel time below Check 13 is presented for two simulations, TRCR1 and TRCR2, as is the average flow for at each check structure for these two runs. Notice that the variation in average flow is related to the difference in travel time between the two runs, as expected. The variation in flow along the aqueduct between TRCR 1 and TRCR2 diminishes in the downstream direction. The difference in travel time between the two runs occurs mainly because of the large difference in the flows through the upstream portion; the tracer travels at roughly the same speed in the lower portion of this section because of the similarity in flows between the two simulations, a direct result of larger diversions in TRCR2. There is relatively little change in travel time between the two simulations downstream of the 150 mile point below Check 13.

Figure 6. Comparison of Travel Times between Check 13 and Check 42 for TRCR1 and TRCR 2 with net flows.

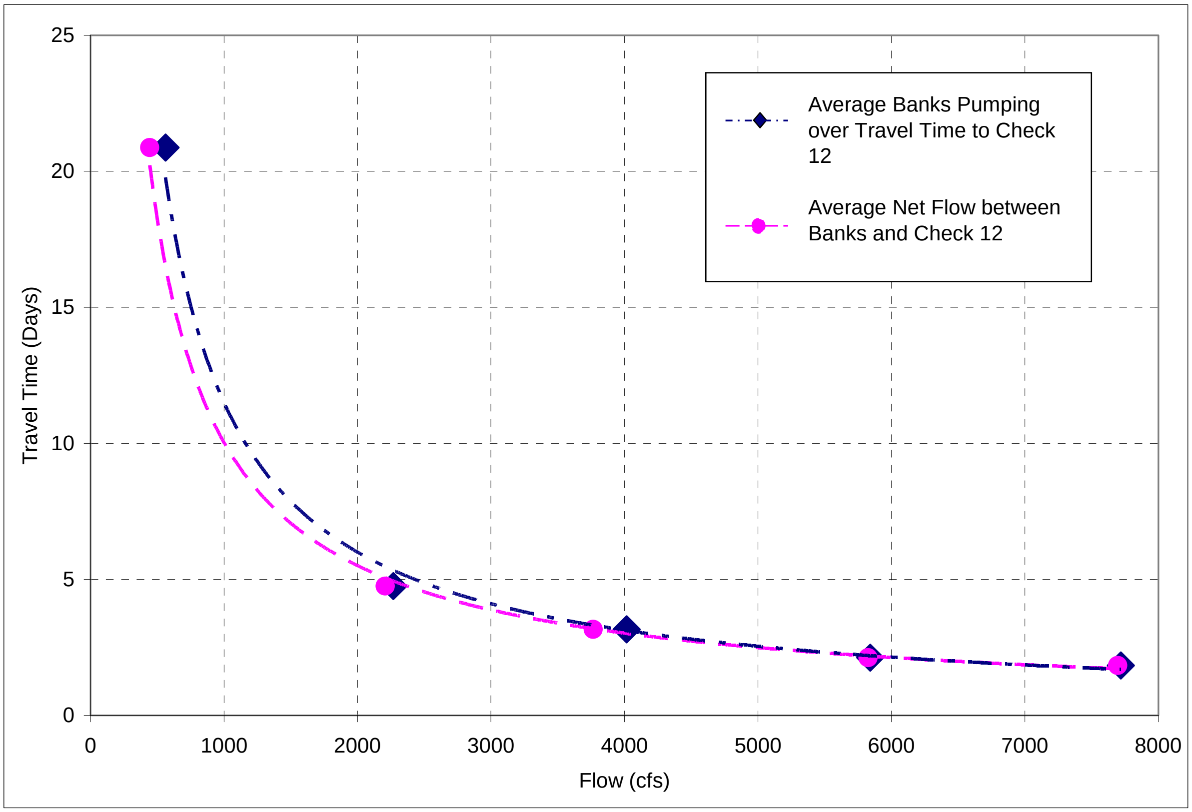


Results from the second set of travel time simulations (TRCR6 through TRCR10), which focused on travel from Banks to O'Neill Forebay, are summarized in Figure 7. Travel time results are plotted against Banks pumping and the net flow between Banks and O'Neill Forebay. The flows have been averaged over the travel time from Banks to O'Neill Forebay. The travel times exhibit the expected decrease with increases in the flow through Banks Pumping Plant. Trend lines have been added to Figure 7 considering the large difference in travel time between the two simulations with the lowest flows; the graphs should not be interpreted as piecewise linear between the data points, for this does not indicate the true inverse relationship, especially at low flows. Table 9 demonstrates that only a small fraction of flow is diverted in this reach, so the net flow is very similar to the Banks Pumping Plant flow.

Table 9. Banks pumping rates and Net Flow from Banks to O'Neill Forebay

Simulation	**Banks Pumping Rate Averaged Over Travel Time (cfs)**	**Average Net Flow from Banks to CK 12 over Travel Time (cfs)**
TRCR6	561	461
TRCR7	2267	2242
TRCR8	4017	3801
TRCR9	5841	5800
TRCR10	7719	7698

Figure 7. Travel time vs. average Banks pumping rate and average net flow to O'Neill Forebay (Check 12).



Figures 8 through 11 present travel times by distance along the aqueduct. These figures demonstrate the magnitude of decreases in travel time with increases in flow. Figure 8 shows the variation in travel time between Banks Pumping Plant and O'Neill Forebay for the first set of five tracer simulations. The anomaly in the travel time curves for the "TRCR1" and "TRCR 5" simulations stems from the flow regime at Banks immediately before the tracer simulation was initiated. The travel time to the first output location is compromised by the ramping up of the flow during the start of the simulation. Notice that the slope of the travel time curve from the second point onward is smaller than the other four curves; this is the true curve for this high flow scenario. Figure 9 shows the travel times for the section of the aqueduct between O'Neill and the bifurcation of the East and West Branches. Figure 10 shows the travel times for the East Branch of the aqueduct downstream of the bifurcation to Silverwood Lake. Figure 11 displays the travel times to each check structure between Banks Pumping Plant and the entrance to O'Neill Forebay (Check 12) for simulations TRCR6 to TRCR10.

A complete summary of travel time to individual check structures for the first five simulations (TRCR1 to TRCR5) is provided in Table 10, and results from the latter five simulations (TRCR6 to TRCR10) are summarized in Table 11.

Figure 8. Travel Time between Banks and O'Neill for Tracer Simulations (TRCR1 to TRCR5)

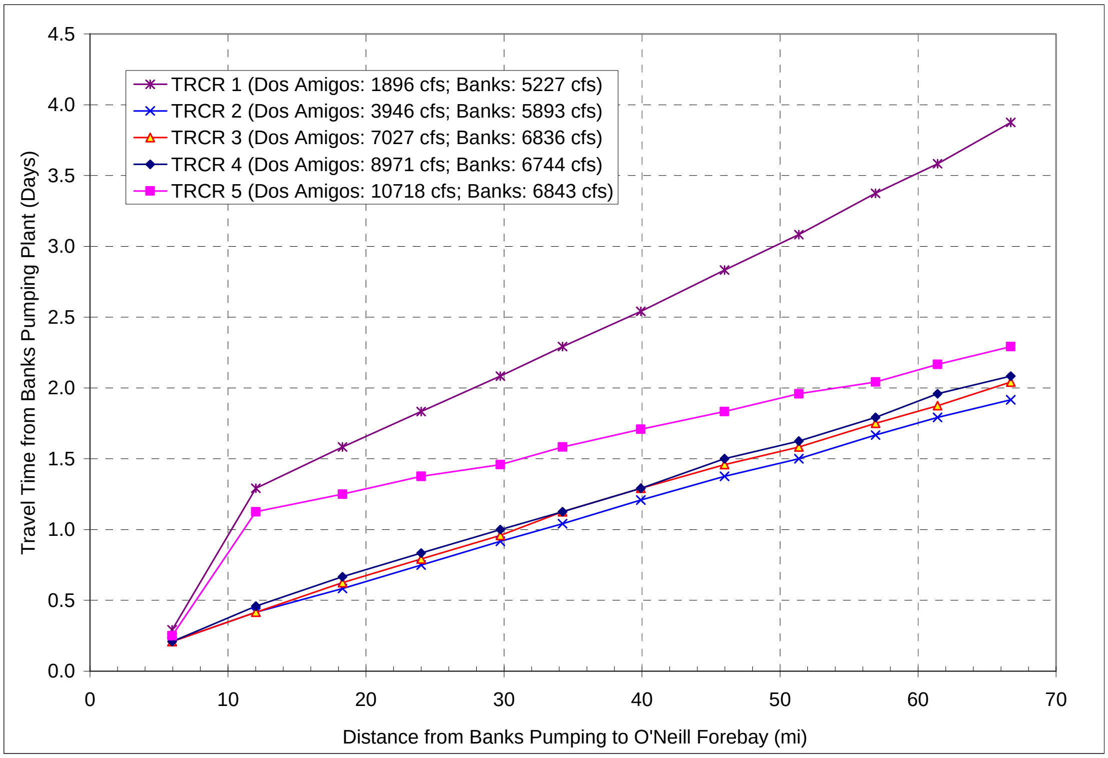


Figure 9. Travel Time from Banks to O'Neill Forebay through West Branch Diversion for Tracer Simulations (TRCR1 to TRCR5)

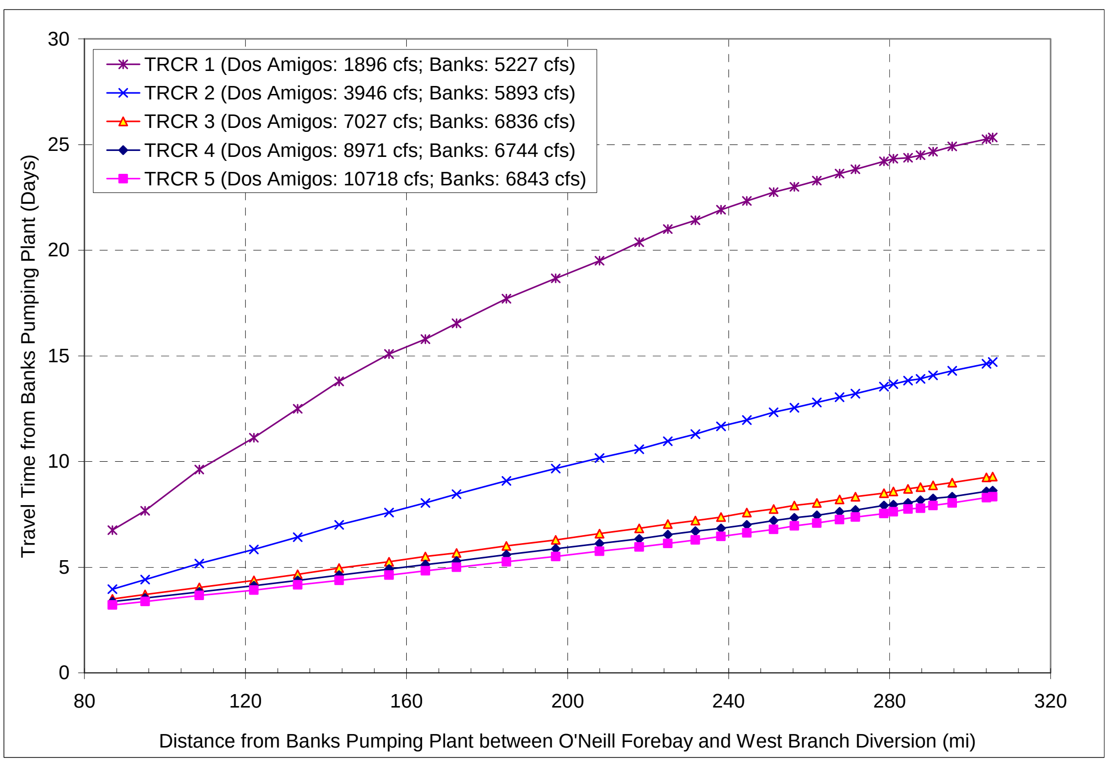


Figure 10. Travel Time from Banks to West Branch Bifurcation through Silverwood

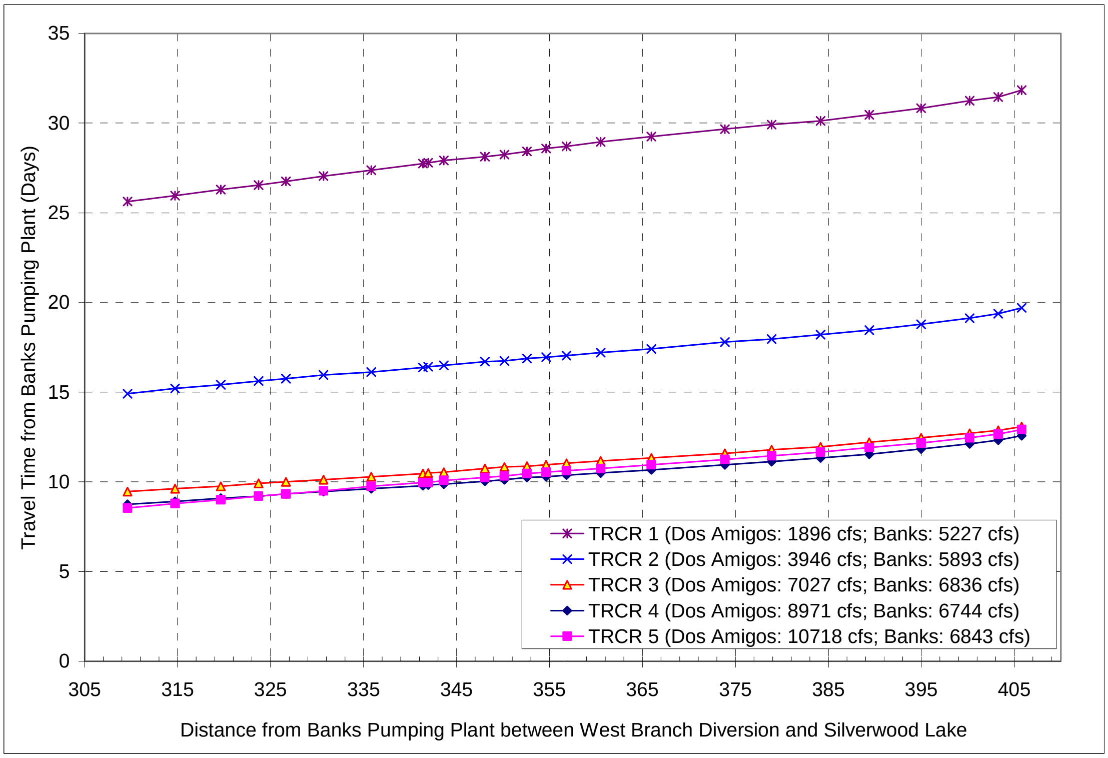


Figure 11. Travel Time between Banks Pumping Plant and O'Neill Forebay for the five tracer simulations (TRCR6 to TRCR10)

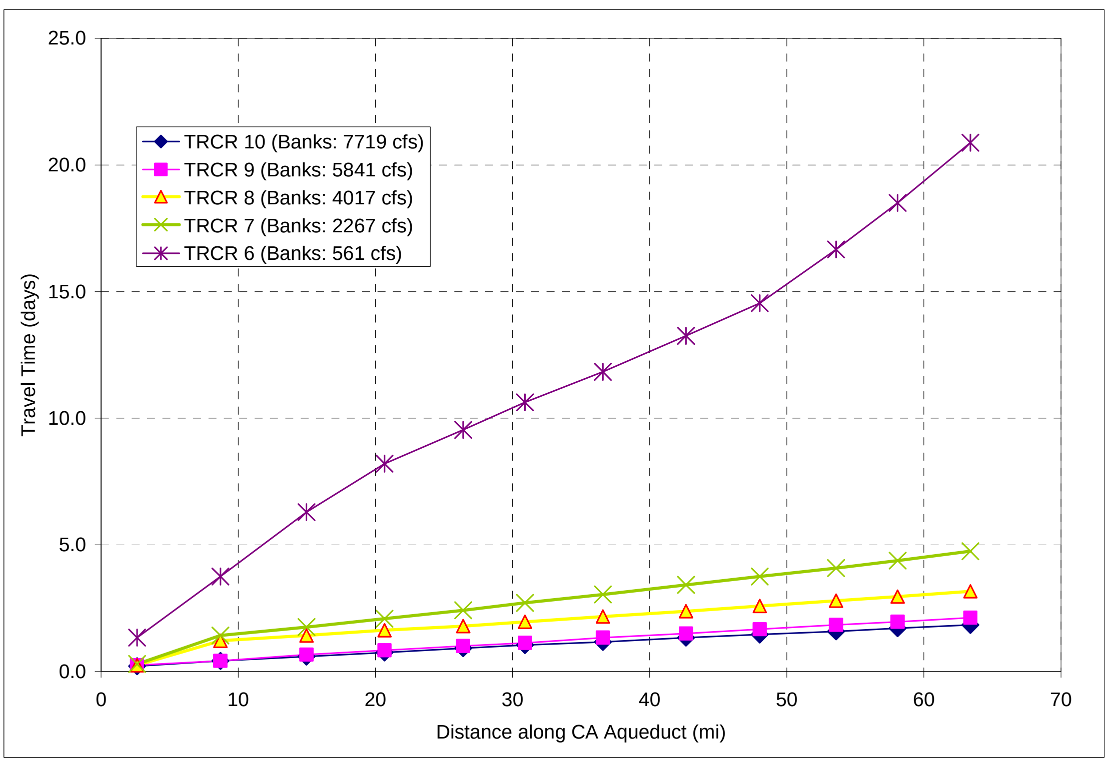


Table 10. Summary of travel times to each check structure in the five simulations.

Simulation	TRCR 1	TRCR 2	TRCR 3	TRCR 4	TRCR 5
Tracer Release Date	11/24/01	1/26/02	8/13/02	7/15/02	7/5/03
Banks Pumping (cfs)	5,227	5,893	6,836	6,744	6,843
Dos Amigos Pumping (cfs)	1,900	4,141	6,381	8,612	10,866
Pool Inflows (cfs)	0	69	0	0	0
Pool Diversions (cfs)	590	2,172	4,683	6,452	7,981
Closure Inflows (cfs)	421	484	416	426	263
Closure Diversions (cfs)	108	346	435	308	370
Check Structure	**Travel Time (Days)**				
Check 01	0.29	0.21	0.21	0.21	0.25
Check 02	1.29	0.42	0.42	0.46	1.13
Check 03	1.58	0.58	0.63	0.67	1.25
Check 04	1.83	0.75	0.79	0.83	1.38
Check 05	2.08	0.92	0.96	1.00	1.46
Check 06	2.29	1.04	1.13	1.13	1.58
Check 07	2.54	1.21	1.29	1.29	1.71
Check 08	2.83	1.38	1.46	1.50	1.83
Check 09	3.08	1.50	1.58	1.63	1.96
Check 10	3.38	1.67	1.75	1.79	2.04
Check 11	3.58	1.79	1.88	1.96	2.17
Check 12 (O'Neill Forebay Entrance)	3.88	1.92	2.04	2.08	2.29
Check 13 (O'Neill Forebay Exit)	6.75	3.96	3.50	3.38	3.21
Check 14	7.67	4.42	3.71	3.54	3.38
Check 15	9.63	5.17	4.04	3.83	3.67
Check 16	11.13	5.83	4.38	4.13	3.92
Check 17	12.50	6.42	4.67	4.38	4.17
Check 18	13.79	7.00	4.96	4.63	4.38
Check 19	15.08	7.58	5.25	4.92	4.63
Check 20	15.79	8.04	5.50	5.13	4.83
Check 21	16.54	8.46	5.67	5.29	5.00
Check 22	17.71	9.08	6.00	5.58	5.25
Check 23	18.67	9.67	6.29	5.88	5.50
Check 24	19.50	10.17	6.58	6.13	5.75
Check 25	20.38	10.58	6.83	6.33	5.96
Check 26	21.00	10.96	7.04	6.54	6.13
Check 27	21.42	11.29	7.21	6.71	6.29
Check 28	21.92	11.67	7.38	6.83	6.46
Check 29	22.33	11.96	7.58	7.00	6.63
Check 30	22.75	12.33	7.75	7.21	6.79
Check 31	23.00	12.54	7.92	7.33	6.96
Check 32	23.29	12.79	8.04	7.46	7.08
Check 33	23.63	13.04	8.21	7.63	7.25
Check 34	23.83	13.21	8.33	7.71	7.38

Simulation	TRCR 1	TRCR 2	TRCR 3	TRCR 4	TRCR 5
Tracer Release Date	11/24/01	1/26/02	8/13/02	7/15/02	7/5/03
Banks Pumping (cfs)	5,227	5,893	6,836	6,744	6,843
Dos Amigos Pumping (cfs)	1,900	4,141	6,381	8,612	10,866
Pool Inflows (cfs)	0	69	0	0	0
Pool Diversions (cfs)	590	2,172	4,683	6,452	7,981
Closure Inflows (cfs)	421	484	416	426	263
Closure Diversions (cfs)	108	346	435	308	370
Check Structure	**Travel Time (Days)**				
Check 35	24.21	13.54	8.50	7.92	7.54
Check 36	24.33	13.67	8.58	7.96	7.63
Check 37	24.38	13.83	8.71	8.04	7.75
Check 38	24.50	13.92	8.79	8.17	7.79
Check 39 (Upstream of Edmonston PP)	24.67	14.08	8.88	8.25	7.92
Check 40	24.92	14.29	9.00	8.33	8.04
Check 41 (Upstream of Bifurcation)	25.25	14.63	9.25	8.58	8.29
Check 42 (Downstream of Bifurcation)	25.33	14.71	9.29	8.63	8.33
Check 43	25.63	14.92	9.46	8.75	8.54
Check 44	25.96	15.21	9.63	8.92	8.79
Check 45	26.29	15.42	9.75	9.08	9.00
Check 46	26.54	15.63	9.92	9.21	9.21
Check 47	26.75	15.75	10.00	9.33	9.33
Check 48	27.04	15.96	10.13	9.46	9.50
Check 49	27.38	16.13	10.29	9.63	9.75
Check 50	27.75	16.38	10.46	9.79	9.96
Check 51	27.79	16.42	10.50	9.83	9.96
Check 52	27.92	16.50	10.54	9.88	10.08
Check 53	28.13	16.71	10.75	10.04	10.25
Check 54	28.25	16.75	10.83	10.13	10.33
Check 55	28.42	16.88	10.88	10.25	10.46
Check 56	28.58	16.96	10.96	10.29	10.54
Check 57	28.71	17.04	11.04	10.38	10.63
Check 58	28.96	17.21	11.17	10.50	10.75
Check 59	29.25	17.42	11.33	10.67	10.96
Check 60	29.67	17.79	11.58	10.96	11.25
Check 61	29.92	17.96	11.79	11.13	11.46
Check 62	30.13	18.21	11.96	11.33	11.67
Check 63	30.46	18.46	12.21	11.54	11.92
Check 64	30.83	18.79	12.46	11.83	12.17
Check 65	31.25	19.13	12.71	12.13	12.46
Check 66	31.46	19.38	12.88	12.33	12.67
Check 67 (Entrance to Silverwood Lake)	31.83	19.71	13.08	12.58	12.92

Table 11. Summary of travel time to each check structure between Banks and O'Neill Forebay

	Simulation	TRCR 6	TRCR 7	TRCR 8	TRCR 9	TRCR 10
	Tracer Release Date	4/26/2003	11/22/2003	8/4/2001	6/28/2003	1/1/2002
	Banks Pumping (cfs)	561	2,267	4,017	5,841	7,719
	Pool Inflows (cfs)	0	0	0	0	0
	Pool Diversions (cfs)	12	2	10	2	17
	Closure Inflows (cfs)	22	0	0	240	28
	Closure Diversions (cfs)	0	0	0	0	0
Check Structure	**Distance (mi)**	**Travel Time (Days)**				
CK_01 (Bethany Reservoir Exit)	2.63	1.33	0.29	0.25	0.25	0.21
CK_02	8.70	3.75	1.42	1.21	0.42	0.42
CK_03	14.98	6.29	1.75	1.42	0.67	0.58
CK_04	20.68	8.21	2.08	1.63	0.83	0.75
CK_05	26.41	9.54	2.42	1.79	1.00	0.92
CK_06	30.92	10.63	2.71	1.96	1.13	1.04
CK_07	36.59	11.83	3.04	2.17	1.33	1.17
CK_08	42.65	13.25	3.42	2.38	1.50	1.33
CK_09	48.04	14.54	3.75	2.58	1.67	1.46
CK_10	53.59	16.67	4.08	2.79	1.83	1.58
CK_11	58.09	18.50	4.38	2.96	1.96	1.71
CK_12 (O'Neill Forebay Entrance)	63.39	20.88	4.75	3.17	2.13	1.83

Modeling Uncertainties

The travel times estimated in this analysis are based in part on field data used to specify boundary flows, diversions, and inflows to the California Aqueduct. Previous work by CH2M HILL (2005) documented mass balance inconstancies in the published flow data. As a result, the Phase 1 modeling effort adopted the use of closure flows to achieve a mass balance at select locations throughout the system. The use of closure flows (both inflows and outflows) may impact the travel time calculations. Closure flows account for the errors associated with other system data including pump station flow records, diversion estimates, and pump–ins. Closure flows can account for as much as 30% of the average flow in a reach over short durations, but average on the order of about 10%. Considering that closure terms can lead to an underestimation or overestimation of the travel time, model predicted travel times through the system should viewed as having a confidence range on the order of plus or minus 10 percent .

Conclusions

The DSM2 Extension for the California Aqueduct was used to determine travel time through the aqueduct system for the full range of expected flows in the aqueduct. Five runs were simulated to characterize the travel times below O'Neill Forebay, encompassing the range of flows through Dos Amigos. Five additional runs were simulated to determine the travel times between Banks and O'Neill Forebay, capturing the range of pumping at Banks. Travel times to each major system component are tabulated.

As expected, travel times decrease with increasing upstream flow. This inverse relationship is generally true between the travel times and flow through Dos Amigos Pumping Plant, since this flow serves as the primary flow boundary condition for the aqueduct below O'Neill Forebay. Travel times between Banks and O'Neill Forebay are not necessarily related to flow at Dos Amigos, but are correlated to flows at Banks Pumping Plant. Flows at Banks and at Dos Amigos are not expected to be related because of draining and filling patterns associated with San Luis Reservoir.

The complexity of the operations of the aqueduct system is such that simplistic relationships between travel time and upstream flow are not adequate to assess travel time through the system. Model results show the dynamic nature of the operations of the aqueduct and the effect that the location and timing of the diversions have on the travel time through the system. Deviations from the expected inverse relationship between upstream flow and travel time through a given reach are associated with diversions from the aqueduct system. Travel times show a better correlation to the net flows through a reach, than to the upstream inflow to a reach. For a given reach inflow, the dynamic nature of diversions from the system, can result in a range of net flows through the lower portion of the reach. The location at which diversions occur, and their variation with time, will influence the travel time through the aqueduct.

Aqueduct modeling for emergency response planning, near term planning, or real-time forecasting analyses needs to include the use of real-time, or best estimates of, boundary condition flows (Tracy and Banks) and system diversions to provide a reasonable basis for simulating the dynamics of aqueduct operations and developing estimates of system travel times. Better data quantifying the volume and water quality of turn-ins in the southern portion of the aqueduct system would also help to improve model results.

References

CH2M HILL, 2005. DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal. Prepared for State Water Contractors and Municipal Water Quality Investigation Program. June, 2005.

Appendix B:
Task 2 Technical Memorandum

Phase II DSM2 Extension for the California Aqueduct

Task 2: Analysis of San Luis Reservoir and O'Neill Forebay

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DATE: October 5, 2007

Introduction

This technical memorandum is the second of four describing tasks completed under Phase II of the Delta Simulation Model 2 (DSM2) Extension for the California Aqueduct Project. Work under Task 2 investigated the treatment of San Luis Reservoir and O'Neill Forebay in the California Aqueduct DSM2 Extension model.

The purpose of Task 2 was to determine if a more complex representation of San Luis Reservoir would improve the calibration and predictive ability of the model as compared to the Phase I calibration simulation. Efforts were focused on San Luis Reservoir, since this part of the system controls electrical conductivity (EC) in the O'Neill Forebay and all points downstream during times when flow is being released from San Luis Reservoir. Since O'Neill Forebay serves as a boundary condition to points downstream during all months of the year, methods of improving EC predictions in O'Neill Forebay were also investigated. Field data showing vertical EC profiles in San Luis Reservoir were reviewed to assess if the dataset provided useful information on the vertical structure of the reservoir. Finally, an analysis of DSM2 results and historical field data was conducted to investigate alternative operations to reduce average annual salinity levels in San Luis Reservoir.

The Phase I model (CH2M HILL, 2005) was constructed and calibrated for flow and water quality for a 3-year period (January 1, 2001 to December 31, 2003). The model includes the main branch of the California Aqueduct, the East Branch through Silverwood Lake, the West Branch through Pyramid Lake, the South Bay Aqueduct through the Santa Clara Tank, and the Delta-Mendota Canal (DMC) to the Mendota Pool. The Coastal Branch is treated as a diversion in the model; it is not specifically modeled.

San Luis Reservoir is represented in the Phase I model by a single DSM2 reservoir, which is assumed to be completely (instantaneously) mixed and have a constant surface area (vertical-walled vessel). Results from the Phase I study indicated that DSM2 could not account for certain variations in historical EC in San Luis Reservoir and O'Neill Forebay. Figure 1 presents the model predictions for EC in San Luis Reservoir from the Phase I

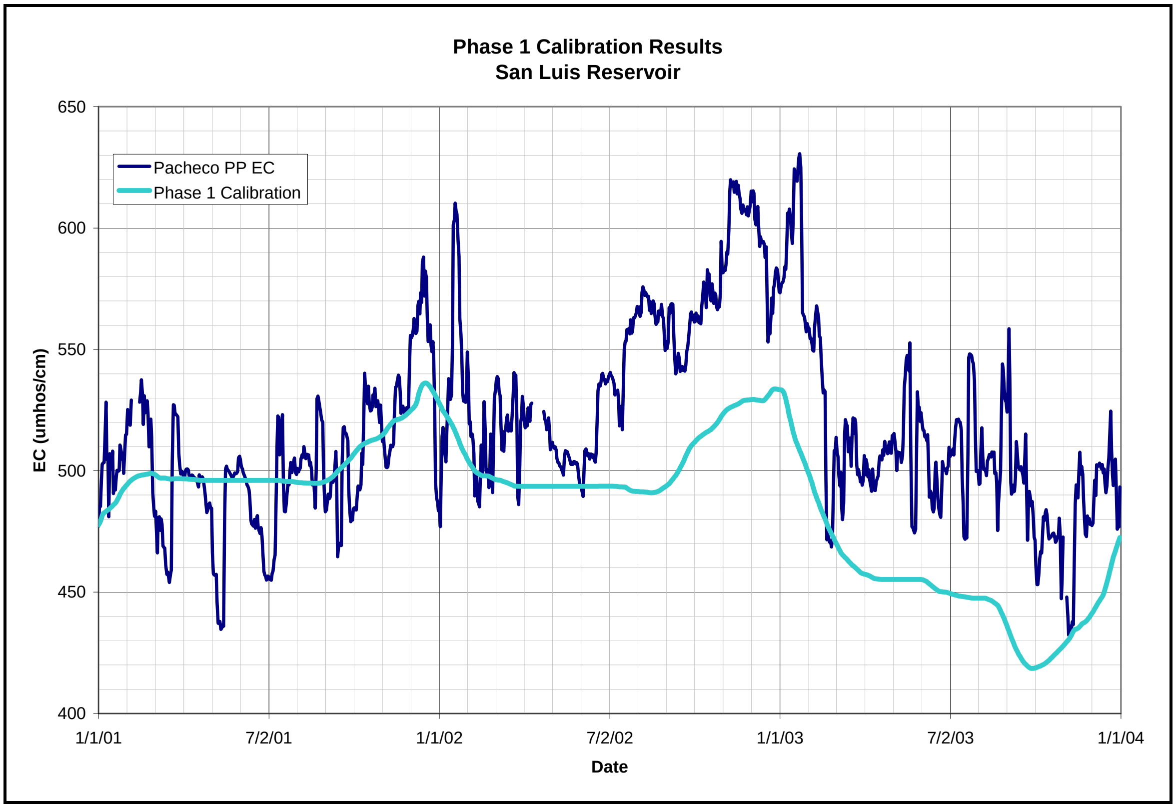

FIGURE 1
Calibration Results for San Luis Reservoir EC (Phase I)

calibration simulation, and includes the measured EC at Pacheco Pumping Plant for comparison.

These are primary conclusions regarding the ability of the model to predict EC in San Luis Reservoir and O'Neill Forebay derived from the Phase I analysis:

- Based on the field data, San Luis Reservoir undergoes considerable short-term fluctuations in EC concentration. These fluctuations occur at times when there is little or no flow into San Luis Reservoir from O'Neill Forebay, and thus the model does not reproduce these events.
- The model EC predictions in San Luis Reservoir follow the general trend of the field dataset aside from a roughly 4-month period (May through August 2002), when EC increases according to the field data but remains relatively constant according to the model.
- Field data indicate increases in EC in San Luis Reservoir when hydraulic data indicate that water is being released from San Luis Reservoir. It is difficult to explain the increase in EC if no total dissolved solids (TDS) are being delivered to the reservoir from O'Neill Forebay. The watershed surrounding San Luis Reservoir is small, and the high frequency increases in EC cannot be explained by evaporative concentration of salts.

- Differences in measured EC between Banks Pumping Plant and Check 12 in the aqueduct just upstream of O'Neill Forebay indicate that there are influences on EC, such as inflows, between Banks and O'Neill Forebay.
- Differences in measured EC between Jones (Tracy) Pumping Plant and Check 12 in the DMC, just upstream of the O'Neill Pumping-Generation Plant indicate that there are influences on EC in the DMC between Jones Pumping Plant and the O'Neill Pumping-Generation Plant.

Approach

The approach adopted under this task was to review the Phase I calibration results to identify specific time periods where model refinements would most likely lead to the greatest improvements in model performance. Several calibration issues were identified at the conclusion of Phase I, including discrepancies between measured EC at Jones Pumping Plant and Banks Pumping Plants and the resulting EC at Check 12 on the DMC and Check 12 on the aqueduct. These discrepancies were evaluated in this review, and the model was refined to the extent possible based on available information. In addition, a range of physical changes to the representation of San Luis Reservoir in the DSM2 model were evaluated, and potential improvements in the predictive capability of the model were quantified. Finally, field data, obtained subsequent to the Task 2 modeling evaluation, that provide information on the vertical and temporal structure of EC in San Luis Reservoir near Pacheco Pumping Plant were analyzed.

Review of Phase I Model Results

Analyses were conducted on the Phase I model calibration results to more completely understand the areas where the Phase I model could be improved. Review of the Phase I EC predictions in San Luis Reservoir indicated that aside from a 4-month period (May through August 2002), the general timing and pattern of the EC predictions matched the field data fairly well. Figure 2 presents a 30-day average of the measured EC data (at Pacheco Pumping Plant) in order to smooth out short-term fluctuations in the dataset. Notice that the EC predictions from the calibration simulation are reasonably accurate for the first 16 months of the simulation, and then begin to deviate rather dramatically from the measured data on June 2002. Beginning in September 2002, the predicted EC shows a somewhat constant offset from the measured data. To show the similar pattern between the model-predicted EC and the measured EC, a line was added to the plot reflecting a constant 50 μmhos/cm offset from the model prediction.

Effort was subsequently focused on the period of time with the greatest divergence between measured and predicted EC values in San Luis Reservoir. Figure 3 focuses on the period of time where the predicted EC in San Luis Reservoir deviates from the measured values (June 2002). To assist analysis, the flows into and out of San Luis Reservoir from O'Neill Forebay (7-day averages) have been included along with the EC at Banks. Note first that the EC in San Luis increases by over 15 percent (500 to 575 μmhos/cm) in a 2-month period beginning June 1, 2002. This occurs while the reservoir is being drained to meet water demands farther south in the system. Thus, the EC increase is not related to the transport of salt into the reservoir from O'Neill Forebay, according to the flow data.

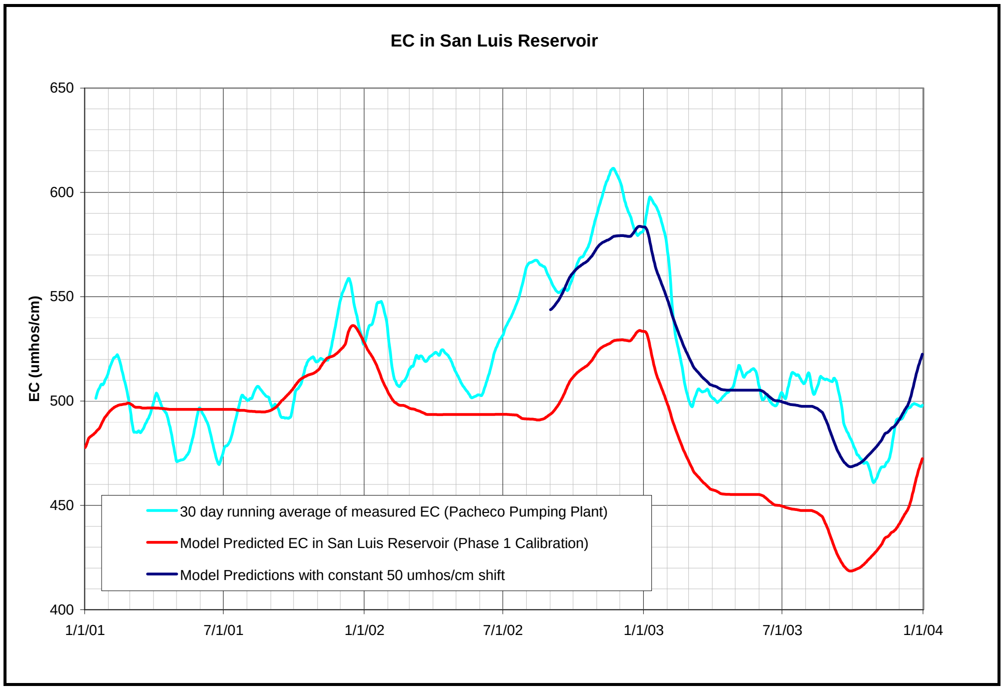

FIGURE 2
Comparison of Predicted EC in San Luis Reservoir with Smoothed Historical Data

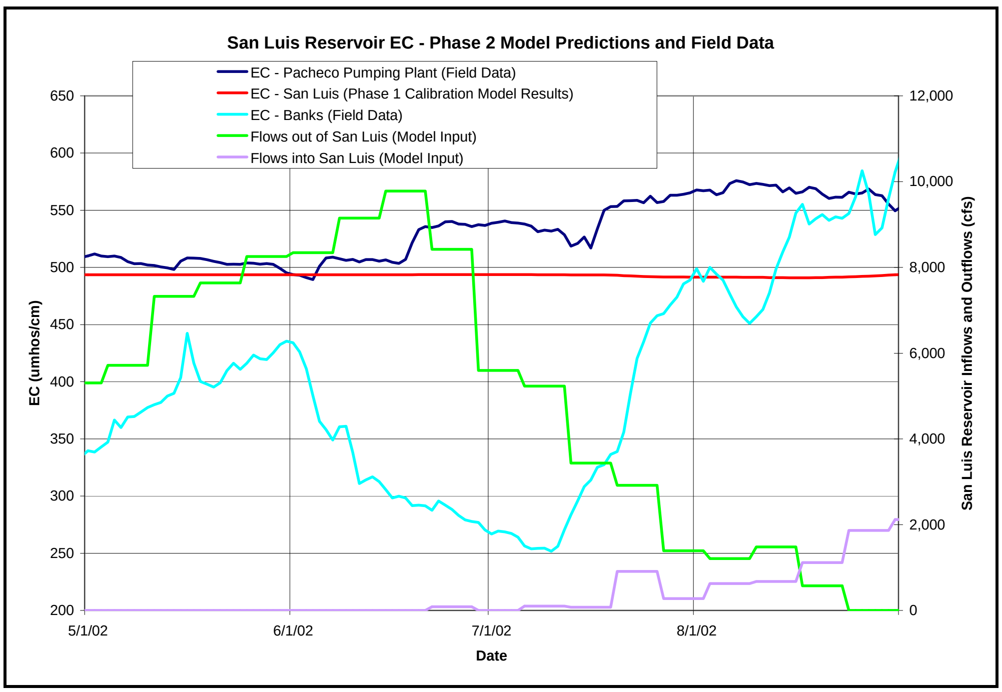

FIGURE 3
Comparison of Predicted and Measured EC in San Luis Reservoir, and Flows into and out of San Luis Reservoir

Figure 4 presents a comparison of model-predicted fractional salt loading to O'Neill Forebay from three sources: the DMC, the California Aqueduct upstream of O'Neill Forebay, and releases from San Luis Reservoir. Since the EC in O'Neill Forebay strongly influences predicted EC in the California Aqueduct downstream of the forebay, discrepancies between predicted and measured EC at Check 13 downstream of O'Neill Forebay can be compared with data presented in Figure 4 to determine the potential sources of the salt load (EC), and thus shed light on the model performance.

For example, model-predicted EC in San Luis Reservoir is below recorded field data beginning in June 2002. By determining when the salt load in O'Neill is most influenced by releases from San Luis, underestimations in predicted EC in O'Neill Forebay can be explained by the EC discrepancy in San Luis Reservoir during the period when San Luis is contributing the vast majority of the salt load to O'Neill Forebay. In Figure 5, two distinct periods of higher-than-average error in San Luis EC predictions, as quantified by the root mean squared (RMS) error between predicted results and field data, are highlighted by shaded circles. In the period represented by the first (green) circle, there is little or no flow from San Luis Reservoir to O'Neill Forebay, and thus errors in predicted EC in O'Neill Forebay are likely associated with either model-predicted EC in the aqueduct upstream of O'Neill or the DMC. Conversely, the second (blue) circle indicates a period where the errors in San Luis EC may be directly influencing O'Neill Forebay and thus all points downstream. Attempts to improve model predictions in a given time period must account for the likely sources of error during that period. No systematic sources of error were found in the review of model results, so it is possible that changes to model parameters to improve model predictions in one specific time period may increase error during other periods.

Boundary Condition Refinements

The differences between observed and predicted EC values at O'Neill Forebay (Check 13 on the aqueduct) were quantified in terms of the RMS error. The time series of RMS error was plotted against various parameters to help determine the potential sources of error. By correlating increases in RMS error in O'Neill Forebay to results of the fractional salt loading analysis, the likely source of error for a particular time period could be isolated. For example, the error in predicted EC in O'Neill Forebay during December 2002 is driven by the model's underestimation of EC in the DMC during that month. Figure 6 shows the measured EC at Tracy and at Check 12 on the DMC just upstream of O'Neill Forebay. The area enclosed by the blue circle indicates a spike in EC at Check 12 that is considerably above the data measured at Jones Pumping Plant. Since no tributary inflows or pump-ins to the DMC were included in the model, the model cannot replicate this EC spike, which leads to an underestimation of EC in the inflow to O'Neill Forebay and points downstream.

The fractional salt load analysis presented in Figure 4 demonstrates a correlation between relatively high errors in model-predicted EC in O'Neill Forebay (aqueduct Check 13) and salt load to O'Neill Forebay from the California Aqueduct, specifically during the months of August and September 2001. A review of the EC boundary condition applied at Banks during this period revealed that the Banks EC was based on a simple linear interpolation used to fill in data gaps in the measured salinity record. To improve this boundary condition, the piecewise linear fill was discarded, and measured EC data at Check 12 were lagged by 3 days and used to fill the data gaps in the Banks record.

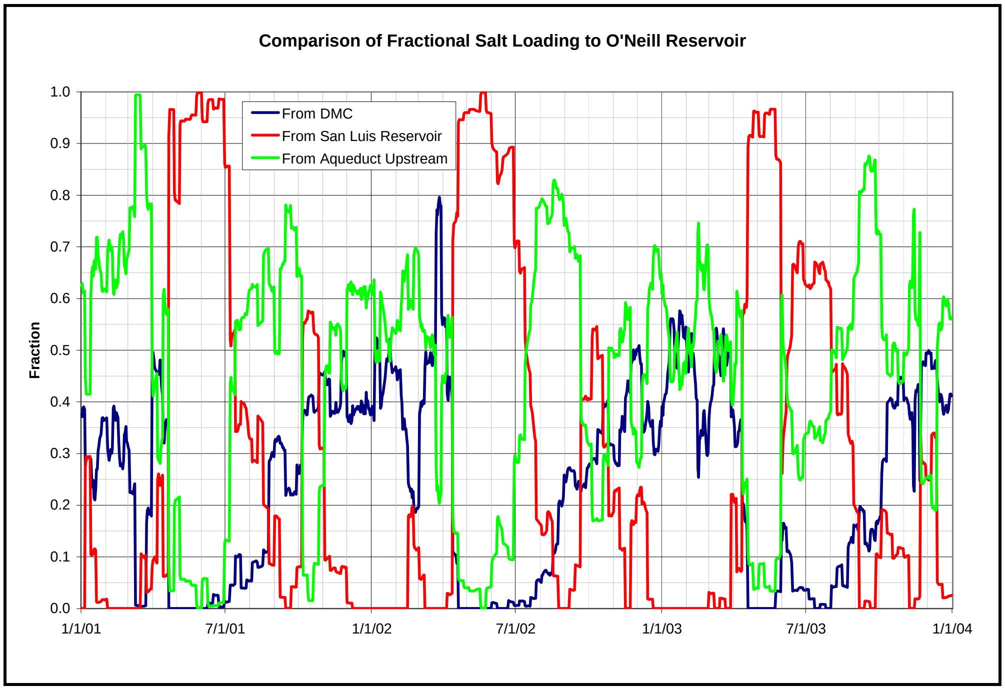

FIGURE 4
Comparison of Fractional Salt Loading to O'Neill Forebay
(Derived from Phase I Calibration Simulation)

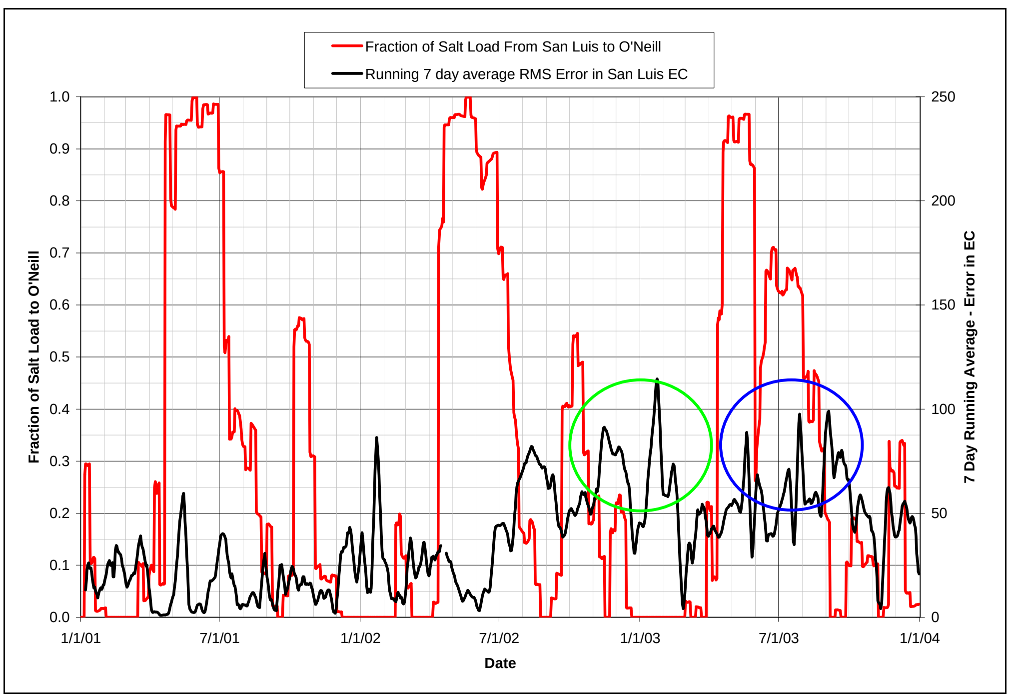

FIGURE 5
Comparison of Salt Load from San Luis and Error in San Luis Reservoir EC

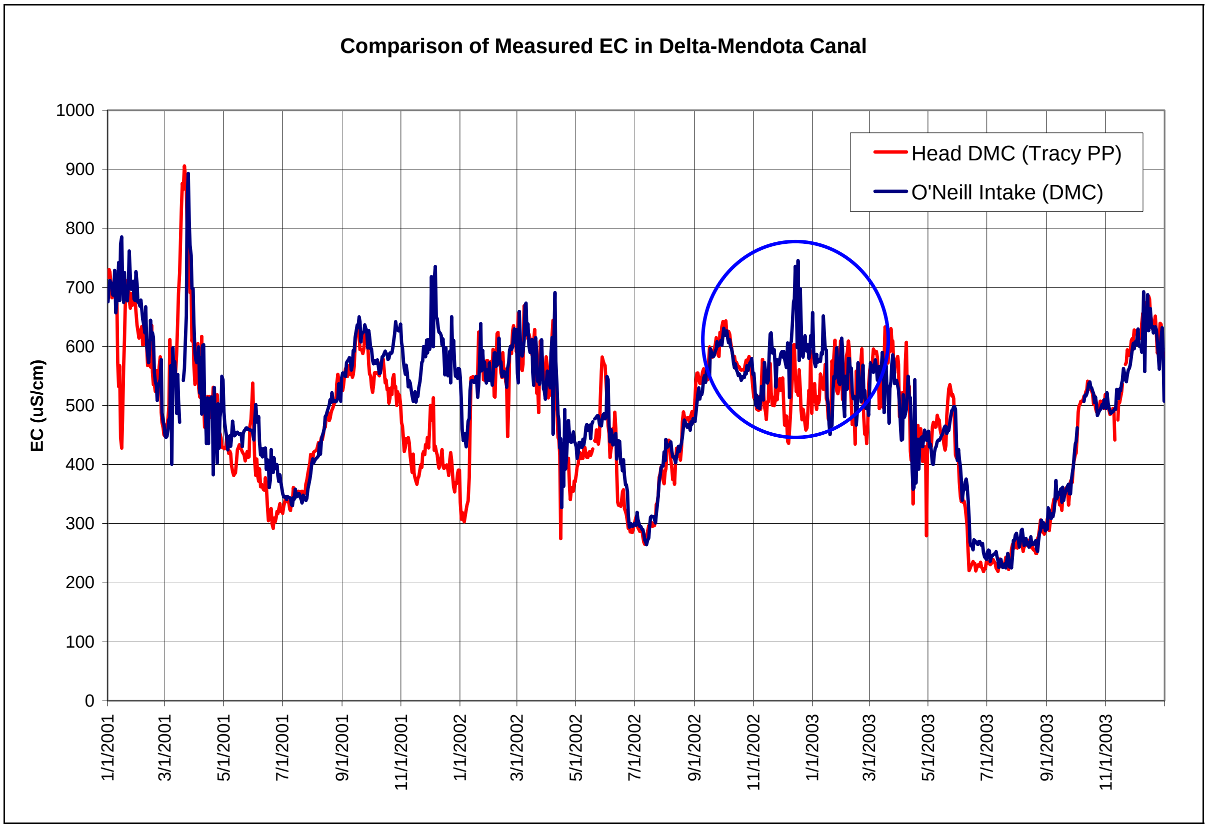

FIGURE 6
Comparison of Measured EC at Jones Pumping Plant and the Check 12 on the DMC

During the review of the Phase I results, it was also noted that the Banks EC boundary condition applied in the Phase I final simulation was applied with an erroneous 1-day shift in the time-series data. This was corrected in model simulation Test3, and the results showed a very minor reduction in the RMS error at Check 13, where the error was reduced to 39.53 μmhos/cm as compared to an error of 39.72 μmhos/cm in final Phase I simulation.

Figure 7 presents the improvement in model-predicted EC after incorporation of these refinements in the Test4 simulation. The EC just upstream of O'Neill Forebay is presented for the original Phase I calibration simulation, which used the piecewise linear fill at Banks, and for the revised Test4 simulation, which used the correctly shifted EC time series and lagged EC measurements from Check 12 for the Banks boundary condition. Note the marked difference in predicted EC at Check 12 for the months of August and September.

The ability to refine the model calibration through improvements in the EC boundary time series prompted a review of how the DMC is treated in the analysis, because the DMC effectively serves as the other upstream boundary condition for O'Neill Forebay. A sensitivity study was conducted to ascertain the influence of the DMC on O'Neill Forebay and thus San Luis Reservoir and points downstream. Field data provide EC records at both Jones Pumping Plant and at Check 12 in the DMC, just upstream of the connection to O'Neill Forebay. A model simulation (Test5) was conducted that assigned the measured EC at Check 12 in the DMC to the flows entering O'Neill Forebay from the DMC, effectively removing the influence of any data or model deficiencies upstream in the DMC.

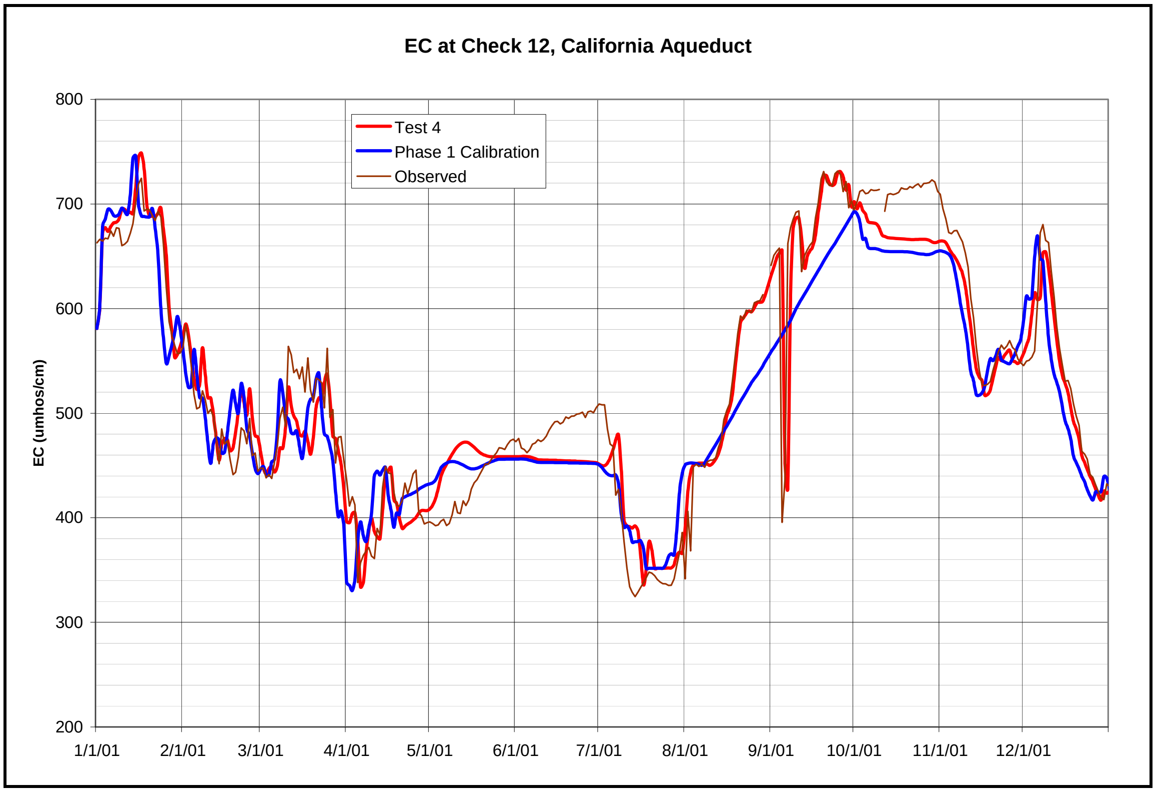

FIGURE 7
Simulated and Observed EC at Check 12 with Banks EC Adjustments

Figure 8 demonstrates the improvement in predicted EC in O'Neill Forebay (Check 13 on the aqueduct) resulting from both the refinement to Banks EC in the Test4 simulation and the additional specification of EC in the flows to O'Neill Forebay from the DMC in the Test5 simulation. The Test4 simulation results indicate improvements in O'Neill Forebay during September 2001, as highlighted in the green circle. The Test5 simulation demonstrates improvements during December 2002, as highlighted by the blue circle. The Test5 simulation was built on the Test4 simulation, and thus contains improvements in the boundary EC for both the aqueduct and the DMC.

These boundary condition refinements led to improvements in the model-predicted EC at O'Neill Forebay, particularly during times when flows from the DMC are being diverted into O'Neill Forebay and then San Luis Reservoir. The average RMS error for the Test5 simulation over the 3-year simulation period was 33.70 μmhos/cm, a reduction in error of 8 percent from the Test4 simulation. The Test5 simulation showed a 15 percent reduction in RMS error at O'Neill Forebay as compared to the Phase I calibration run. The Test5 simulation demonstrates the potential improvement that may be possible in the model with better specification of inflow data between Jones Pumping Plant and Check 12 on the DMC.

Figure 9 shows the improvement in predicted EC in San Luis Reservoir for Test5 as compared to the Phase I calibration simulation results. The improvement in simulated San Luis EC is minor. This demonstrates that the improvements in O'Neill EC, as a result of refinements to the boundary conditions upstream of O'Neill, have little impact on San Luis Reservoir EC predictions.

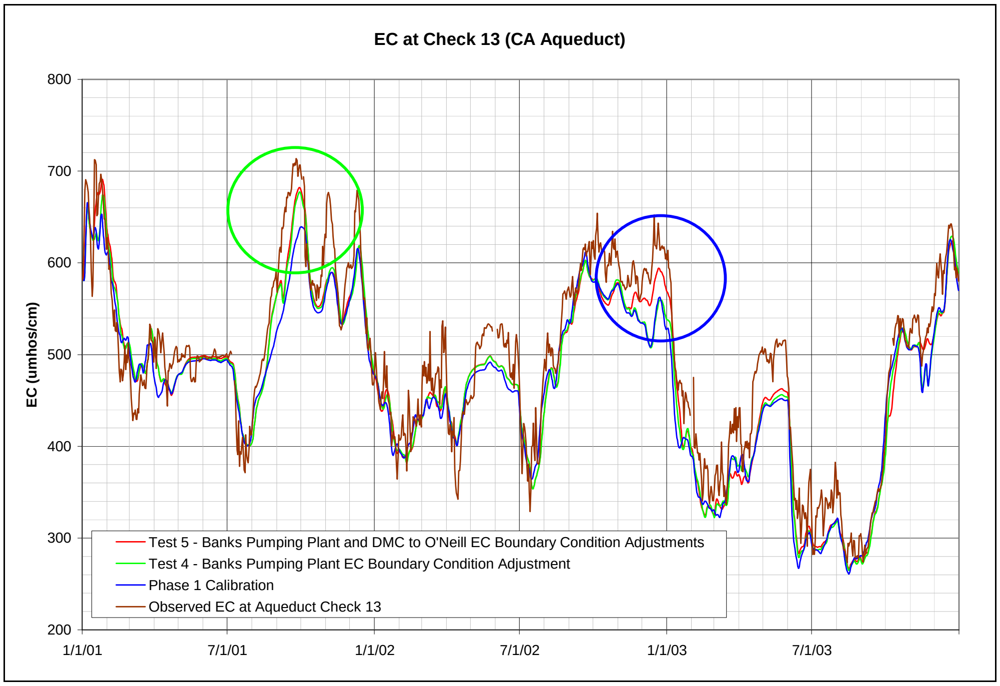

FIGURE 8
Simulated EC at California Aqueduct Check 13 with Banks Pumping Plant and DMC EC Refinements

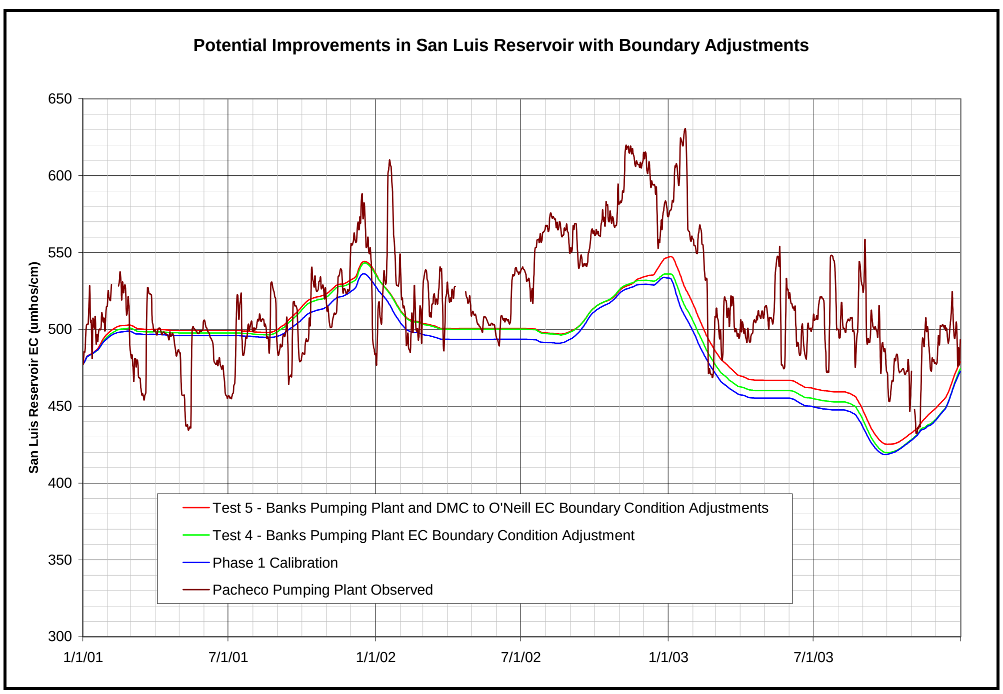

FIGURE 9
EC in San Luis Reservoir with Banks Pumping Plant and DMC EC Refinements

Figure 10 presents a time-series comparison of the average monthly RMS error at Check 13 for the Phase I calibration simulation, the Test4 simulation, and the Test5 simulation. The figure shows that there is no consistent improvement as a result of the model boundary condition refinements. Some months show a significant decrease in error, while other months show an increase in error. The month with the highest RMS error in the Phase I calibration simulation (September 2001) shows a significant improvement as a result of the Banks EC refinement included in the Test4 simulation. The month with the second highest RMS error (December 2002) shows a considerable improvement as a result of specifying the historical measured DMC EC at Check 12 as the EC for the DMC inflow to O'Neill Forebay. The period of increased error in April and May 2003 is associated with the underestimation of EC concentrations in San Luis Reservoir and the release of this water into O'Neill Forebay. Overall, the figure shows that there is a lack of any distinct seasonal pattern associated with the RMS error.

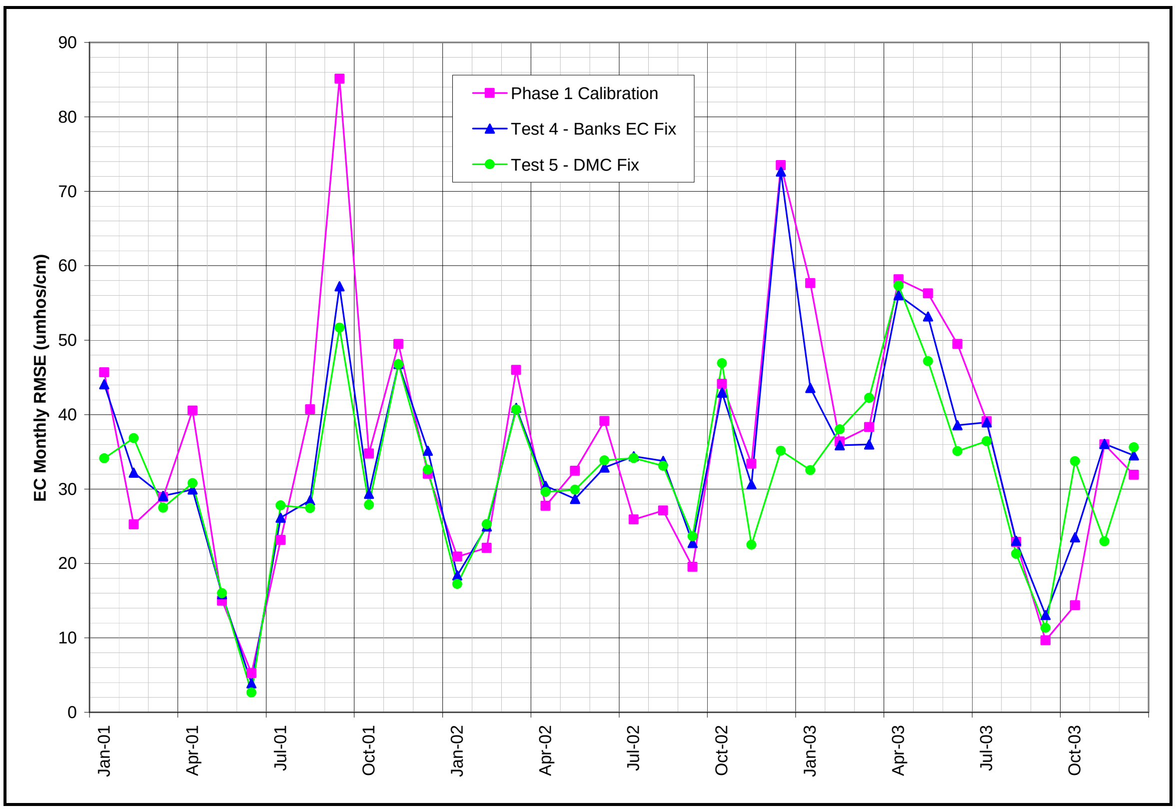

FIGURE 10
Time Series of Monthly EC RMS Error at Check 13 for Simulations with Boundary Condition Refinements

Representation of San Luis Reservoir

The Phase I analysis demonstrated that predicted EC in San Luis Reservoir was at times considerably different than EC measured at the Pacheco Pumping Plant, which is the only location with EC data representative of conditions in San Luis Reservoir. The Phase I report noted that further investigation was needed to assess how best to simulate San Luis Reservoir and its operations. The report also discussed that the representation of San Luis Reservoir in DSM2 and the resulting EC prediction potentially could be improved through the use of a two-reservoir system. The first reservoir would represent the smaller effective mixing volume near the dam, and a second larger reservoir would represent the remaining lake volume. The EC in the first reservoir would more closely match the EC in O'Neill Forebay, and the larger reservoir would show less variation and more closely match the EC recorded at Pacheco Pumping Plant.

As part of Task 2, an extensive series of DSM2 simulations were made to determine if changes in the representation of the reservoir would improve the model's ability to reproduce measured EC concentrations in San Luis Reservoir. Numerous variations of the two-reservoir concept were investigated. Figures 11 through 14 present four of the alternative reservoir configurations used in this study.

Figure 11 presents a schematic of the first setup using two reservoirs. San Luis East (SLREAST) and San Luis West (SLRWEST) have replaced the single reservoir used in the Phase I model. Object-to-object flows from O'Neill Forebay enter the eastern reservoir, which is hydraulically connected to the western reservoir through channels 900 and 901. The reservoirs can be initialized at different EC values. The inclusion of channel 902, node 904, and the dummy boundary condition were necessary to get the model to run, since the two reservoirs do not have direct channel connections to the rest of the model grid.

Figure 12 shows the second alternative representation of San Luis Reservoir. Here, an object-to-object flow was added to control mixing between the two reservoirs. The object-to-object flows simulate the mixing between the highly mixed zone near the outlet works and the buffer zone comprising the rest of San Luis Reservoir. Object-to-object flows were varied from 50 cubic feet per second (cfs) to 1,000 cfs in a series of sensitivity studies.

Figure 13 presents the third alternative, in which San Luis Reservoir water release to O'Neill Forebay was changed from the eastern reservoir to a node that draws from both reservoirs, and the mixing flows between the reservoirs was set at 1,000 cfs after a series of sensitivity runs. The release point was moved to increase the influence of the buffer reservoir (SLRWEST) on release flows.

The schematic in Figure 14 shows the fourth alternative, which includes gates on channels 900 and 901 such that the releases between the two reservoirs can be controlled by the user. This configuration was used to test seasonal releases from the reservoirs.

Table 1 summarizes the RMS error calculated for the model simulations performed as part of this San Luis Reservoir analysis. The improvement in EC prediction as a result of the model adjustments was quantified as the RMS error at Check 13 in the California Aqueduct (downstream of O'Neill Forebay), which was compared to the RMS error from the Phase I calibration simulation. The San Luis configuration used in each simulation (Figures 11 through 14) is listed in the table.

As shown in Table 1, the first several runs resulted in no consistent improvements in the RMS error downstream of O'Neill Forebay. Variations were made in the relative size of the two reservoirs, in the magnitude of the object-to-object flows connecting the two reservoirs, and in the location where releases back to O'Neill Forebay originated. The object-to-object flows were varied as a surrogate for the effective mixing between the two reservoirs. None of the changes indicated a net improvement over the Phase I calibration simulation, but

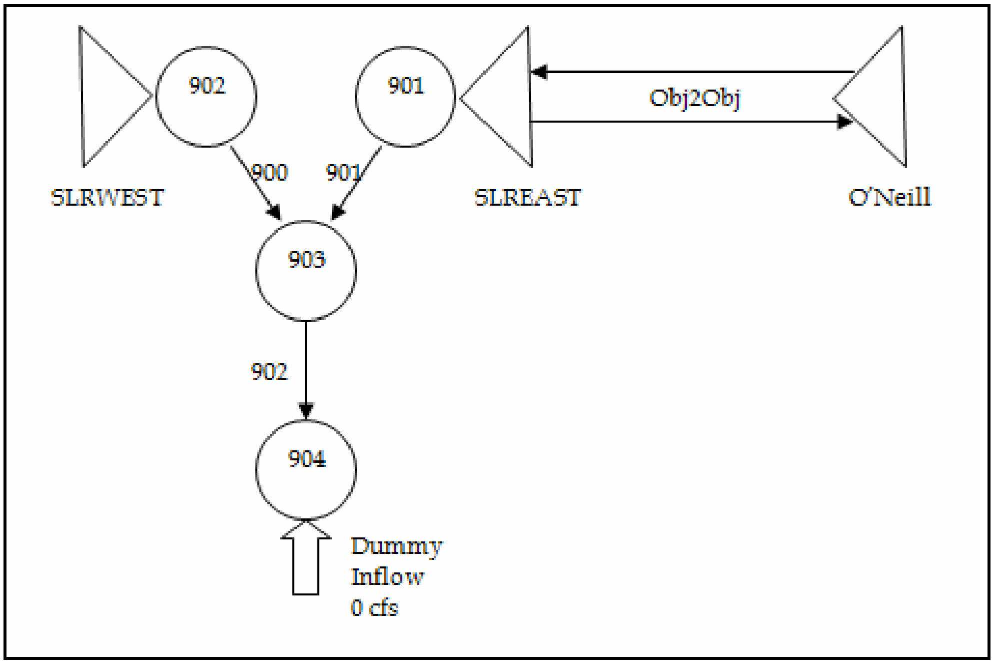

FIGURE 11
First Two-reservoir Representation of San Luis Reservoir

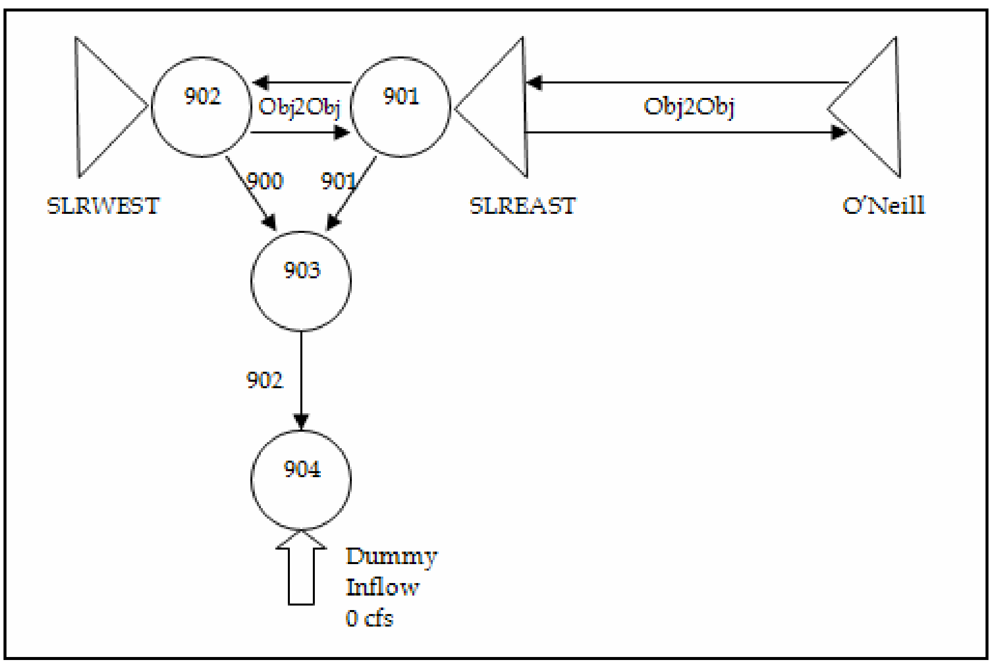

FIGURE 12
Second Two-reservoir Representation of San Luis Reservoir

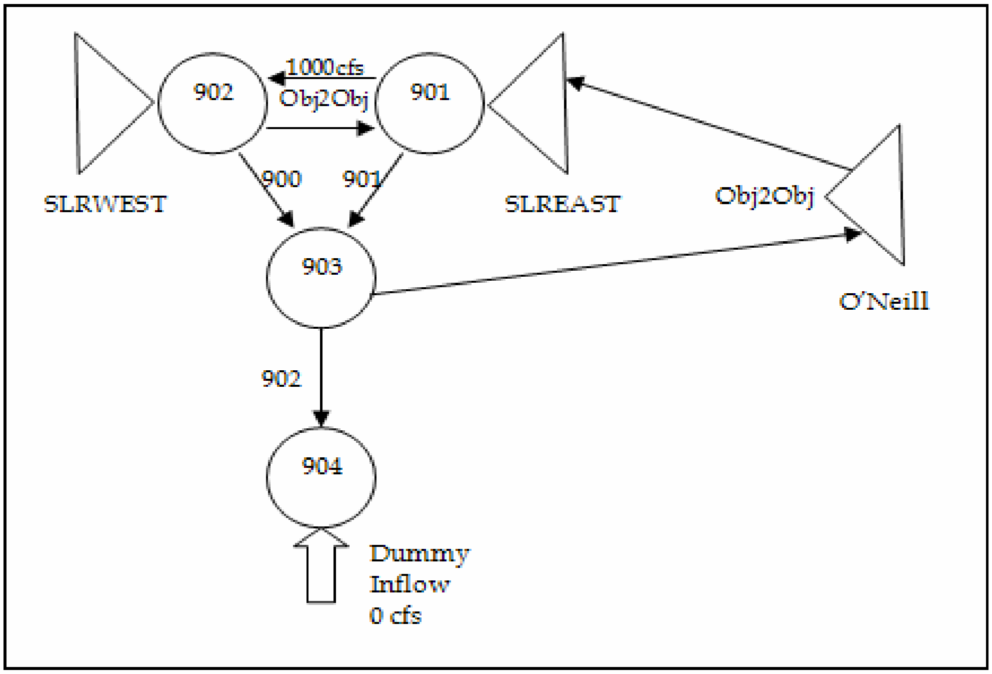

FIGURE 13
Third Two-reservoir Representation of San Luis Reservoir

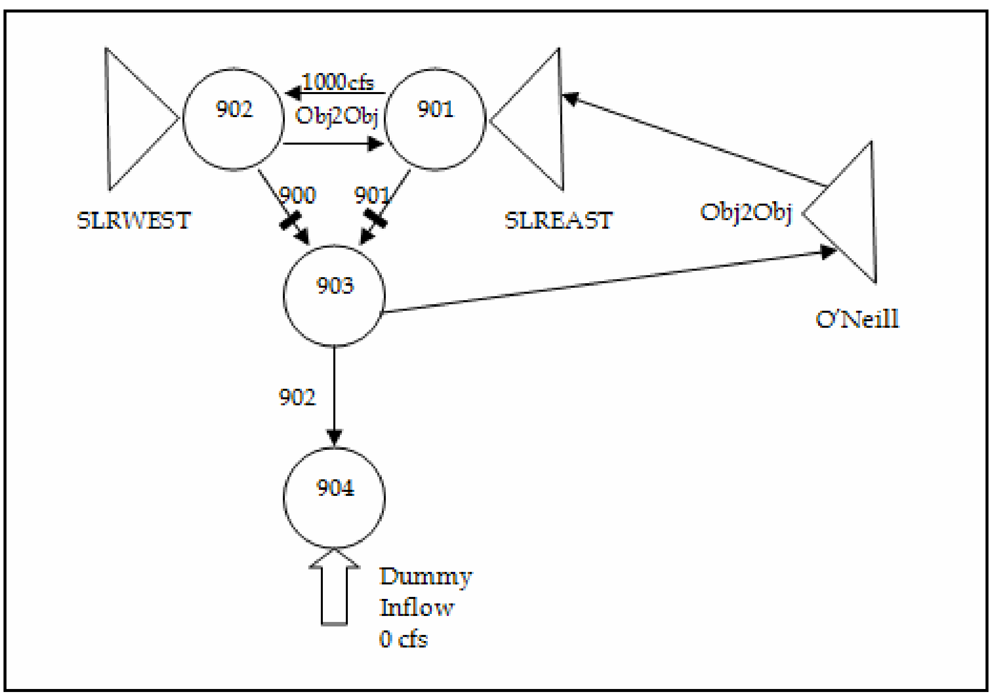

FIGURE 14
Fourth Two-reservoir Representation of San Luis Reservoir

TABLE 1
Definition of Simulations and Corresponding RMS Error at Check 13
Phase II DSM2 Extension for the California Aqueduct—Task 2: Analysis of San Luis Reservoir and O'Neill Forebay

Run ID	Description	Geometry	Check 13 RMS Error	Improvement from Phase I RMS Error
Test2	Phase I calibration	Phase I	39.72	0.00%
SL2	Two equal-volume reservoirs each with surface area half of San Luis Reservoir and depth equal to San Luis Reservoir. The two parts were connected hydraulically. The object-to-object flow was maintained between O'Neill Forebay and San Luis Reservoir East part. The two reservoirs were initialized with different EC.	1	41.83	-5.32%
SL3	SL2 setup was modified such that the surface areas of the two reservoirs were not equal. For the west part, 75% of the surface area of San Luis Reservoir was assumed, and for the east part, 25%, with total volume equal to that of San Luis Reservoir.	1	41.03	-3.32%
SL4	SL2 setup was modified such that the two equal-volume reservoirs have surface areas equal to San Luis Reservoir and half the depth of San Luis Reservoir.	1	42.46	-6.92%
SL6	SL4 setup was modified by increasing the length of the channels connecting the east and west parts of San Luis Reservoir.	1	41.88	-5.45%
SL7	SL2 setup was modified by increasing the length of the channels connecting the east and west parts of San Luis Reservoir.	1	41.93	-5.57%
SL8	SL6 setup was modified to establish a constant-flow exchange between the two parts with 50 cfs object-to-object flow. The hydraulic connection between the two parts was removed, and no flow was allowed in channels 900 and 901 by zeroing the coefficients COEFF2RES and COEFF2CHAN.	2	41.16	-3.63%
SL9	SL8 setup was modified such that the object-to-object flow exchange was increased to 200 cfs.	2	41.03	-3.30%
SL10	SL8 setup was modified such that the object-to-object flow exchange was increased to 1,000 cfs.	2	39.96	-0.61%
SL11	SL10 setup was modified to reestablish the hydraulic connection between the two parts of the San Luis Reservoir in addition to the 1,000 cfs constant-flow exchange.	2	40.48	-1.92%
SL12	SL6 setup modified by establishing the object-to-object connection between Node 903 and O'Neill Forebay instead of SLREAST and O'NEILL.	3	39.20	1.29%

TABLE 1
Definition of Simulations and Corresponding RMS Error at Check 13
Phase II DSM2 Extension for the California Aqueduct—Task 2: Analysis of San Luis Reservoir and O'Neill Forebay

Run ID	Description	Geometry	Check 13 RMS Error	Improvement from Phase I RMS Error
SL13	SL11 setup modified by establishing the object-to-object connection between Node 903 and O'Neill Forebay instead of SLREAST and O'NEILL.	3	38.91	2.03%
SL14	SL13 setup was modified such that the object-to-object constant-flow exchange was increased to 10,000 cfs between two reservoir parts.	3	38.75	2.43%
SL15	SL13 setup was modified by adding gates in the channels connecting the two reservoir parts. Predetermined seasonal releases were made between the two reservoirs, controlled through gate operations in the channels.	4	39.12	1.49%
SL16	SL15 setup was modified to include a 200 cfs object-to-object flow between two reservoirs.	4	39.32	0.99%
SL18	SL13 setup was modified to include seasonally varying object-to-object flows between the two reservoir parts instead of a constant flow of 1,000 cfs.	3	38.67	2.62%
SL19	SL13 setup was modified such that the two reservoir parts were initialized with the same initial EC of 477 µmhos/cm.	3	39.54	0.45%
Test3	Test2 (Phase I calibration setup) was modified by removing the erroneous 1-day lag in the Banks EC boundary condition	Phase I	39.53	0.47%
SL27	SL 13 setup was resimulated by using Test3 boundary condition for Banks EC.	3	38.69	2.58%
Test4	Test3 with Banks EC data gaps filled with lagged Check 12 data	Phase I	36.63	7.77%
SL28	SL 13 setup was resimulated by using Test4 boundary condition for Banks EC.	3	36.06	9.20%

simulation SL10 indicated that a 1,000 cfs object-to-object flow performed better than smaller mixing flows.

Run SL12 demonstrated the first net improvement over the Phase I calibration simulation. This simulation used a continuous 1,000 cfs object-to-object flow between the reservoirs, and released water to O'Neill Forebay from a node connected to both San Luis reservoirs (east and west), as shown in Figure 13. Simulation SL13 added a hydraulic connection between the two reservoirs in addition to the object-to-object flows, and resulted in slightly better predictions.

Subsequent simulations (SL14 through SL19) investigated controls on which of the two San Luis reservoirs (east or west) provided water released to O'Neill Forebay. This was implemented through the use of two gates connecting the reservoirs to a common node, as shown in Figure 14. Additional changes in this set of runs included variations in the object-to-object flows on a seasonal basis, and changes in the initial EC specification in the two reservoirs. As summarized in Table 1, none of these runs showed a significant reduction in the RMS error at Check 13 below O'Neill Forebay as compared to the Phase I calibration simulation.

Run SL13 was chosen as the most promising run, even though it did not have the absolute lowest RMS error at Check 13, because it had more reasonable assumptions than either of the two runs with lower RMS errors. Run SL14 had a slightly lower RMS error (38.75 μmhos/cm versus 38.91 μmhos/cm), but the 10,000 cfs object-to-object flow used in SL14 was deemed unrealistically high. Run SL18, which investigated seasonal patterns in the object-to-object flows between the two reservoirs, had an error of 38.67 μmhos/cm. This minor improvement over SL13 was not enough to outweigh the uncertainty in prescribing the seasonal variations in the object-to-object flows. This approach was viewed as rather contrived, because flows could be reverse engineered solely to reduce errors and not to represent any physical mixing in the system.

Simulations SL2 through SL19 did not include the DMC and Banks EC boundary condition refinements discussed previously. Run SL28 combined the San Luis Reservoir configuration from run SL13 with the Banks EC boundary condition refinements made in run Test4. The SL28 simulation results showed a 9 percent reduction in the RMS error at Check 13 downstream of O'Neill Forebay as compared to the Phase I calibration simulation. As shown in Table 1, about 2 percent of the error reduction can be attributed to the configuration change (SL13) with the remaining 7 percent associated with the refinements to the Banks EC boundary condition (Test4).

Figure 15 presents a time-series comparison of the monthly average EC RMS error at Check 13 below O'Neill Forebay for the following four simulations:

1. Phase I was the calibration simulation.
2. Run SL13 used third reservoir configuration shown in Figure 13.
3. Run Test4 included improved boundary condition representation of EC at Banks by filling dataset gaps with values from Check 12 lagged by 3 days as opposed to linearly interpolating across the gaps.

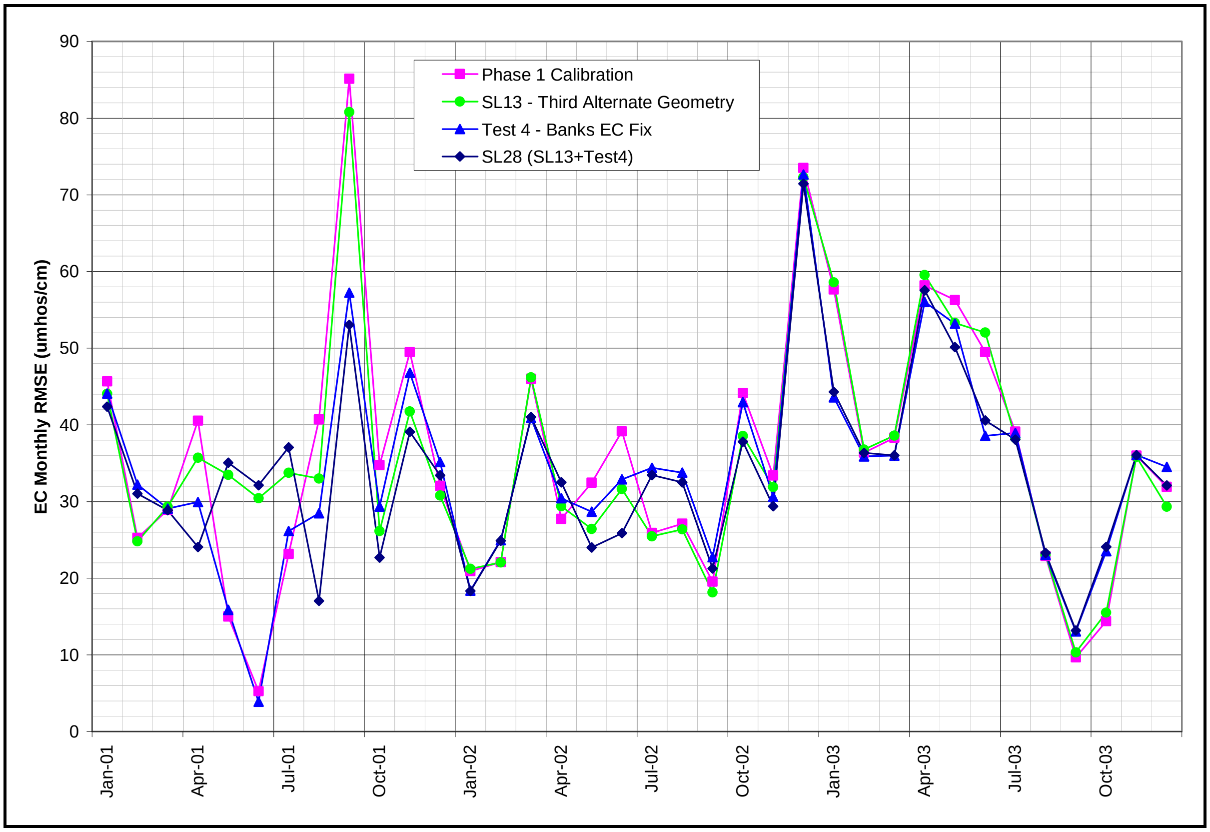

FIGURE 15
Comparison of Average Monthly RMS Error at Check 13 below O'Neill Forebay

4. Run SL28 combined the geometry from run SL13 with the boundary condition refinements from run Test4.

The time-series comparison confirms that the configuration changes to San Luis Reservoir in run SL13 did not lead to any significant improvements in EC predictions as measured at Check 13 below O'Neill Forebay. Comparing results of simulation SL28 to the Phase I calibration run indicates periods of lower RMS error and periods with higher RMS errors. The average RMS error over the 3-year period was reduced by 9 percent between the Phase I calibration simulation (39.72 µmhos/cm) and simulation SL28 (36.06 µmhos/cm). The majority of the improvement was associated with the change in boundary condition at Banks (RMS error 36.63 µmhos/cm), not the change in the geometric representation of San Luis Reservoir.

Therefore, it is concluded that the small reduction in RMS error attributed to the SL13 configuration does not justify the added model complexity associated with this alternative representation of San Luis Reservoir.

Review of Field Data

Subsequent to the completion of the DSM2 modeling effort conducted in this task, Robert Duvall (Water Quality Section, California Department of Water Resources) provided vertical profile data for San Luis Reservoir covering the period 2001 through 2003. Data was collected on the northwest side of the reservoir, near the Pacheco Pumping Plant intake, which is located near the deepest portion of the lake, as shown in Figure 16.

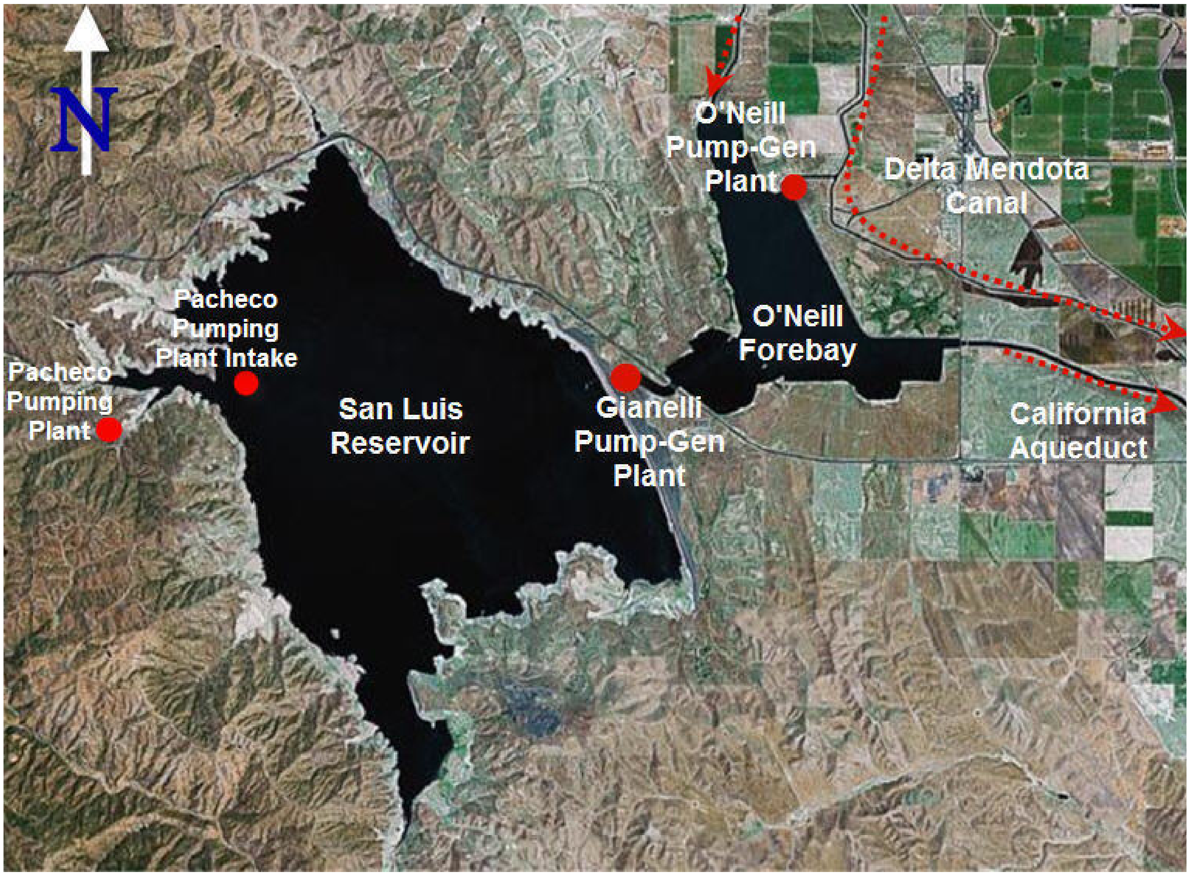

FIGURE 16
San Luis Reservoir and O'Neill Forebay

Profiles were collected on a monthly interval with a Hydrolab instrument, and included the following parameters:

- Electrical conductivity
- Temperature
- pH
- Turbidity
- Dissolved oxygen

Figure 17 presents a comparison between the profile data collected in San Luis Reservoir and the Pacheco Pumping Plant EC data used in the Phase I model calibration. The Phase I model results are also included in the figure. The profile data have been plotted with the profile maximum and minimum EC value for each sampling event. Note the general similarity between the maximum and minimum profile values, indicating that the reservoir is generally well mixed vertically. Also, note that the profile data generally agrees with the data collected from the Pacheco Pumping Plant, removing suspicions about data quality as a possible explanation for the problems associated with quality of the San Luis Reservoir calibration. The profiles were taken near the Pacheco Pumping Plant Intake, and thus do not provide information on the lateral variability of EC in San Luis Reservoir. It is possible that EC conditions are more variable near the dam, because that portion of the reservoir would be under greater influence of daily inflows from and outflows to O'Neill Forebay.

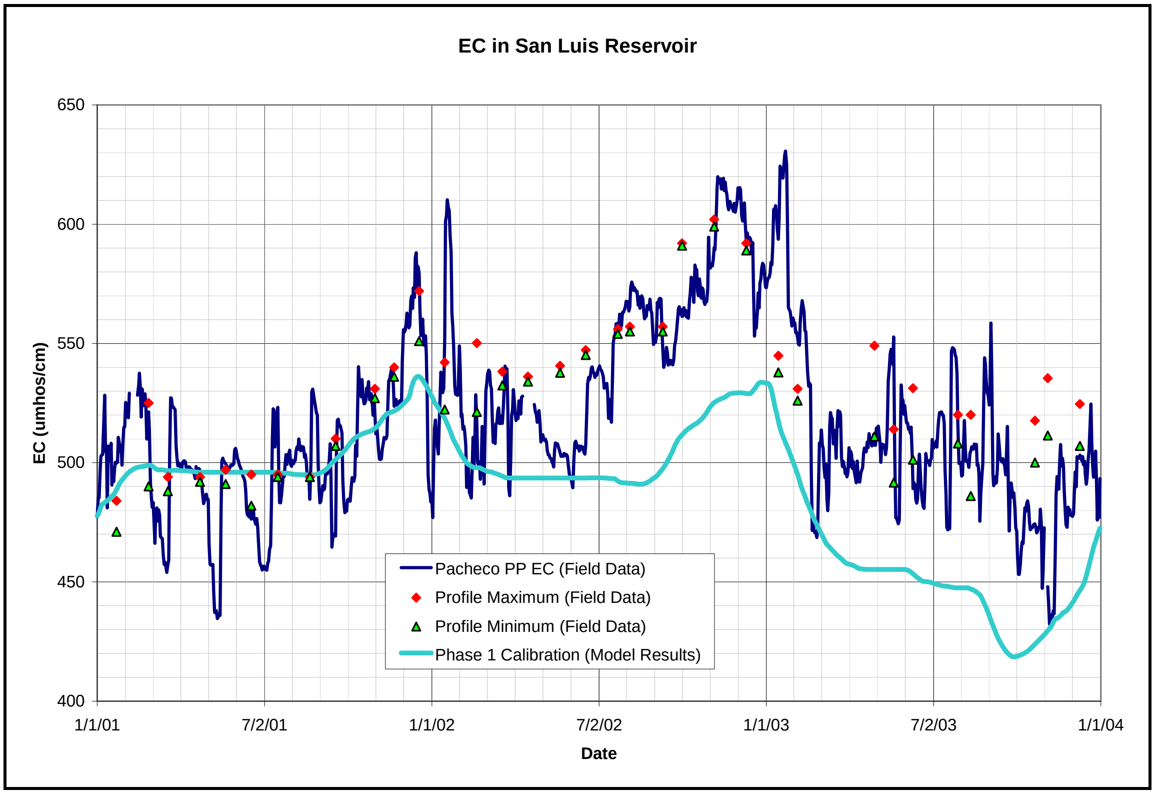

FIGURE 17
Comparison of Daily EC Data at Pacheco Pumping Plant and Profile Data near Dam

Figures 18, 19, and 20 present the results of this data collection effort for the 3 years used in the Phase I calibration effort. Figure 18 indicates that the reservoir was completely mixed vertically for each month except December through February, when stratification was very week and confined to the lower section of the reservoir. Figure 19 shows that the range in EC throughout the year narrowed in 2002, and that EC increased from 2001 levels. Again, only January and February profiles indicate any stratification. Finally, Figure 20 demonstrates an even narrower range in annual EC variation occurred in 2003.

Figure 21 demonstrates the time history of stratification quantified by the range in EC throughout each individual profile along with the percent difference between the maximum and minimum EC throughout the water column. For the 3-year record, the average EC range is 12 μmhos/cm, which corresponds to a difference of 2.4 percent.

The profile data demonstrate that the reservoir is well mixed vertically, at least near the Pacheco Pumping Plant Intake. Furthermore, the profile data generally demonstrate good agreement with the EC measured at the Pacheco Pumping Plant, thus supporting the quality of this dataset for calibration purposes. Additional profile data collected near the dam would verify whether the entire reservoir can be considered well mixed.

Analysis of Opportunities to Reduce Average Annual Salinity Levels in San Luis Reservoir

Project staff investigated opportunities to lower the average annual EC concentration in San Luis Reservoir through alternative operations strategies. Two methods of lowering the

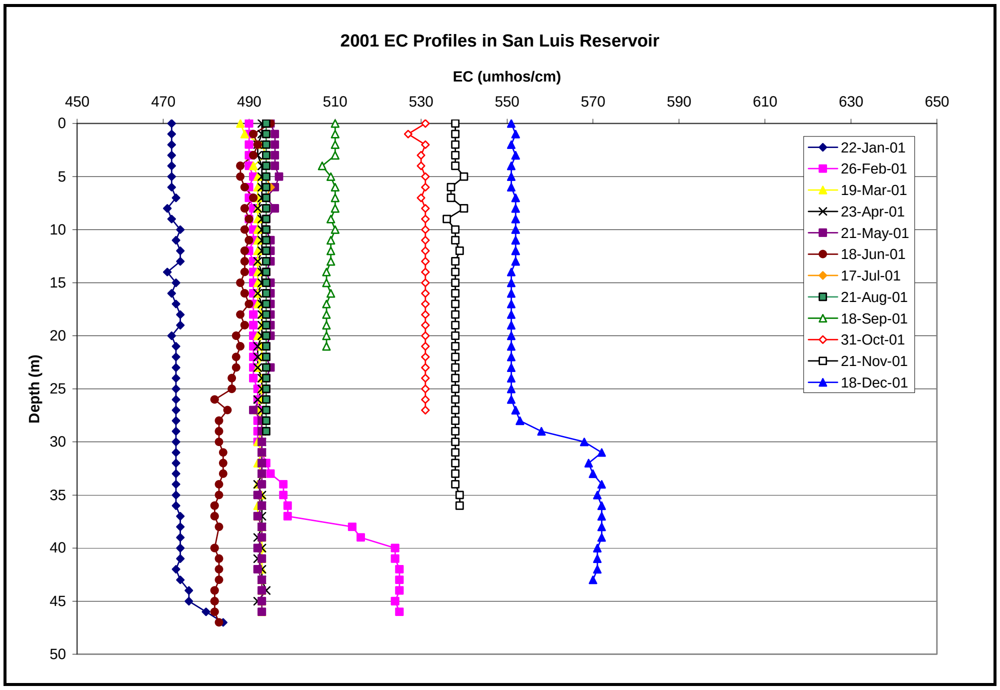

FIGURE 18
EC Field Data Profiles in San Luis Reservoir (2001)

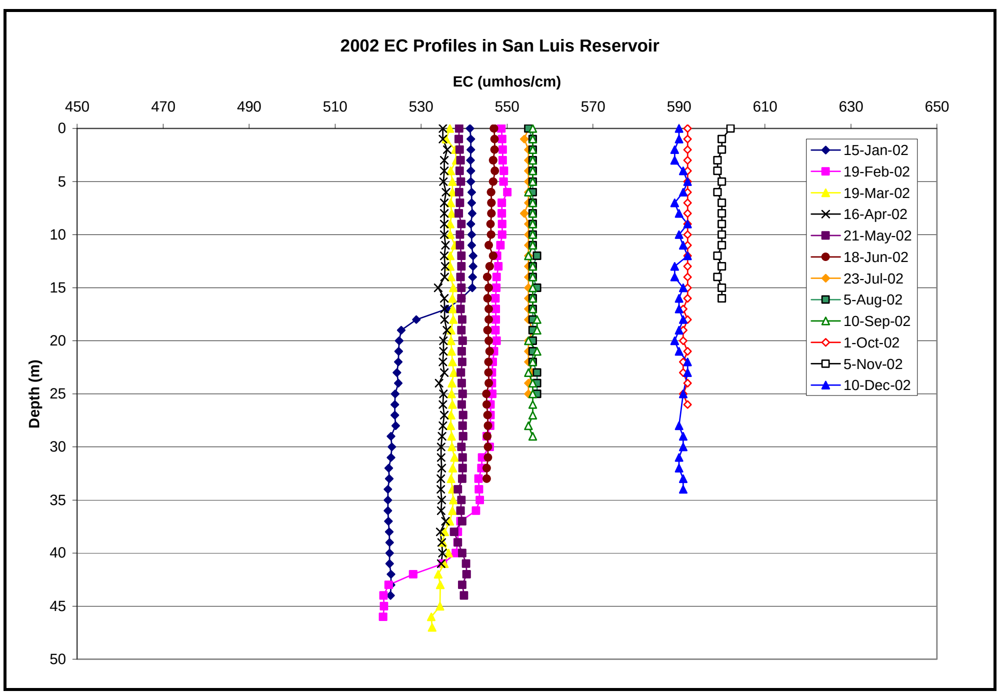

FIGURE 19
EC Field Data Profiles in San Luis Reservoir (2002)

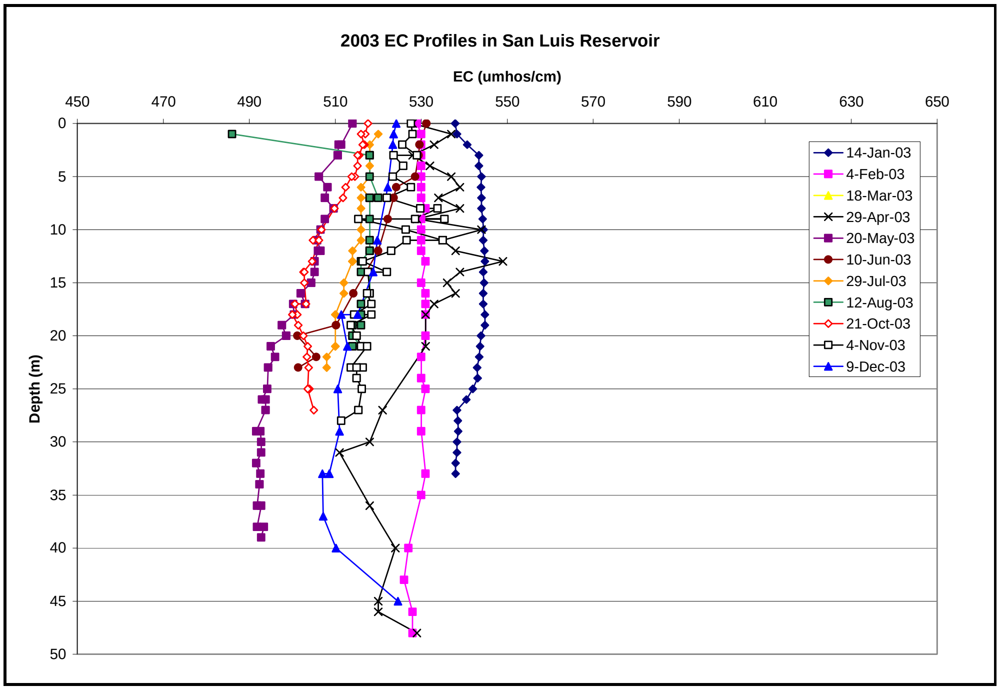

FIGURE 20
EC Field Data Profiles in San Luis Reservoir (2003)

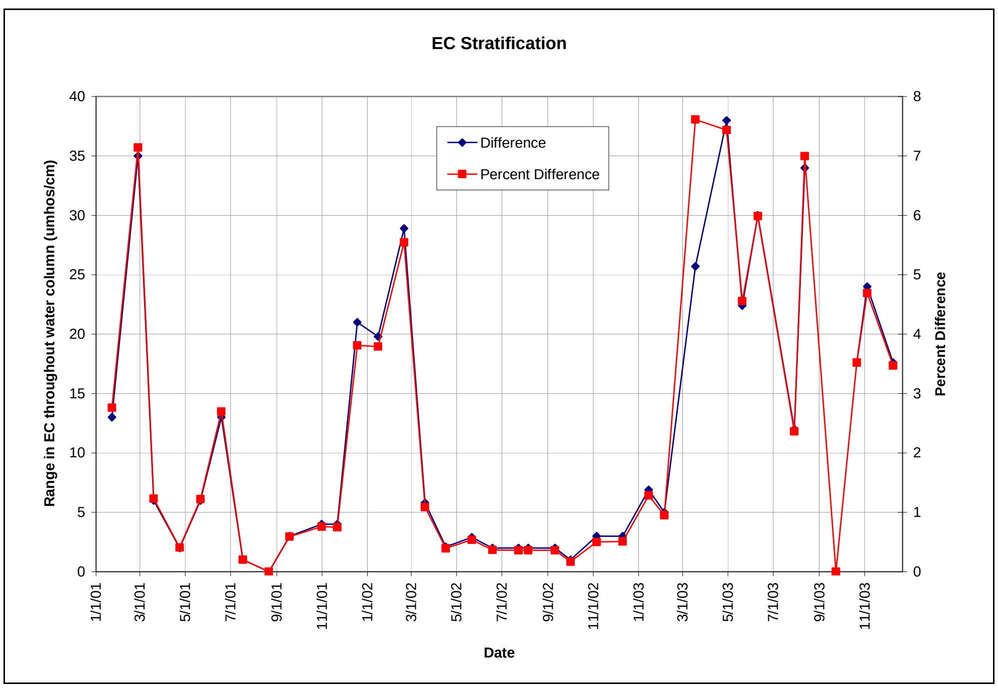

FIGURE 21
Degree of Stratification in San Luis Reservoir (2001–2003)

average annual EC concentration in the reservoir were investigated. The first involves shifting inflows to San Luis Reservoir from periods of higher than average EC at Banks and Jones Pumping Plants to periods with lower-than-average EC at these boundaries. The second involves operating Banks Pumping Plant around the spring/neap tidal cycle.

Historical data and numerical model predictions were used in the analysis. A DSM2 Temporary Barriers Baseline simulation was analyzed with respect to variations near Clifton Court, and the causes of those variations. This study is considered representative of existing conditions. QUAL fingerprinting simulations were also analyzed, and volumetric and constituent source tracking were included in the analysis.

Figure 22 presents an 18-year record of daily EC in San Luis Reservoir. Data were obtained from the Pacheco Pumping Plant Station, and are considered representative of EC in San Luis Reservoir. The dataset indicates a high degree of variability in annual average EC (year to year) and the inter-year range in EC inside San Luis Reservoir.

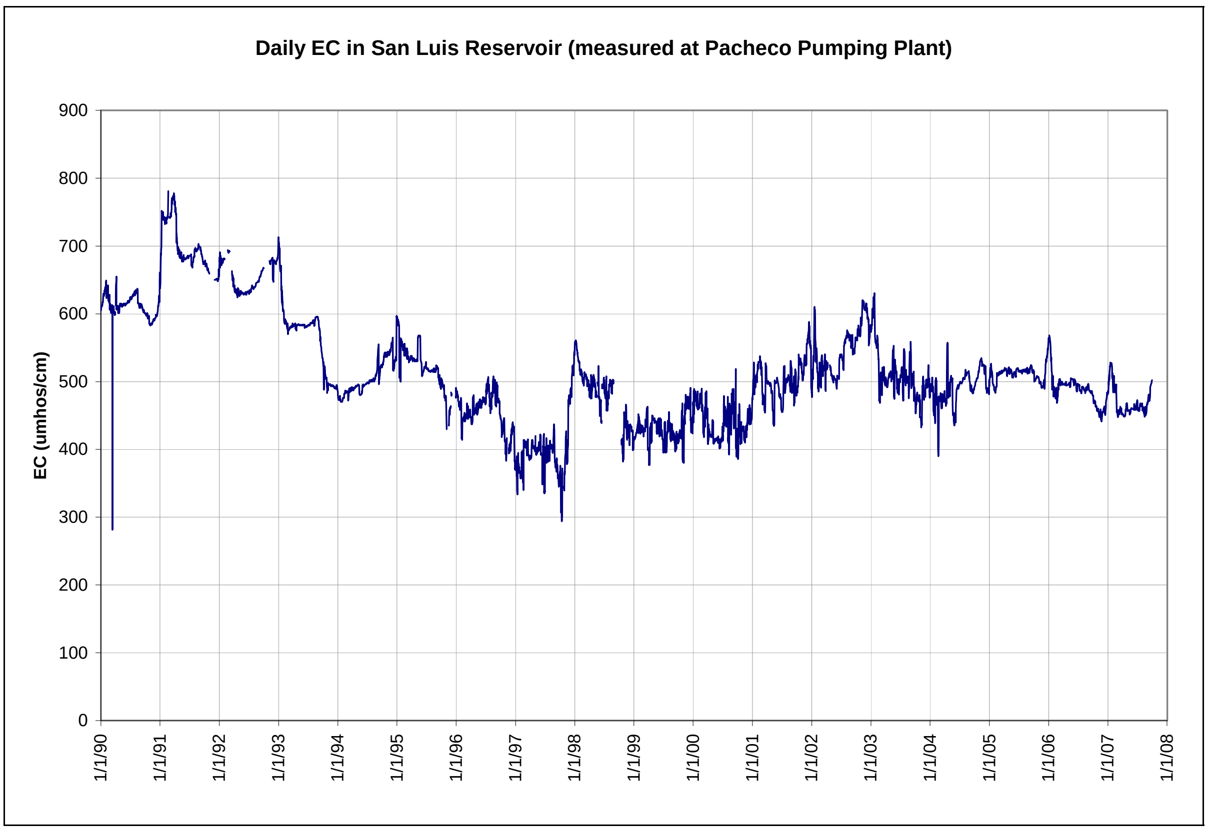

FIGURE 22
Measured EC in San Luis Reservoir (1990–2007)

Shifts in San Luis Reservoir Inflows

The current operation cycle at San Luis Reservoir has inflows generally commencing in September, increasing in magnitude through December and January, and concluding in April. Inflows in the months of January through March can be highly variable, because pumping is correlated to excess water in the Delta associated with winter storms.

Figure 23 presents San Luis Reservoir inflow data used in the DSM2 Aqueduct Model for the 3-year period beginning in 2001, and demonstrates the general annual pattern in flows into San Luis Reservoir as well as the year-to-year variation. Figure 23 uses the 7-day average flows used in the DSM2 Aqueduct Model. Figure 24 superimposes a 3-year history of measured EC at Banks over the San Luis Reservoir inflows presented in Figure 23. Annual patterns indicate that EC at Banks is generally lowest in the summer months, when inflows to San Luis are also at their annual minimum. During the summer months, water is released from storage in San Luis to meet contractor needs, since demands can exceed the flow capacity at Banks Pumping Plant. Thus, the low-EC water being pumped through Banks during the summer months cannot be used to fill San Luis Reservoir.

In order to lower annual EC in San Luis Reservoir, there must be a decrease in the salt transport into San Luis Reservoir. This can be accomplished by decreasing inflows to San Luis Reservoir when EC at Banks is relatively high and increasing inflows to San Luis Reservoir when EC at Banks is relatively low. One way to accomplish this would be to shift pumping from late fall months, when EC is generally at its annual peak, to winter months, when EC may be slightly lower.

Annual patterns of EC at Banks are presented in Figure 25. Field data is presented for the period from January 1986 to September 2007. The range in monthly average EC at Banks throughout the 21-year record is noted in Figure 25. The field data indicates that EC is generally highest in December.

Historical monthly average patterns of flow into San Luis Reservoir are presented in Figure 26. Field data is presented for a 14-year period covering water years 1991 to 2004. The portion of that dataset used in the DSM2 Aqueduct Model (2001–2003) is also presented for comparison. The fill cycle generally runs from September to March, with peak inflows to San Luis Reservoir in January.

The potential to lower EC concentrations in San Luis Reservoir by shifting inflows from fall to winter months was investigated by using the historical monthly averaged data provided in Figures 25 and 26. This is a screening-level analysis and does not account for such factors as Net Delta Outflow requirements or fisheries concerns. This analysis merely demonstrates the potential for decreased salt transport into San Luis Reservoir.

Table 2 summarizes the monthly average EC measured at Banks Pumping Plant and the monthly average flows into San Luis Reservoir. Values were calculated from field measurements, not model results, and are presented for water years (WY) 1991 to 2003, the period where both datasets overlap. EC values are shaded to represent values above 600 µmhos/cm (red) and between 500 and 600 µmhos/cm (yellow). The monthly values presented in Table 2 were used to calculate the percent of the annual salt load to San Luis Reservoir on a monthly basis; Figure 27 presents this data.

The potential improvement in San Luis Reservoir EC was demonstrated by selecting years with higher-than-average EC in San Luis EC, and then shifting these flows from the September-November period (higher EC inflows) to the January-March period (lower EC inflows). Results of the screening analysis are presented in Table 3. Flows were decreased in months with high EC (September through January, purple cells) and shifted to months with

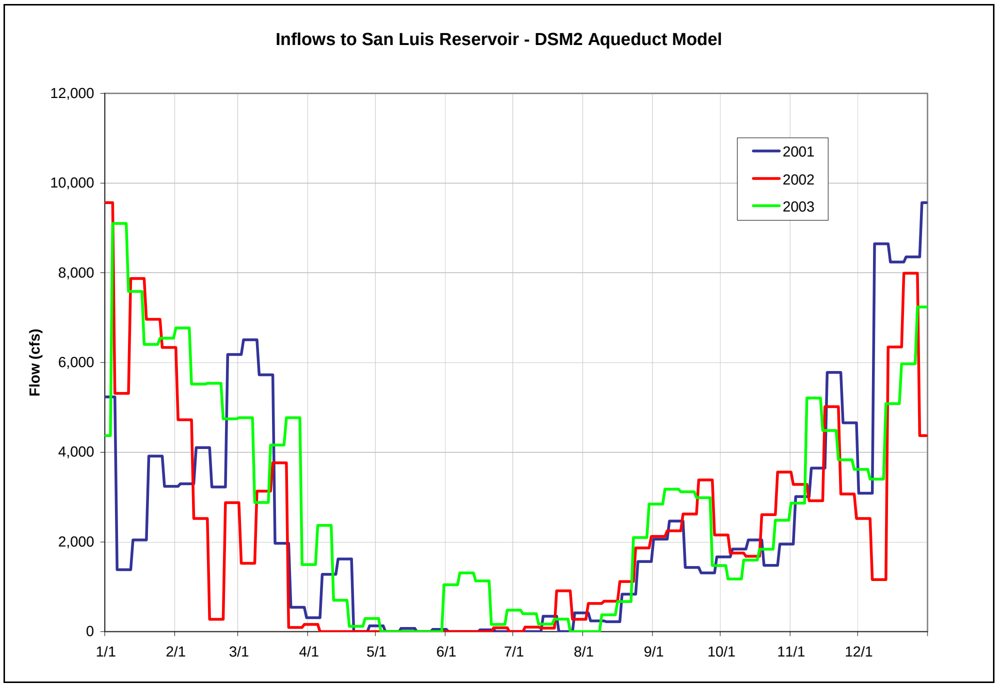

FIGURE 23
Inflows to San Luis Reservoir (7-day Averages from DSM2 Aqueduct Model)

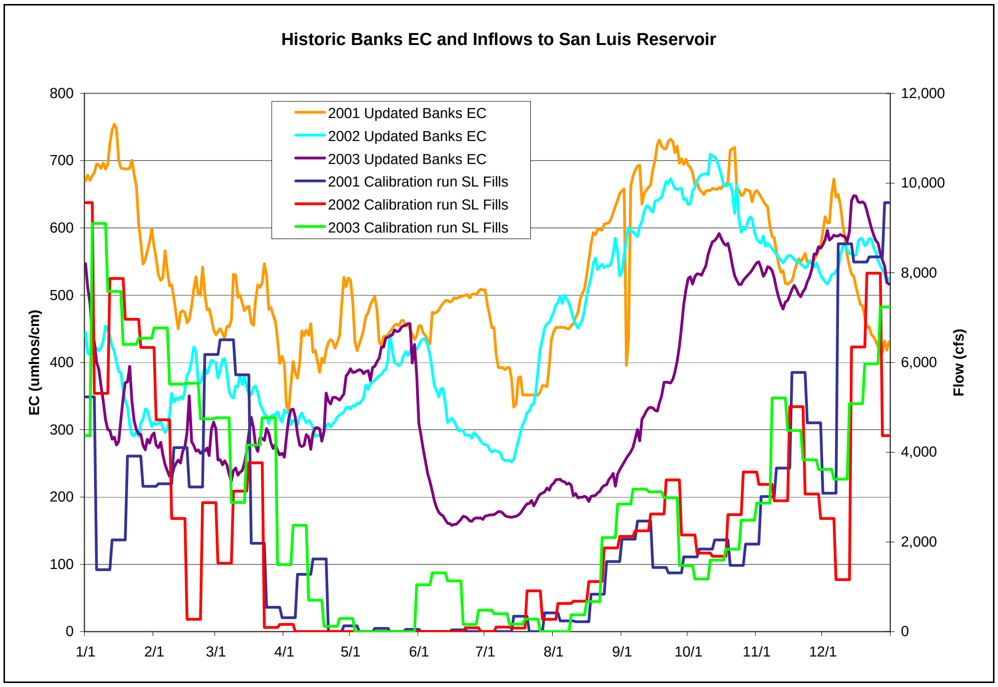

FIGURE 24
Comparison of Patterns in Banks EC and San Luis Reservoir Inflows

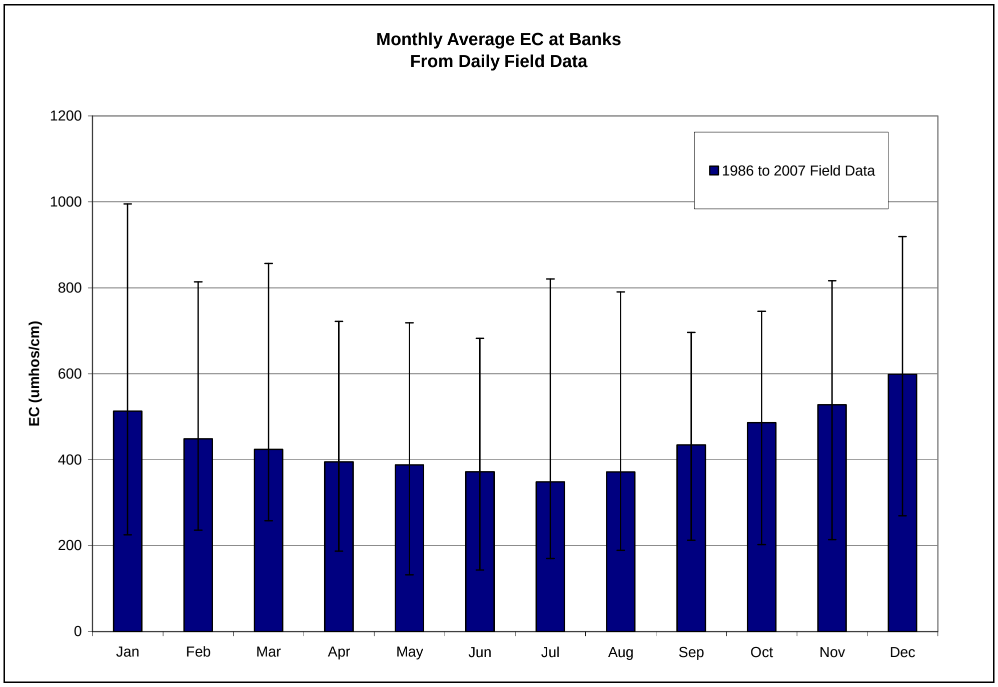

FIGURE 25
Historic Monthly Pattern of EC at Banks Pumping Plant

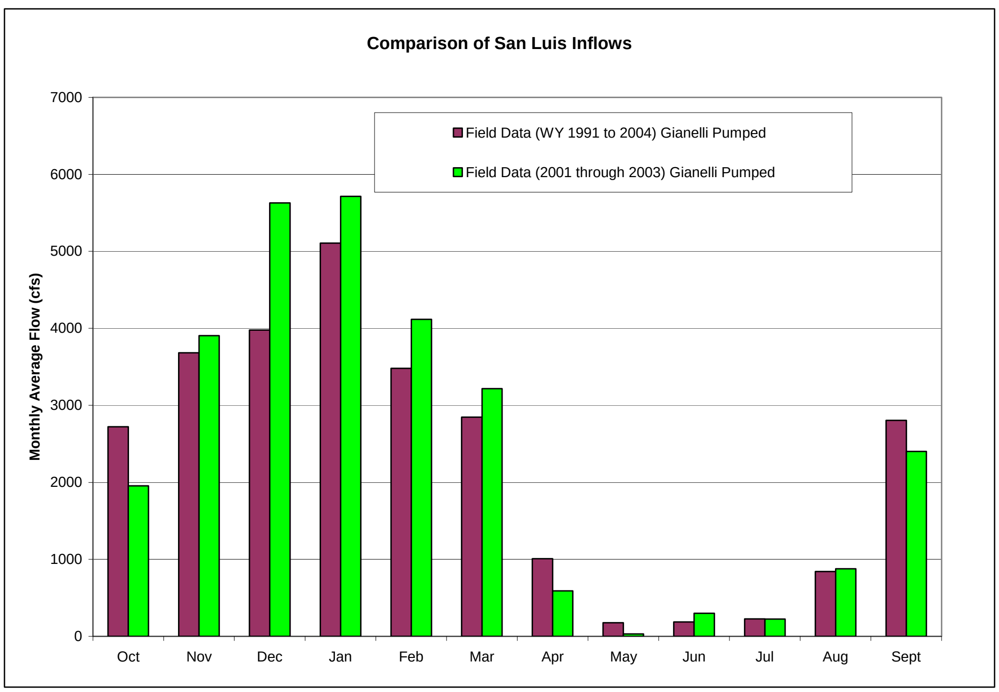

FIGURE 26
Historic Monthly Patterns of Flow into San Luis Reservoir

TABLE 2
Monthly Average Recorded EC at Banks Pumping Plant and Flow into San Luis Reservoir
Phase II DSM2 Extension for the California Aqueduct—Task 2: Analysis of San Luis Reservoir and O'Neill Forebay

Field Data Monthly Average Banks EC (umhos/cm)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
WY 1991	600	768	919	995	814	857	402	444	591	567	494	494
WY 1992	571	654	873	743	728	393	411	427	682	820	790	680
WY 1993	697	798	785	528	470	527	471	493	427	218	189	238
WY 1994	325	423	420	426	455	477	533	558	586	553	560	675
WY 1995	601	620	580	454	419	473	496	256	197	217	210	213
WY 1996	202	214	269	303	340	271	331	308	216	203	231	254
WY 1997	345	431	380	225	236	304	383	462	370	310	279	309
WY 1998	502	556	631	526	460	446	634	452	192	170	254	300
WY 1999	255	313	602	526	379	333	449	375	387	270	254	361
WY 2000	444	493	708	432	337	318	312	384	298	244	250	369
WY 2001	458	544	601	668	501	475	424	455	442	381	451	
WY 2002	660	570	524	371	357	354	313	384	338	320	511	627
WY 2003	654	556	553	346	270	267	316	415	189	185	215	342

Field Data Monthly Average Gianelli Pumping (cfs)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
WY 1991	266	1159	2975	2479	1688	8604	6185	273	139	87	964	2788
WY 1992	2001	1003	1307	5071	5186	8732	1585	0	0	0	455	1312
WY 1993	67	825	2652	10949	8073	3220	3287	0	0	53	899	4786
WY 1994	5157	3507	5091	895	72	209	0	0	0	0	675	3955
WY 1995	2332	4353	5890	9749	4395	1	127	251	402	804	743	1195
WY 1996	2225	2449	0	4850	1861	89	191	718	606	1040	968	3992
WY 1997	4748	7434	5425	2115	766	1037	418	0	203	44	1747	4425
WY 1998	4451	5940	8140	4606	2899	138	115	1152	63	179	0	1794
WY 1999	4420	2606	324	1498	1336	1487	151	0	0	208	1478	3585
WY 2000	2791	4994	3071	5741	5987	3664	82	0	339	104	1212	4088
WY 2001	3917	5441	4159	3105	3971	3688	748	56	9	89	726	1833
WY 2002	1681	4203	7340	7017	2734	1980	37	0	20	246	1109	2601
WY 2003	2321	3481	4380	7292	5641	3932	936	28	851	298	831	2905

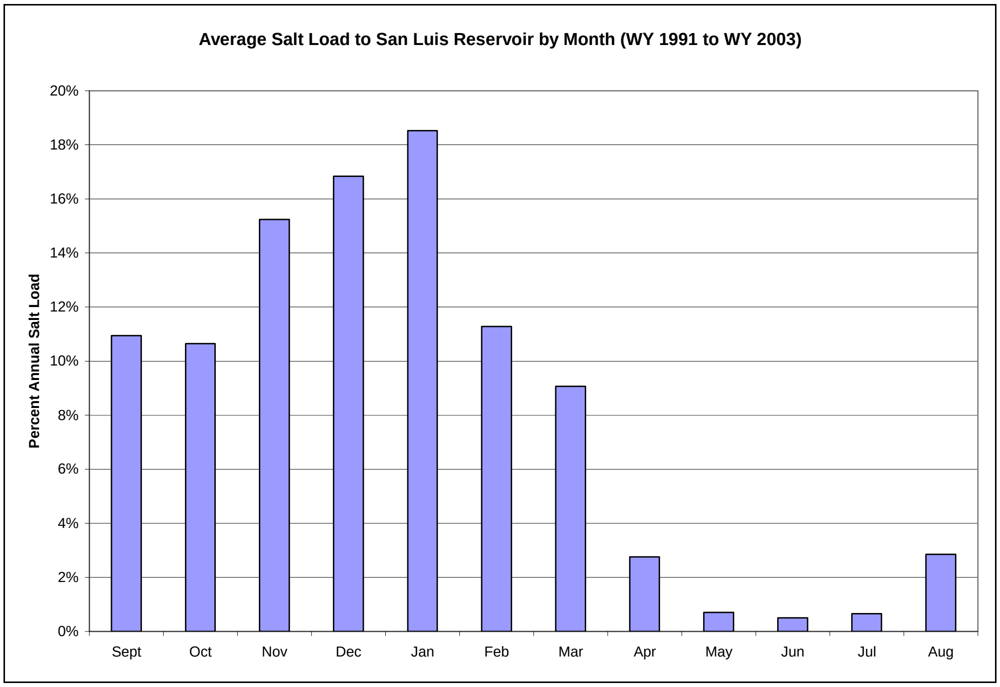

FIGURE 27
Distribution of Salt Load to San Luis Reservoir (WY 1991 to 2003)

TABLE 3
Reoperation of San Luis Reservoir Inflows to Reduce Salt Load
Phase II DSM2 Extension for the California Aqueduct—Task 2: Analysis of San Luis Reservoir and O'Neill Forebay

Field Data Monthly Average Banks EC (umhos/cm)

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
WY 1991	494	600	768	919	995	814	857	402	444	591	567	494
WY 1992	680	571	654	873	743	728	393	411	427	682	820	790
WY 1993	238	697	798	785	528	470	527	471	493	427	218	189
WY 2002	627	660	570	524	371	357	354	313	384	338	320	511
WY 2003	342	654	556	553	346	270	267	316	415	189	185	215

Field Data Monthly Average Gianelli Pumping (cfs)

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
WY 1991	2788	266	1159	2975	2479	1688	8604	6185	273	139	87	964
WY 1992	1312	2001	1003	1307	5071	5186	8732	1585	0	0	0	455
WY 1993	4786	67	825	2652	10949	8073	3220	3287	0	0	53	899
WY 2002	2601	1681	4203	7340	7017	2734	1980	37	0	20	246	1109
WY 2003	2905	2321	3481	4380	7292	5641	3932	936	28	851	298	831

Reoperation Monthly Average Gianelli Pumping (cfs)

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
WY 1991	2788	266	1159	1475	979	4688	8604	6185	273	139	87	964
WY 1992	1312	2001	1003	1307	5071	5186	8732	1585	0	0	0	455
WY 1993	4786	67	825	1152	10949	8073	4720	3287	0	0	53	899
WY 2002	1101	1181	4203	7340	7017	4734	1980	37	0	20	246	1109
WY 2003	2905	321	3481	6380	7292	5641	3932	936	28	851	298	831

Months with decreases in flow (magenta)
Months with increases in flow (cyan)

lower average EC at Banks (blue cells). As with Table 2, EC values for Banks are shaded to represent values above 600 µmhos/cm (red) and between 500 and 600 µmhos/cm (yellow).

These shifts led to only minor reductions in annual average EC in San Luis Reservoir. Table 4 shows that improvements of 2 to 4 percent were possible, but that certain years could not be improved. WY 1992, for example, had an extended period (November through February) during which EC concentration at Banks Pumping Plant exceeded 650 µmhos/cm. Overall, the results are not promising, considering the water supply risks associated with postponing diversions into San Luis Reservoir.

TABLE 4
Summary of Improvement in EC with Reoperation
Phase II DSM2 Extension for the California Aqueduct—Task 2: Analysis of San Luis Reservoir and O'Neill Forebay

Water Year	Annual Average EC (µmhos/cm)		Improvement
	Historical	With Reoperation	
WY 1991	679	665	2.2%
WY 1992	653	653	0.0%
WY 1993	615	601	2.3%
WY 2002	528	507	4.0%
WY 2003	539	530	1.6%

Operating Banks Pumping Plant According to Spring / Neap Variations

A second way to potentially lower the average annual salinity in San Luis Reservoir would be to take advantage of salinity variations associated with spring/neap tidal cycles. This possibility was investigated by analyzing hourly EC values in and around Clifton Court Forebay.

Figure 28 presents DSM2-predicted EC concentrations in Clifton Court Forebay and in Old River upstream and downstream of Clifton Court Forebay. Daily fluctuations in EC are considerably higher in the South Delta upstream of Clifton Court Forebay (Old River at Clifton Court Ferry) than in Old River downstream of Clifton Court Forebay (Old River at Highway 4). The daily fluctuations in the South Delta are magnified by the local Delta Island Consumptive Use (DICU) influence and the influence of the San Joaquin River. On flood tides, the South Delta fills with water from the north, which generally has relatively lower EC. On ebb tides, the South Delta drains, and the elevated EC is a reflection of agriculture drains and the San Joaquin River, which have relatively high EC. Note that the predicted EC inside Clifton Court Forebay, included in Figure 28, closely tracks the minimum daily EC at Clifton Court Ferry, and does not seem to be affected by the daily spikes in EC. This could be associated with the gate operation at Clifton Court Forebay and the buffering capacity of the reservoir.

Figure 29 demonstrates that the daily variation in EC is relatively minor in Old River at Highway 4 and at Tracy, indicating that the sources of water controlling EC at these

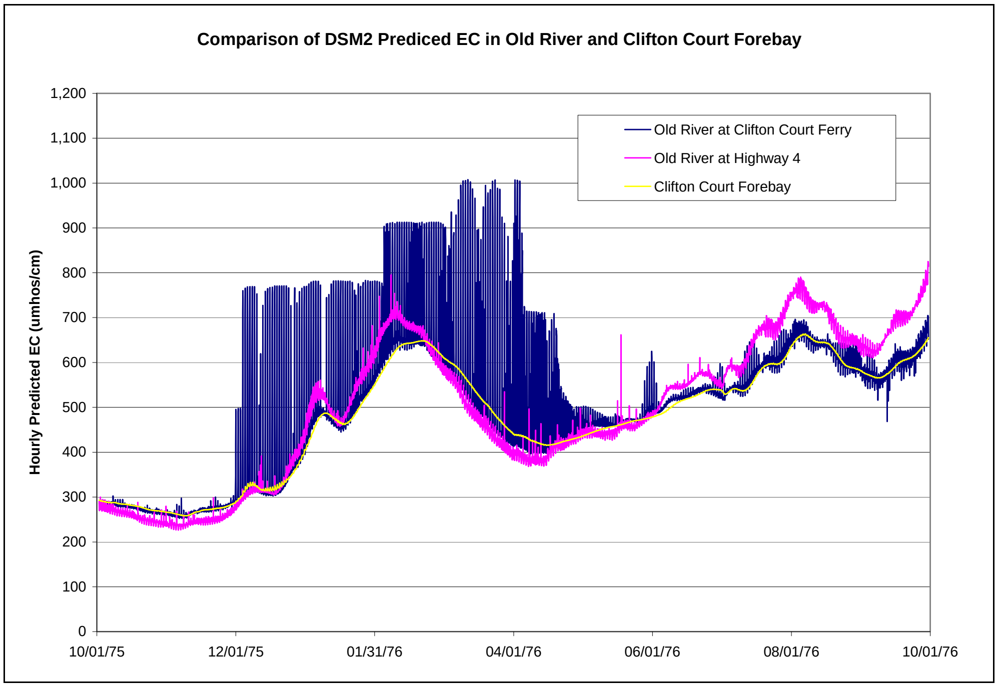

FIGURE 28
Comparison of Predicted EC in Old River and Clifton Court Forebay

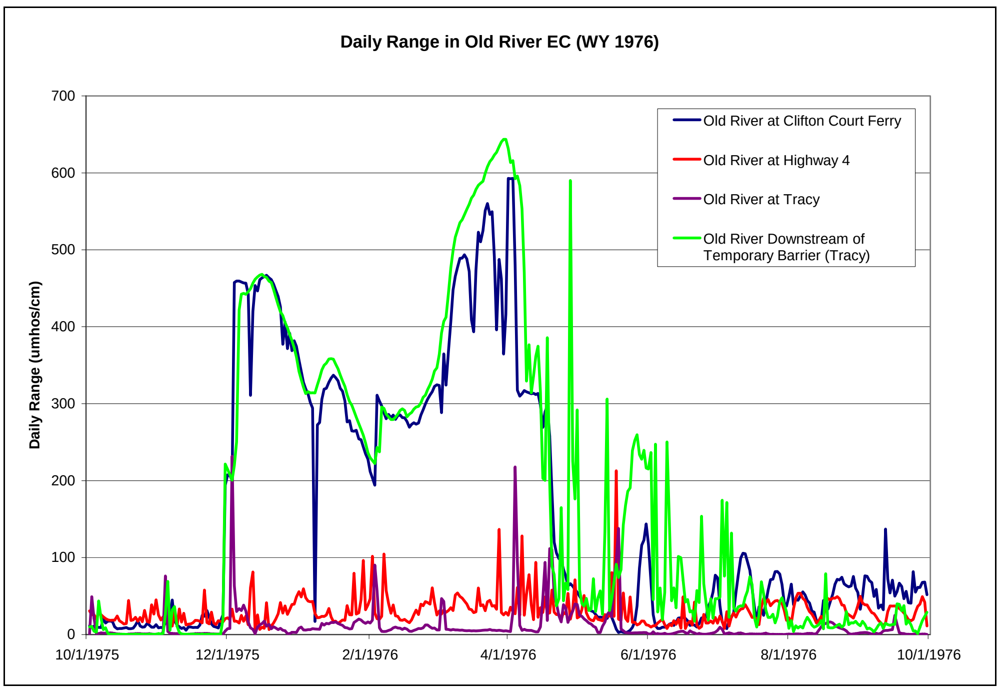

FIGURE 29
Comparison of Daily Range in DSM2 Predicted EC in Old River

locations are relatively constant over time periods on the order of days. Between these two points, however, the control oscillates as described previously.

Figure 30 presents a comparison between DSM2-predicted EC in Old River at Clifton Court Ferry, Old River at Highway 4, and in Clifton Court Forebay. The predicted tide at Clifton Court Ferry, just upstream of Clifton Court Forebay gates, is included to demonstrate the variability in EC with spring and neap tides. Note that there is little variation in the daily EC pattern at Clifton Court Forebay throughout the spring/neap cycle. The red arrows indicate neap tide cycles where EC at Clifton Court Ferry shows decreasing influence from the San Joaquin River and South Delta agriculture return flows. These temporary decreases in daily average salinity at Clifton Court Ferry do not seem to influence the EC in Clifton Court Forebay, as shown in Figure 31, which presents a more detailed look at the third neap tide shown in Figure 30.

Analysis Summary

Attempts to improve the predictive capacity of the DSM2 model resulted in reductions in RMS errors of approximately 9 percent from the Phase I calibration simulation as measured at Check 13 on the aqueduct downstream of O'Neill Forebay. The majority of this error reduction was the result of refinements in the boundary EC applied at Banks Pumping Plant. Changes to the model representation of San Luis Reservoir and its connection with O'Neill Forebay resulted in only minor reductions in RMS errors. Although specific time periods (on the order of a few months) were found to improve significantly, such improvements were not consistent throughout the 3-year simulation period. In fact, the reduction in error during one time period often led to increases in errors during other periods.

Boundary Condition Refinement

Overall, refinements in the representation of the EC boundary conditions demonstrated the potential to reduce the calculated RMS error in EC by up to 15 percent at Check 13. A simple correction in the application of the Banks EC boundary condition (Test3) resulted in a 0.5 percent improvement in predicted EC. An additional refinement in the treatment of data gaps in the Banks EC boundary conditions (Test4) yielded an improvement of 8 percent as compared to the Phase I simulation. A sensitivity study on potential improvements on the DMC upstream of O'Neill Forebay (Test5) resulted in an improvement of 15 percent when coupled with changes to the Banks EC boundary discussed above.

The recognition that the current DSM2 model application does not account for all influences on EC between the upstream pumps and O'Neill Forebay demonstrates the importance of having a complete understanding of all model boundary conditions. Field data indicate that there are influences on EC between the upstream pumps and O'Neill Forebay. Groundwater pump-ins may be responsible for the differences between measured EC at Jones Pumping Plant and Check 12 on the DMC. Quantification of the volume and the water quality associated with these inflows will improve the predictive capacity of the model. Furthermore, calibration of flow measurement devices quantifying all flows into and out of O'Neill Forebay could lead to a reduction in the use of closure flows and improvements in model predictions, since assumptions had to be made regarding the water quality of the closure flows.

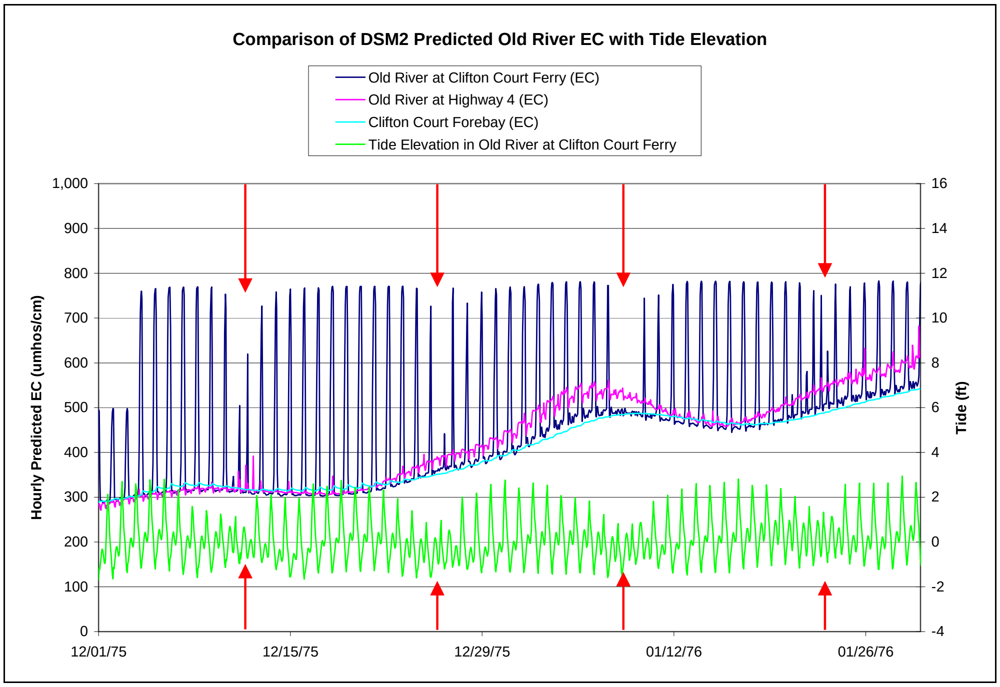

FIGURE 30
Comparison of DSM2 Predicted EC during Spring/Neap Cycles
(December 1, 1975, to January 31, 1976)

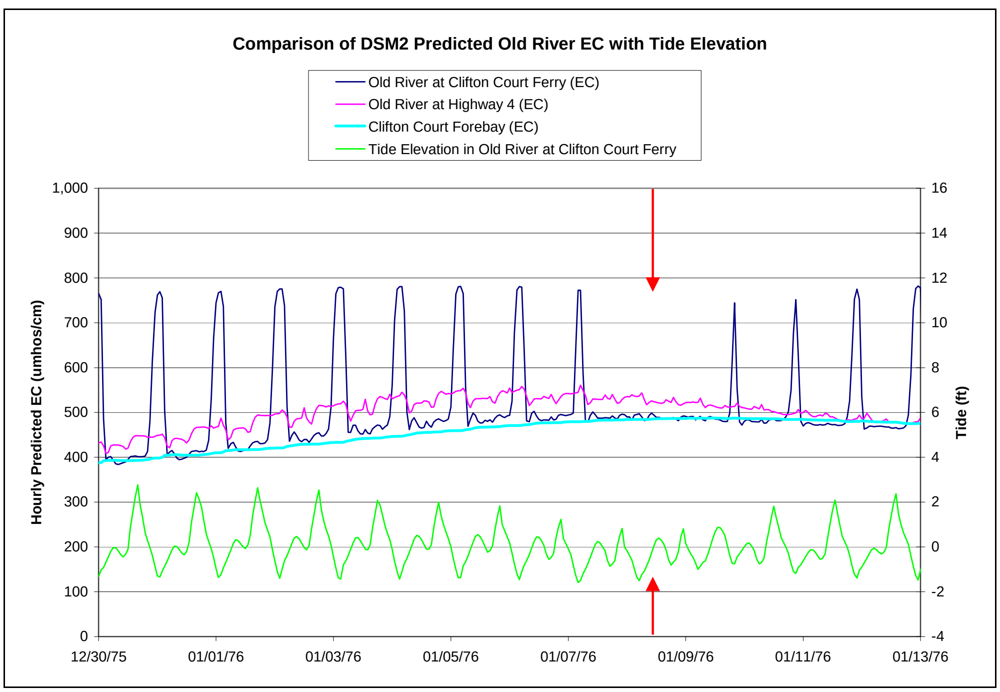

FIGURE 31
Comparison of DSM2 Predicted EC during Spring/Neap Cycles
(December 30, 1975, to January 13, 1976)

San Luis Reservoir Representation

The alternative model configurations of San Luis Reservoir used in DSM2 during attempts to improve the predictive capacity of the model did not show any considerable improvement in the simulation of San Luis Reservoir EC. Run SL13 demonstrated a 2 percent improvement over the Phase I calibration simulation as measured by the RMS error in predicted EC at Check 13. Considering the net outflow from San Luis Reservoir in the model during May through September 2002, EC predictions were not improved during this critical period by changes in either the boundary conditions or the geometric representation of the reservoir in the model. The small reduction in RMS error attributed to the SL13 configuration does not justify the added model complexity associated with this alternative representation of San Luis Reservoir.

Field data obtained subsequent to the Task 2 modeling exercise indicate that at one particular location in the reservoir, there is generally very little variation in EC throughout the water column. Thus, the field data indicate that it may be unnecessary to model San Luis Reservoir with distinct upper and lower layers. Project staff are not aware of any field datasets that demonstrate whether or not the reservoir is laterally homogeneous in terms of EC. Additional data collection (profiles of EC near the dam) would provide valuable information on whether the entire reservoir shows the same vertical structure as the profiles collected near the Pacheco Pumping Plant Intake.

San Luis Reservoir Operational Opportunities

Adjustments to the annual filling pattern of San Luis Reservoir could result in minor reductions in San Luis Reservoir EC on an annual basis. Shifts in flow from October and November to February and March could lower annual average EC in San Luis Reservoir by a few percentage points. However, there are water supply concerns associated with such moves. A review of historical data indicates that for the periods reviewed, water would have been available later in the year, but this is by no means a guarantee. Passing up available water in the fall with hopes of making up that water later in the winter may provide better water quality but could decrease water supply.

Spring/neap variations do not seem to have a discernable influence on short term variations in EC in the vicinity of Clifton Court Forebay. Other factors, including pumping rates through Banks Pumping Plant, San Joaquin River flows and EC, and agricultural return flows, seem to exert more influence on the EC near Clifton Court Forebay. Thus, variations in operations at Clifton Court Forebay on a biweekly basis are not likely to cause significant changes in EC concentrations in Clifton Court Forebay or San Luis Reservoir.

To lower the average EC into Clifton Court Forebay and thus San Luis Reservoir, pumping operations would have to be adjusted to capture more water from the north and less water from the South Delta. Improvements in EC at Clifton Court Forebay would result in decreases in water quality elsewhere, absent changes in boundary flows. If the annual salt transport out of the South Delta through Banks decreases, more salt will remain in the South Delta, since the South Delta has net inflows on average. Absent any structural changes in the South Delta, the benefit of decreased salt transport through the pumps would likely lead to adverse impacts on agricultural diversions in the South Delta.

Reference

CH2M HILL. 2005. *DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal*. Prepared for State Water Contractors and Municipal Water Quality Investigation Program. June.

Appendix C:
Task 3 Technical Memorandum

Phase II DSM2 Extension for the California Aqueduct Task 3 – Planning Simulation Model

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DATE: August 24, 2007

Introduction

The California Department of Water Resources' (DWR) Municipal Water Quality Investigation (MWQI) program is interested in developing the capability to do DSM2 simulations for water quality planning and forecasting based on the use of CALSIM2 Model results. This technical memorandum presents the development of a planning mode simulation of the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal (DMC) systems using the Delta Simulation Model 2 (DSM2) model.

This work builds on the previous Phase 1 study (CH2M HILL, 2005), where the DSM2 Aqueduct Model was developed and calibrated for a three-year period beginning January 1, 2001. Use of a three year calibration period allowed for simulation of a wide range of historical flow conditions that may be experienced under different planning level analyses. The DSM2 Aqueduct model predicts both the hydraulics (flow and stage) and salinity transport through the system.

To allow use of CALSIM2 model results with DSM2, a processor was developed to disaggregate CALSIM model results for South Delta pumping and diversions along the Aqueduct and DMC and assign them to appropriate nodes in DSM2. The preprocessor was developed in Excel to take advantage of publicly available tools that allow for import and export of DSS data into and out of Excel. When used in planning simulation mode, the DSM2 Aqueduct Model allows simulation of the full 73-year CALSIM simulation period of water years 1922 through 1994.

CALSIM Overview

CALSIM II is the current planning model used and developed by DWR and the U.S. Bureau of Reclamation (USBR). It is a general-purpose simulation model of the combined California's State Water Project (SWP) and the Federal Central Valley Project (CVP) systems as well as a host of smaller water supply entities with which the CVP/SWP systems interact. A geographically comprehensive model, CALSIM II includes the Sacramento River basin, the San Joaquin River basin, and the Delta, as well as portions of the Tulare Basin and Southern California areas served by the CVP and the SWP. CALSIM II includes a hydrology developed jointly by DWR and USBR and a delivery logic dependent on runoff forecast information to represent the available water supply in the system. The focus of CALSIM II is on the major CVP and SWP facilities, but operations of many other facilities are included to varying degrees. CALSIM II uses DWR's Artificial Neural Network (ANN) model to simulate the flow-salinity relationships for the Delta and predict salinity at four critical locations inside the Delta to ensure that water quality requirements are met as Delta operations are changing. CALSIM II provides a platform for assessing changes in Delta water quality and water supply operations of the CVP and SWP projects.

The CALSIM II study used in this report to develop the DSM2 Aqueduct planning mode simulation is OCAP Study 2 with existing facilities, B2 actions, and does not contain the Environmental Water Account (EWA) component.

Utilizing CALSIM Results with DSM2

CALSIM II and the extended DSM2 model overlap and simulate South of Delta SWP and CVP operations. Both model grids include the California Aqueduct and Delta Mendota Canal (DMC), and include Delta exports at Banks and Tracy Pumping Plants, San Luis Reservoir operations, and diversions to contractors or other Aqueduct segments (i.e. South Bay Aqueduct, Coastal Branch, and West Branch). CALSIM II is used to make monthly decisions about water supply distribution and allocation based on storage and forecasted inflows over a broad hydrologic range. DSM2 is used to understand the hydrodynamics and water quality at any point in the system. By utilizing both models, DSM2 can be run in planning mode, enabling agencies to assess the impacts of water quality and supply along the Aqueduct and DMC.

Simulation Period

The 73-year CALSIM planning simulation period begins in October of 1921 and ends in September of 1994. The calibrated DSM2 Aqueduct model simulation period is from January, 2001 to December, 2003. For the planning mode simulation, the DSM2 Aqueduct model was updated to run for the same 73-year simulation period.

Boundary conditions

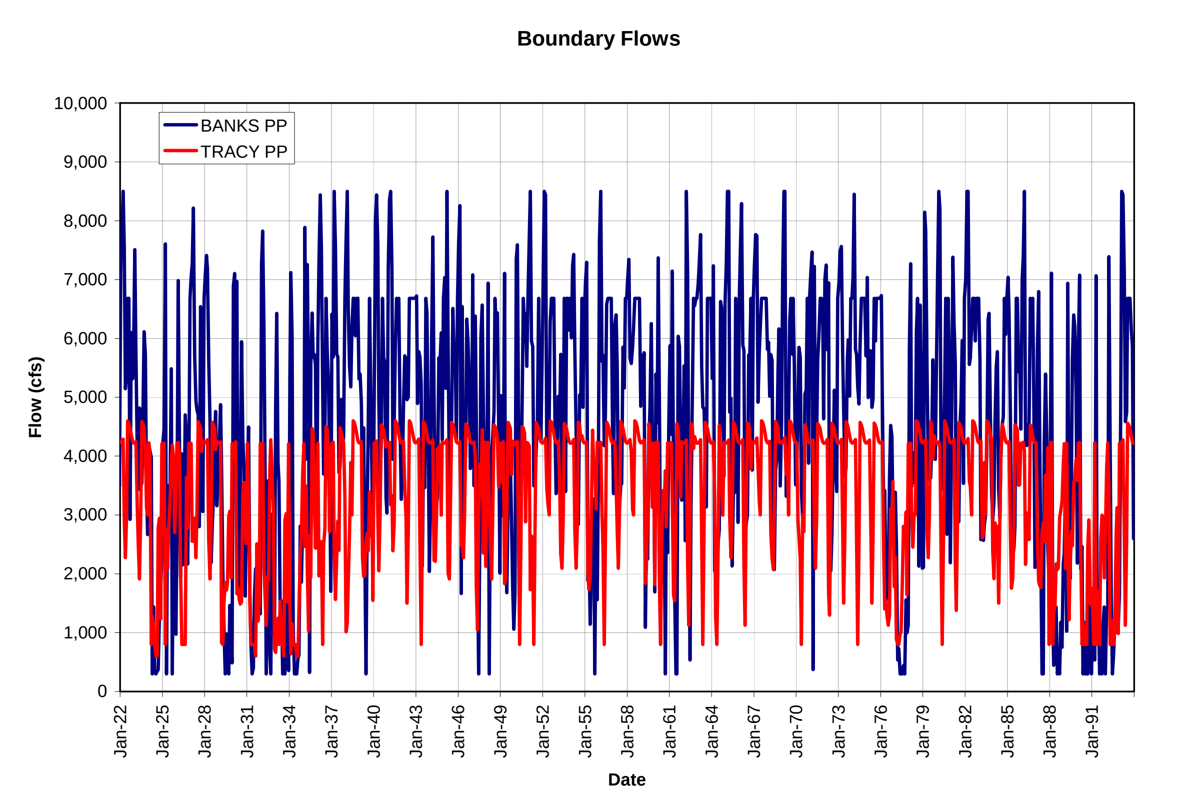
Stage

Since CALSIM II is strictly a volume based monthly time step water supply planning model, CALSIM II doesn't calculate water levels within the aqueduct system. Appropriate levels for downstream water surface elevations at the end of the main stem of the Aqueduct, the DMC, and the West Branch were developed for the DSM2 Aqueduct model in the previous phase of work. No adjustments to these elevations were made in the planning mode simulation.

Flow

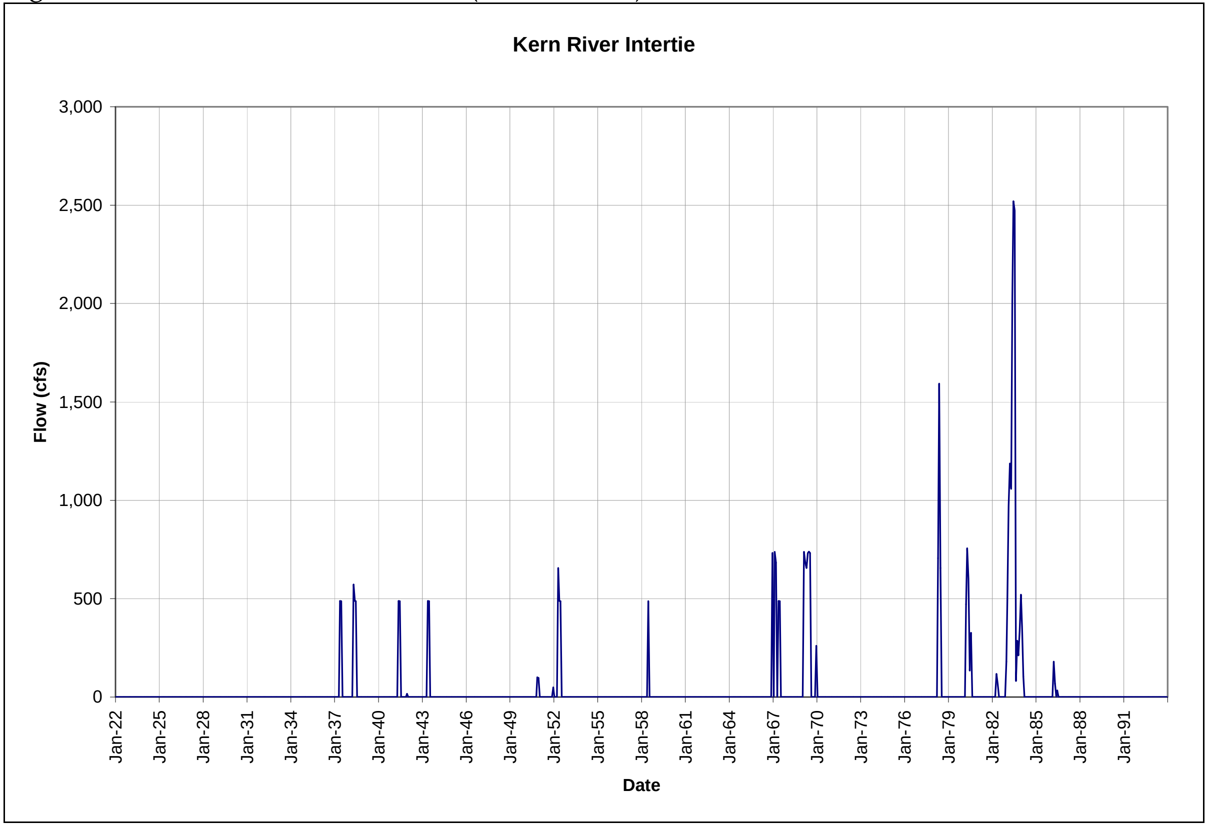
CALSIM II uses reservoir storage, pumping capacity, and Delta water quality requirements to determine the amount of water exported from Banks and Tracy Pumping Plants to the Aqueduct and DMC. These exports, corresponding to CALSIM II delivery arcs D418 (Tracy PP) and D419 (Banks PP), are used to define the boundary flows in the DSM2 Aqueduct planning model for the 73-year planning period. Figure 1 presents the monthly flows through Banks and Tracy Pumping Plants from the CALSIM simulation.

Figure 1. Upstream Boundary Flows; Banks and Tracy Pumping Plants



Another inflow to the system is the Kern River Intertie, located just before Buena Vista Pumping Plant. The Kern River Intertie is a state variable in the CALSIM II model, corresponding with CALSIM arc I860. The flows in this CALSIM arc are used to define the time series inflow for node 431 in the DSM2 Aqueduct model. The timing of the flow into the Aqueduct from the Kern River Intertie is presented in Figure 2.

Figure 2. Kern River Intertie Flows (1922 to 1993)



South Bay Aqueduct

For the purposes of the planning study, the South Bay Aqueduct is not included as a full hydrodynamic system, but simply as a diversion off of the Aqueduct main stem. It is a relatively short system with an average flow around 220 cfs. The Phase 1 DSM2 Aqueduct model included the South Bay Aqueduct; however, flows diverted from the main stem to the South Bay had to be adjusted to maintain a minimum channel flow of 50 cfs, otherwise the channels would dry up. The same method could be employed in the planning simulation, but then the results would not be a true reflection of the CALSIM II simulation model. Since low flows in the South Bay Aqueduct lead to numerical instability in DSM2, it is modeled as a diversion, rather than a branch of the Aqueduct system.

Water Diversions

It was necessary to disaggregate CALSIM's representation of diversions from the California Aqueduct and DMC and assign them to appropriate nodes in DSM2. This task was not straightforward due to differences in the number of diversions and the varying representation of the individual contractors in each model.

Methodology

CALSIM delivery arcs are mapped to DSM2 model segments (several pools grouped together between major facilities, such as pumping plants) so that the CALSIM deliveries are aligned with the correct reaches of the DSM2 system. A check was conducted to ensure that the total deliveries for each segment are comparable between models. Segments along the Aqueduct main stem include:

- Banks Pumping Plant to the South Bay Aqueduct;
- South Bay Aqueduct to O'Neill;
- O'Neill to Dos Amigos Pumping Plant;
- Dos Amigos to Check 21;
- Check 21 to Check 22;
- Check 22 to Buena Vista Pumping Plant (Check 30);
- Buena Vista to Teerink Pumping Plant (Check 35);
- Teerink to Chrisman Pumping Plant (Check 36);
- Chrisman to the Bifurcation between East and West Branch;
- The Bifurcation to Pearblossom Pumping Plant (Check 58); and
- Pearblossom to Silverwood Lake (Check 67).

The DMC was split into two major segments; Tracy Pumping Plant to O'Neill and O'Neill to the Mendota Pool. Exchange at O'Neill between the DMC, Aqueduct, O'Neill Forebay and San Luis reservoir was handled as a separate segment and is discussed later in this report. Figure 3 provides a schematic of the California Aqueduct DSM2 grid.

During the development of the DSM2 Aqueduct model, contractor diversions pulling water within the same pool (Aqueduct or DMC) were aggregated into a single diversion for that pool at the downstream node. In several pools, there is only one contractor or there is one contractor pulling significantly more than the other contractors, such that the other contractors' contribution to the full diversion is negligible. Many CALSIM II delivery arcs (same as a diversion) represent only one contractor, but there are also single arcs that represent several contractors. The first step in matching CALSIM II delivery arcs to DSM2 diversions was to assign delivery arcs representing a single contractor to a diversion at a DSM2 node with diversions from the same contractor. In some instances, a contractor diverts water from several pools in the DSM2 model, whereas in CALSIM the contractor is represented with a single delivery arc. In these situations, the single CALSIM delivery arc is split between the DSM2 nodes with this contractor, using historical average monthly flow data (obtained in the previous study) to determine the percentage of the delivery that goes to each node.

In some segments of the Aqueduct and DMC, the total diversions in a given segment of the system are similar between the calibrated DSM2 Aqueduct model and CALSIM II model, but the names associated with the diversions are inconsistent. In these situations, the total CALSIM diversions for the segment are split among the DSM2 nodes according to the historical percent contribution of each node to the total segment diversion.

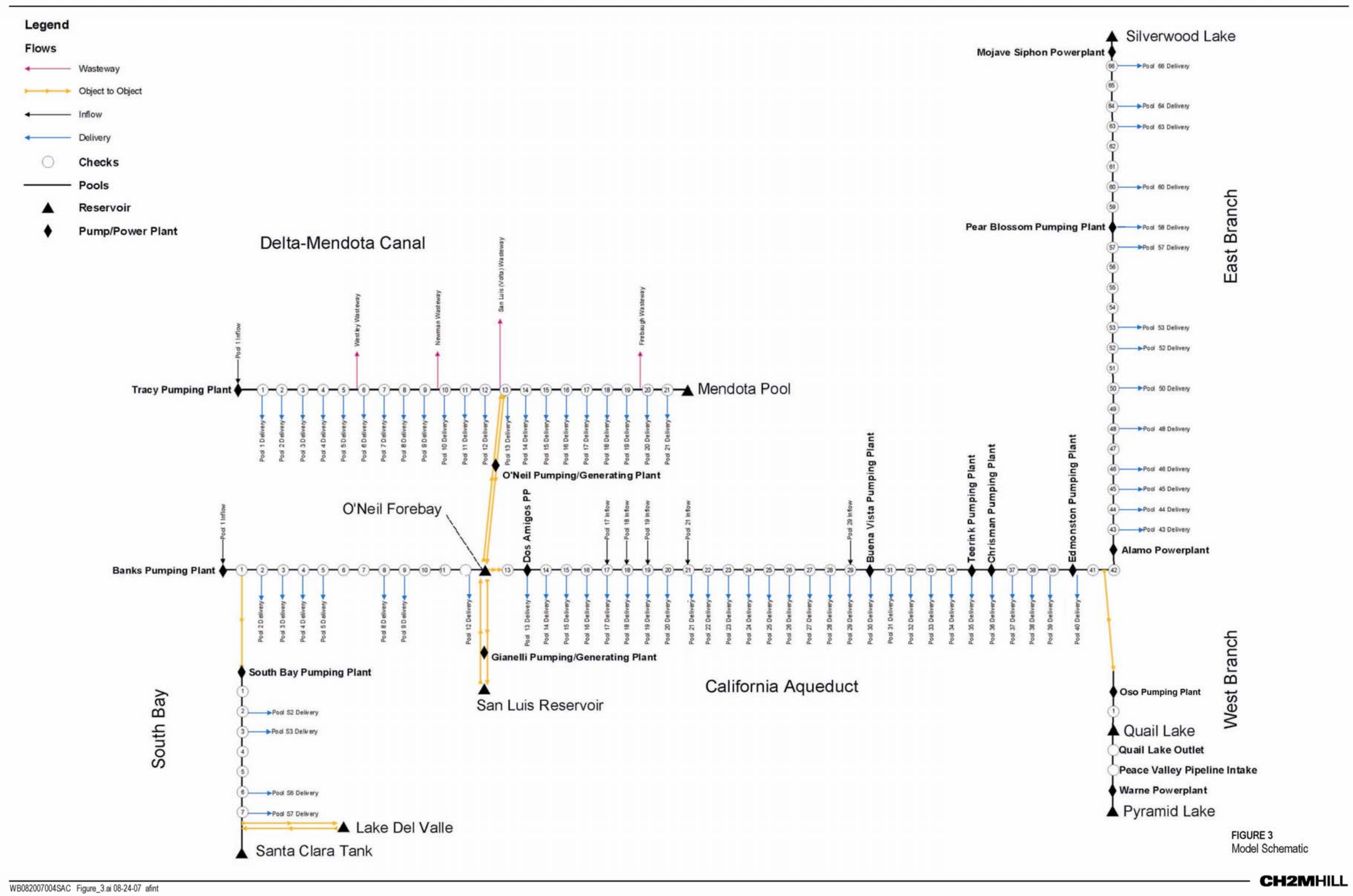


FIGURE 3
Model Schematic

Table 1 presents an example of how CALSIM arcs were mapped to DSM2 nodes. The three columns on the left hand side of the table represent flow arcs in CALSIM, the contractor assigned to the arc, and the 73-year monthly averaged flow for that arc. The five columns on the right hand side of the table show the corresponding nodes in DSM2 to which the CALSIM contractor deliveries were mapped. Two distinct examples are presented in the figure, differentiated by shading.

In the first example, CALSIM delivers water to Oak Flat Water District via arc D802 at an average rate of 6.11 cfs. In DSM2, Oak Flat Water district pulls from nodes 409 and 410 (Checks 8 and 9), at a combined average flow rate of 6.92 cfs, based on the 2001 to 2003 delivery data compiled in Phase 1 of the project. The CALSIM deliveries (6.11 cfs) were partitioned between nodes 409 and 410 based such that the ratio of flow between the two channels is maintained.

In the second example, several contractors pull from node 424 (Pool 22) according to the compilation of delivery data. In CALSIM, there are separate delivery arcs assigned to these contractors (Tulare Lake Basin WSD, Dudley Ridge WD, and the Coastal Branch). The three CALSIM arcs (D848, D849, and D850) representing these deliveries were aggregated and applied at node 424.

Table 1. Example of CALSIM to DSM2 Delivery Mapping Scheme

CALSIM			DSM2 Aqueduct				
CALSIM delivery arc	Contractor(s)	73-yr Avg CALSIM Monthly Flow (cfs)	Aqueduct node	Contractor(s)	Historical (2001-2003) Avg Monthly Flow	CALSIM arc split	73-yr Avg DSM2 Monthly Flow (cfs)
D802	Oakflat	6.11	409	Oak Flat Water District-A, Western Hills WD, Oak Flat Water District-B, Oak Flat Water District-C, Oak Flat Water District-D	4.96	71.84%	4.39
			410	Oak Flat Water District-D	1.94	28.16%	1.72
D848	Tulare	158.46	424	TLB WSD TL - A (aggregated), TLB WSD (aggregated), Coastal Branch, Dudley Ridge WD (aggregated)	326.17	100.00%	443.21
D849	Dudley	58.03					
D850	Coastal Branch	226.72					

A detailed explanation of how each DSM2 diversion is calculated from CALSIM II delivery arcs is provided in the conversion spreadsheets used to develop the DSM2 time series input. The master conversion spreadsheet shows the percentage of each CALSIM II arc that is applied to each DSM2 node. Note that the distributions of diversions from CALSIM to DSM2 nodes are based in part on a three year historical record of diversions. This record should be updated as additional data becomes available.

Mendota Pool diversions

The DSM2 Aqueduct model grid extends to the Mendota Pool, which is connected to a "dummy" channel that serves as a downstream water level boundary condition. Diversions from Mendota Pool are not modeled in the DSM2 Aqueduct model because the Mendota Pool is not part of the study area. Therefore, diversions from Mendota Pool are not simulated in the planning mode. Diversions from Mendota Pool are included in the CALSIM II model, however, and could be added to the DSM2 Aqueduct planning model if desired in the future.

O'Neill Forebay and San Luis Reservoir

The California Aqueduct and DMC exchange water at O'Neill Forebay. CVP water from the DMC can be pumped into O'Neill Forebay and either flow downstream or be pumped into San Luis Reservoir. SWP water can be pumped into San Luis Reservoir from O'Neill Forebay, flow downstream to meet delivery requirements, or be released to the DMC. Water from San Luis Reservoir can be released into O'Neill Forebay for delivery requirements on the Aqueduct or the DMC.

O'Neill Forebay

The CALSIM grid represents O'Neill Forebay with 6 nodes, not as a reservoir. In the Aqueduct DSM2 grid, O'Neill Forebay is modeled as a reservoir with an upstream channel connection and an object-to-object flow releasing water from O'Neill Forebay to the downstream pool. In order to convert the CALSIM O'Neill Forebay operations to DSM2, a control volume was drawn around the 6 nodes representing O'Neill Forebay. CALSIM arcs flowing into the O'Neill control volume from upstream on the Aqueduct are ignored, as DSM2 will model these as open channel flow (C803). CALSIM arcs flowing out of the O'Neill Forebay control volume downstream into the Aqueduct are summed to create the object-to-object O'Neill Forebay flow release term (C806, D704, and D705). CALSIM arcs flowing from the DMC into the O'Neill Forebay control volume are assigned to the object-to-object flow from the DMC to O'Neill Forebay (C702). CALSIM arcs flowing out of the O'Neill Forebay control volume downstream into the DMC are assigned to the object-to-object flow from O'Neill Forebay to the DMC (C705).

San Luis Reservoir

San Luis Reservoir is modeled in CALSIM II as two reservoirs; one for the CVP and one for the SWP. In the DSM2 Aqueduct model grid San Luis Reservoir is modeled as one reservoir with no open channel connections so that all flow exchange is handled through object-to-object connectivity. Using O'Neill Forebay as the control volume, all CALSIM arcs leaving the O'Neill Forebay and going into either of the San Luis reservoirs (as modeled by CALSIM) are summed to create the San Luis Diversion object-to-object flow (D703 and D805). All CALSIM arcs leaving either of the San Luis reservoirs and returning to the O'Neill Forebay are summed to create the San Luis Release object-to-object flow (C11 and C12).

In addition to the exchange with O'Neill Forebay, water is diverted directly from San Luis Reservoir to meet contractor demands (San Felipe Project). In CALSIM II this is represented with arc D11. CALSIM II also simulates reservoir evaporation with one evaporative flow arc for each San Luis reservoir (CALSIM arcs E11 and E12). The contractor diversion and evaporative arcs are summed to create a total San Luis Reservoir diversion.

Salinity

In DSM2's water quality model (QUAL), all model inflows require specification of the EC of the inflow. The following section describes how water quality inputs were determined for the DSM2 Aqueduct planning mode simulation.

Pumping Plants

CALSIM II uses an Artificial Neural Network (ANN) to ensure that salinity requirements within the Delta are met for any given simulation. The ANN uses a flow-salinity relationship to model chloride concentration within the Delta at four locations:

- Jersey Point
- Emmaton
- Collinsville, and
- Contra Costa Canal.

DSM2 models salinity as a function of electrical conductivity (EC). A method to convert Contra Costa Canal chloride concentration to Banks Pumping Plant and Tracy Pumping Plant EC concentrations was developed by Metropolitan Water District of Southern California (Hutton, 2005), and is presented in the following equations:

$$Banks\ [EC] = CCC\ [Cl] \times 1.9818 + 218.1084$$
$$Tracy\ [EC] = CCC\ [Cl] \times 1.6225 + 303.3852$$

where EC is calculated in μS/cm provided Chloride is given in mg/l.

Monthly CALSIM output for chloride concentration at Contra Costa Canal was fed into the equations above to generate time series of monthly EC at Banks and Tracy for use as boundary conditions in the DSM2 QUAL model simulation; results are presented in Figure 4. Figure 5 presents these boundary data as cumulative frequency distributions. Figure 6 presents 8 years of daily measured EC for Banks PP and Tracy PP. The equations put a floor on the EC predictions that is considerably higher than the field data in the 1999-2007 period presented in Figure 6. Thus, the average EC predicted by the model is likely conservative. Alternate means of prescribing EC boundary conditions for Tracy and Banks could include using the DSM2 Delta model results, which utilize CALSIM hydrology and operations to describe boundary conditions, or combining the DSM2 Delta model and the DSM2 Aqueduct model into a single model.

Figure 4. Comparison of Calculated Time Series EC at Banks PP and Tracy PP

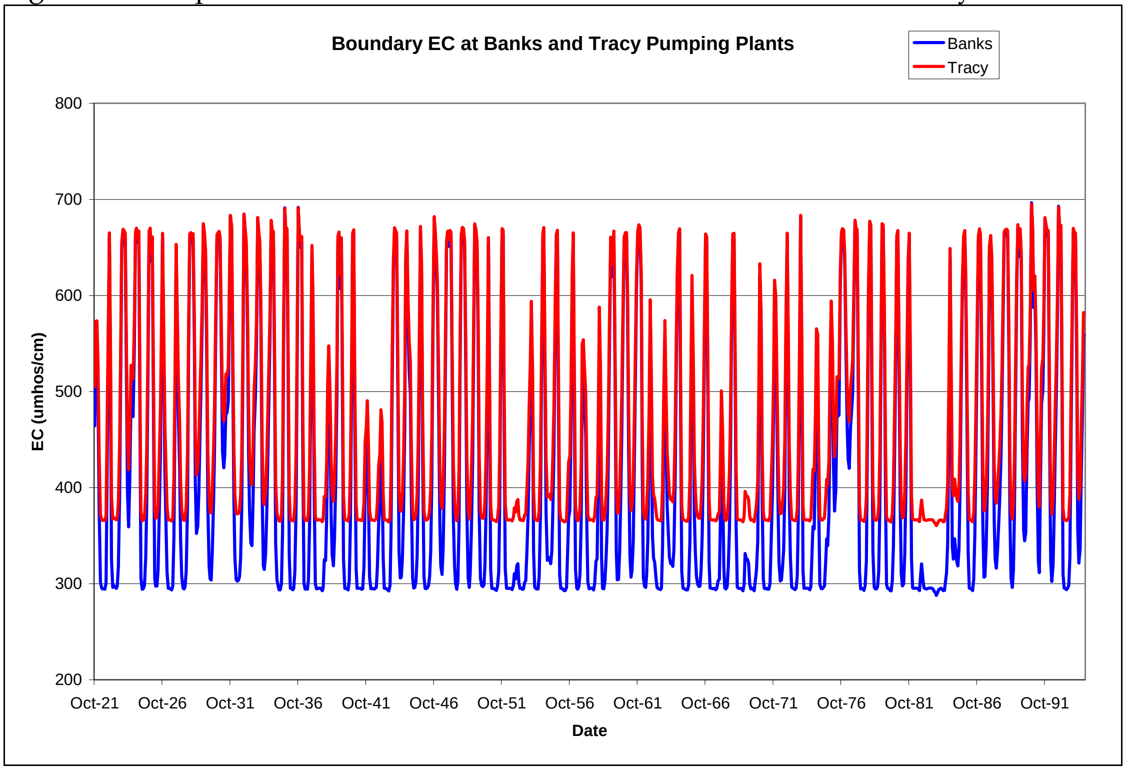


Figure 5. Comparison of Calculated EC Distribution at Banks PP and Tracy PP

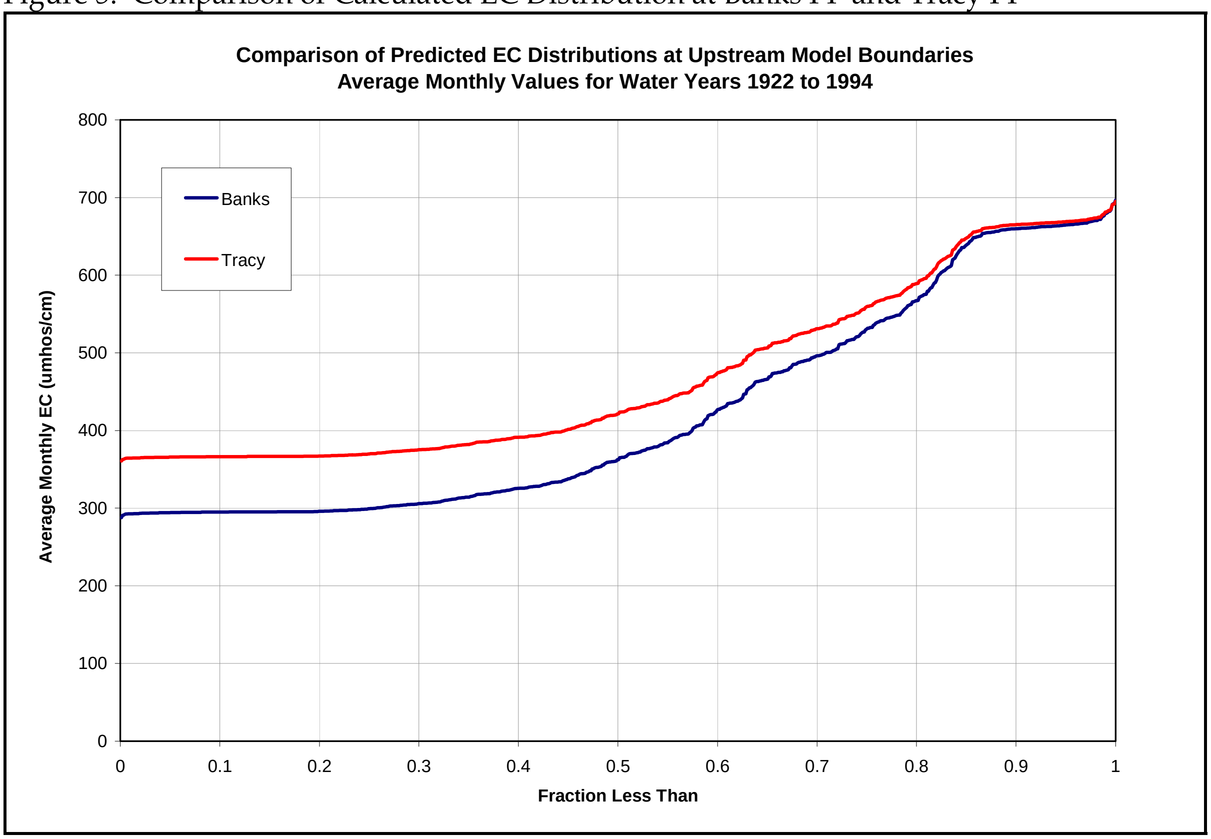
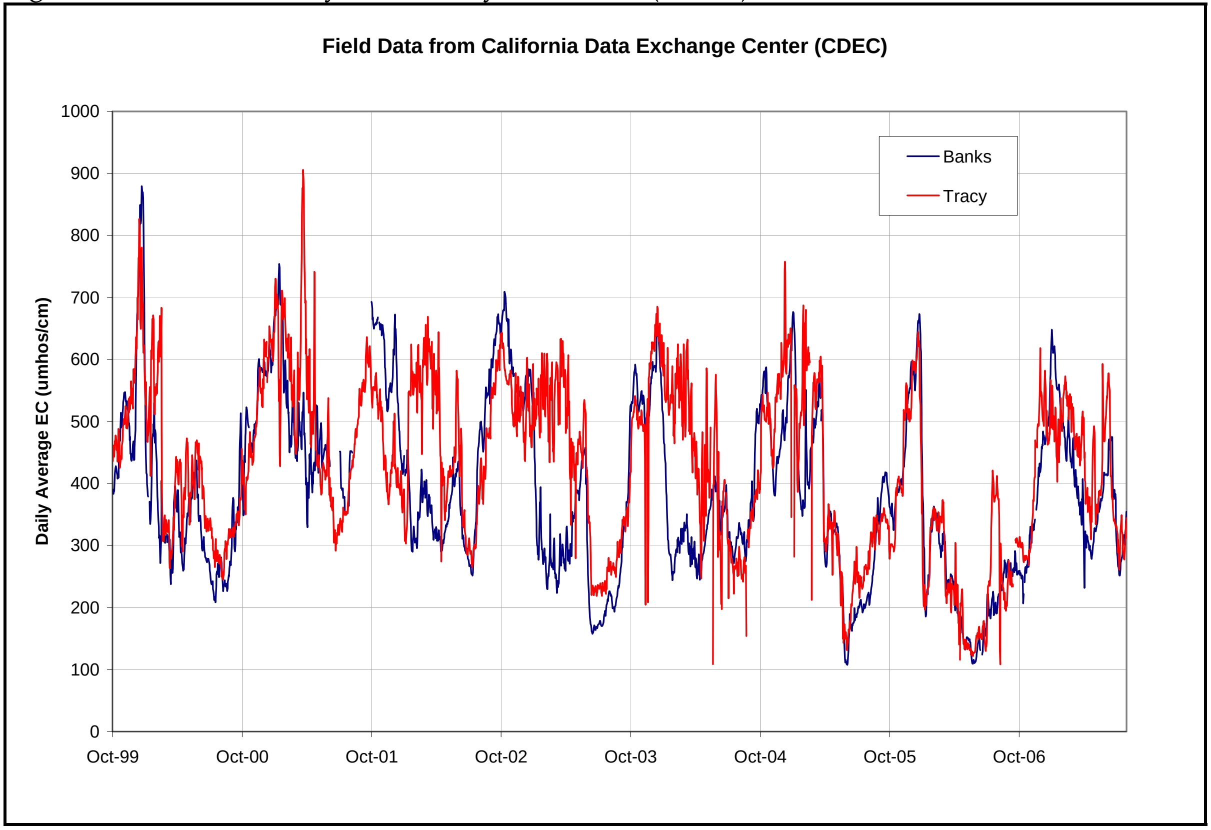


Figure 6. Measured Daily EC at Tracy and Banks (CDEC).



Kern River Intertie

The final inflow to the Aqueduct-DMC system is The Kern River Intertie. Since the Intertie is not part of the Delta, CALSIM II's ANN has no measure of the salinity of this flow. Historical data for the EC of Intertie flows are also unavailable. The real-time DSM2 Aqueduct model applies a constant EC concentration of 516 μS/cm to the Intertie boundary inflow. The same concentration is used for the planning mode simulation. The EC concentration applied at this boundary should be updated as additional data becomes available.

System Initialization

The DSM2 Aqueduct model salinity was originally initialized with historical data from locations throughout the system. Since historical salinity data does not extend back to 1921, historical salinity data from January 1st, 2001 was used to specify the initial conditions for both the calibration and the planning mode simulations. The data was obtained from the CDEC website. San Luis Reservoir is initialized with data at Pacheco Pumping Plant (477 μS/cm). O'Neill Forebay was initialized with salinity from Aqueduct Check 13 (581 μS/cm). All other channels and reservoirs were also initialized at 581 μS/cm, under the assumption that any inaccuracy will be flushed out of the system in the first few months of the simulation.

Time scale

CALSIM II operates on a monthly time scale while the DSM2 Aqueduct model (Phase 1) used flows specified on a daily basis, reflecting a seven day average of measured flows. Using CALSIM II arcs as inputs to DSM2 requires changing the specification of the flows (boundary flows, reservoir operations, and contractor diversions) to a monthly time scale, and interpolating between data points to avoid large hydraulic changes. Large changes in inflows or outflows can cause instability in the system, resulting in model failure.

DSM2 Planning Mode simulation

Initializing Simulation

A 2.5-year initializing simulation was run before the planning simulation in order to obtain appropriate initial water surface elevations and boundary flows. The model was initialized with a flat water surface that was slowly ramped down over a 13-month period (November 1st, 1921 to November 30th, 1922) so that the model ends in dynamic equilibrium with the appropriate water surface profile. During the first year when stage was being ramped down, boundary flows were defined at low, constant rates to create numerically favorable conditions for DSM2 to solve. Stage and flow conditions were held constant for an additional month (December 31st, 1922). Then over the following 12 months, the boundary flows were gradually ramped up from the previously low constant flow rates to the initial CALSIM flow rates given for October 31st, 1921. Flow ramping was complete by December 31st, 1923, but the simulation was run through March 31st, 1924 with constant flow values to ensure model equilibrium is met. Downstream stage boundaries were held constant during the entire flow ramping portion of the initializing simulation. Contractor diversions were not modeled at all during this initializing simulation.

A HYDRO restart file was written at the end of this simulation to be used for a hot start to the planning simulation. The file was copied to the planning simulation output directory, renamed, and the date within the file was changed from March 31st, 1924 to October 31st, 1921.

Planning Simulation

The DSM2 planning mode simulation was conducted for the 73-year planning period, from October 31, 1921 to September 30, 1994. Downstream stage boundaries are held constant during the entire simulation. The output hydro restart file from the initializing simulation is used as an input hydro restart file to initialize the planning model in dynamic equilibrium. All CALSIM boundary flows, contractor diversions, and flow exchanges at O'Neill discussed previously in this report were included in the first attempt at running the full planning mode simulation.

CALSIM II's accounting for water supply and delivery in the Delta Mendota Canal has numerous months (over 10% of the time) over the 73 year planning period where the flow to the Mendota Pool is expressly zero. DSM2 experienced difficulties reaching a stable solution during months with no flow at the end of the Delta Mendota Canal. To alleviate this problem, two "arbitrary" 50 cfs flows were added to the southern end of the Delta Mendota Canal, downstream of Check 13 and Check 20, to supply enough minimum flow to maintain the numerical stability of the simulation. These flow additions will cause a slight overestimate of the travel time in the southern portion of the DMC, and can have a dilutive effect on concentrations. If there is a need to conduct planning model simulations with a focus on water quality entering Mendota Pool, the impact of these additional "arbitrary" flows will need to be considered.

Results

The results of the planning simulation are provided below to illustrate the capability of the DSM2 planning model. Figures below present comparisons between the distribution of EC at various key locations throughout the system for the 1922 to 1994 simulation period. Both time series and frequency distributions are used to demonstrate differences in EC throughout the system. The figures were constructed using monthly averaged EC values. Considering the monthly boundary input, this approach is considered appropriate.

Figure 7 presents the cumulative frequency of EC at the end of the month for the upstream boundaries (Banks and Tracy) and the southernmost point of the Aqueduct model, Check 67 on the East Branch. This is the inlet to Silverwood Lake. Note that the range in EC at San Luis Reservoir throughout the simulation period is muted as compared to the range in EC at the boundaries. The decreased annual EC range in San Luis as compared to Banks influences the EC in the system downstream of San Luis Reservoir. Table 2 presents a summary of the variations in the distribution of EC throughout the system, in terms of percentiles. Note that the median EC at Check 67 is 418 μmhos/cm, whereas the median at Banks is 344 μmhos/cm. The lowest 20 percent of the frequency distribution at Check 67 does not reflect the lowest EC at Banks (300 μmhos/cm), because the low EC water from Banks is mixed with higher EC water from San Luis before reaching Check 67.

Figures 8a and 8b presents time series plots of the monthly average EC Banks Pumping Plant, San Luis Reservoir, and Check 67 (Silverwood Lake inlet). The two plots split results of the 73-year simulation, with Figure 8a showing results from WY1922 to WY1957, and Figure 8b showing results from WY1958 to WY1994. Note the annual minimums in EC at Banks are consistently lower than those at Check 67, and that the annual minimums in San Luis are generally above 400 μmhos/cm. The increase in EC at Check 67 during the spring of 1983 is associated with an inflow to the Aqueduct from the Kern River Intertie.

Figure 7. Comparison of DSM2 EC Frequency Distribution at Boundaries, San Luis Reservoir, and Downstream terminus of Aqueduct Model

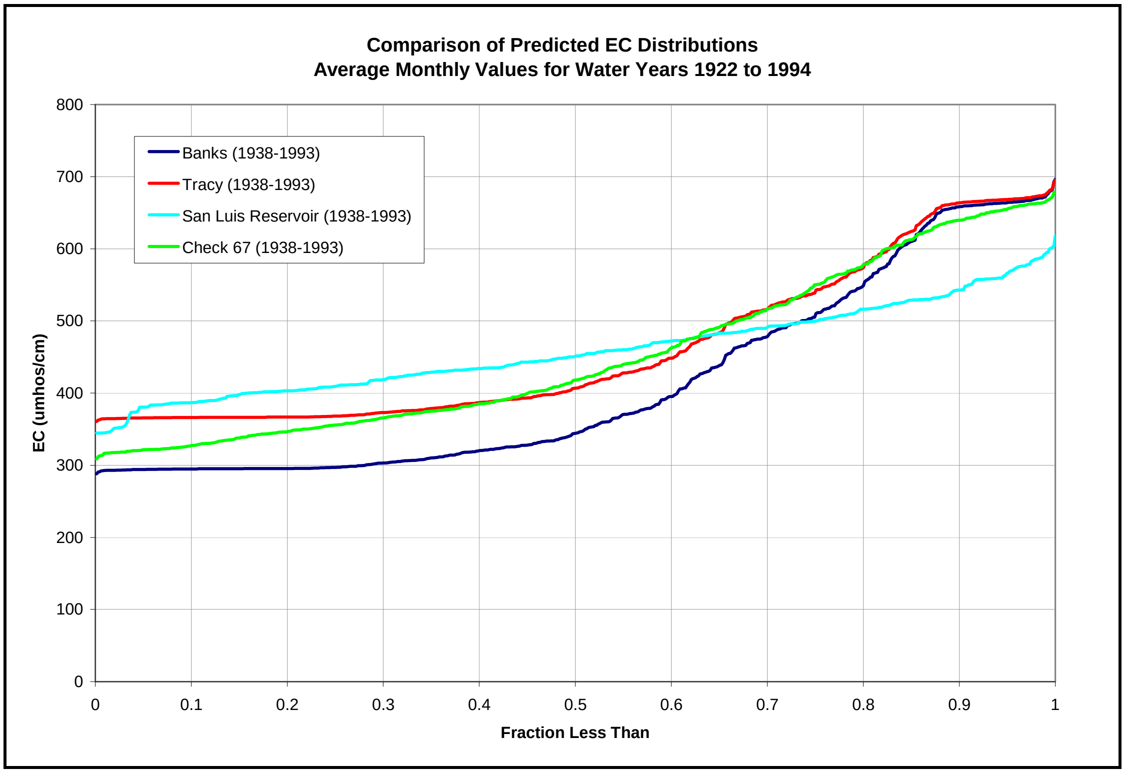


Table 2. Percentiles of EC Distribution throughout Aqueduct (WY1922 to WY 1994)

	Banks	Tracy	San Luis Reservoir	O'Neill Forebay	Check 13	Check 67
0.0	288	361	345	309	309	309
0.1	295	366	387	323	323	327
0.2	295	367	403	335	334	347
0.3	303	373	419	350	351	365
0.4	320	387	434	371	371	385
0.5	344	407	451	400	400	418
0.6	395	448	472	442	444	463
0.7	478	516	491	495	496	517
0.8	549	574	516	549	549	579
0.9	659	664	543	643	641	640
1.0	697	695	618	678	678	678

Figure 8a. Time series comparison of DSM2 simulated Monthly EC (WY22 to WY57)

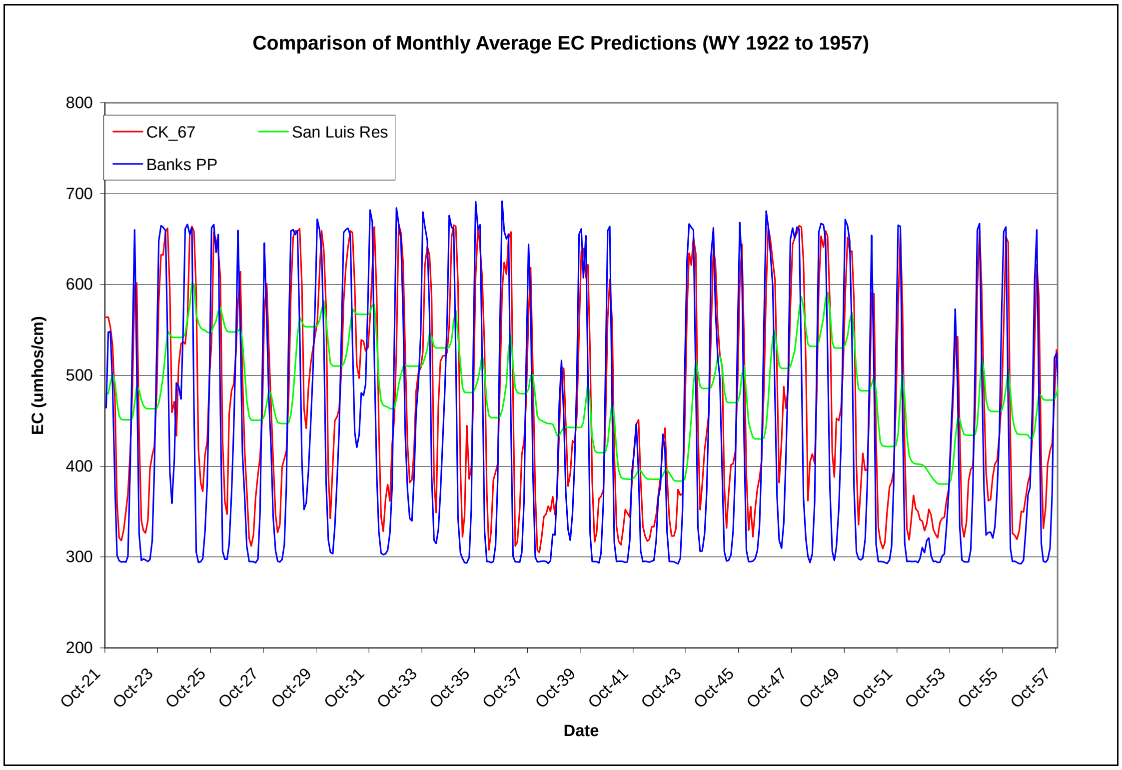


Figure 8b. Time series comparison of DSM2 simulated Monthly EC (WY58 to WY94)

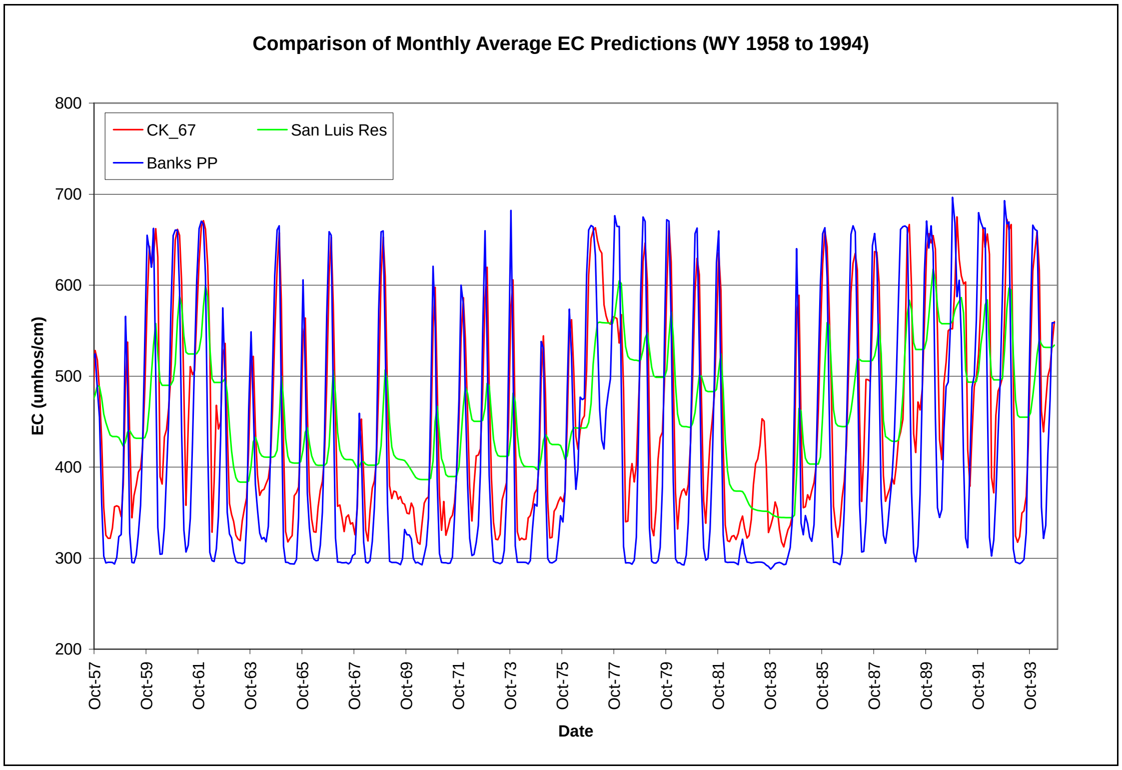


Figure 9. Time Series Comparison of DSM2 Simulated Monthly Average EC (San Luis Reservoir Influence)

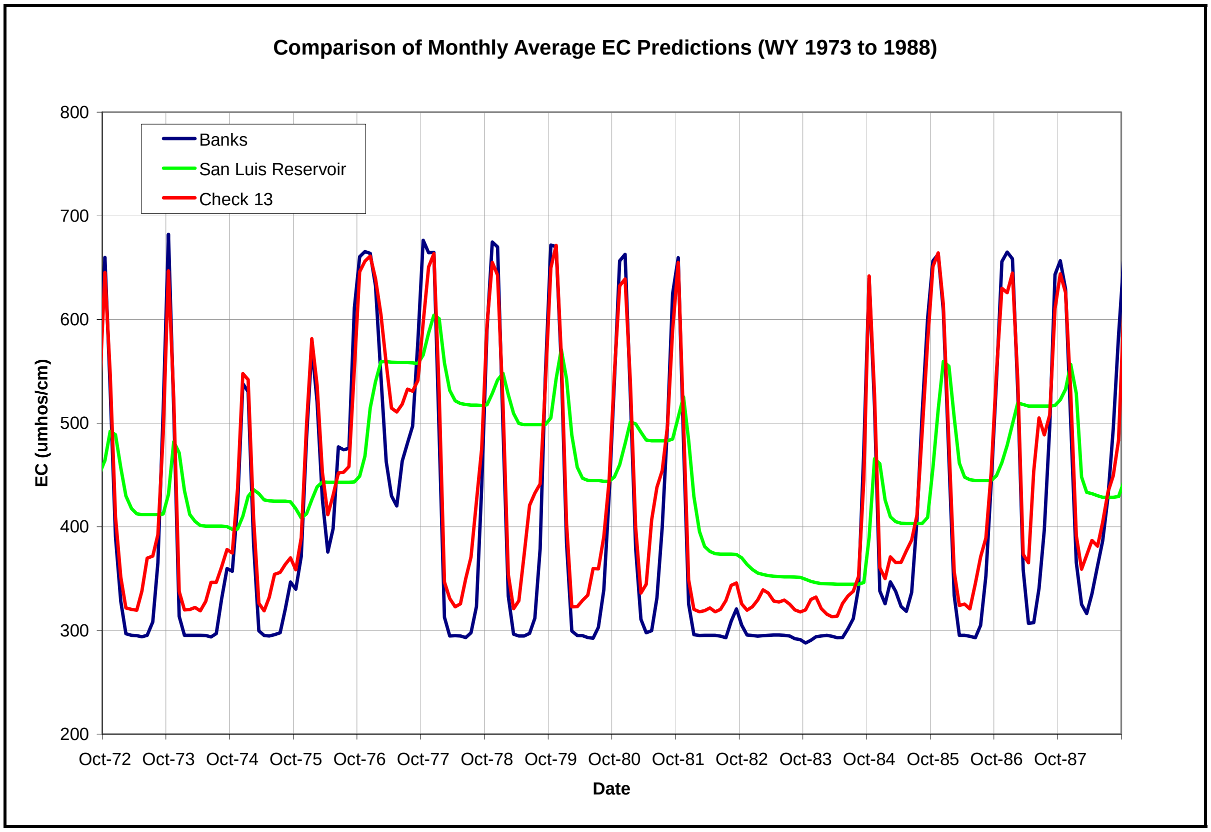


Figure 9 presents a time series comparison of the end-of-month EC at Banks, in San Luis Reservoir, and at Check 13. The time series plots present a 16-year snapshot of the model results from 1972 to 1988. This period includes an extreme dry years (1976/1977) and wet years(1982/1983).The influence of San Luis Reservoir releases on EC in the Aqueduct downstream of O'Neill Forebay is more pronounced during periods of low EC than during periods of high EC. The seasonal cycle of draining and filling San Luis Reservoir explains this observation. San Luis Reservoir is generally filled between the months of September and March, and drained between the months of April and August. During the filling of San Luis Reservoir, the EC downstream of O'Neill Forebay is more closely related to boundary EC at Banks than when the reservoir is releasing water in the late spring and summer months.

Figure 10 provides a close up of the seasonal cycle of EC concentration at Banks, San Luis Reservoir, and Check 13. The CALSIM II monthly flows into and out of San Luis Reservoir are included in Figure 10. The period averaged monthly average flows into and out of San Luis Reservoir (WY1922 to WY1994) are shown in Figure 11.

Figure 10. Close-up of Simulated Annual EC Patterns For Normal Years

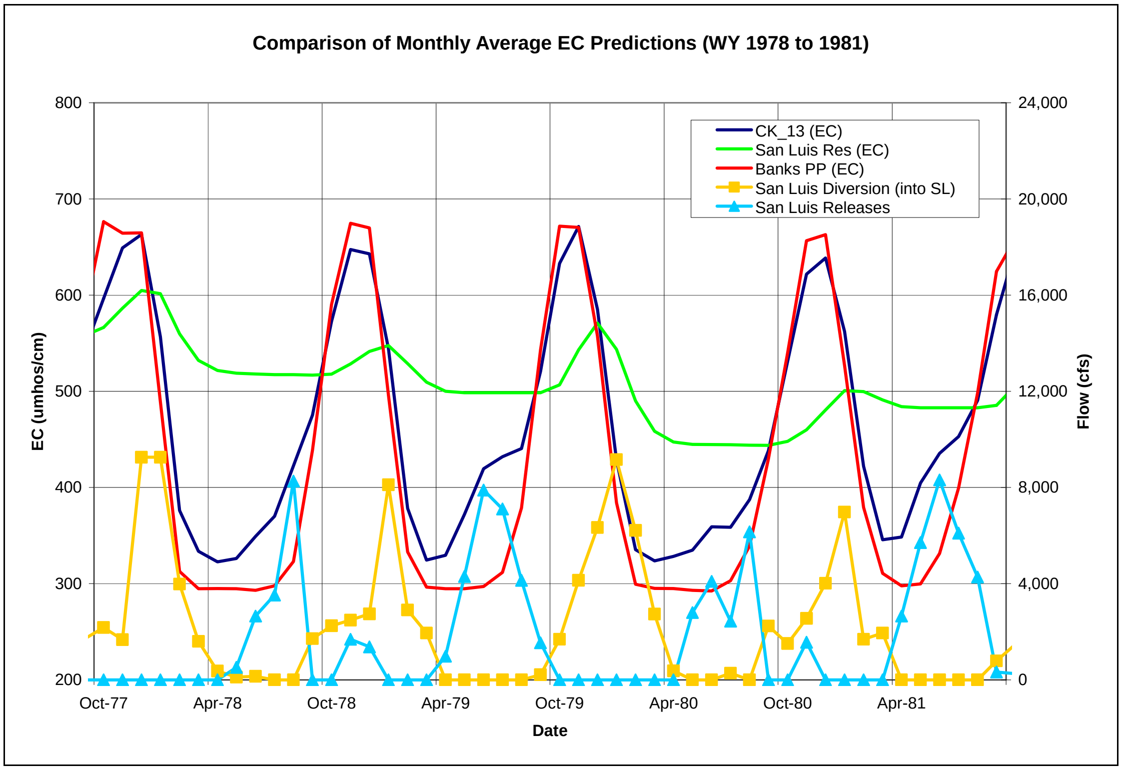
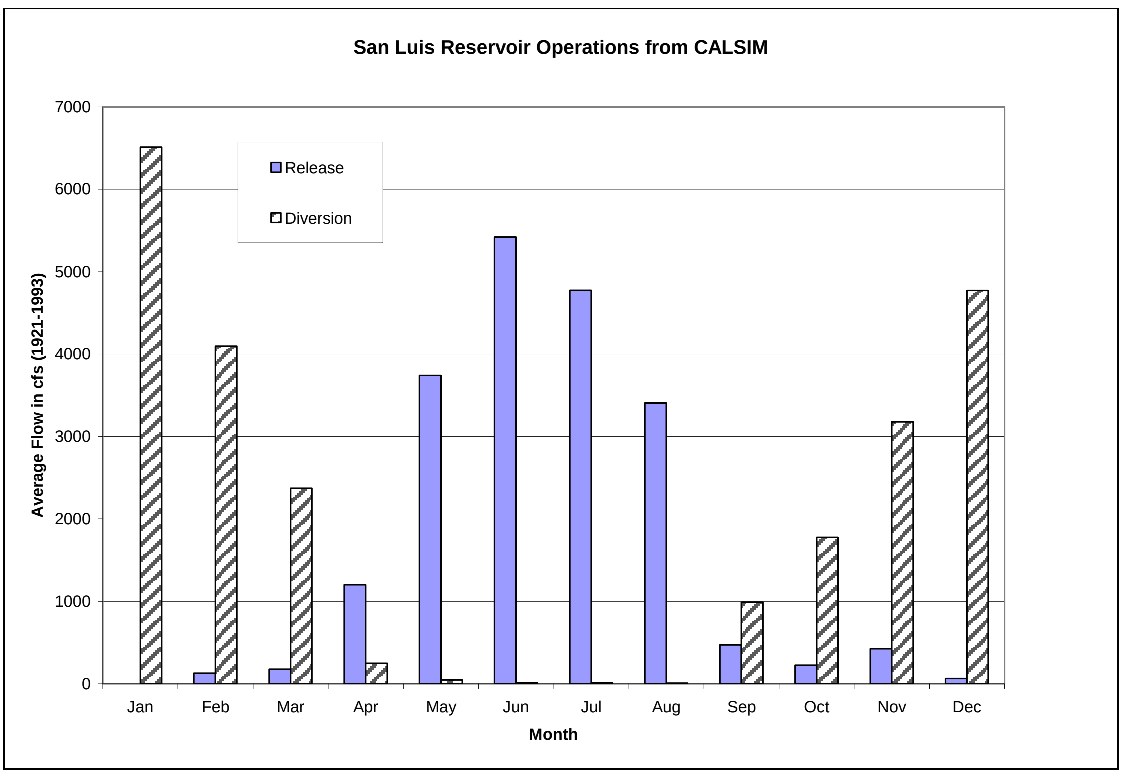


Figure 11. Simulated Monthly Average San Luis Reservoir Releases and Diversions to Storage



Summary and Conclusions

The California Aqueduct Extension DSM2 HYDRO model has been run in "Planning mode" for a 73-year period using CALSIM model results as boundary conditions. An EXCEL-based tool has been developed to apply flows from CALSIM as boundary data for use with DSM2. The tool generates time-series data that is exportable into DSS format for the following:

- Flows at Banks and Tracy,
- San Luis Reservoir and O'Neill Forebay operations,
- Contractor Deliveries from the Aqueduct,
- Diversions for the South Bay Aqueduct, the Coastal Branch, and the West Branch, and
- Kern River Intertie.

CALSIM results were also used to specify boundary EC concentrations at Banks and Tracy Pumping Plants for use in the simulations. Full period runs with QUAL were conducted for the 73-year period of water years 1922 to 1994. Results demonstrate the damping capacity of San Luis Reservoir on annual EC fluctuations in the Aqueduct.

The planning mode version of the DSM2 Aqueduct Model can be used to ascertain changes to the Aqueduct system (flow and water quality) associated with significant changes in flow or water quality conditions at Banks Pumping Plant and/or Tracy Pumping Plant. Several potential actions under review in the Delta, including pumping curtailments associated with the decline of pelagic organisms, as well as re-plumping of the system (Through-Delta Facilities, Franks Tract, etc), could be studied with the planning mode version of the DSM2 Aqueduct model to determine the impacts of these potential Delta actions on aqueduct water quality.

References

CH2M HILL, 2005. DSM2 Extension for the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal. Prepared for State Water Contractors and Municipal Water Quality Investigation Program. June, 2005.

Hutton, Paul. 2005. "SANMAN: Decision Support for the DIP's San Joaquin River Salinity Management Plan", presented at the California Water and Environmental Modeling Forum Annual Meeting, Pacific Grove, Calif., March 2005.

Appendix D:
Task 4 Technical Memorandum

Phase 2 DSM2 Extension for the California Aqueduct Task 4 – Forecast Mode Implementation Plan

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DATE: June 5, 2008

Introduction

The California Department of Water Resources' (DWR) Municipal Water Quality Investigation (MWQI) program is developing the capability to conduct DSM2 simulations for drinking water quality planning and forecasting.

This work builds on the previous Phase 1 study (CH2M HILL, 2005), where the DSM2 Aqueduct Model was developed and calibrated for a three-year period beginning January 1, 2001. Use of a three year calibration period allowed for simulation of a wide range of historical flow conditions that may be experienced under different planning level analyses. The DSM2 Aqueduct model predicts both the hydraulics (flow and stage) and salinity transport through the aqueduct system.

Purpose

The purpose of this memo is to outline a plan to implement the DSM2 Aqueduct Model in forecast mode. The memorandum includes a brief review of ongoing forecasting activities, discusses the data needs for running the aqueduct model, provides sources for the required data, and outlines an implementation plan to run the aqueduct model in forecasting mode.

Review of Current Forecasting Activities

Currently, forecasting activities related to the SWP and CVP are conducted by several different groups, including the DWR SWP Operations Control Office (SWP OCO), CVP Operations Office (CVO), and DWR Operations and Maintenance Transactions and Financial Hedging Section (Power Forecasting). A review of forecasting activities conducted by these groups is included below.

DWR DSM2 Delta Forecasting

SWP OCO performs DSM2 forecasts on a weekly basis, providing a three week outlook of hydrodynamic and salinity (EC) conditions in the Delta and at the export locations. The total DSM2 Delta model simulation period is four weeks:, one week is simulated with the observed data (model spin-up) and the remaining three weeks are simulated with the forecasted data. Prior to running the forecast model for future salinity (EC) condition simulation, a historical run is made in order to estimate the initial salinity (EC) conditions. This consists of a weeklong simulation using the observed data available from Interagency Ecological Program (IEP) and California Data Exchange Center (CDEC) internet resources. As part of initializing DSM2 QUAL with observed data from the IEP and CDEC websites, near real time data are downloaded from 20 to 30 locations throughout the Delta, and a script is used to interpolate the observed data to all nodes in the DSM2 model grid. As part of updating historical simulation regularly with current data, Bay-Delta Modeling Section of DWR (Bay-Delta Modeling) conducts long-term historical simulation on a monthly basis and maintains an up to date historical simulation. This activity involves appending the time series files prescribing all boundary conditions on a weekly basis with recent data. It may be desirable to combine the weekly simulation and the monthly update simulation in order to develop a more robust procedure to estimate initial salinity (EC) conditions for DSM2 forecast runs.

Abdul Khan (Delta Compliance and Modeling Section of SWP OCO) generally performs the forecast simulations. Input data for the simulations is provided on a weekly basis by Loi Tran (Export Management Section of SWP OCO) in a spreadsheet, which is compiled from a variety of sources. The spreadsheet includes projected flows for a three week period for the Sacramento River, San Joaquin River and Eastside streams and export data for SWP, CVP, and Contra Costa Canal. Export Management Section of SWP OCO also provides the Clifton Court Forebay gate operation schedule, while projected operations of the Delta Cross Channel gates are obtained from CVO.

Information on forecasted operations of the South Delta temporary barriers is provided by Mike Burns (DWR South Delta Branch). Flow forecast data for the San Joaquin River are provided by DWR's San Joaquin Field Division. EC forecast data for the San Joaquin River at Vernalis are prepared on the basis of previous week's flow and EC data in San Joaquin River at Vernalis and projected flow and EC data for the tributaries of San Joaquin River. Delta Island Consumptive Use (DICU) data are provided by Bay-Delta Modeling; these data are year type specific and thus do not change every week. DICU dataset is a boundary condition for the Delta forecasts, and any inaccuracies in this dataset will be reflected in the predicted water quality at the export locations.

DWR SWP Allocation Model Forecasts

The SWP allocation model (an Excel -based spreadsheet) incorporates current and forecasted hydrologic conditions, actual and projected contractor deliveries, and actual end of month storage conditions in order to determine the amount of water that can be delivered to SWP contractors between January and December of a given year. The allocation is expressed as a percentage of the State Water Contractor's Table A value. By October 1st of each water year, the SWP contractors supply DWR with their demands at three different allocation levels. An initial allocation is determined by December 1st of each year. The model is updated each month and generates end of month storages for San Luis Reservoir and Lake Oroville based upon the above mentioned inputs.. The allocation model is run for a range of hydrologic forecasts, covering the 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 99^{th} percentiles of probable hydrologies. Results of the allocation model are also used in the planning of power operations. The allocation model is generally run by Molly White (SWP OCO).

DWR Energy Resources Forecasting

Tuan Bui (DWR) provided CH2M HILL staff with a summary of forecasting activities conducted by SWP with regards to scheduling power consumption and generation. Additional information was obtained from Bulletin 132, Chapter 10 (DWR, 2006).

DWR forecasts its long-term power requirements annually after reviewing water delivery requests from contractors. Power forecasts extend through 2035, and are based on the delivery of a specific amount of Table A water (determined by SWPAO) to contractors, water to replace storage in reservoirs south of the Delta, and water to account for evaporation, percolation, and seepage losses in aqueducts and reservoirs. These long-term forecasts, based on a series of independent historical years that are near median conditions, are used by the State Water Project Analysis Office (SWPAO) for planning and billing purposes (DWR, 2006.)

A second, annual power requirements forecast is also made by DWR for use by the Operations Control Office. These forecasts are based on actual reservoir storage, the snow survey water supply forecast, planned outages, the current year's allocation, and the State Water Contractors' delivery trend. This annual power forecast is updated on a monthly basis or as often as conditions warrant.

SWP power requirements can differ considerably from forecasted conditions for several reasons, including variations in forecasted deliveries associated with hydrologic conditions. Abnormally wet and dry years both lead to a decrease in power consumption by the SWP; dry conditions decrease the available supply of water, and wet conditions allow for use of local water resources (DWR, 2006).

DWR also schedules power operations for a one-week window. This forecasting operation takes into account current conditions for the past few days with respect to contractor deliveries, since day-to-day deliveries can vary considerably from forecasts provided at the beginning of the year. This short-term power schedule also relies on estimates from CVP operators for flows through the O'Neill Pumping-Generation Plant. Data from the short term model may provide information to allow for specification of exchange flows through Gianelli.

CVP Operations Forecasts

Paul Fujitani (Chief of Water Operations Division, Central Valley Operations Office, U.S. Bureau of Reclamation) provided an overview of forecasting activities for CVP Operations. CVO uses an EXCEL spreadsheet model to develop the annual CVP water allocation on a monthly time step. This annual allocation is released in February of each year and is subject to revision as hydrologic and operational changes occur during the spring. Water districts provide annual demand forecasts at the beginning of the year, which are then updated monthly throughout the year. Calls are placed to CVO by water districts on a daily basis, but South of Delta demands rarely control pumping at Jones Pumping Plant. Rather, pumping at Jones is generally controlled by upstream water releases and in-Delta restrictions. When water is available in the Delta the CVP pumps as much as possible for delivery to contractors and storage in San Luis Reservoir.

Historical daily flow data through the O'Neill Pumping-Generating Plant are available as part of the Joint Facility daily operations summary published monthly by DWR's Division of Operations and Maintenance, Operations Records and Reports Section. Data are contained in monthly reports titled "State Water Project operations Data" and can be found in the table titled "Consolidated State-Federal O'Neill Forebay/Daily Operations". These reports are available in PDF format on DWR's OCO website (http://wwwoco.water.ca.gov/monthly/monthly.menu.html), but not in a timely manner. The current lag in thee published reports is approximately two years. It is assumed that these data can be obtained in near-real time through DWR or USBR for use in forecasting operations. Forecasted O'Neill operations are provided by USBR to DWR staff for use in SWP Energy Resources Scheduling.

USBR staff record aggregated deliveries through gauges on turnouts on a weekly basis. These field recordings represent the finest available resolution for deliveries on the DMC; there is no historical database of data available to describe any daily variations for given contractors within a given month.

Data Needs and Potential Sources / Current Monitoring Efforts

This section describes the data inputs required to run the DSM2 Aqueduct model. Potential sources of real-time data are discussed where applicable.

Current Conditions

The DSM2 model needs to be initialized to reflect current conditions in the aqueduct system, including the distribution of water quality parameters throughout the system, and current storage levels in San Luis Reservoir and O'Neill Forebay. Water levels in the aqueduct are generally kept within a small range of elevations, and thus it is assumed that specification of elevations in individual aqueduct pools is unnecessary.

The California Data Exchange Center database contains hourly EC at Checks 12, 13, 18, 21, 29, 41, and 66 in the California Aqueduct. Data is also available at San Luis Reservoir (Pacheco Pumping Plant), O'Neill Forebay and the Banks Pumping Plant. In the DMC, CDEC contains hourly data for Checks 13, 20, and 21, as well as at Jones Pumping Plant.

EC data will have to be reviewed for quality and any data gaps will need to be addressed. DWR has a standard approach for addressing missing EC data when running the Delta model in forecast mode; a similar approach could be adopted for the aqueduct forecast application.

While sufficient EC data is available through CDEC to initialize the aqueduct model, the same cannot be said for other potential constituents of concern, such as organic carbon. Real time data collections systems will have to be deployed before expanding the aqueduct model to constituents other than EC.

Boundary Flows at Banks and Jones Pumping Plants

Boundary flows at Banks and Jones Pumping Plants are required to run the DSM2 Aqueduct model. For short term forecasts, a combination of observed data and export flows generated by the DSM2 Delta forecasts can be used as boundary conditions for the DSM2 Aqueduct model. During periods of high flow and thus short travel time through the aqueduct system, the flows in the southern reaches of the aqueduct are more strongly influenced by recent flows at the export pumps, not forecasted flows.

For long term forecasts, the SWP Allocation model can provide a time series of demands that can be used to provide monthly average flows at Banks Pumping Plant for a period of up to one year. Exports are currently specified as daily averages in the Delta model, and thus inputs to the aqueduct model would have a daily resolution. Any increase in resolution of the Delta forecasts (i.e. hourly export flows) could be used for the aqueduct model, but this is not expected to improve the performance of the aqueduct model, except perhaps in the reach between Banks and of O'Neill Forebay.

Boundary Water Quality at Banks and Jones Pumping Plants

The DSM2 Delta model can provide a three-week prediction of EC (or other water quality parameters such as DOC) for use in short term forecasting simulations. For long term forecasts, the application of water quality boundary conditions at Banks and Jones Pumping Plants will be more difficult. One available option is to use the SWP allocation model and hydrologic forecasts to run the DSM2 Delta model for a 1 year period. Astronomical tides would have to be used in DSM2, which will add a further level of uncertainty to the model predictions. Historical hydrologic forecasts (e.g., 2006, 2007) and the accompanying allocation model output could be used to run a one-year DSM2 simulations for comparison against measured EC conditions to determine potential shortcomings and opportunities for refinement with this approach.

Deliveries and Diversions

The SWP Allocation model provides the percentage of contract deliveries requested by contractors on the California Aqueduct. Coupled with the actual database of requests, the allocation level allows specification of diversions to contractors averaged on a monthly basis. CVP annual forecasts will provide data for deliveries on the DMC, since short-term delivery forecasts are not conducted. Contractor demands vary on a daily basis, but monthly allocations may be adequate for forecasting purposes considering the relatively consistent diversion of larger SWP contractors. The database of annual CVP contractor requests may be obtained from the Bureau for use in forecasting. There is no long term database of daily CVP contractor deliveries from the DMC available for analysis of historical trends (Joe Martin, pers. comm.). Diversions are monitored on a weekly basis, but the limited historical data indicate relative consistency in diversion flows on a day to day basis.

The use of monthly averaged data for specifying contractor deliveries could introduce errors in travel time predictions considering the daily variability of actual contractor deliveries. In order to investigate the potential error associated with using monthly average data, an analysis was conducted on daily diversions to Westlands Water District (WWD), the largest diversion in the San Luis Field Division. Daily delivery data was obtained from the monthly summary tables provided by DWR's State Water Project Operations and Controls Office (OCO), titled "Consolidated State-Federal Sal Luis Canal Daily Operations".

Figure 1 presents a comparison between the daily flow and the monthly average flow for a one year period of diversion to WWD. On a daily basis, the flow can range from 405 cfs above the monthly mean to 747 cfs below the monthly mean (June 2002). In order to avoid the complexity of having to balance flows on a daily basis, during the calibration effort the aqueduct model used a 7-day average for specification of boundary flows. To maintain consistency and avoid similar issues with mass balance, the diversion to WWD was analyzed to see how the 7-day average compared to the monthly average. Figure 2 presents a comparison between the maximum and minimum 7-day averages for each month and the monthly average for a one-year period. Results indicate that the 7-day average is generally similar to the monthly average. Note that the largest variation between the 7-day average data occurs during periods of highest average flow (June 2002). In forecasting mode, the boundary flows may not have to be averaged over a specified interval since projected flows are likely to be more consistent than actual flows. The main reason for the need to average inflows to the aqueduct was the high variation in export flows on a day to day basis.

Discrepancies between daily and monthly average flows could introduce errors in the predicted aqueduct hydraulics and water quality. Errors introduced during periods of high flow are likely to be more pronounced when results are analyzed over short distances, simply because the diversions during high flow can be large, and thus misrepresentations of the timing of these diversions could have a larger influence on model accuracy. For example, the predicted travel time through the aqueduct system from Banks Pumping Plant to Check 67, which ranged from 12 to 31 days for a reasonable range of flows (CH2M HILL, 2007a), would likely demonstrate less error associated with misrepresentation of diversion flows than would the predicted travel time over a shorter reach of the aqueduct, such as the reach between Dos Amigos and Check 21. The magnitude of a predicted error in travel time is relative to the total travel time; an error in predicted travel time of 12 hours is more noticeable through a reach with a 2 day travel time than a reach with a 14 day travel time. For planning purposes, the use of monthly average diversions is likely adequate. For emergency response planning, discrepancies between monthly average diversions and actually daily diversions may introduce significant errors in predicted travel times over short distances.

A simple calculation demonstrates the potential influence of variations from average monthly contractor diversions on travel time predictions. Consider the reach between Dos Amigos Pumping Plant and Check 21 (lower boundary of San Luis Field Division) for the period June 2002, when average flows through Dos Amigos were 9163 cfs and average flows through Check 21 were 6135 cfs. Of the 3028 cfs diverted and lost from this reach on an average monthly basis, the majority of the water (2823 cfs) was delivered to Westlands Water District. The actual daily flow to Westlands Water District varied from 2076 cfs to 3228 cfs. Assuming an approximate travel time of 1.9 days for this reach (Run TRCR4, Phase 2 Task 1 TM, CH2M HILL, 2007a), the maximum variation in daily diversions (3028 cfs – 2076 cfs = 747 cfs) accounts for approximately 10% of the average flow in the reach, considering the average flow in the reach is 7650 cfs. Thus, the short term predicted travel times could be off by as much as 10% if monthly averaged diversions are used in the model.

Figure 1. Comparison of Daily and Monthly Diversions to Westlands Water District

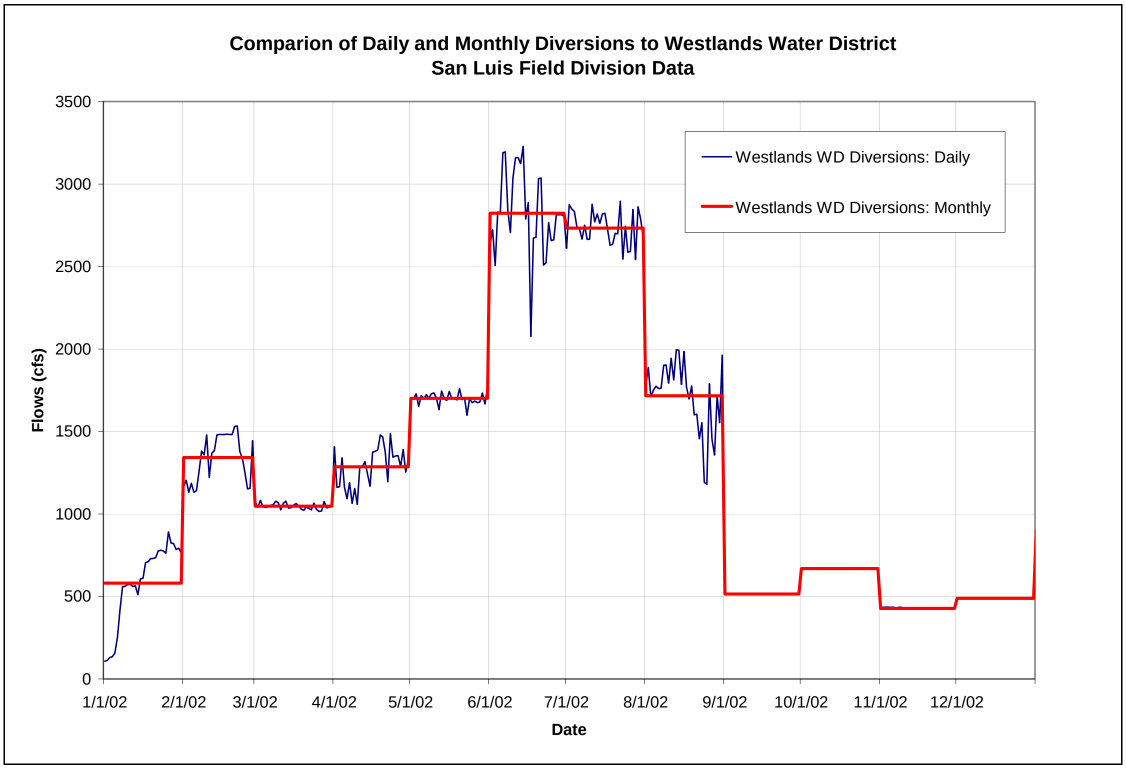
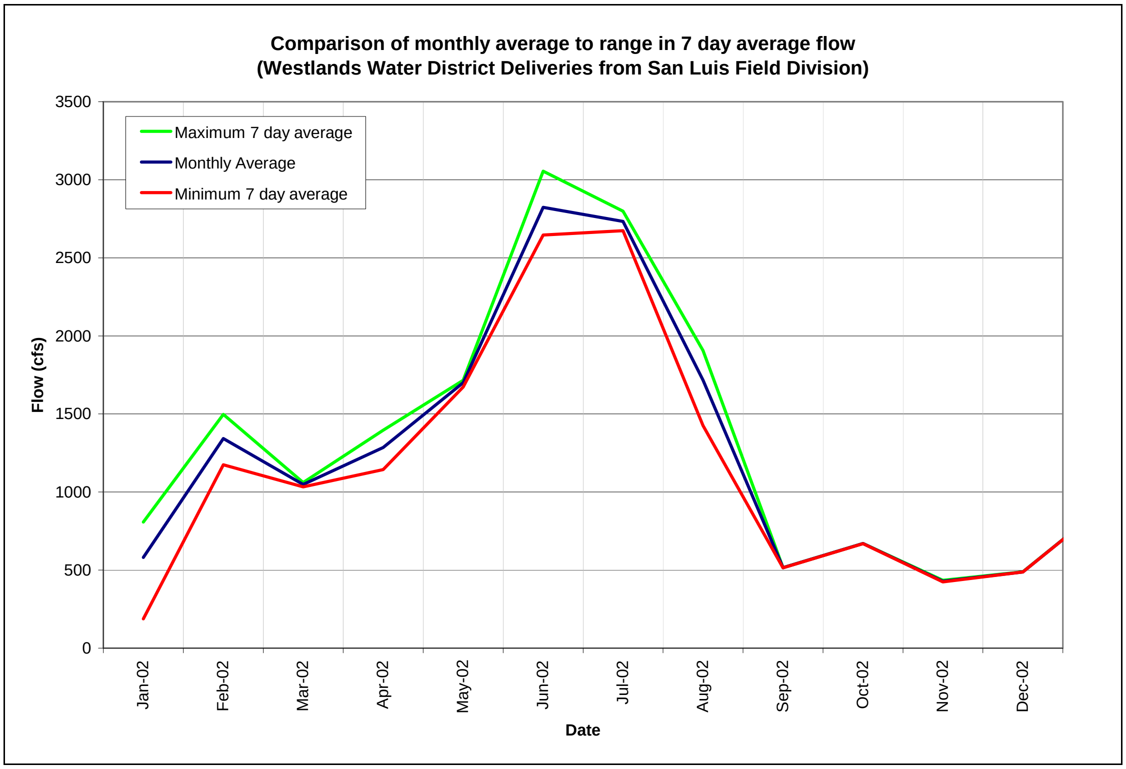


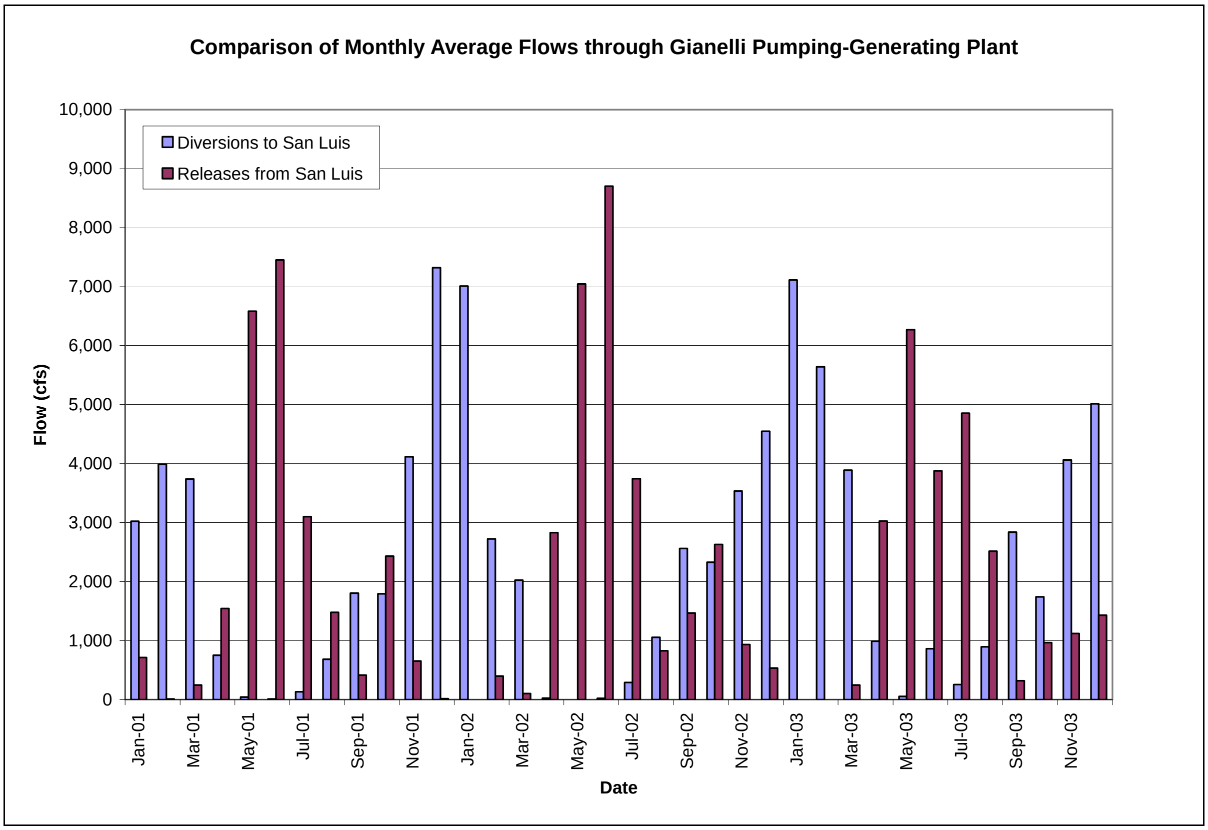
Figure 2. Comparison of monthly average Westlands Diversion to minimum and maximum 7 day averages



San Luis Reservoir and Gianelli Pumping-Generating Plant Operations

The flows between San Luis Reservoir and O'Neill Forebay utilized in the Phase 1 calibration simulations indicate that on a daily basis, there can be flows into San Luis Reservoir from O'Neill Forebay on the same day that water is released from San Luis Reservoir to O'Neill Forebay. Figure 3 presents a monthly summary of the exchange flows between O'Neill Forebay and San Luis Reservoir, demonstrating the annual patterns of flows into and out of San Luis Reservoir through the Gianelli Pumping-Generating Plant; note the months of August through October generally have significant flows through Gianelli in both directions.

Figure 3. Comparison on Monthly Average Flows through Gianelli Pumping-Generating Plant (2001 through 2003).



DWR provided CH2M HILL staff with a two-month record of hourly pumping data for the Gianelli Pumping-Generating Plant to evaluate the nature of intraday exchanges between San Luis Reservoir and O'Neill Forebay. DWR provided data from the ACES system for July and August, 2006. The daily average data for this two month period is presented in Figure 4, demonstrating the consistent occurrence of daily pumping flows into San Luis Reservoir during periods of high release flows. The average intraday patterns, developed from hourly data, are presented in Figure 5. It is clear that pumping flows occur in the morning hours, followed by release flows throughout the remainder of the day. For the two month sample dataset provided by DWR, the pumping flows into San Luis average approximately 40% of the flows released to O'Neill Reservoir, on a daily basis. Thus, on average, 40 percent of the volume of water released from San Luis Reservoir on a daily basis during July and August 2006 was pumped into San Luis Reservoir earlier in the day.

Forecast data for Gianelli operations can be obtained from either DWR's allocation model (long term forecasts) or their short term power scheduling model (short term forecasts).

Figure 4. Daily Flows through Gianelli Pumping-Generating Plant for July/August 2006

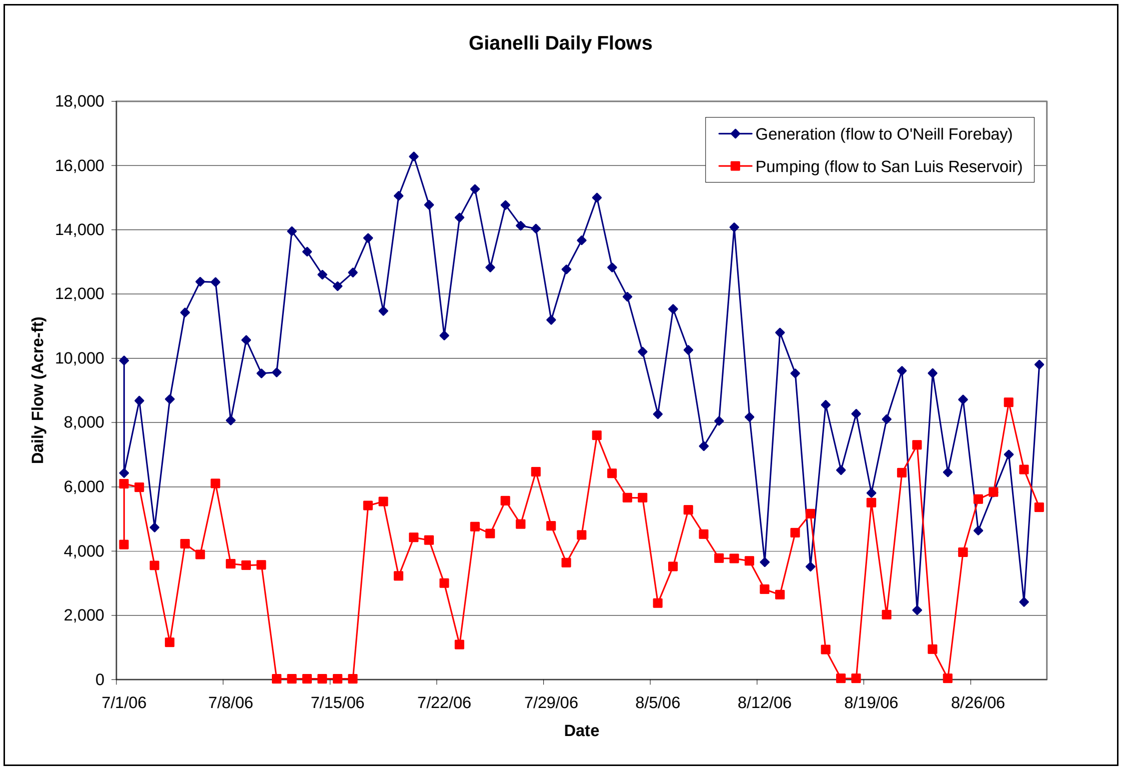
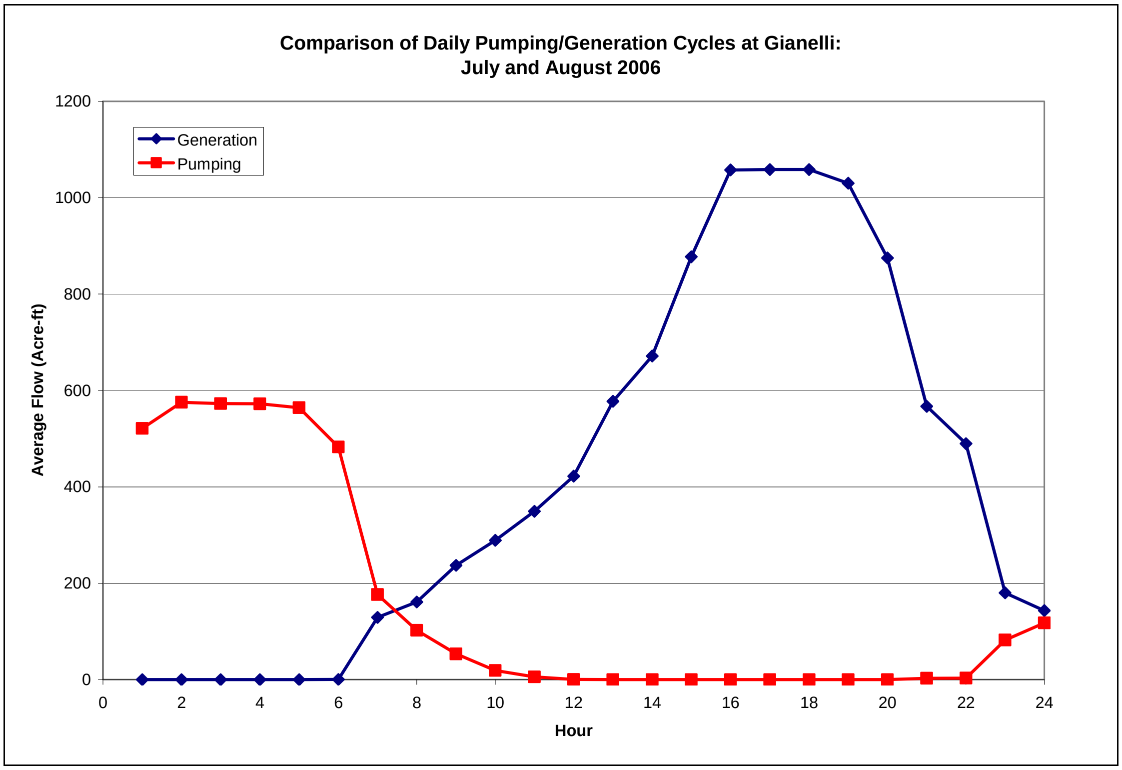


Figure 5. Average Hourly Flows through Gianelli Pumping-Generating Plant

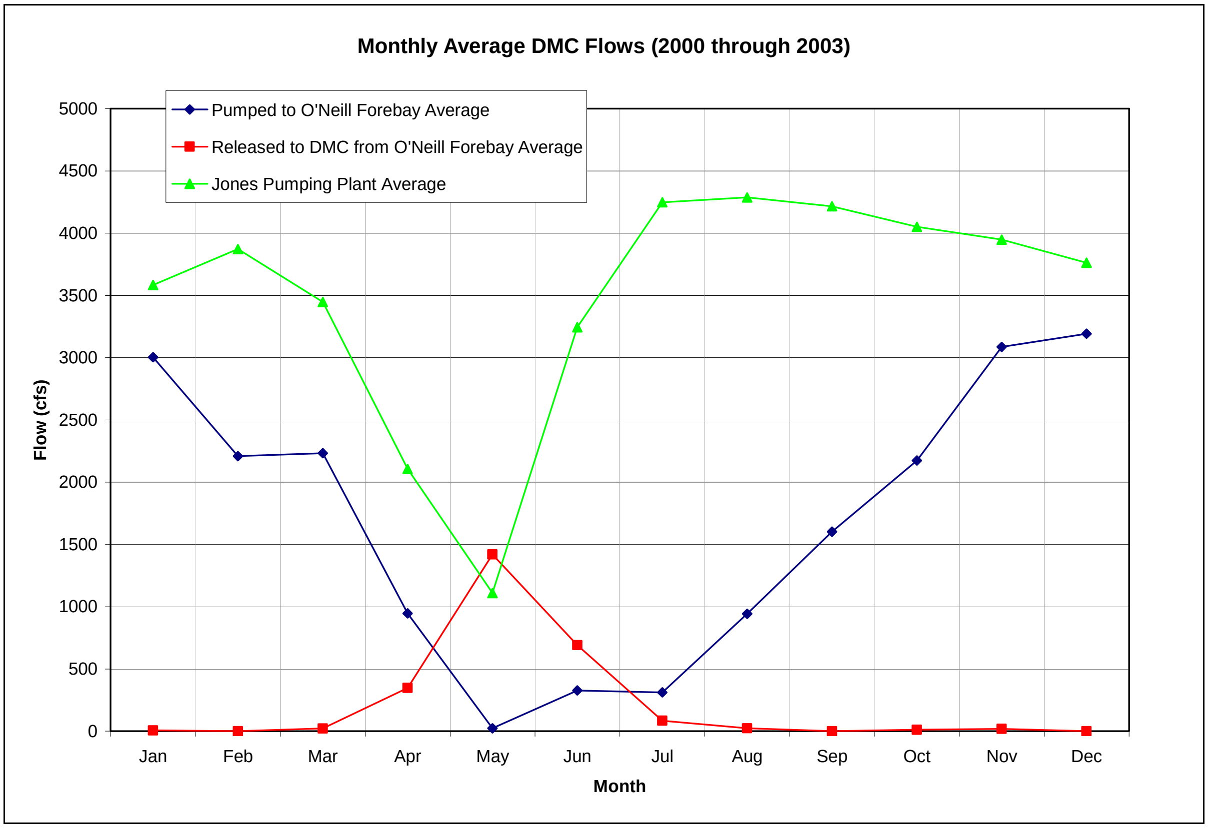


O'Neill Pumping/Generating Plant Operations

CVO attempts to fill the CVP portion of San Luis Reservoir by April 1st of each year. Water is pumped into O'Neill Forebay by the O'Neill Pumping/Generating Plant, and then moved into San Luis Reservoir through the Gianelli Pumping-Generating Plant. Releases from storage in San Luis Reservoir to the DMC are generally made in April through June of each year, when Jones pumping cannot meet contractor demand. Recall that pumping is curtailed for environmental purposes in April and May (VAMP). CVP Operations provide DWR Power Planning with a short term forecast of projected flows through O'Neill Pumping-Generation Plant.

Historical daily flows for the exchange between the DMC and O'Neill Forebay are available from DWR. Figure 6 presents the average annual pattern of flows at Jones Pumping Plant and between the DMC and O'Neill Forebay. These monthly averages were calculated from daily data for a four year period (2000 through 2003). This dataset was analyzed to determine the frequency of days in which water was both pumped and released through the O'Neill Pumping-Generating Plant

Figure 6. Monthly Average Flows at Jones Pumping Plant and through O'Neill Pumping–Generating Plant



Data indicates that flows are released from storage an average of 86 days per year, and that pumping flows occur on 20 of those 86 days per year. On average, seven of these days happened in the months of April, May, and June, when the majority of flow releases occur. Thus, it is assumed that the use of daily averaged object to object flows quantifying the exchange between the DMC and O'Neill Forebay is sufficient for simulation of the forecast.

Miscellaneous Inflows (Groundwater Pump-ins, Stormwater Inflows)

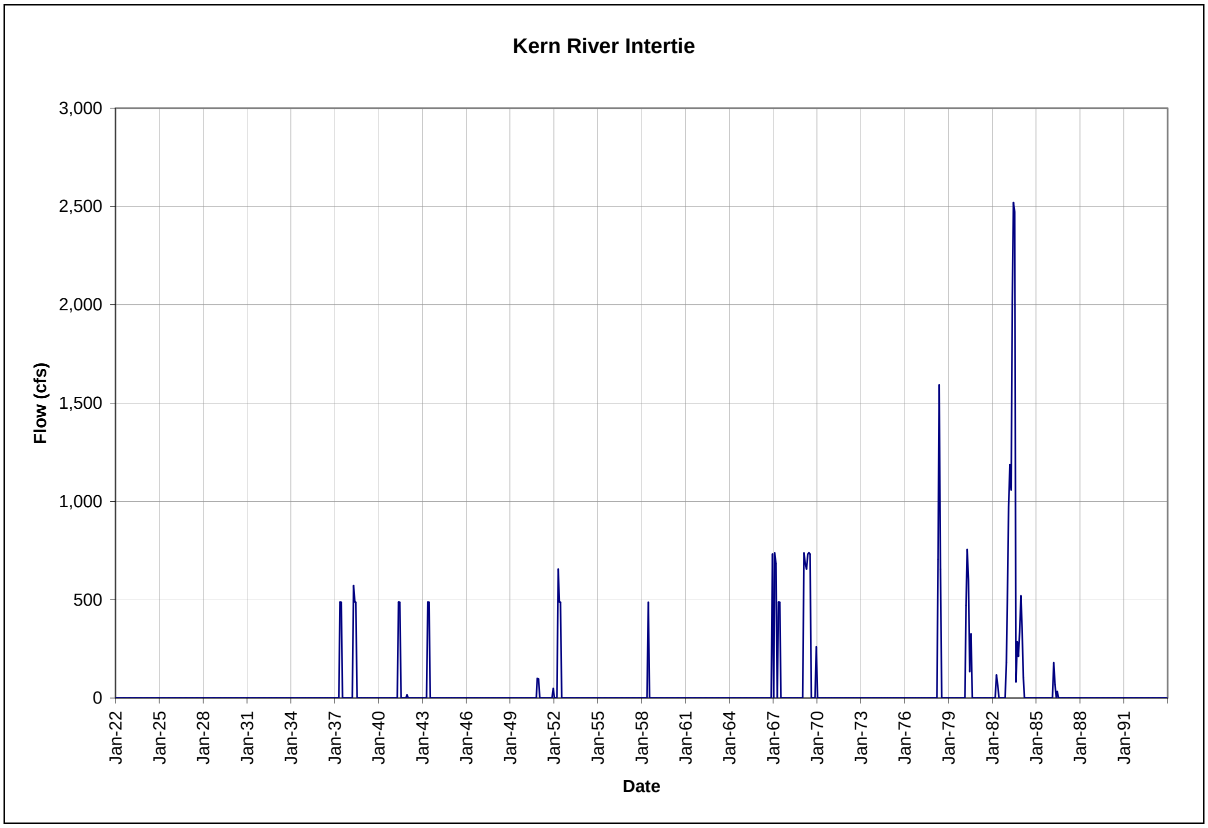
Historical groundwater pump-ins are not included in the monthly OCO reports, and were not included in the Phase 1 model. DWR publishes an annual report titled "Water Quality in the State Water Project (DWR, 2007). The report contains estimates of the volume of groundwater pumped into the aqueduct. The latest annual report covered the years 2002 and 2003. Over this period approximately 100,000 acre feet of groundwater was conveyed into the aqueduct, primarily from the Kern Fan Project. This compares to approximately 6.3 million acre feet of water that was pumped through Banks during the same period. In planning mode, these flows can likely be considered negligible from a total flow perspective. With regards to water quality, groundwater turn-ins are monitored for water quality and subject to water quality standards, and have been shown to lower TOC levels in the aqueduct (DWR, 2007). Potential sources of groundwater pump-ins include individual water agencies and DWR (OCO and Municipal Water Quality Investigations program).

Historic stormwater inflows are included in the monthly OCO reports. For the 2000-2003 calibration period, stormwater inflows occurred in pools 17, 18, 19, 21, and 29 (Kern River Intertie). The DWR Water Quality Assessment of the State Water Project, 1998-1999 (DWR 2000) presents data on stormwater inflows to the aqueduct. In 1998, there was a total of approximately 20,600 acre feet of stormwater inflow to the San Luis Canal. In 1999, there was no stormwater inflow to the San Luis Canal. The report presents annual storm water inflow volumes from 1973 to 1999, with an annual average inflow of approximately 6100 acre feet. For short term forecasts coinciding with extreme rainfall events, the inclusion of stormwater inflows is recommended. This would require development of a tool to correlate recent or forecast rainfall to stormwater inflows.

The Kern River Intertie, constructed by the Kern County Water Agency in 1977, can contribute a significant volume of water to pool 29 of the aqueduct. In the first six months of 1998, 188,000 acre feet of Kern River water entered the aqueduct (DWR, 2000). Unfortunately, the inflow to the aqueduct is not measured or reported in real time. Monthly inflow volumes are estimated and published by DWR. Flow on the Kern River at the outlet of Lake Isabella is measured and published in real-time by the US Army Corps of Engineers. A correlation between historical gage data and inflows into the aqueduct could be used to estimate aqueduct inflows.

To provide some perspective on the frequency of these inflows, the time series of Kern River inflows used in the CALSIM model for the year 2001 level of development is presented in Figure 7. In the 73 year CALSIM simulation period, there are 57 months with inflows through the Kern River Intertie into the aqueduct (approximately 23% of months). The majority of the inflows occur during the months of April through June.

Figure 7. Time Series of monthly CALSIM model Kern River inflows to California Aqueduct



Data Gaps

The primary data gaps include forecasted groundwater pump-ins and stormwater inflows to the aqueduct system. Forecasting Del Valle operations on the South Bay Aqueduct will have to be addressed, as the operation of Lake Del Valle is not included in the current model.

Finally, water quality data (EC) currently available in San Luis Reservoir has been shown to be of questionable quality during certain periods of the historic record. EC is currently available at the Pacheco Pumping Plant, located on the western shore of the reservoir. Installation of a new monitoring station on the eastern shore adjacent to the inlet/outlet works could provide more relevant data for use in forecasting operations.

Implementation Plan

This section describes the tasks required to implement the DSM2 Aqueduct model in forecasting mode. This implementation plan was developed to maintain consistency with current DSM2 Delta forecasting activities (DWR, 2001; Mierzwa and Suits, 2004).

Goals

The goal of the Real-Time Data and Forecasting (RTDF) project is to provide short term and long term predictions of water quality in the Delta and California Aqueduct to water contractors and stakeholders. DWR's Municipal Water Quality Investigations (MWQI) program is charged with monitoring and protecting the drinking water quality of deliveries to urban State Water Project Contractors. The continued development of predictive tools is in alignment with the stated goals of the MWQI program.

Frequency and duration of forecast simulations

Current Delta forecasting activities undertaken by DWR include both short term (4 week) and long term (annual) forecasts. A similar approach could be adopted with the aqueduct model, since several of the boundary conditions needed to run the aqueduct model will come directly from output of the Delta forecast simulations

DWR short term Delta forecasts are run on a weekly basis. Short term aqueduct forecasts could also be run on a weekly basis as results from the Delta forecasts become available. DWR's Allocation Model is run on a monthly basis. Therefore, by developing procedures and tools to use outputs from the Allocation Model, long term Delta forecasts could be run on a monthly basis. Using outputs from the long-term Delta forecasts, long term aqueduct forecasts could also be run on a monthly basis.

Accuracy of forecasts

The accuracy of aqueduct forecasts will be dependent on several factors. Since the Delta forecasts will be used to specify flow and water quality boundary conditions at Banks and Jones Pumping Plants for the aqueduct model, the accuracy of the aqueduct model forecasts will depend on the accuracy of the Delta model forecasts. Considering the high level of complexity in the Delta as compared to that in the aqueduct, it is reasonable to assume that the uncertainty associated with the results from the Delta model, with regards to predicted EC, will be considerably higher than uncertainty introduced during the simulation of water quality through the aqueduct system.

San Luis Reservoir imparts a strong influence on water quality downstream aqueduct sections during periods of release from the reservoir. The calibration effort of the DSM2 Aqueduct Model indicated an inability to reproduce certain EC changes in San Luis Reservoir, as measured by the available dataset at Pacheco Pumping Plant. Analysis demonstrated that this dataset may contain questionable data not representative of EC conditions in the reservoir. The availability of accurate EC data in San Luis Reservoir could significantly improve the predictive accuracy of the forecasts of EC in downstream aqueduct sections. Furthermore, for short term forecasts, real time water quality data in San Luis Reservoir could be used as a boundary condition, especially during times of release from the reservoir. As a result, it is recommended that an additional water quality monitoring station be installed in San Luis Reservoir on the eastern side of the reservoir adjacent to the dam.

Mierzwa and Suits (2004) present results of model simulations demonstrating the accuracy of the Delta model for long term (8 to 12 month) forecasts. Results varied widely, with predictions for EC at Banks as much as 200% higher than measured EC. Potential sources of error in predicted EC at export locations include, but are not limited to, variations in assumed riverine inputs, export levels, DICU, and barrier operations.

Assumptions

The implementation plan described herein assumes the following:

- Future boundary flows and water quality at Banks and Jones Pumping Plants are adequately described by DWR's Delta forecast simulations. Furthermore, for short duration forecasts, recent observed data specifying conditions at Banks and Jones adequately represent the boundary conditions.
- Future diversions and contractor deliveries, for use in long term forecasts, are currently best described by DWR's Allocation Model. Potential data sources for short term forecasts (weekly) are available through the field divisions and DWR's SAP database; however, procedures and tools may need to be developed to access these data for real-time forecasting.
- The monthly time step used by the allocation model is sufficient to represent contractors' diversions from the aqueduct. High resolution data are desired but are not currently available. Flow gauges at contractors' turn-outs are currently read by DWR Field Division staff on a weekly basis
- The end-of-month storage in San Luis Reservoir, as provided by the CVP and SWP forecasts, is sufficient to calculate average exchanges with O'Neill Forebay and the DMC.
- Stormwater inflows are infrequent, difficult to quantify, and difficult to forecast. The influence of these flows is considered negligible for long term planning purposes. For short term forecasts, inflows from larger sources, such as the Kern River Intertie, should be accounted for.
- Groundwater pump-ins are increasing in magnitude. Metropolitan, for example, received 149 TAF of water through the SWP from groundwater programs in 2007, and forecasts delivery of 190 TAF in 2008. The influence of these flows on hydraulics and water quality cannot be considered negligible for short or long term planning purposes. Groundwater pump-ins should be added to the aqueduct model; this will likely require coordination with individual water agencies. DWR OCO may have compiled groundwater pump-in data, including short term forecasts.

Implementation Plan Steps

There are five main steps in the implementation plan, including

1. Retrieval of appropriate data for specification of boundary conditions
2. Perform data review, QA checks, and process data into correct format for use in DSM2
3. Conduct model simulations (including the maintenance of an up-to-date historical simulation)
4. Process and review model results

5. Distribute model results

These individual steps are discussed in further detail below. Potential difficulties are discussed where appropriate.

Step 1 - Data Retrieval

The primary sources of boundary condition data are DWR's Delta forecasts and Allocation Model. The Delta forecasts, whether short term or long term, will provide flow and water quality time series data for Banks and Jones Pumping Plants. The short term Delta forecasts use daily average export flows, while the long term forecasts assume monthly average flows. DSM2 Hydro and QUAL model results available in DSS format will allow for efficient processing for use in the aqueduct model.

The Allocation Model will provide the basis for specification of diversions along the aqueduct. Monthly average contractor deliveries are available from the Allocation Model, and are updated every month when a revised annual Allocation Model is generated by DWR staff. The allocation model provides aggregated contractor deliveries; in order to disaggregate these deliveries for use in the model, the current delivery requests of individual contractors will also be required. Forecasted CVP allocations provide data for diversions along the DMC; individual contractor demands can be disaggregated from total CVP demands by developing an Excel spreadsheet tool, similar to that developed by CH2M HILL for the CALSIM planning simulations (CH2M HILL, 2007c). Appendix C includes a table that shows the mapping of contractor agency diversions to DSM2 nodes for each pool along the aqueduct.

The Allocation Model also provides end of month target storage for San Luis Reservoir. These target values can be used to specify daily average flows through Gianelli Pumping-Generating plant for use by the Aqueduct Model for forecasting purposes. Historical data should be used to develop a time series of pumping flows to San Luis Reservoir during times of net release from San Luis Reservoir. These flows (see Figure 5) should be included because of their influence on water quality in San Luis Reservoir.

An alternate source for forecasts of flow through Gianelli Pumping-Generating Plant is the power forecasting model run by Tuan Bui at DWR. This model balances power needs with water delivery with a short term (one week) timeframe. The DWR model receives input from the CVP regarding operations at O'Neill Pumping-Generating Plant and DMC demands, but does not have information on the scheduling of pumps at O'Neill. DWR coordinates with CAL ISO on an hourly basis. DWR also conducts a longer term power forecast, which could provide pumping plant estimates for long term (annual) aqueduct forecasts. Mr. Bui indicated that pump back operations are not included in the model.

Kern River flows below Lake Isabella are available online through the U.S. Army Corps of Engineers at http://www.spk-wc.usace.army.mil/cgi-bin/hr_rep.pl?isb%20Isabella. Data are available at an hourly basis in near real time. In order for the data to be used to estimate inflows to the California Aqueduct through the Kern River Intertie, a correlation will have to be developed between flows below Lake Isabella and through the Intertie.

If short term forecasts are made during spring months of wet years, it may be advisable to include stormwater inflows when modeling TSS, TDS, or other constituents known to occur at elevated levels in floodwater inflow. Regressions would need to be developed to correlate historical storm water inflows to local hydrologic conditions, which could be monitored in near real-time.

For the purposes of forecasting simulations, it is assumed that groundwater pump-ins could be neglected without introducing significant errors in model results. The ability to accurately forecast groundwater pump-in operations should be investigated to determine if these flows could be added to forecasting simulations.

Initial conditions in the aqueduct can be obtained from an up-to-date historical simulation or by obtaining near real-time water quality data through CDEC. EC data are available on an hourly interval through CDEC for Banks Pumping Plant, San Luis Reservoir (Pacheco Pumping Plant), and checks 12, 13, 18, 21, 29, 41, and 66 along the aqueduct. Data are also available for the DMC at Jones and Checks 13, 20, and 21. An EXCEL processor needs to be developed to interpolate between these data points to specify EC conditions throughout the aqueduct.

Current Reservoir Operations Reports containing daily data for San Luis Reservoir elevation, flows, and storage is available online (through previous day) at http://www.usbr.gov/mp/cvo/vungvari/snldop.pdf. Similar data for O'Neill Forebay can be found at http://www.usbr.gov/mp/cvo/vungvari/onfdop.pdf. These data can be used to specify initial hydraulic conditions in San Luis Reservoir and O'Neill Forebay.

Table 1 lists contact information for data required to run the aqueduct model. Table 2 presents a summary of all data needs, provides recommendations for obtaining the data, and identifies data which will require significant effort to obtain, develop, and format for use in the Aqueduct model. Table 3 details further the pre-processing tools required to transform data in useable formats for use in DSM2.

Table 1. Contacts for Required Data

Tracy Hinojosa Operations Control Office	DWR	Delta Compliance and Modeling	tracyh@water.ca.gov 916-574-2655
Abdul Khan Tracy Pettit Molly White	DWR DWR DWR	Delta Compliance and Modeling Water forecasts and scheduling Water forecasts and scheduling	akhan@water.ca.gov pettit@water.ca.gov (916) 574-2662 mwhite@water.ca.gov 916-574-2651
Tuan Bui Senior Engineer	DWR	Power forecasts and scheduling	tbui@water.ca.gov 916-574-2663
Ted Swift Municipal Water Quality Investigations	DWR	Office of Water Quality, Real Time Data and Forecasting Project	tswift@water.ca.gov 916-651-9694
Paul Fujitani Chief, Water Operations Div.	USBR	CVO Forecasts	pfujitani@mp.usbr.gov 916-979-2197

Table 2. Summary of Data Requirements for Aqueduct Forecasting Model

DATA ISSUES										
DSM2 Aqueduct Data File Name	**Description**	**Physical Location**	**Model ID/Node # (If Applicable)**	**Period**		**Temporal Resolution**	**Potential Data Source**	**Pre-processing Tool Reference**	**Major Issues (If Any)**	**Comments**
				From	To			Pre-processing Tool Name		
Boundary_daily.dss	Banks Flow	Banks Pumping Plant	Node 400	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "HRO" has daily flow
Boundary_daily.dss	Jones Flow	Jones Pumping Plant	Node 100	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "TRP" has daily flow
Balance_final.dss	Contractor Diversions/Deliveries	Turnouts in Aqueduct and DMC	Various	Start of simulation	End of simulation	Monthly or daily	SWP/CVP Allocation and Contractor requested deliveries	Contractor Deliveries Mapping Tool	Critical item; will require significant effort both in terms of conceptualization and implementation.	Obtaining contractor delivery requests could be an issue. EXCEL tool will disagregate SWP and CVP Allocations to appropriate DSM2 nodes.
Boundary_daily.dss	Gianelli Pumping/Generating Plant Operations	Gianelli Pumping - Generating Plant	Reservoirs "SANLUISR" and "ONEILLR"	Start of simulation	End of simulation	Daily or hourly	DWR Power Operations Forecasts and historic hourly flow data	Reservoir Operations Tool	Some issues, but can be addressed with some effort.	Substantial work required; DWR forecasts are done monthly with shorter term forecasts available for 1 week.
Boundary_daily.dss	O'Neill Pumping/Generating Plant Operations	O'Neill Pumping - Generating Plant	Reservoir "ONEILLR" and DMC Node 280	Start of simulation	End of simulation	Daily or hourly	DWR Power Operations Forecasts and historic hourly flow data	Reservoir Operations Tool	Some issues, but can be addressed with some effort.	Substantial work required; DWR forecasts are done monthly with shorter term forecasts available for 1 week.
Balance_final.dss	Stormwater Inflow rates	Various	Various	Start of simulation	End of simulation	Event	Historic inflow data and precipitation forecasts	Stormwater Inflows	Some issues, but can be addressed with some effort.	Stormwater inflows are expected to be negligible except during extreme rainfall events.
Balance_final.dss	Kern River Intertie Inflow	Kern River Intertie	Node 431	Start of simulation	End of simulation	Event	Realtime Kern River Flow and flow forecasts	Kern River Intertie Flows	Some issues, but can be addressed with some effort.	Kern River flow forecasts (at Lake Isabella) available from California/Nevada River Forecast Center (www.cnrfc.noaa.gov)
Balance_final.dss	Groundwater Inflow rates	Various	Various	Start of simulation	End of simulation	Event	Water agency estimates; historical daily pump-in records		Some issues, but can be addressed with some effort.	Substantial work required; availability of forecasts unknown. Could estimate monthly inflows based on recent historical data.
All_EC_daily.dss	Banks EC	Banks Pumping Plant	Node 400	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "HBP" has hourly EC
All_EC_daily.dss	Jones EC	Jones Pumping Plant	Node 100	Start of simulation	End of simulation	Daily or hourly	DSM2 Delta Forecasts and/or Realtime Data	(input formatting only)	No major issues.	CDEC Station "DMC" has hourly EC
All_EC_daily.dss	Inflow (stormwater, groundwater) EC	Various	Various	Start of simulation	End of simulation	Event	Historic groundwater water quality records (MWQI program)		Some issues, but can be addressed with some effort.	Substantial work required; survey of historic SW and GW EC could provide range of estimates; without real time monitoring assumptions will be required
*.hrf restart file	Initial Stage	Entire Model Grid	All	Start of simulation	N/A	Real Time	Realtime data (CDEC)	(input formatting only)	No major issues.	CDEC stations with hourly stage: SNL and ONF; channel stages from historical simulation
reservoirs.inp	Initial Reservoir Elevations	San Luis Reservoir, O'Neill Forebay	SANLUISR and ONEILLR	Start of simulation	N/A	Real Time	Realtime data (CDEC)	(input formatting only)	No major issues.	CDEC Stations ONF and SNL have hourly reservoir elevations
*.qrf restart file	Initial EC	Entire Model Grid	All	Start of simulation	N/A	Real Time	Realtime data (CDEC)	EC Interpolator	No major issues.	CDEC Stations ONF and SNL have hourly reservoir elevations

Table 3. Summary of Suggested Pre-processing Tools

PRE-PROCESSING TOOLS ISSUES

DSM2 Aqueduct Data File Name	Pre-processing Tool Name	Pre-processing Tool Function	Model ID/Node # (If Applicable)	Pre-processing Input/Output		Recommended Platform	Major Issues (If Any)	Comments	LOE Estimate for Tool Development (Person Days)
				Input	Output				
Balance_final.dss	Contractor Deliveries Mapping Tool	Map proposed contractor deliveries to DSM2 nodes in the Aqueduct and DMC	Various	SWP Allocation and contractor delivery requests	Time series of diversions and deliveries	Excel/VB	Critical item; will require significant effort both in terms of conceptualization and implementation.	Obtaining contractor delivery requests could be an issue. EXCEL tool will disagregate SWP and CVP Allocations to appropriate DSM2 nodes.	10
Boundary_daily.dss	Reservoir Operations Tool	Develop Time series for flows into and out of San Luis Reservoir and O'Neill Forebay through Gianelli and O'Neill Pumping-Generating Plants	Reservoirs "SANLUISR" and "ONEILLR"	DWR Power Operations Forecasts and historic hourly flow data	Time series of flows through Gianelli and O'Neill P/G plants	Excel/VB	Some issues, but can be addressed with some effort.	Review of historic data indicates significant variations in intraday operations, such that use of daily average flows could mischaracterize salinity transport into and out of San Luis Reservoir.	5
Balance_final.dss	Stormwater Inflows	Develop tool to assign predicted stormwater inflows to appropriate DSM2 nodes	Various	Historic inflow data and precipitation forecasts	Stormwater inflows for DSM2 nodes	Excel/VB	Some issues, but can be addressed with some effort.	OCO reports list inflows into pools 17, 18, 19, and 21 (Nodes 419, 420, 421, and 423)	4
Balance_final.dss	Groundwater Pump-ins	Develop tool to assign predicted groundwater pump-ins to appropriate DSM2 nodes	Various	Historic inflow data and forecasts	Groundwater pump-ins for DSM2 nodes	Excel/VB	Some issues, but can be addressed with some effort.	Will require coordination with individual water agencies, predictive capability is unknown	4
Balance_final.dss	Kern River Intertie Flows	Develop tool to predict Kern River Intertie flows into California Aqueduct	Node 431	Kern River real time flows (CDEC Station "ISB" and Kern River flow forecasts	Kern River Intertie Inflow to Aqueduct	Excel/VB	Some issues, but can be addressed with some effort.	Kern River flow forecasts (at Lake Isabella) available from California/Nevada River Forecast Center (www.cnrfc.noaa.gov)	3
*.qrf restart file	EC Interpolator	Interpolate real time EC at select locations for specification of initial EC conditions throughout DSM2 model grid	All Nodes	Real Time EC from CDEC	Initial EC values for every node/reservoir	Excel/VB	Some issues, but can be addressed with some effort.	CDEC Stations with real time (hourly) EC: Aqueduct Checks 13, 21, 29, 41, and 66; Jones PP (DMC), Banks (HBP), San Luis Res (PPP), and O'Neill Intake (ONI). Real time EC data is no longer available at Checks 12 and 18.	3

Step 2 - Data Processing and Quality Review

Once the required data have been retrieved, the data need to be reviewed for quality and formatted for use in the aqueduct model. EXCEL spreadsheets or other tools will need to be developed to collate and process data for use with DSS and the forecasting model. Table 3 provides a summary of these tools, which will be needed to process data for short term and long term forecasts. Table 3 also includes a rough estimate of the level of effort required to develop each recommended tool. Tools that need to be developed include:

- Tool to map proposed contractor deliveries from DWR's Allocation Model and CVP's Allocation Model to DSM2. This tool can be similar to the tool developed to map CALSIM demands to the DSM2 model grid.
- Tool to develop flow time series for exchanges between O'Neill Forebay, San Luis Reservoir, and DMC. This tool will rely on projected end-of-month storage in San Luis Reservoir (from the Allocation Model) and on historical data to develop flows through Gianelli and O'Neill Pumping-Generation Plants.
- Tool to predict Kern River Intertie flows. A tool will need to be developed to correlate real time flow measurements on the Kern River to flows into the aqueduct.
- Tool to predict stormwater inflows. A tool will need to be developed to relate real time rainfall data to projected storm water inflows to the aqueduct.
- Tool to predict groundwater pump-ins and assign to appropriate nodes. A tool will need to be developed to relate recent and/or forecasted groundwater pump-in data to appropriate nodes in the Aqueduct model.
- Tool to interpolate between real time EC check measurements, at select locations along the aqueduct system, to generate EC values for all DSM2 grid nodes for specification of initial water quality conditions in the aqueduct.

Data must also undergo several quality assurance steps before the data can be used in DSM2. One important data quality check is to verify that the data when applied to the model, does not cause errors in the mass balance. For example, flows into and out of O'Neill Forebay should balance, considering the water surface elevation in O'Neill is operated within a narrow range. Historical daily stage and storage data for O'Neill Forebay and San Luis Reservoir should be used to verify the quality of forecast plant operations. A sensitivity analysis should be conducted with a previous months forecast data and the actual measured change in storage in San Luis Reservoir to determine how close real operations are to forecasts.

A second important issue is to make sure that minimum flows are maintained throughout the system to prevent channels from drying up. The DSM2 model will not simulate a condition where there is no flow in a given channel. For example, if all of the flow at Jones Pumping Plant is diverted upstream of Check 12 and pumped into O'Neill Forebay, such that there is no flow in the DMC downstream of Check 12, the model will cease simulation. A similar issue in the South Bay Aqueduct must also be checked.

Step 3 – Model Simulation

Model simulations should be conducted on a weekly basis following the release of Delta forecasts by DWR staff. A staff position should be dedicated to running the model simulations and maintaining an up-to-date historical version of the model. At least one other engineer/scientist should be capable of running the model and post-processing the data should the need arise.

Step 4 – Processing and Review of Model Results

After completion of the model simulations, the model results will need to be carefully processed and reviewed for reasonableness. Quality control review of model results will be critical to the success of the forecasting effort. An EXCEL spreadsheet or other processing tool will need to be developed to allow efficient data processing and technical review.

Once the results have been approved for release, relevant results can be processed and summarized in a format useful to stakeholders. Time series of predicted flow, reservoir elevation, and water quality parameters at select locations in the Delta could be included in the standard output. Feedback from stakeholders should be included in deciding which variables should be included in the analysis.

Step 5 – Distribution of Model Results

Model results can be disseminated to interested stakeholders following the weekly model simulation and analysis of results. A weekly report could provide a summary of near-term forecast conditions and real time conditions in the aqueduct.

Ted Swift (DWR Office of Water Quality, tswift@water.ca.gov) currently distributes results of the weekly Delta forecasts to interested parties (Real Time Data Forecasting Project, Weekly Water Quality Report). This weekly communication provides a summary of current and near-term forecasted conditions, in addition to a standard set of figures describing temporal variation of several key parameters. The report includes discussion of predicted flows, exports, salinity, organic carbon, and changes in Delta operations, such as the Delta Cross Channel Gate position and the South Delta temporary barriers. This report could serve as a guide for the distribution of short-term aqueduct model forecast results, as well as the long-term Delta and aqueduct forecast results.

Limitations of Forecasting Model

It is important to understand the potential limitations associated with the DSM2 aqueduct model for application to short term and long term forecasts. Limitations of the DSM2 aqueduct model were described in the Phase 1 report (CH2M HILL, 2005), and include proper specification of flows that achieve a mass balance, the variability in actual daily diversion and the compromise of using monthly averaged diversions, the treatment of reservoirs as completely and instantaneously mixed, and the representation of gate structures and their influence on average flow in the aqueduct. Potential limitations associated with the forecast application are presented below.

For short term forecasts, the ability to adequately forecast boundary flows, including inflows and diversions, influences the quality of the forecasts. Contractors' diversions are not easily forecasted; daily diversions from the aqueduct may be considerably higher or lower than requests by individual contractors. Currently, there is no short term (weeks to months) forecast of contractors' diversions aside from the Allocation Model. The Power forecasting and scheduling group makes short term (1 week) estimates for contractors' diversions; these estimates rely heavily on recent contractor diversion patterns. These data, however, are often forecasted for only a week in the future.

For short duration forecasts, recent observed data specifying flow and water quality conditions at Banks and Jones could be used for boundary conditions. In particular, if short duration forecasts of conditions in the southern portion of the aqueduct are desired, conditions in the aqueduct may be controlled by antecedent conditions at Banks and Jones rather than future forecasted conditions.

As discussed above, the primary limitation on the long term predictive capability of the aqueduct model is the accuracy of forecasts from the Delta model. The DSM2 Delta model, in turn, is limited by the accuracy in simulating hydrodynamics and water quality in the Delta, as well as the accuracy of predicted hydrology used in the Delta model. The aqueduct is primarily a conveyance system, and thus conveys EC from Banks and Jones to the terminal reservoirs, with off-stream storage in San Luis Reservoir offering minor complications. Compared to the potential variation in EC at the Banks and Jones Pumping Plants, boundary conditions (diversions) in the aqueduct have a relatively minor influence on the water quality at the aqueduct terminus; misrepresentations of diversions may introduce errors in predicted travel time through the system, but in simple terms the EC at the upstream end will be conveyed to the downstream end of the system, so proper specification of EC at the upstream boundaries is of critical importance.

Improvements in forecasting accuracy may be possible with the installation of an additional water quality monitoring station in San Luis Reservoir adjacent to the inlet/outlet works. Real time EC data could be used for specification of initial conditions and even as a boundary condition for short period simulations.

Conclusions and Recommendations

This technical memorandum describes a plan to implement forecasting studies with the DSM2 California Aqueduct model. Forecast simulations for south of Delta water quality and hydraulics will complement current Delta forecast simulations conducted by DWR. The report describes the various data required to run the model in the forecast mode, and discusses the availability and potential sources of the data. Where data are not readily available in near real time, methods are proposed to relate the required data to other available datasets.

Some data required to run short term forecasts with the aqueduct model are not readily available. For example, operations at Gianelli and O'Neill Pumping-Generation plants are not forecasted more than a week in advance by DWR Power Scheduling Section. For certain data, assumptions will have to be made to develop daily patterns from monthly forecasts. End of month storage in San Luis, which is forecasted in the Allocation Model, can be used to derive time series data for flows through Gianelli. However, the more coarse but available data may be sufficient for certain model simulations.

Initialization of the Aqueduct model should be feasible by obtaining observed data from the IEP and CDEC websites. Near real time data are available from these sources. A script similar to that developed by DWR for initialization of the Delta model should be developed. The script should be written to interpolate values between locations with available EC data to provide initial condition data for all nodes in the aqueduct model grid.

The tabulation of required data will require assistance from several agencies who have developed forecasting models of their own (DWR, USBR). The USBR, for example, has developed estimates of monthly delivery patterns to CVP contractors on the DMC based on historical data. These estimates vary with the annual allocation level. This work could be adopted for use in forecasting studies with approval from the Bureau.

The viability of long term water quality forecasts south of Delta with the DSM2 aqueduct model can be demonstrated through a comparison of model results driven by historical forecasts to historical water quality data. Similar estimates performed with MWD's aqueduct model indicate that the predictive ability over an annual time frame can range considerably. Continued studies can isolate the parameters to which model results are most sensitive, and further efforts can be focused on reducing these uncertainties. Forecasting simulations run with a range in inputs bracketing expected conditions will yield a range of results reflective of the inputs. The predictive ability of the forecast simulations are expected to increase as the duration of the forecast decreases. The results of forecast simulations can provide valuable insight on the range of expected water quality conditions south of the Delta.

The quality of the forecast simulations will be heavily influenced by boundary conditions at Banks and Jones Pumping Plants. An analysis of DWR's forecasting simulations should be undertaken to estimate the magnitude of average errors between DWR Delta forecasts (i.e. water quality at export locations) and actual field measurements. This will allow for a description of the potential errors introduced into the aqueduct model at the boundaries. Discussions with Abdul Khan (SWP OCO) indicate that weekly Delta forecasts have been archived since August 2007, and that SWP OCO has a plan to undertake a systematic comparison to trace model forecasts with observed values.

The current real time data collection system is adequate for running the aqueduct model in forecast mode for the prediction of salinity. Improvements in forecasting accuracy may be possible with the installation of an additional water quality monitoring station in San Luis Reservoir adjacent to the inlet/outlet works. Real time EC data could be used for specification of initial conditions and even as a boundary condition for short period simulations. For accurate simulation of other constituents of concern (i.e. organic carbon), additional data collection instrumentation will need to be deployed throughout the system.

Finally, it is suggested that an up to date historical simulation of the aqueduct and DMC be maintained. This would involve appending the time series files prescribing all boundary conditions on a weekly basis with recent in-Delta and aqueduct flow and EC measurements.

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Appendix A

Meeting Summary

Discussion of Forecasting Capabilities Nov 21, 2006

MEETING SUMMARY

Phase 2 – Delta Simulation Model II California Aqueduct, Delta Mendota Canal and South Bay Aqueduct Extension

Discussion of Forecasting Capabilities Nov 21, 2006

ATTENDEES:

Rob Duvall (DWR-O&M)
Loi Tran (DWR-O&M)
Kevin Sun (DWR-O&M)
Ted Swift (DWR-MWQI)
Tara Smith (DWR-Delta Modeling Section)
Austine Eke (DWR-O&M)
Paul Hutton (MWD)
Kyle Winslow (CH2M HILL)
Rob Tull (CH2M HILL)
Chandra Chilmakuri (CH2M HILL)

PHONE PARTICIPANTS:

Rich Losee (MWD)
Tony Liudzuis (MWD)

Introduction

Kyle Winslow provided a brief background of the project for the new participants. He informed the group that as part of the Phase 2 work, CH2M HILL is attempting to outline an implementation plan to run California Aqueduct DSM2 Model in a forecasting mode. Paul Hutton stated that reliable and continuous data sources are necessary to run the model in forecasting mode. He suggested that the Delta forecasting model could be a prototype for this work. Paul pointed out that Kevin Sun, Loi Tran and Tony Liudzius have experience dealing with different forecasting models. Kevin Sun runs the DSM2 for Delta forecasting. Loi Tran runs the Allocation Model. Tony Liudzuis has experience with MWD's Aqueduct Model. Rob Tull reiterated that this work is to outline an implementation plan but not to setup the model in the forecasting mode.

Discussion of Current Forecasting Efforts

Kyle Winslow asked DWR staff for a summary of their forecasting process. Kevin Sun provided the following information about the current Delta forecasting efforts.

Delta forecasting DSM2 simulations are performed every week, providing a three week outlook. The total model run time is four weeks:, one week is simulated with the observed data (model spin-up) and the remaining three weeks are simulated with the forecasted data. Prior to running the forecast model, two historic runs are simulated in order to keep the initial conditions for the model up to date. One is a long-term historic simulation, which is not done that often. The second historic run is a weeklong simulation using the observed data from the websites (IEP, CDEC). Kevin receives the forecasted data from Alan Ng.

Every week, Alan provides a spreadsheet compiled with forecasted input data for DSM2 for the next three weeks. Alan compiles this data from many sources. The spreadsheet includes the flow data for Sacramento River, San Joaquin River and Eastside streams and export data for SWP, CVP, and CCC. It also has the DXC operation schedule and Clifton Court gate operation schedule. South Delta Planning Branch staff (Mike Burns) provides the coefficients representing the forecasted temporary barrier operations. DWR San Joaquin Division provides daily San Joaquin Flow and EC forecasts. DWR provides DICU data (year-type specific but not recent conditions data). DICU data is fixed and does not change every week. Some of the folks in the group suggested that DICU data used for forecasting might be the historical data for a representative water year.

Rich Losee asked if QA/QC is performed on the observed data used to run the first week (downloaded from IEP and CDEC). Tara Smith confirmed that it is not done. Kyle enquired about the time lag for the real-time data on CDEC and IEP. Ted Swift replied that the data is up to date until the last recorded observation on the websites. Rob Duvall noted that CDEC can be automatically queried.

The initial conditions for QUAL are generated from the observed data. Observed EC data from 20 or 30 locations in the entire Delta are downloaded from IEP and/or CDEC websites. This data is interpolated onto all the nodes in the DSM2 grid using a script developed by DWR. The following table outlines the Delta forecasting process.

	Day -7	Day 0	Day 21
	Observed BC Data	Forecasted Boundary Condition (BC) Data	
Observed Initial Conditions	DSM2	HYDRO	
	DSM2	QUAL	

The entire process to setup the Delta forecast simulation and process the results takes up to 2 days effort, according to Kevin Sun.

Paul Hutton mentioned that the output from the Delta forecasting model could be used as the boundary conditions (Banks and Tracy) of the Aqueduct Model. He also suggested that maintaining an up–to-date historical simulation of the aqueduct model would provide accurate initial conditions for forecasting simulations.

Loi Tran summarized the Allocation Model used by DWR Operations. The allocation model, a monthly forecasting tool, is run every month with a 12-month outlook. Every month the model is updated to the actual existing conditions prior to the new 12-month run. An ensemble of forecasts is generated for various hydrologies ranging from very dry to very wet. The model generates end-of-month storage conditions for the entire system. The output includes monthly San Luis storage conditions. Although O'Neill storage is used an input to the model, it does not generate output for O'Neill. USBR Operations has a similar model. DWR uses some of the Bureau's model output as input to DWR's Allocation Model. The output from Bureau's model for San Luis is published on their operations website. Loi noted that the Bureau model forecasts SWP's San Luis storage and the DWR model forecasts the Bureau's share of San Luis storage.

Data needs for California Aqueduct DSM2 Model

Kyle outlined the data needs for the Aqueduct Model and requested input from the group on the available data sources. Following is the list of data required and the suggested data source:

Flow and EC at Banks and Tracy pumping plants – Delta forecasting (Flows from Alan's spreadsheet and EC from the forecasted output)

Diversions and Inflows – Rob Tull suggested that it would be better to be consistent with the power forecasting model used by Tracy Pettit's group. Rich Losee agreed to talk to Tracy requesting her to release the Aqueduct turn in and turn out data. Rob Duvall suggested that Rick Woodard from MWQI has been summarizing Aqueduct turn-in data.

San Luis operations – DWR Operations Allocation Model gives monthly storage conditions for San Luis. However, having the need of higher temporal resolution data for San Luis operations, Rob suggested the power forecasting model might have information that would be helpful. Rich noted that Tracy Pettit is the best contact on the actual San Luis operations and offered to talk to her on getting the related information from the power forecasting model. He would also talk to her about the availability of the Allocation Model.

Implementation of Aqueduct Model in Forecasting Mode

As part of this discussion, Paul suggested that he would like to see the Aqueduct Model forecast for nine months. He also wanted the aqueduct model to align with the allocation model on long-term forecasts. Tony cautioned that there might be mass balance issues with the measured flow data down the aqueduct.

It was determined to have another meeting with Tracy Pettit, to understand their forecasting process and to discuss the possibility of sharing the San Luis operations forecasting methodology, Allocation Model availability and Aqueduct turnin and turnout data.

The next meeting was tentatively proposed for the week of December 4.

Action Items

Rich Losee:

- Talk to Tracy Pettit requesting her to share the Allocation Model, San Luis operations forecasting methodology, and Aqueduct turn-in and turnout data.

Kyle Winslow:

- Contact Rich Losee about the outcome of the discussion with Tracy and convene the next meeting in the week of December 4.

Appendix B

Meeting Summary

Data Availability for Forecasting Implementation Aug 27, 2007

MEETING SUMMARY CH2MHILL

Phase 2 – Delta Simulation Model II California Aqueduct, Delta Mendota Canal and South Bay Aqueduct Extension

Data Availability for Forecasting Implementation Aug 27, 2007

ATTENDEES:

Tracy Hinojosa (DWR-O&M)
Abdul Khan (DWR-O&M)
Tuan Bui (DWR-O&M)
Ted Swift (DWR-MWQI)
Dan Otis (DWR-MWQI)
Rich Losee (MWD)
John Coburn (SWC)
Paul Hutton (MWD)
Kyle Winslow (CH2M HILL)
Rob Tull (CH2M HILL)
Chandra Chilmakuri (CH2M HILL)

PHONE PARTICIPANTS:

Tony Liudzius (MWD)

Background

After the introductions, Paul Hutton gave a brief description of the Phase 1 and Phase 2 projects with CH2M HILL to develop, calibrate and improve the DSM2 Model for the California Aqueduct and the Delta Mendota Canal. He explained that the objective of this task (Task 4 of Phase 2) is to develop a plan to implement the DSM2 California Aqueduct Extension model in forecasting mode. Rich Losee explained the need for a tool to forecast water quality along the California Aqueduct during emergencies, noting that the tool should be flexible enough to address water quality parameters in addition to salinity (EC). Paul Hutton outlined goals for the meeting, which included:

- who has the necessary data,
- how can we get the data needed for forecasting,
- how can we automate and standardize dataflow, and
- who would initiate contacts between CH2M HILL and the person in charge of the necessary data

Rob Tull reminded the group about the November 2006 meeting with staff from the DWR O&M office, where DWR staff provided information on current DSM2 forecasting procedures. Rob Tull noted that meeting minutes were distributed and remain available. He also pointed to the spreadsheet with the data needs (Table 1), which was a result of this meeting.

Paul Hutton informed the group that the State Water Project Contractors were funding seven new positions, and that one of the seven new hires is slated to carry out the implementation of the Aqueduct Model in the forecasting mode.

Paul said that the forecasting tool would potentially help MWD with their short-term operations planning. Kyle Winslow enquired about the forecasting period and asked what would be the time period for “short term”. Paul responded by saying that short term would be in line with the current Delta Forecasting, which simulates three weeks into future and long-term would be in line with the DWR Allocation Model (12 Months). Kyle, highlighting that travel times through the Aqueduct can be greater than three-weeks, mentioned the potential issue of specifying boundary conditions past the three-week simulation period in order to track the flow released during the three-week period. In response to that, Paul said that the three-week simulation period should be sufficient for forecasting. However, in addition to this three-week forecasting simulation, the historical model of the Aqueduct needs to be up to date. A historical version of the model should be maintained similar to the DSM2 Delta model; as field data is processed for use in a current week’s forecasting simulation, the same dataset is appended to a separate run, providing an up-to-date run simulating recent and historic conditions Data Needs for Forecasting using DSM2 Aqueduct Model

Kyle informed the group that the Aqueduct Model is not that complex to work with, as long as the necessary boundary condition data is available. The model currently uses monthly average values to specify contractor diversions. For the calibration simulation, these monthly average values were obtained from monthly reports published by the Operations Control Office (DWR). As part of Task 3 in Phase 2, a spreadsheet tool was developed to convert the monthly CALSIM diversions along the aqueduct to various turnouts in the DSM2 model. He stated that the weakest links in this model are the resolution of available data for diversion flows and long term San Luis Operations.

Paul said that he would like to know if there is a forecast of diversions along the aqueduct and if so what would be the shortest time step at which this information is available. Secondly, he pointed out the water mass balance problem with the published historic O’Neill and San Luis operations data.

Abdul asked Kyle if we found any historical daily diversion data. Kyle said that he did not come across any data. Ted said that the diversion data is reported by diverters, he is not aware of the person with that information. Tuan said that the diversion totalizers are manually read, generally on a weekly basis. As the field offices have limited staff, data from a group of gages are recorded once every 3 to 4 days. Currently, none of these gages are tracked continuously. John added that any change in the gate position at the check structures is noted.

John further mentioned that in the San Luis Field Division, contractors south of Dos Amigos provide seven-day forecasts. Tuan added that the forecasts are very different from what actually occurs in the field, and that actual flow values can vary by over 100% from the forecasted flow rates. The delivery values used for power forecasting are adjusted by taking into account recent trends in deliveries (3 to 4 day window) in addition to the forecasted

Description	Physical Location	Model ID/ Node #	Period		Temporal Resolution	Potential Data Source	Comments
			From	To			
Current stage and velocity conditions from which to initiate the DSM2 hydrodynamic model (HYDRO) simulation	System wide	System wide	Start of the forecast simulation	--	Instantaneous	Running the historical aqueduct model to the current date, for accurate initial conditions	
Current EC conditions from which to initiate the DSM2 water quality model (QUAL) simulation	System wide	System wide	Start of the forecast simulation	--	Instantaneous	Observed values, if available, or by running the historical aqueduct model to the current date, for accurate initial conditions	
Forecasted pumping plant inflows to the California Aqueduct system as HYDRO boundary condition	Banks Pumping Plant	400	Start of the forecast simulation	End of the forecast simulation	Hourly	Inputs to CA DWR DSM2 Delta forecast model	
Forecasted pumping plant inflows to the DMC system as HYDRO boundary condition	Jones Pumping Plant	100	Start of the forecast simulation	End of the forecast simulation	Hourly	Inputs to CA DWR DSM2 Delta forecast model	
Forecasted EC as the QUAL boundary condition	Banks Pumping Plant	400	Start of the forecast simulation	End of the forecast simulation	Hourly	Output from CA DWR DSM2 Delta forecast model	
Forecasted EC as the QUAL boundary condition	Jones Pumping Plant	100	Start of the forecast simulation	End of the forecast simulation	Hourly	Output from CA DWR DSM2 Delta forecast model	
System diversions/deliveries	System wide	System wide	Start of the forecast simulation	End of the forecast simulation	Highest resolution available	Aqueduct turn in and turn out data from CA DWR O&M Power forecasting model or Rick Woodward/MWQI	Currently, monthly average values are forced as constant over the month
Groundwater or other inflows to the system	System wide	System wide	Start of the forecast simulation	End of the forecast simulation	Highest resolution available	Aqueduct turn in and turn out data from CA DWR O&M Power forecasting model or Rick Woodward/MWQI	Currently, monthly average values are forced as constant over the month
Pumping rates into O'Neill Forebay from DMC and Releases from O'Neill Forebay	O'Neill Pump-Gen Plant	Reservoir ONEILLR & Node 280	Start of the forecast simulation	End of the forecast simulation	Hourly	CA DWR O&M Power forecasting model	Current data indicates a lack of mass balance in O'Neill Forebay
Pumping rates into San Luis and Releases from San Luis	Gianelli Pump-Gen Plant	Reservoir SANLUISR & Reservoir ONEILLR	Start of the forecast simulation	End of the forecast simulation	Hourly	CA DWR O&M Power forecasting model	
Flow rates at intermediate pump stations along the Aqueduct	System wide	System wide	Start of the forecast simulation	End of the forecast simulation	Hourly	CA DWR O&M Power forecasting model	

Table 1. Data needs for implementing DSM2 Aqueduct Model in Forecasting Mode.

flows provided by the contractors. Paul asked Tuan who would have this data. Tuan said that they should be stored in a database used for billing purposes ("SAP"). John Leahigh's group may be able to provide this data. John asked if this data was proprietary. Tuan said no but added that not everyone in DWR can access this (sensitive) information.

Kyle suggested that we could rerun a historical period (2003-04) with the contractor delivery dataset to validate the performance of the model but avoid any sensitivity with current data. Abdul suggested that we apply some sort of a distribution function to disaggregate the monthly diversion values to daily. Kyle suggested that the most logical dependency would be with the crop stage and temperature. Ted asked Tuan how far back we have the data. Tuan said that it might be available from 2000 onwards.

Kyle inquired about the power scheduling model and the potential to use this model to verify operations in San Luis Reservoir. Tuan added that the San Luis pump back within a day is not forecastable. Kyle said that the water quality in O'Neill Forebay and San Luis could be impacted if there are pump backs at Gianelli plant. John said that daily dispatchers have reports every midnight for San Luis operations. Ted asked if we have similar dispatcher's reports on any of the gages. Tuan said that Check 21 is reported. Rich said those reports have Check 13 and Check 21 data.

Discussion of the Data Sources and Contacts

At this point in the discussion, Paul wanted Kyle to go through the Table 1 and asked the group to identify the data source for each item and the corresponding contact. Results of this discussion are summarized by dataset.

<u>Initial Conditions: Hydrodynamics and Water Quality</u>

Kyle started by explaining the data required to describe initial conditions for the forecasting simulation. This information could be downloaded from CDEC website (EC distribution throughout the system) or could be the provided by the historic DSM2 Aqueduct Model, which would be kept up to date each week as part of the forecasting simulations.

Kyle brought up the issue of the missing volume of water (mass balance error) in the published San Luis/ O'Neill Forebay Operation reports from DWR OCO. Tuan said that he was surprised at the magnitude of the error and recommended that we examine the power meter data at Gianelli. He suspected that since the power curves are different for different pumps, whoever might be recording the flows could have mistakenly used incorrect pump curves. Kyle mentioned that Mike Nolasco from DWR had been analyzing these discrepancies and thought that the data from Check 12 on the Aqueduct was likely the source of error. Kyle demonstrated a simplistic comparison of errors and flow magnitudes and concluded that the measurement of flow being released from San Luis Reservoir could also be a significant source or error.

<u>Boundary Flows at Banks and Jones Pumping Plants</u>

Kyle said that the flows at Tracy and Banks Pumping Plants, could be obtained from the input dataset to the existing Delta forecasting model (short term forecasting). Tracy and Abdul said that these the flows were forecasted on a daily basis and not hourly time step as noted in the Table 1. For longer forecasts, the Allocation model could provide information for flows at Tracy and Banks on a monthly basis.

Boundary Water Quality at Banks and Jones Pumping Plants

EC at Banks and Jones Pumping Plants are direct outputs from the existing Delta forecasting model. The short-term Aqueduct forecasts could use this data to specify boundary conditions at the upstream end of the system. Kyle suggested that for long-term forecasting, outputs from the Allocation Model could be used to run Delta forecasting model, which would in turn provide the EC boundary conditions at Banks and Jones for the Aqueduct model. Assumptions on future hydrologic inputs to the Delta would have to be made if the approach were followed. Alternatively, simulations could be performed for the full range in expected hydrologic conditions.

Paul asked if there was a restriction on the minimum time step for boundary conditions in DSM2. Abdul said someone at Delta Modeling Section informed him that DSM2 could not take anything less than daily data. Kyle and Chandra said that DSM2 can take boundary conditions at finer time steps than a day. Abdul suggested that while doing the forecasting, it would be better to provide an estimate of uncertainty by doing an ensemble of runs with differing boundary conditions instead one single run. Paul suggested that it could be taken up in future while implementing this model in the forecasting mode.

Contractor Diversion Data

Tuan mentioned that contractor delivery data are available in ACES or SAP database system. Tracy will initiate the contact between Coe Hall and CH2M HILL for a detailed discussion about the nature of the data and its availability.

While discussing the availability of long-term forecasts for diversions, Tuan explained that the contractors provide delivery pattern forecasts for the next calendar year in every October, for 100%, 50% and 30% allocations. This information is provided at the turnout level. On a monthly basis, the contractors O&M office update their requested delivery patterns through the rest of the calendar year based on the current allocation provided by DWR. DWR then reruns the Allocation model and provides updated estimates of contractor deliveries. Tuan said that in addition to these calendar year forecasts from all the contractors, MWD and Kern provide him with unofficial monthly delivery forecasts. Tuan also noted that for daily level power planning turnout level data is used.

Paul said that Tony was using some assumptions to disaggregate allocation model data to the MWD’s Aqueduct Model.

Ted asked that since MWD & Kern constituting 75% of demand are at the south end of the system, does the remaining 25% demand in the north end of the system have any effect on water quality. Kyle said that the diversions in the north end of the system impact the travel time through the Aqueduct. Tuan added that Westlands Water District’s take from the Aqueduct was high (CVP contractor).

Groundwater and Storm water Inflows

Tuan said that groundwater pump-ins and storm water inflows are not included in the Allocation Model. Rich asked if the inflow data was available in a database with Mike

Nolasco. San Luis Division estimates Kern River Intertie flows in conjunction with Kern River Intertie Users. There is no direct measurement of Kern River inflow. Tuan noted that the Kern River Intertie is not gauged when it overflows into the aqueduct. For Cross-Valley Canal, monthly lump sum values would be available from the Kern Water Bank information. Someone suggested that Dan Peterson would have all the turn-in flow data. Tony asked if someone is tracking historic data. Paul said that this forecasting group would do it.

Ted said that Barry Montoya from SWP Water Quality group should have flow and water quality information on the pump-ins. Tuan added that no one could pump in until Dan Peterson approves the volume and water quality. Tony said that Arvin-Edison Water District and Kern County Water District record the turn-in schedules. Ted said he would initiate the discussion about the turn-in flows and water quality with Barry Montoya.

<u>O'Neill Forebay Operations</u>

Tuan said that they do not have any information about O'Neill pumping plant since it is the Bureau's facility. John said that San Luis – Delta Mendota Authority should have this information. Tuan said that they receive faxes from WAMPA about the power schedules for O'Neill pumping and generation plant. CH2M HILL will meet with operations staff from CVO to determine the availability of data.

<u>San Luis Reservoir Operations</u>

Kyle asked Tuan if we could get San Luis pumping data with finer resolution than the daily data we currently have. Tuan said that they have historic data detailing the hourly pump operation at Gianelli. This data, coupled with the pump capacity, would be able to provide flow rates. The data is stored in the ACES database. This system came online in 2003 or 2004. Prior to that, this information was stored in "Mapper". In addition to this schedule, the actual executed schedule at San Luis is also available in ACES. Tuan said that Coe Hall would be the appropriate contact for inquiries about the ACES system.

<u>Flows at Pumping Plants downstream of O'Neill Forebay</u>

Flow data at pumping plants between O'Neill Forebay and the terminal reservoirs would be useful for back checking the deliveries assigned in the model and verifying the simulated values. Tuan said that ACES should have this information. However, hourly pool storages levels are not in ACES. Kyle said they should be available in the SCADA system.

Tony suggested there should be continuous monitoring at some check structures such as Check 13. Kyle said that Check 13 and Check 21 are monitored. Hourly water quality data are available online through CDEC for Checks 12, 13, 18, 21, 29, 41, and 66. Flow and stage data is not available through CDEC. Tuan added that, although he would not vouch for the accuracy of these two gages, the data is used for daily/hourly scheduling purposes.

Paul asked Rob if we had contacts on the Bureau side. Rob said we have some contacts and we would arrange some meetings in near future (Rob – please include names of contacts).

Paul asked Kyle if we should specify San Luis EC as a boundary condition considering the model's performance in calibration. Kyle said that he does not think it is needed since the model does a good job in simulating San Luis' EC over short periods of time when properly initialized. Rob added that it would be good to have the San Luis EC data and this approach will be considered.

Action Items

Tracy Hinojosa:

- Initiate CH2M HILL's contact with Coe Hall
- Initiate CH2M HILL's contact with David Roose to get in touch with Field Divisions

Ted Swift:

- Initiate CH2M HILL's contact with Barry Montoya

CH2M HILL:

- Talk to Coe Hall
- Talk to Barry Montoya
- Talk to Mike Nolasco
- Talk to San Luis & Delta-Mendota Water Authority
- Talk to Bureau folks about O'Neill Pump-Gen Plant

Appendix C

Table of Diversions and DSM2 Nodes in California Aqueduct

Appendix C. Map of Diversions and DSM2 Nodes in the California Aqueduct

Mile	Pool	DSM2 Node	Diversion Agency
4.49	1	402	Bethany Reservoir Inlet
5.95	1	402	South Bay Aqueduct
8	2	403	Mountain House Golf Course
12.47	3	404	Musco Olive
22.16	4	405	Tracy Golf & Country Club
35.22	7	408	Turlock Fruit Company Inflow
42.9	8	409	Western Hills WD
	8	409	Oak Flat Water District - total
46.18	9	410	Oak Flat Water District-D
66.14	12	413	Veteran's Cemetery
66.14	12	413	Merced Irrigation District
70.85	13	415	Department of Parks and Recreation
70.85	13	415	Cattle Program
70.85	13	415	Department of Fish & Game
85.08	13	415	San Luis Water District
85.08	13	415	(Floodwater Inflow)
SL Res	13	415	Department of Parks and Recreation
	13	415	San Felipe Division - total
89.67	14	416	Pacheco Water District
89.68	14	416	Panoche Water District
89.7	14	416	City of Dos Palos
94.06	14	416	San Luis Water District
102.64	15	417	Panoche Water District
102.64	15	417	(Floodwater Inflow)
102.64	15	417	Broadview Water District
104.2	15	417	San Luis Water District
122.05	16	418	(Reverse flow, Kings River)
122.05	16	418	Department of Fish and Game
	16	418	Westlands Water District - total
132.74	17	419	Floodwater Inflow
132.74	17	419	Westlands Water District
142.61	18	420	(Floodwater Inflow)
143.16	18	420	City of Coalinga
	18	420	Westlands Water District - total
151.19	19	421	Westlands Water District
151.19	19	421	(Floodwater Inflow)

Appendix C. Map of Diversions and DSM2 Nodes in the California Aqueduct

Mile	Pool	DSM2 Node	Diversion Agency
151.19	19	421	City of Huron Parks & Recreation
156.34	19	421	Garrett Wheeladartor Frye Energy Company
156.34	20	422	City of Huron
163.69	20	422	Westlands Water District
164.79	21	423	City of Avenal
171.67	21	423	Westlands Water District
171.67	21	423	(Floodwater Inflow)
184.63	22	424	Coastal Branch
184.78	22	424	DRWD (aggregated)
	22	424	TLB WSD - total
	23	425	KCWA - total
	24	426	KCWA - total
209.71	25	427	USBR ST Pen
	25	427	KCWA - total
	25	427	Kern National Wildlife - total
	26	428	KCWA - total
230.37	27	429	Kern County Water Agency Buena Vista - 6
238.04	28	430	Tulare Co.
238.04	28	430	Kern Tulare
238.04	28	430	Rag Gulch
238.04	28	430	Hills Valley
238.04	28	430	Tri Valley
238.04	28	430	Hacienda DWR Wells
238.04	28	430	DRWD CVC
238.04	28	430	Arvin Edison WD CVC
238.04	28	430	Friant Water Users Authority
238.04	28	430	Lower Tule River
238.04	28	430	Fresno Co.
238.04	28	430	Pixley ID
	28	430	KCWA - total
241.02	29	431	Kern River Intertie (inflow)
244.54	29	431	Buena Vista WSD
	29	431	KCWA - total
	29	431	Kern Water Bank (in - out)
249.85	30	433	Kern County Water Agency Buena Vista - 4
	31	434	KCWA - total
	32	435	KCWA - total

Appendix C. Map of Diversions and DSM2 Nodes in the California Aqueduct

Mile	Pool	DSM2 Node	Diversion Agency
	33	436	KCWA - total
270.24	34	437	Kern County Water Agency Wheeler Ridge-Maricopa - 7
277.31	35	439	KCWA Arvin-Edison
	35	439	KCWA - total
	36	440	KCWA - total
282.06	37	441	Kern County Water Agency Wheeler Ridge-Maricopa - 12
	38	442	KCWA - total
287.62	39	443	Kern County Water Agency Wheeler Ridge-Maricopa - 14
	40	444	KCWA - total
298.65	41	446	Kern County Water Agency Tej.-Cas
305.73	43	450	Alama Power Plant (Cottonwood Chutes)
308.05	43	450	Antelope Valley-East Kern WA
311.84	44	451	LADWP Connection
313.5	44	451	AVEK 245th Street West
	45	452	AVEK WA - total
323.19	46	453	Mojave Water Agency Fairmont
	46	453	AVEK WA - total
	48	455	AVEK WA - total
	50	460	AVEK WA - total
	52	462	AVEK WA - total
346.98	53	464	Palmdale
348.14	53	464	Antelope Valley-East Kern WA Acton Treatment Plant
354.97	57	468	Littlerock Creek I.D.
	58	469	AVEK WA - total
366.5	60	471	Antelope Valley-East Kern WA
389.2	63	474	Mojave Water Agency Mojave River
394.6	64	475	Mojave Water Agency Temporary

Appendix C. Map of Diversions and DSM2 Nodes in the California Aqueduct

Mile	Pool	DSM2 Node	Diversion Agency
	66	477	Mojave Water Agency - total
405.48	67		Las Flores Ranch
405.65	67		Mojave Power Plant
405.65	67		(Does not include 7,713 AF of Bypass flow)
405.7	67		Mojave Water Agency
407.65	67		Crestline Lake Arrowhead Water Agency
407.65	67		Mojave Water Agency Outlet Works
407.65	67		Calif. State Park Silverwood Agency (Rec.)
	67		Mojave Water Agency
0	1	601	(into South Bay Aqueduct)
3.17	1	601	Granite - Vasco Rd. (Temp.)
3.18	1	601	Oakland Scavenger Zone 7
7.21	3	603	Zone 7 Altamont
9.49	3	603	Zone 7 Patterson (aggregated)
13.55	6	605	DeSilva-Gates (Temp)
13.55	6	605	Zone 7 Wente #1
14.16	6	605	Zone 7 Wente #2
14.31	6	605	Zone 7 Ising (Temporary)
14.31	6	605	Ising Inflow Exchange
14.31	6	605	Ising Project Water
	7	608	Zone 7 Arroyo Mocho - total
16.57	8	609	Zone 7 Wente #3
16.69	8	609	Zone 7 Norman Nursery
16.7	8	609	Zone 7 Concannon
16.7	8	609	Zone 7 Wente #4
18.63	8	609	(Flow out of South Bay Aqueduct)
18.63	8	609	(Flow into South Bay Aqueduct)
19.2	8	609	Del Valle Branch Pipeline (aggregated)
19.2	8	609	So. Livermore (aggregated)
19.21	8	609	Zone 7 - Kalthrof Detjens
35.86	8	609	S.C.V.W.D. Meter
	8	609	ACWD - total
	8	609	City of San Francisco - total
8	W2		AVEK Water Agency
Pyr Lake	W3		Calif. State Park Pyramid Recreation
14.1	W3		United Water Conservation Dist.
17.1	W3		Piru Creek Fish Enhancement

Appendix E:
DSM2 Model Schematic

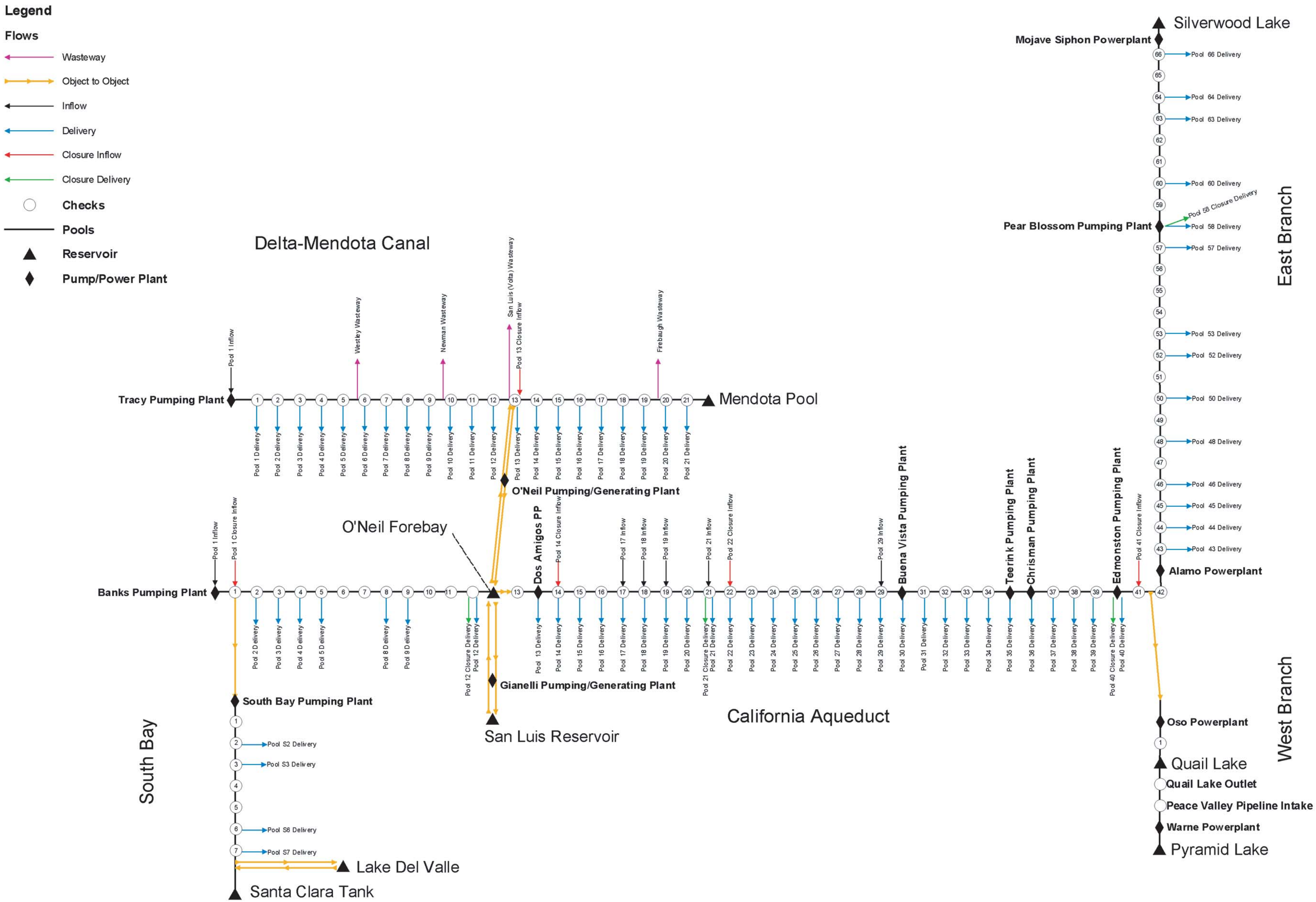


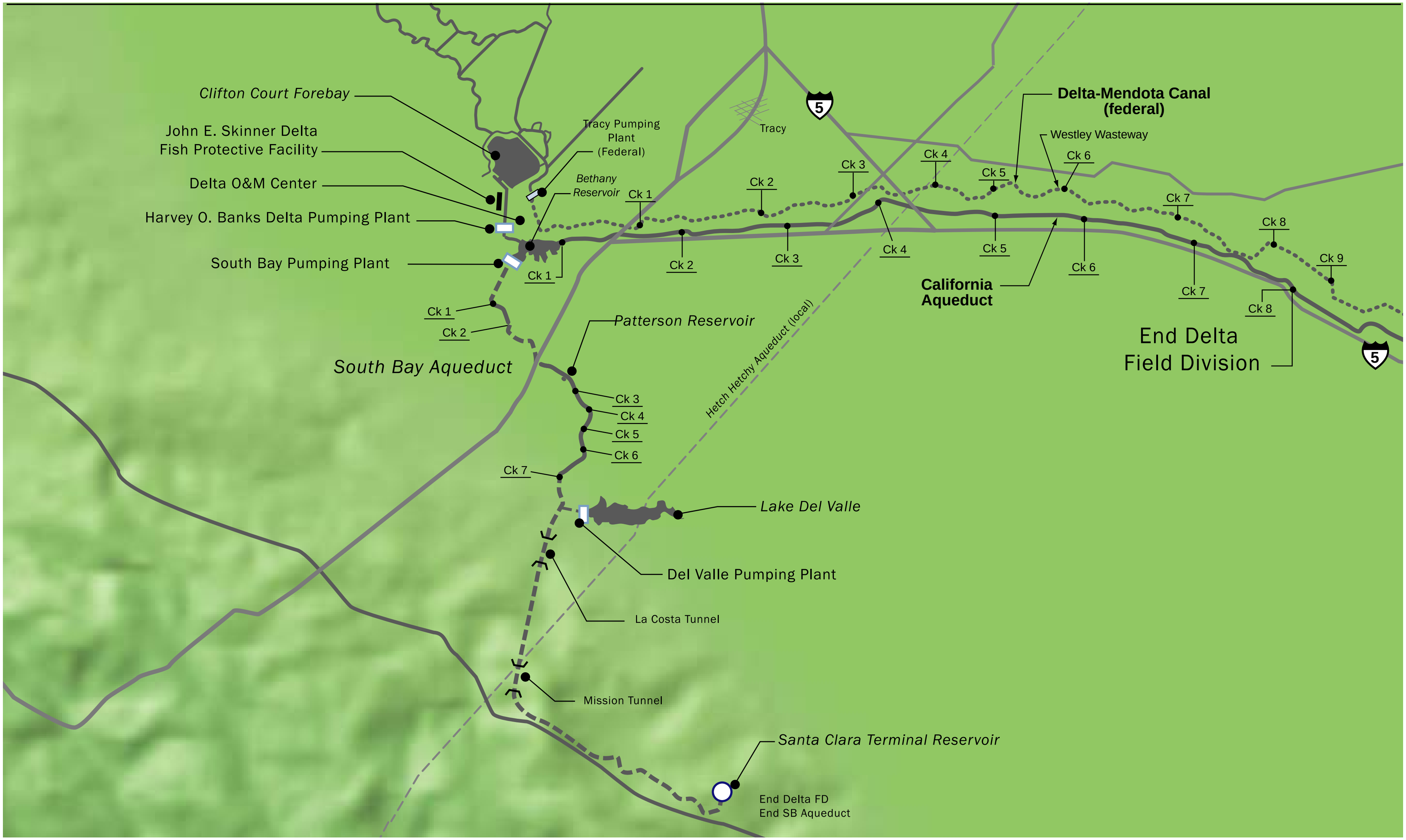
FIGURE E-1
DSM2 Extension
Model Schematic

CH2MHILL

Appendix F: SWP Maps

MAP 1
California Aqueduct
State Water Project

CH2MHILL

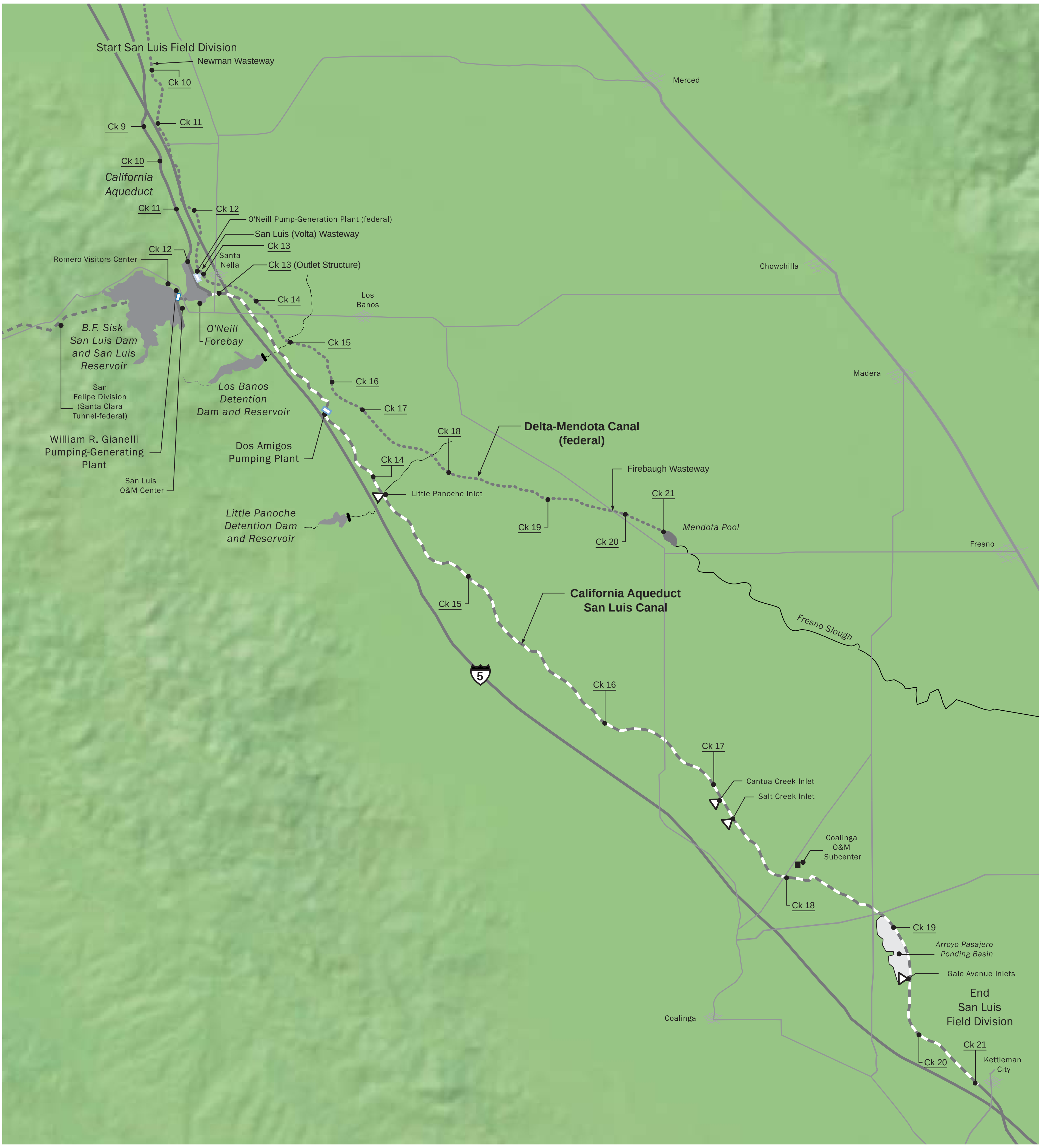


Source: California DWR

MAP 2
California Aqueduct
Delta Division including South Bay Aqueduct
plus Delta-Mendota Canal

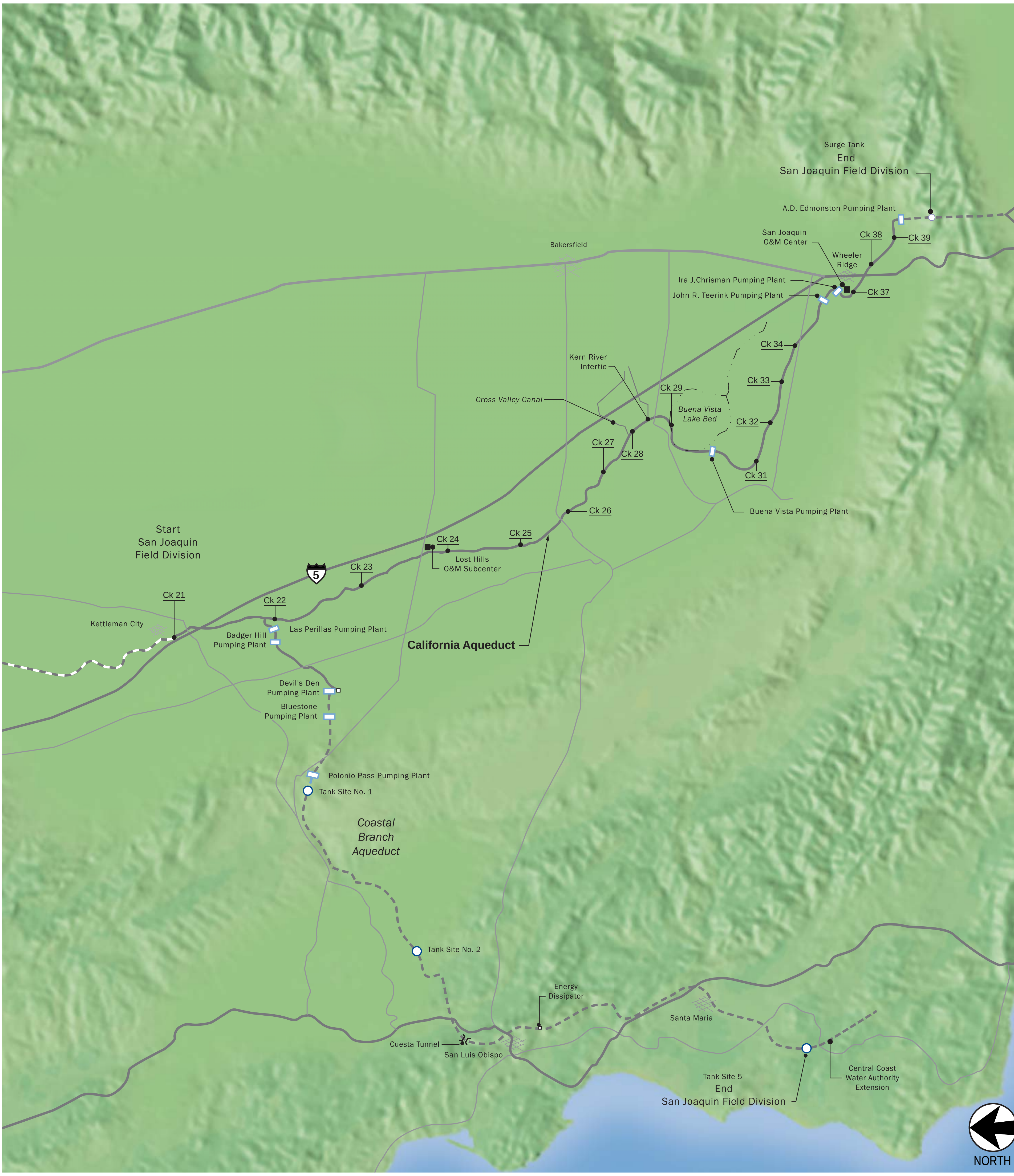
CH2MHILL

WB082007004SAC Map_2.ai 06-16-08 afint



Source: California DWR

MAP 3
California Aqueduct
San Luis Division plus Delta-Mendota Canal



Source: California DWR

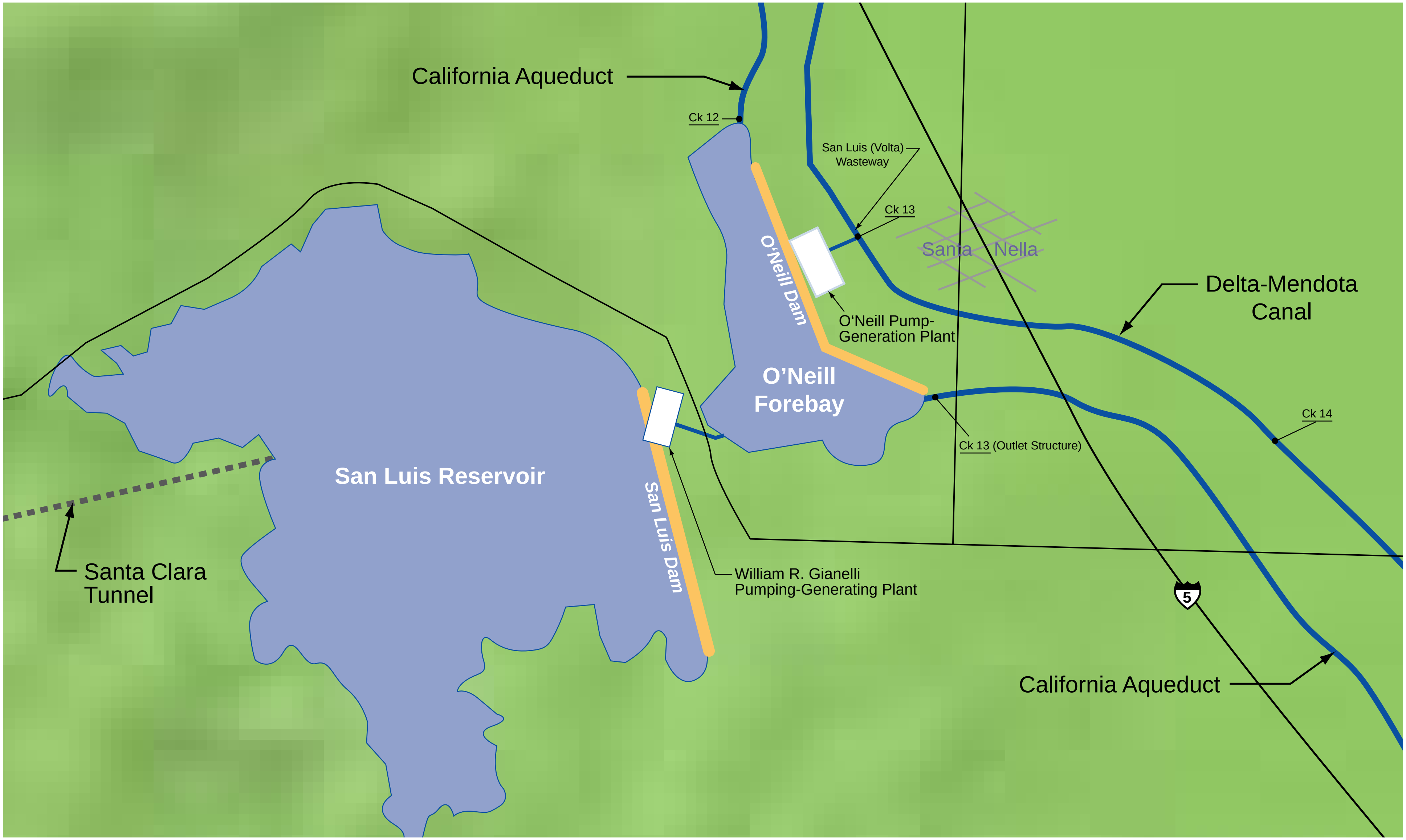
MAP 4
California Aqueduct
San Joaquin Division

Source: California DWR

MAP 5
California Aqueduct
Southern Division

CH2MHILL

WB082007004SAC Map_5.ai 06-16-08 afint



MAP 6
California Aqueduct
San Luis Reservoir and O'Neill Forebay