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

Prepared for

State Water Contractors and Municipal Water Quality Investigation Program

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Acronyms and Abbreviations

μS/cm	microSiemens per centimeter
Aqueduct	California Aqueduct
CDEC	California Data Exchange Center
CFS	cubic feet per second
CVO	Central Valley Operations
CVP	Central Valley Project
DMC	Delta-Mendota Canal
DOC	dissolved organic carbon
DSM2	Delta Simulation Model 2
DWR	Department of Water Resources
EC	electrical conductivity
MWQI	Municipal Water Quality Investigation
OCO	Operations and Control Office
PTM	particle tracking model
QUAL	water quality model
Reclamation	U. S. Bureau of Reclamation
RTDF	real-time data and forecasting
SCDA	Supervisory Control Data Acquisition
SLDMWA	San Luis Delta Mendota Water Authority
SWP	State Water Project
TDS	total dissolved solids
TOC	total organic carbon
USGS	U.S. Geological Survey

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 presents the development and calibration of a Delta Simulation Model 2 (DSM2) model to simulate the California Aqueduct, South Bay Aqueduct, and Delta-Mendota Canal (DMC) systems. The model predicts both the hydraulics (flow and stage) and salinity transport through the system.

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.

The approach adopted for the project includes the following steps:

- Review system operations
- Collect and review hydrologic, operational, and water quality data
- Collect and review physical system data
- Develop DSM2 application
- Calibrate and verify model
- Document model

Data collection sources included internet resources, meetings with SWP and U. S. Bureau of Reclamation (Reclamation) Central Valley Operations (CVO) personnel, and previous studies and publications for the project area.

Following the data collection effort, the preliminary DSM2 model grid for the system was developed. The grid was built in sections to allow systematic testing of each portion of the model before the sections were joined to run the entire system. Model calibration covered a three-year period beginning January 1, 2001. Use of such an extensive calibration period allowed for a wide range of flows expected in the system.

SECTION 2

Review of System Operations

2.1 California Aqueduct and South Bay Aqueduct

The California Aqueduct is the primary conveyance facility for the SWP (Figure 2-1). It delivers water to the southern San Francisco Bay area, the San Joaquin Valley, and Central and Southern California. The Aqueduct extends from the Harvey O. Banks Pumping Plant in the southern Sacramento-San Joaquin Delta, along the western side of the San Joaquin Valley, through the Tehachapi and San Bernardino Mountains, and terminates in Riverside County. The Aqueduct is managed by four field divisions:

- Delta Field Division, which includes Banks Pumping Plant to O'Neill Forebay and the South Bay Aqueduct
- San Luis Field Division, which includes San Luis Reservoir, O'Neill Forebay, and the 103-mile, joint-use San Luis Canal, which extends from O'Neill Forebay to Check 21
- San Joaquin Division, which includes Check 21 to Edmonston Pumping Plant and the Coastal Aqueduct
- Southern Division, which includes the East Branch below Edmonston Pumping Plant and the West Branch to Los Angeles County

A series of pumping plants on the Aqueduct provides incremental lifts in head where required to maintain the average down stream slope of three inches per mile along the Aqueduct. These pumps include the Banks Pumping Plant, the Dos Amigos Pumping Plant, the Buena Vista Pumping Plant, the Teerink Pumping Plant, the Chrisman Pumping Plant, and the Edmonston Pumping Plant. The Oso Pumping Plant, the Warne Powerplant, and the Castaic Powerplant are located on the West Branch. The Castaic Powerplant is below Pyramid Lake and, thus, is not included in this model. On the south side of the Tehachapi Mountains (East Branch), pumping and power generating plants include the Alamo Powerplant, the Pearblossom Pumping Plant, the Mojave Siphon Powerplant, and the Devil Canyon Powerplant. The Devil Canyon Powerplant is located below Silverwood Lake and, thus, is not included in the model. Figures 2-2 through 2-5 provide an overview of the four field divisions, including the facilities and check structures in each. Figure 2-6 shows the relationship between San Luis Reservoir, O'Neill Forebay, the Delta-Mendota Canal, and the California Aqueduct.

The California Aqueduct delivers water to agricultural and municipal contractors through over 270 diversion structures. The majority of diversions are made between O'Neill Forebay and Edmonston Pumping Plant. The largest contractor south of Edmonston is the Metropolitan Water District of Southern California.

FIGURE 2-1
California Aqueduct
State Water Project

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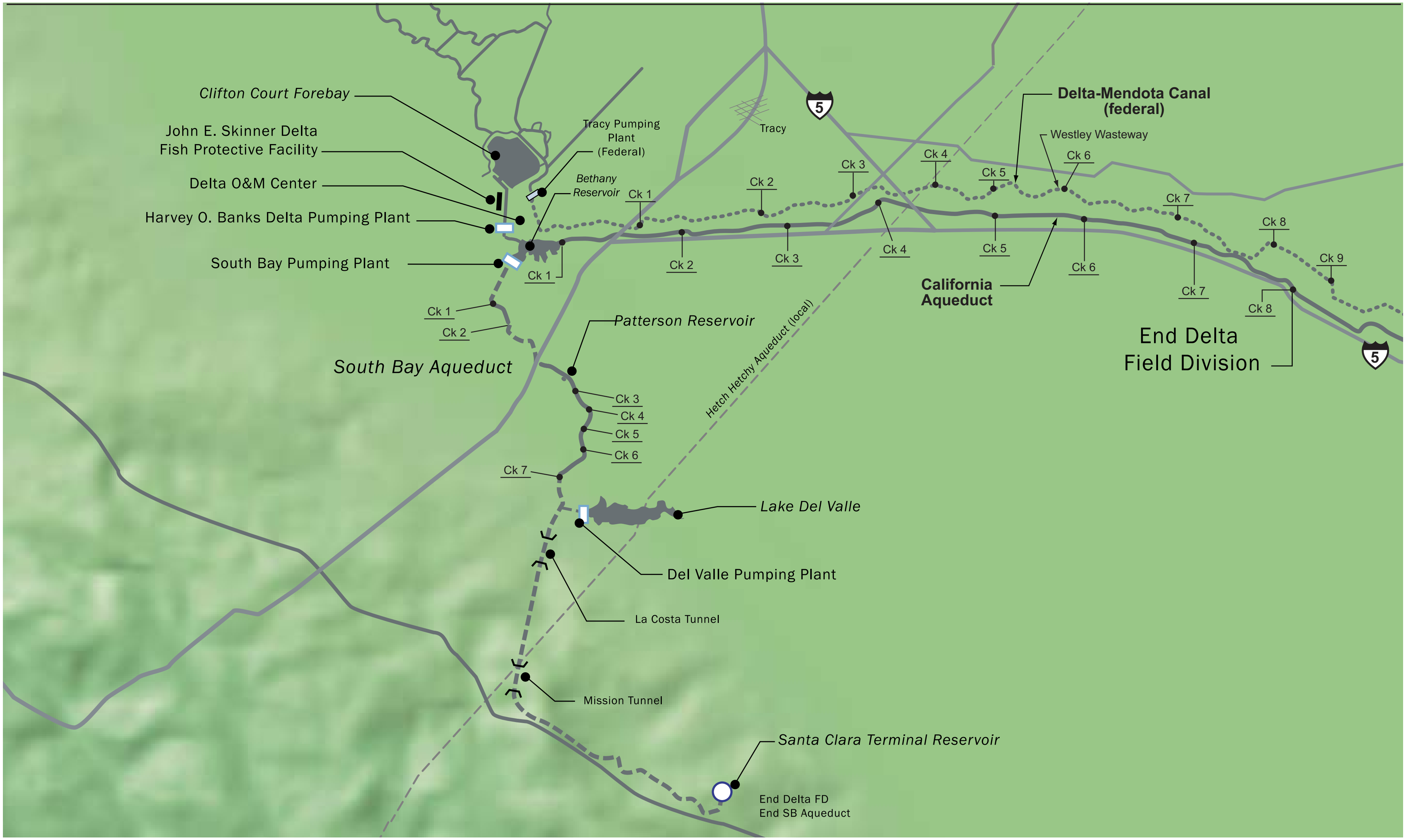

Source: California DWR

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

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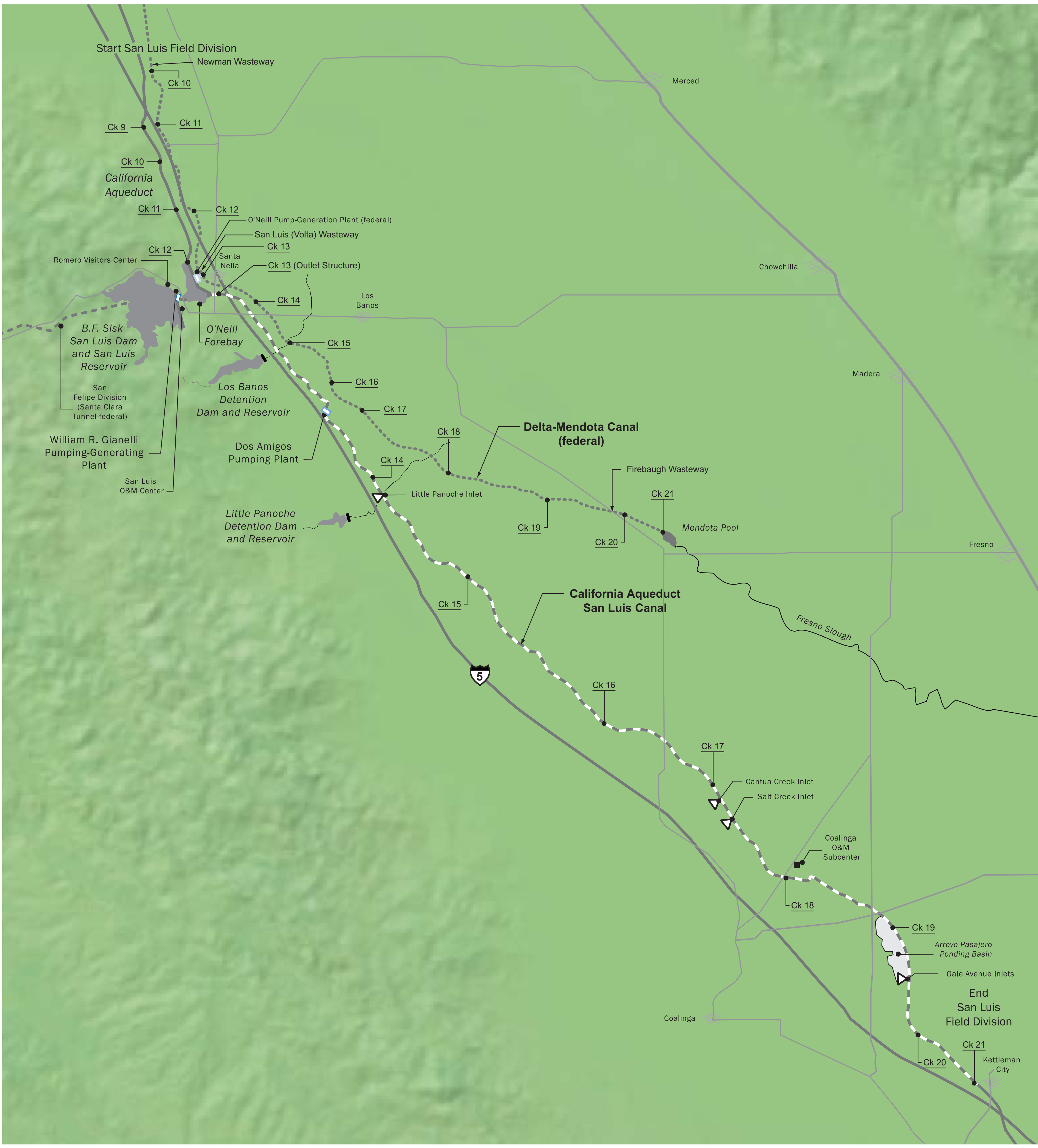
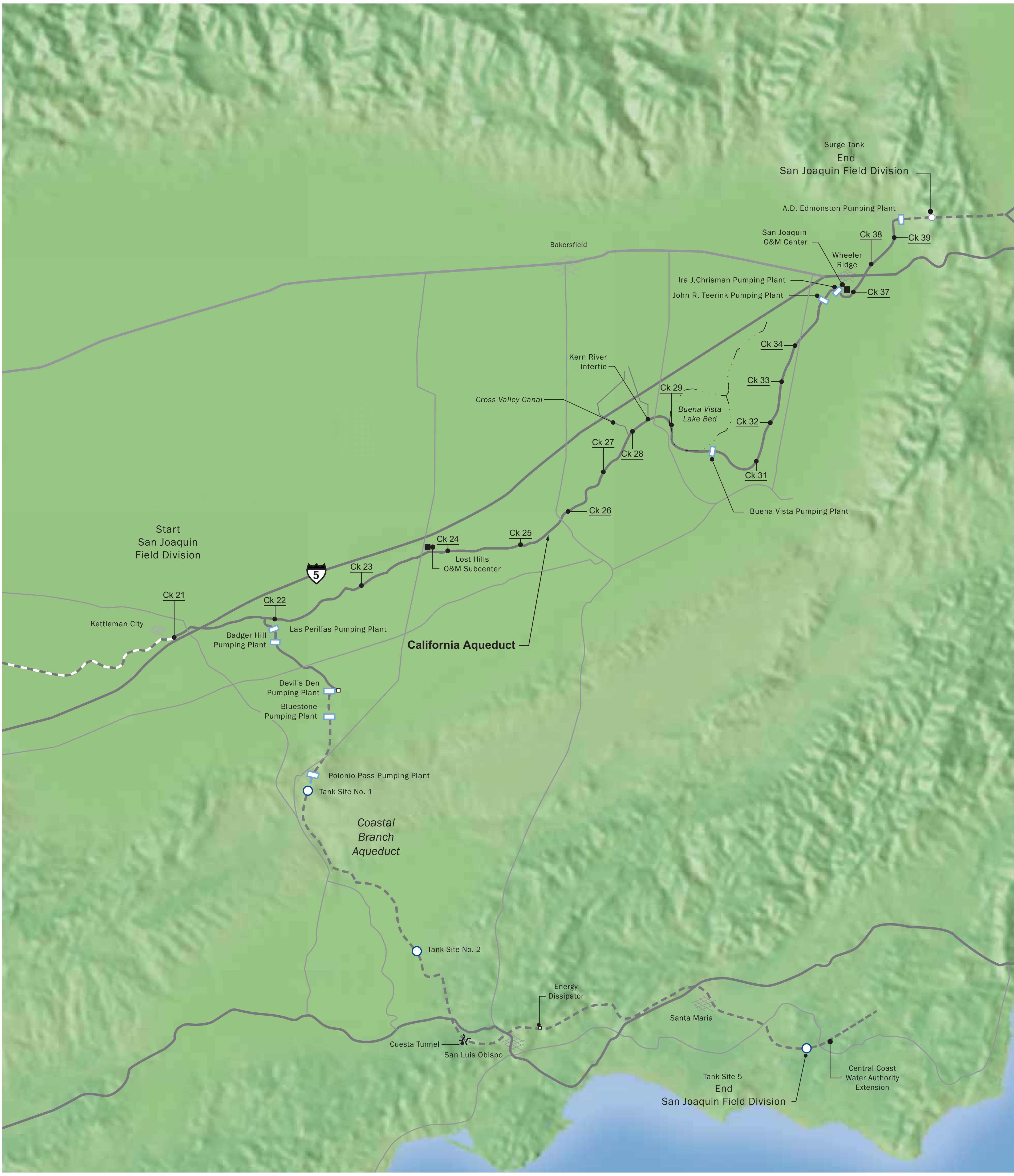


Source: California DWR

FIGURE 2-3
California Aqueduct
San Luis Division plus Delta-Mendota Canal



Source: California DWR

FIGURE 2-4
California Aqueduct
San Joaquin Division

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Source: California DWR

FIGURE 2-5
California Aqueduct
Southern Division

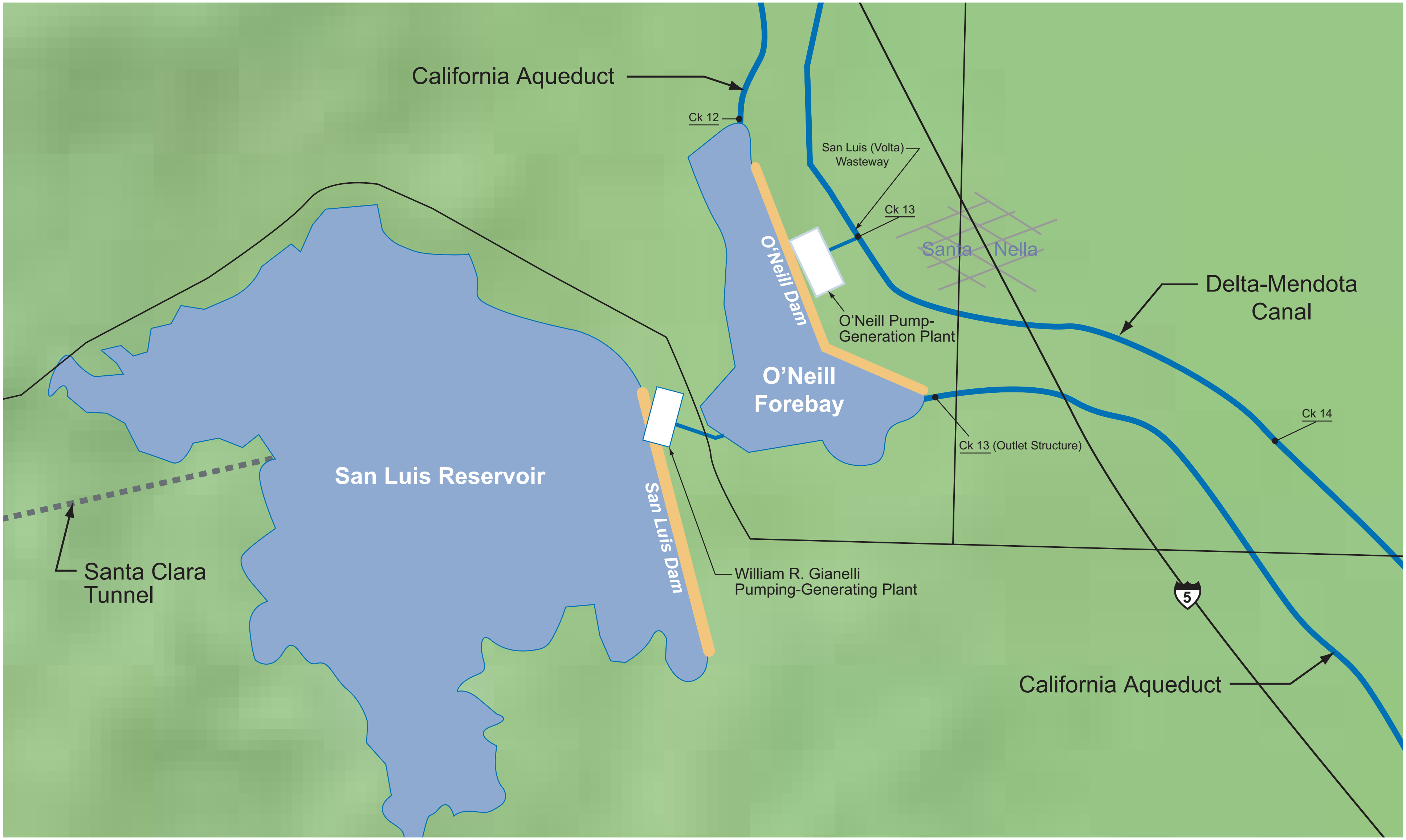

FIGURE 2-6
California Aqueduct
San Luis Reservoir and O'Neill Forebay

The South Bay Aqueduct is part of the Delta Field Division of the California Aqueduct. It was the first delivery system completed under the SWP and is used to convey water from the Sacramento-San Joaquin Delta to the Alameda County and Santa Clara Valley Water districts. The South Bay Aqueduct consists of 42.18 miles of canals and pipelines. It begins at the South Bay Pumping Plant, drawing water from Bethany Reservoir and lifting it 566 feet. The South Bay Aqueduct ends at the Santa Clara Terminal Reservoir. The Del Valle Branch Pipeline branches off of the South Bay Aqueduct 18.57 miles downstream of the pumping plant and delivers water to Lake Del Valle. The South Bay Aqueduct has a design capacity of 300 cfs.

2.1.1 SWP Operations

CH2M HILL staff met with staff from the DWR Division of Operations and Maintenance, Operations and Control Office (OCO), including Curtis Creel, Chief of the Project Operations Planning Branch, and Terry Dennis, Chief Dispatcher at the SWP Project Operations Center. This meeting provided an opportunity to gain knowledge of the day-to-day operations of the California Aqueduct system.

Terry Dennis provided an overview of the system operations and the parameters influencing changes in operations. He discussed the operations of the Banks Pumping Plant. The SWP Data Handbook states the design discharge of Banks Pumping Plant as 10,300 cubic feet per second (cfs). DWR attempts to minimize daytime pumping because of higher energy costs. Clifton Court Forebay is filled on high tides, and the water is generally pumped out at night. DWR will pay the extra electricity charges associated with daytime pumping, if required, because the water is more valuable than the difference in energy costs to pump during the day versus at night.

Mr. Dennis also discussed the water contractor diversions. He explained that the water contractors turn on pumps and divert at will. They generally adhere to a diversion plan published on a weekly basis, but they often give no notice of changes to the plan. Aqueduct operators often adjust check structures on the fly to cover a sudden drop in pool elevation resulting from diversions at a turnout.

Discussions also included actual operations of the check structures. In general, the check structures try to maintain a near constant pool elevation in any given pool. The drawdown is limited because of structural concerns with the concrete panels that line the aqueduct. The drawdown is limited to 12 inches in the first hour followed by 6 more inches in the next 23 hours.

Check operations are set by a computer program and are based on flows. Operators then use this as a baseline for fine-tuning the system. The program looks at pumping at Dos Amigos and Buena Vista Pumping plants. Generally checks 14 to 30 are all operated at the same time (Dos Amigos to Buena Vista). Planned pumping schedules generally change at least once a day.

The Supervisory Control Data Acquisition (SCDA) database holds real time data for 190 days at a 15-minute interval. It stores data on flow and stage both upstream and downstream of check structures. DWR staff have an internet interface to access the database. Ratings curves have been developed for flow through each check structure based on the water surface elevation difference across the check structure.

Mr. Dennis mentioned that groundwater pump-ins are rare in the California Aqueduct. Other episodic inflows include the Kern River Intertie and floods on Arroyo Pasajaro.

2.2 Delta-Mendota Canal

The DMC is a Central Valley Project (CVP) facility that extends 116 miles from the Tracy Pumping Plant to the Mendota Pool. The DMC delivers water to contractors through over 200 turn-outs. Four wasteways extend westward from the DMC toward the San Joaquin River. These include the Westley Wasteway, the Newman Wasteway, the San Luis (Volta) Wasteway, and the Firebaugh Wasteway. There are no pumping plants or generating plants on the DMC aside from the Tracy Pumping Plant.

2.2.1 DMC Operations

CH2M HILL staff met with staff from Reclamation's CVO office and the San Luis Delta Mendota Water Authority (SLDMWA). The purpose of this meeting was to collect available data and develop an understanding of the physical system and its operational criteria.

CH2M HILL staff presented a summary of the data collected to date as well as the existing data gaps. Resources within CVO and SLDMWA were identified to assist in the collection of the remaining data.

Joe Martin, the Watermaster at the SLDMWA, provided specific information on the day-to-day operations of the DMC. Mr. Martin explained that the operators use check gates to limit the water surface elevation. The depth of the canal should be maintained at 16.5 to 17.5 feet. The water volumes are measured by SCADA for the first 13 checks and these gates are controlled automatically. The subsequent checks are controlled manually. SCADA records water surface elevation upstream and downstream of each check, flow through the checks, gate position data, and delivery data. Mr. Martin explained that every turnout on the DMC is metered.

Mr. Martin explained that the gates are operated sequentially during significant flow change over a short period of time, such as during the VAMP period. In these events, gates are usually operated in series with two or three checks at a time. These operations are usually performed at 7:00 a.m. and are completed within four hours. He mentioned that the operations can react to flow changes fairly quickly.

Mr. Martin mentioned that he has an EXCEL spreadsheet with daily delivery data by milepost back to 1975. However, he advises against using data that are more than 10 years old because of subsequent changes, including land use and pump upgrades, and allocation policies. There is daily variability in the operations; the contractors are mandated to report the amount of water they plan to take each day, but they do not always do so.

Mr. Martin mentioned that most groundwater pumps-ins have been shut down because of water quality regulations. Only three to four wells pump into the canal. Mr. Martin explained that losses due to seepage and evaporation along the canal are not explicitly measured. Differences between meter readings and the measured deliveries are used to estimate losses, which average 4,000 to 5,000 acre-feet per month. These average losses are considered to be insignificant compared to the average export of 215,000 acre-feet per month.

Occasionally, there are gains of water in winter months, indicating more inflow than losses associated with evaporation and seepage. Usually, low creek flows bypass the system. Conversely, high flows occasionally overshoot and excess water flows into DMC, typically below check 12 (Salado Creek near Patterson).

SECTION 3

Review of Hydrologic, Operational, and Water Quality Data

An extensive database of hydrologic, operational, and water quality data was collected. A portion of the dataset was used for a three-year calibration/verification period (2001 through 2003). This period was chosen considering the availability of data and the assumption that more recent data would be most representative of the current system. A description of the data collection effort is provided below.

3.1 Hydrologic Data

Hydrologic data was collected for the project area from internet resources. Daily evaporation and rainfall data were obtained for the calibration period from the San Benito CIMIS station near Hollister, California.

3.2 Operational Data

Water operations data for the California Aqueduct (East and West branches) and the South Bay Aqueduct are available from the DWR OCO. DWR publishes monthly and annual SWP operations data reports, which include daily flow rates for pumping plants and system inflows, and monthly flow rates for deliveries to water users. Monthly reports are available for January 1990 through May 2004; annual reports are available for 1989 through 2003, however, years 2000 through 2003 have not been approved for final release. These reports are available in PDF format on OCO's website.

3.2.1 Pumping Plants

Daily pumping plant flow data from monthly OCO reports for April 1990 through May 2004 were compiled to create a time series of operations data along the Aqueduct, West Branch, and South Bay Aqueduct. This time series includes data for the following pumping plants:

- Banks Pumping Plant
- South Bay
- O'Neill Pumping-Generating
- Gianelli Pumping-Generating
- Pacheco Tunnel
- Dos Amigos
- Buena Vista (Check 30)
- Teerink (Check 35)
- Chrisman (Check 36)
- Edmonston (Check 40)

- Oso (West Branch)
- Pearblossom (Check 58)

Daily flow exchange between San Luis Reservoir and O'Neill Forebay are given in the OCO monthly reports for Gianelli Pumping-Generating Plant. Data for O'Neill Pumping-Generating Plant gives the daily exchange between O'Neill Forebay and the DMC.

The record of flows at the head of the DMC is supplied by data from the Tracy Pumping Plant. Daily pumping data are available from the U.S. Geological Survey (USGS) National Weather Service (Station #11313000) beginning in June 1951.

3.2.2 Inflows

The Kern River Intertie conveys a large episodic inflow to the Aqueduct. The Intertie connects to the Aqueduct in Pool 29, at mile post 241.02. Monthly flow data for the Intertie comes from the OCO reports. The only other measured inflows to the system are floodwater inflows. Monthly data from the OCO reports is available for floodwater inflows in pools 17 to 19, and 21 for the years 2001 to 2003. In previous years, additional floodwater inflows occurred in pools 13 and 15, and a reverse flow of the Kings River occurred in pool 16, however, these flows did not occur during the 3-year study period. Groundwater inflows are sporadic and are not included in this analysis.

3.2.3 Deliveries/Diversions

Monthly delivery data along the Aqueduct are available in the OCO reports. The reports include the name of the water user, the mile post of the diversion structure, and the monthly delivery amount (in acre-feet) for each delivery turnout structure listed. Daily deliveries from San Luis Reservoir to Santa Clara and San Benito Water districts through the Pacheco Tunnel are also published in the OCO reports.

Delivery data along the DMC are available on Reclamation's CVO website. From January 1993 through December 2004, CVO's "Report of Operations Monthly Delivery Tables" provides a list of water users and their monthly deliveries in acre-feet. The names of water users from these tables are mapped to the mile posts of the diversion structures listed in the Reclamation report "Milepost at Structure Sites Delta-Mendota Canal" (USBR, 1985 and 1992).

3.3 Water Quality Data

The DWR maintains the California Data Exchange Center (CDEC). CDEC provides daily electrical conductivity (EC) data on their website for several Aqueduct and DMC locations of interest, including: Banks Pumping Plant; Aqueduct Checks 12, 13, 18, 21, 29, 41, and 66; Tracy Pumping Plant; DMC Checks 20 and 21; and South Bay Aqueduct Check 7. CDEC does not provide EC data for the Kern River Intertie or floodwater inflows.

Gaps in the daily EC data exist, so linear interpolation is used to bridge the shorter data gaps (from one day to two weeks in length) for input to the model. However, certain locations are missing longer periods of data. For instance, Check 12 on the Aqueduct is missing data from August 20, 2002 through the end of the study period. Check 18 is missing data from August 14, 2003 through the end of the study period. Data for Check 66 does not begin until December 1, 2003. South Bay Aqueduct Check 7 has several data gaps extending from one month to several months in length. It is unreasonable to attempt to fill these longer gaps using regressions or other estimating techniques, therefore the available data from these stations are only used for calibration/verification comparison purposes.

The OCO monthly SWP Operations Data reports also include monthly water quality information for several Aqueduct locations, including: Banks Pumping Plant, Check 13, 21, 29, and 41, as well as data for the DMC near Check 13, just upstream of the San Luis Wasteway. Data is reported for the following constituents: alkalinity, antimony, arsenic, beryllium, boron, bromide, calcium, dissolved organic carbon (DOC), total organic carbon (TOC), chloride, copper, fluoride, hardness, iron, lead, magnesium, manganese, nitrate + nitrite, ortho-phosphorus, total phosphorus, selenium, sodium, specific conductance, sulfate, total dissolved solids (TDS), turbidity, and zinc.

SECTION 4

Physical System Data

Information on the physical system was collected from a number of sources and converted into DSS format for use with DSM2. A description of the data collection effort is provided below.

4.1 California Aqueduct and South Bay Aqueduct

The primary source of information for the California Aqueduct and South Bay Aqueduct channels, pipelines, and structures was the DWR SWP Data Handbook (DWR, 1997 and 2003). Table 1 of the Data Handbook provides geometry information for each section of the Aqueduct and its branches, including the East branch, West branch, Coastal branch, and the South Bay Aqueduct. The channel geometry information relevant to this project includes length, design depth, maximum depth, canal invert slope, bottom width, side slope, invert elevation, mile post, and design discharge (in cfs). Table 2 of the Data Handbook includes information on aqueduct pools, including length, storage, operating levels, mile posts, and size, number, and elevation of radial gates at the check structures controlling the flow at the downstream end of each pool. Descriptions of power and pumping plants are given in Table 3 and 3A. Table 4 provides detailed information on the dams and reservoirs within the Aqueduct system, including average annual inflow, storage, shore line length, surface area, operating elevations, structural height, crest elevation, and spillway elevation. Finally, Table 6 gives the location of delivery structures throughout the Aqueduct, as well as design flow and barrel diameter.

The SWP Data Handbook was used to define channel locations, channel geometry, and radial gate locations. Location information for structures such as checks, reservoirs, and delivery turnouts was obtained from the California Aqueduct Strip Maps (DWR, 2001). Additional delivery structure locations were taken from DWR OCO monthly reports on SWP Operations Data (DWR, 1996 through 2003), which give mile post and flow data for each listed delivery structure. These three sources were used to compile a list of delivery structures, by mile post, along the aqueduct.

4.2 Delta-Mendota Canal

The primary source of physical system data for the DMC was the Reclamation document "Milepost at Structure Sites – Delta Mendota Canal" (USBR, 1985 and 1992). The document contains geometry information for different sections of the DMC, including earth, concrete lined, and earth lined sections. Short gaps exist in the geometry information between some sections along the canal. Invert elevations are specified at a number of mileposts along the DMC. Wasteway and delivery turnout mile posts are also contained in the document.

4.3 Results of Physical System Data Review

The section of the California Aqueduct to be modeled with DSM2 extends over 400 miles from Banks Pumping Plant to Silverwood Lake. Along that stretch there are many canals, several siphons and tunnels, 66 check structures, and two reservoirs, O'Neill Forebay (in-line) and San Luis Reservoir. Both the South Bay Aqueduct and the West Branch of the California Aqueduct are included in the model. The South Bay Aqueduct is comprised of open channels, siphons, and tunnels. The West Branch is composed mostly of open channels and an in-line reservoir (Quail Lake). The model includes the 116 miles of the DMC, from Tracy Pumping Plant to the Mendota Pool.

The data was compiled in a database of EXCEL spreadsheets. Review of the SWP Data Handbook showed that computed lengths from structure mile posts were not the same as the structure lengths listed. Differences were generally attributed to the precision of the reported lengths (0.01 mile). When defining channel lengths in DSM2, the listed structure lengths were used rather than distance based on mile posts. Only mile post data were available for the DMC, so channel lengths are computed from mile posts. Mile posts in the DMC that are used to define where different canal geometries begin and end are discontinuous, so when a gap existed, the upstream geometry was carried through to the downstream mile post.

An extensive list of delivery turnout locations was compiled. In many locations the mile post distances published in these documents agree; however, there were also several inconsistencies. In certain instances, turnouts that were listed in one source were not listed in others, or the same contractor delivery is listed in multiple sources but at different mile post locations. These differences became insignificant due to the aggregation of deliveries by pool in the model, as described in the Section 5.

SECTION 5

Development of DSM2 Model Application

This section describes the development of the DSM2 model application to the California Aqueduct system, the South Bay Aqueduct, and the Delta-Mendota Canal. A brief introduction to the DSM2 model is provided, as is a discussion of the model's representation of the physical system, conversion of data to DSM2 format, and boundary conditions including inflows and diversions. A water balance for the system is presented along with the need for closure terms to address discrepancies. Available salinity monitoring data is also presented.

5.1 DSM2 Model

DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate water quality conditions in the Sacramento-San Joaquin Delta (DWR, 2002). The model was developed by the California DWR and is frequently used to ascertain impacts associated with projects in the Delta, such as changes in exports or diversions. The DSM2 is used to evaluate potential changes in Delta conditions (salinity, flow, and water level) associated with changes in flow patterns in the Delta caused by variations in boundary conditions or gate operations. EC is used as a surrogate for salinity and, thus, water quality. The DSM2 model has three separate components: HDRO, which calculates water velocities and elevations; QUAL, which calculates EC throughout the Delta; and PTM, which is a particle tracking model. Only HYDRO and QUAL were used in this study.

DSM2 HYDRO was adapted from the FOURPT Model developed by Lew Delong of USGS in Reston, Virginia (Delong et al., 1997). The original model was modified to allow for open water areas (reservoirs), flow control structures (gates, culverts, weirs), and model input format was completely restructured. DSM2 HYDRO uses an implicit, four-point, finite difference scheme that solves a set of simultaneous equations for water velocity and stage throughout the system. DSM2 QUAL, which is used to simulate EC transport in the Delta, was adapted from the BLTM model developed by Harvey Jobson (Jobson, 1980) of USGS in Reston Virginia, in 1980. The DSM2 model has been calibrated at several stations in the Delta. A thorough description of the model, model documentation, and model files can be found on the DWR website.

There are limitations inherent in the use of a one-dimensional model, such as DSM2 to predict hydrodynamics and salt transport in a complicated physical environment like the Sacramento/San Joaquin Delta. A one-dimensional model assumes that velocity in a channel can be adequately represented by a single average velocity over the channel cross section, meaning that variations both across the width of the channel and through the water column are negligible. DSM2 does not have the ability to model short-circuiting of flow through a reach, where a majority of the flow in a cross section is confined to a small portion of the cross section. DSM2 also does not explicitly account for dispersion due to flow accelerating through channel bends.

5.2 Physical System Representation

The first step in the development of the DSM2 schematic of the California Aqueduct was to determine the appropriate grid resolution. Check structures are often the point where channel geometry changes occur, so they are an obvious choice for locating grid nodes. Furthermore, the checks control the flow and, in using these to define channel boundaries, allow for proper specification of the system. With 66 check structures, a starting node at Banks Pumping Plant, and an ending node at Silverwood Lake, the main stem of the Aqueduct contains 67 channels and 68 nodes. The DMC has 21 checks between Tracy Pumping Plant and the Mendota Pool, so it is modeled with 21 channels and 22 nodes. The South Bay Aqueduct begins at the South Bay Pumping Plant, contains 7 checks, and ends at the Santa Clara Tank, so it contains at least 8 channels and 9 nodes. The West Branch contains only one check structure, but investigation of the physical system shows 2 canals separated by an in-line reservoir, which equates to at least 2 channels and 3 nodes in DSM2. Appendix A contains a figure of the model schematic.

5.2.1 California Aqueduct and South Bay Aqueduct

Nodes on the California Aqueduct through Check 45 were placed at check structures, marking the beginning and ending of channels. DSM2 Aqueduct channel lengths are derived from structure lengths in the SWP Data Handbook (DWR, 1997 and 2003) by summing the canal length of the aqueduct pool, the length of the downstream check structure (usually on the order of 150 feet), and any minor intermediate structures (e.g., lining rise transition, short siphons). Nodes are also placed at transitions between differing canal geometries, if they are not separated by a check structure. There is a single occurrence of this in Pool 30 of the California Aqueduct.

Defining channel and node locations on the remaining portions of the Aqueduct (Pool 46 through Silverwood Lake), the South Bay Aqueduct and West Branch is not as straight forward as the first portion of the Aqueduct because model nodes are not always placed at check structures. The multiple types of conveyance structures along these branches are aggregated into sections based primarily on breaks in geometry or structure (e.g. canal into pipeline, canal into siphon). For example, the section of the West Branch extending from the bifurcation to Oso Pumping Plant defines the first DSM2 channel in the West Branch (see Table 5-1). The Oso Siphon is located between these structures, but with a length of 420 feet compared with the total section length of 8,005 feet, the impact the siphon has on travel time is minimal and can be neglected. Appendix B contains tables summarizing the full channel aggregation process for the second half of the California Aqueduct, South Bay Aqueduct, and West Branch.

In cases where multiple channel geometries were present, the geometry from the dominant conveyance structure in a section is applied to the entire DSM2 channel. For the example presented in Table 5-1, the dominant structure is the Oso Canal (totaling 7,240 feet), so the Oso Canal geometry is assumed to be representative of the 8,005-foot channel. Canal geometry information is included in Table 1 of the SWP Data Handbook (DWR, 1997 and 2003).

TABLE 5-1
Example of Channel Aggregation

Structure	Length (ft)	DSM2 Channel Length (ft)
Bifurcation		
Oso Canal	2,560	
Oso Siphon	420	
Oso Canal	4,680	
Forebay	238	
Oso Pumping Plan	107	8,005

Tables 5-2 to 5-4 show DSM2 channel lengths for the main stem of the Aqueduct, South Bay Aqueduct, and the West Branch. Some of the channels on the California Aqueduct main stem were split into multiple channels (with the same geometry) to minimize the ratio of successive channel lengths. Table 5-2 shows the channel lengths before any of the channels were split into multiple channels.

TABLE 5-2
South Bay Aqueduct DSM2 Channel Lengths

South Bay Pool No.	Structure	Mile Post	DSM2 Channel Length (ft)
S1	Surge Tanks	0.78	4,121
S1	Back Surge Pool	3.26	13,166
S2	Dyer Altamont Check Siphon 2	5.21	3,530
S3	Highway 580 Tunnel	7.35	12,250
S3	Patterson Check 3	9.49	10,365
S4	Lupin Check 4	10.68	6,273
S5	Arroyo Seco Check Siphon 5	12.29	8,891
S6	Arroyo Mocho Check Siphon 6	14.65	12,987
S7	Del Valle Check 7	16.38	8,250
S8	Del Valle Branch Junction	18.63	11,860
S8	La Costa Tunnel	19.96	12,400
S8	Mission Tunnel	27.86	39,810
S8	Santa Clara Pipeline	35.86	67,910
S8	Santa Clara Terminal Reservoir	42.24	4,530

TABLE 5-3
California Aqueduct (including East Branch) DSM2 Channel Lengths

Aqueduct Pool	Structure	Mile Post	DSM2 Channel length (ft)
1	Check 1	5.95	13,880
2	Check 2	12.01	32,030
3	Check 3	18.29	33,170
4	Check 4	23.99	30,090
5	Check 5	29.73	30,090
6	Check 6	34.24	23,800
7	Check 7	39.91	29,950
8	Check 8	45.97	32,000
9	Orestimba Creek Siphon/Check 9	51.30	28,440
10	Check 10	56,86	29,320
11	Check 11	61.40	23,730
12	Check 12	66.71	28,015
13	Dos Amigos Pumping Plant/Check 13	86.73	106,756
14	Check 14	95.06	43,035
15	Check 15	108.50	71,005
16	Check 16	122.07	71,670
17	Check 17	132.95	57,410
18	Check 18	143.23	54,320
19	Check 19	155.64	65,520
20	Check 20	164.69	47,730
21	Check 21	172.40	40,670
22	Check 22	184.82	65,496
23	Check 23	197.05	64,580
24	Check 24	207.94	57,500
25	Check 25	217.79	52,001
26	Check 26	224.92	37,660
27	Check 27	231.73	35,960
28	Check 28	238.11	33,700
29	Check 29	244.54	33,940
30	Buena Vista Pumping Plan/Check 30	250.99	34,984
31	Check 31	256.14	27,281
32	Santiago Creek Siphon/Check 32	261.72	29,901
33	San Emigdio Creek Siphon/Check 33	267.36	29,901
34	Pleitito Creek Siphon/Check 34	271.27	20,557
35	Teerink Pumping Plant/Check 35	278.13	37,504
36	Chrisman Pumping Plan/Check 36	280.36	12,335

TABLE 5-3
California Aqueduct (including East Branch) DSM2 Channel Lengths

Aqueduct Pool	Structure	Mile Post	DSM2 Channel length (ft)
37	Salt Creek Siphon/Check 37	283.95	19,217
38	Grapevine Creek Siphon/Check 38	287.09	16,536
39	Check 39	290.21	16,270
40	Edmonston Pumping Plant/Check 40	293.45	25,170
41	Tehachapi Control Structure/Check 41	303.41	45,047
42	Check 42	304.99	8,200
43	Check 43	309.70	20,975
44	Check 44	314.81	26,990
45	Check 45	319.74	26,000
46	Check 46	319.76	21,500
47	Check 47	326.77	15,501
48	Check 48	330.82	21,362
49	Check 49	335.93	27,103
50	Check 50	341.51	29,340
51	Check 51	342.07	2,960
52	Check 52	343.74	8,984
53	Check 53	348.17	23,241
54	Check 54	350.25	11,129
55	Check 55	352.70	12,820
56	Check 56	354.76	10,870
57	Check 57	356.93	11,523
58	Pearblossom Pumping Plant/Check 58	360.61	19,424
59	Check 59	366.09	28,810
60	Check 60	373.94	41,792
61	Check 61	379.00	26,500
62	Check 62	384.26	27,775
63	Check 63	389.50	27,662
64	Check 64	389.51	29,440
65	Check 65	400.32	27,550
66	Check 66	403.41	16,310
	Mohjave Siphon Powerplant	405.65	
67	Silverwood Lake	405.94	13,307

TABLE 5-4
West Branch DSM2 Channel Lengths

West Branch Pool No.	Structure	Mile Post	DSM2 Channel Length (ft)
Aq 42	Oso Pumping Plant	1.49	8,005
W1	Quail Lake Inlet 1	4.64	16,702
	Quail Lake		
W2	Lower Quail Canal	6.21	10,760
	Warne Powerplant 2	14.07	
W3	Pyramid Lake	41.1	30,874

5.2.2 Closed Conveyance Structures: Pipelines, Siphons, and Tunnels

DSM2 simulates only open channel flow systems; it does not have the capability to represent any other flow conveyance structures. Therefore, when an aggregated section of the aqueduct is dominated by a pipe, siphon, or tunnel, a pipe-to-open-channel conversion tool is used to determine the appropriate open channel geometry. This EXCEL-based tool was developed to help choose channel geometries and Manning's coefficients that will closely match the closed structure velocities with open-channel velocities at known levels of design discharge in order to preserve travel time. Embedded in this tool is the assumption that the closed structures flow completely full (verified by Terry Dennis of SWP Operations Center, personal communication, February 7, 2005). Velocity in either a closed structure or open channel is equal to flow (design discharge) divided by cross sectional area (Eq. 1).

$$V = \frac{Q}{A} \qquad \text{Eq. 1}$$

The design discharge and diameter of pipelines in the Aqueduct are published in Table 1 of the Data Handbook (DWR, 1997 and 2003). Flow in the open channel (assuming steady, uniform flow) can be calculated according to Manning's Equation.

$$Q = \frac{1.49}{n} A R_h^{2/3} S^{1/2} \qquad \text{Eq. 2}$$

In this calculation, "n" is Manning's roughness coefficient, "R_h" is hydraulic radius, and "S" is channel invert slope. Area and hydraulic radius are functions of the channel geometry (base width, b, and side slope, ss) and depth of the water in the channel. The EXCEL tool requires input of base width, side slope, Manning roughness coefficient, and invert slope. Then, *Goal Seek* is used to determine the velocity at which given flow values occur by changing the only unknown value, water depth.

Figure 5-1 shows results from this tool for the South Bay Pumping Plant discharge lines. The dashed line shows the velocity of the discharge calculated as a pipe; the solid line shows the velocity of the discharge calculated with the open channel geometry applied to this aggregated section. The design flow of the discharge pipe is 300 cfs. At that level of flow, the velocity calculated for the open channel geometry approximation is very close to the velocity calculated for the pipe.

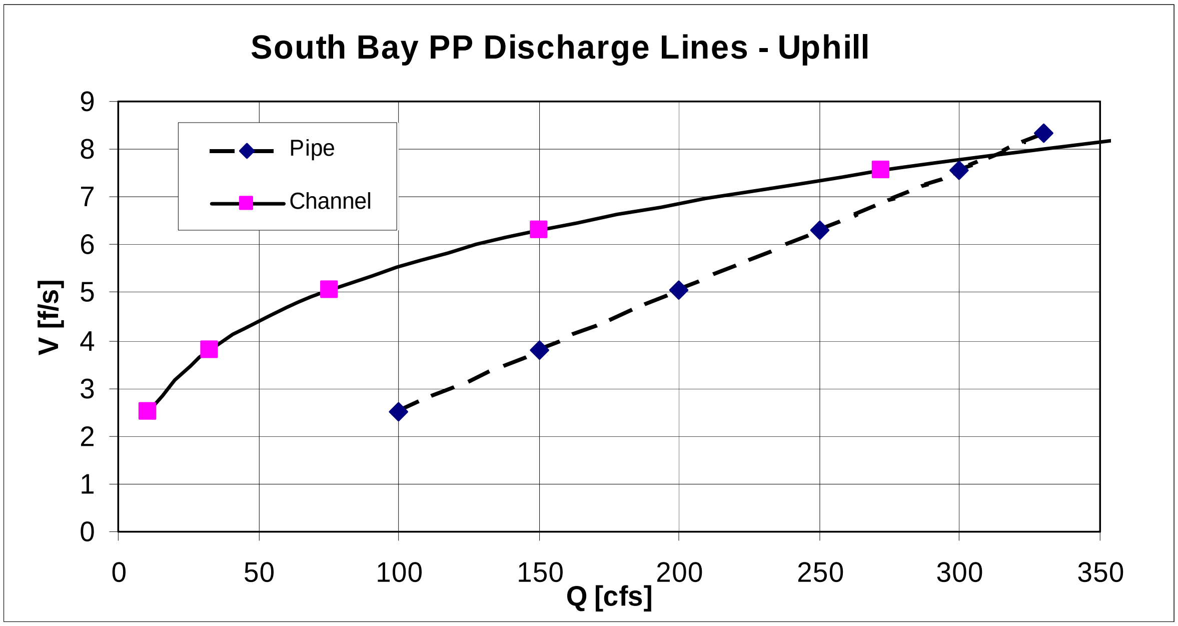

FIGURE 5-1
Comparison of South Bay Pumping Plant Discharge Pipe Flow to Open Channel Flow Approximation

To illustrate the effect that changes in channel geometry have on transport, three channel geometries were used to compare travel time and velocity in a mock 50,000-foot channel (see Figure 5-2 below). All three channels have the same base width (5 feet) and side-slope ratio (1:1), but the channel invert slopes and Manning roughness coefficients vary. Compared with the control geometry ($S=4 \times 10^{-4}$, n=0.01), the channel with a 50 percent decrease in Manning roughness coefficient moved faster than the channel with a 25 percent increase in channel slope. According to Manning's Equation, we would expect that a 25 percent increase in channel slope would cause less than a 10 percent increase in velocity and a 50 percent decrease in Manning roughness would cause velocity to double. Figure 5-2 demonstrates the importance of choosing appropriate channel parameters when converting from a closed-structure to an open channel, as it can influence travel time through the system.

5.2.3 Delta-Mendota Canal

For the DMC, nodes were placed at check structures and transitions in geometry published in Reclamation's "Mileposts at Structure Sites – Delta Mendota Canal" (USBR, 1992). Distances between nodes were determined by the mile post of the check or geometry change. When changes in geometry and check structures were separated by 0.01 mile or less (52 feet), only one node was entered in the grid. Wasteway diversions are located within a few hundred feet of check structures, but due to their relatively large flows, additional nodes were created to account for their effect on the hydrodynamics and water quality. As a standard rule, wasteway nodes were placed 1,000 feet upstream of check structures in the model to remove any channels of less than 1,000 feet in length. In an effort to minimize the ratio of successive channel lengths in the DMC, a maximum channel length of 5,000 feet was adopted. The channels summarized in Table 5-5 below were split into multiple channels such that none was longer than 5,000 feet in length.

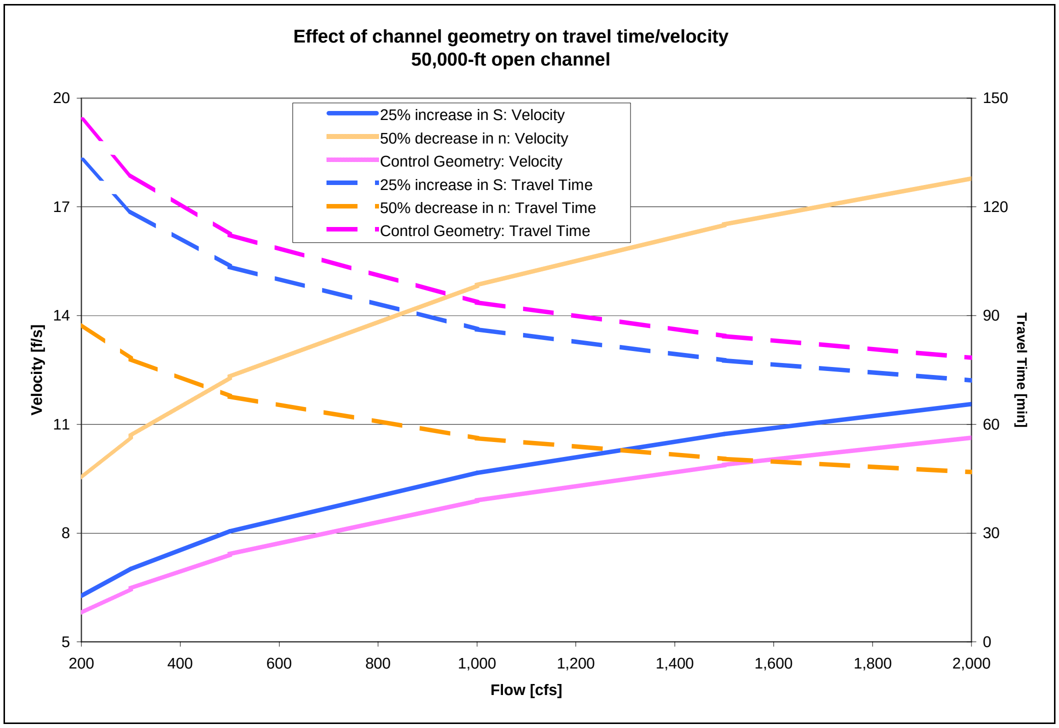

FIGURE 5-2
Comparison of the Effects of Channel Geometry Parameters (Manning roughness and invert slope) on Transport Velocity

TABLE 5-5
Delta-Mendota Canal DSM2 Channel Lengths

DMC Pool	Structure	Mile Post	DSM2 Channel Length (ft)
1	DMC Check 1	11.35	59,928
2	DMC Check 2	16.19	25,555
3	DMC Check 3	20.63	23,443
4	DMC Check 4	24.43	20,064
5	DMC Check 5	29.82	28,459
6	DMC Check 6	34.43	24,288
7	DMC Check 7	38.68	22,493
8	DMC Check 8	44.26	29,462
9	DMC Check 9	48.62	23,021
10	DMC Check 10	54.41	30,571
11	DMC Check 11	58.28	20,434
12	DMC Check 12	63.99	30,149
13	DMC Check 13	70.07	31,786
14	DMC Check 14	74.4	23,179
15	DMC Check 15	79.64	27,667
16	DMC Check 16	85.09	28,776
17	DMC Check 17	90.54	28,776
18	DMC Check 18	96.81	33,106
19	DMC Check 19	105.06	43,560
20	DMC Check 20	111.26	32,736
21	DMC Check 21	116.48	27,562

5.2.4 Reservoirs

There are several reservoirs in the system. O'Neill Forebay is situated between Check 12 and Check 13 on the California Aqueduct. It has a capacity of 56,400 acre-feet. Quail Lake is located on the West Branch, downstream of Oso Pumping Plant, between Quail Canal and Lower Quail Canal. It has a capacity of 5,654 acre-feet. Lake Del Valle (77,110 acre-feet capacity) is connected to the South Bay Aqueduct below Check 7. The Del Valle Pumping Plant, with a capacity of 120 cfs, can pump water from the South Bay Aqueduct into Lake Del Valle. Water is also released from Lake Del Valle to the South Bay Aqueduct. Lake Del Valle is represented as a reservoir linked to the South Bay Aqueduct with object to object flows.

San Luis Reservoir is independent of the channel system, but it is connected by the flow exchange between itself and O'Neill Forebay. The only other flow in or out of San Luis Reservoir is the diversion through Pacheco Tunnel.

The Mendota Pool, Silverwood Lake, and Pyramid Lake all serve as downstream head boundaries of the system. The Mendota Pool is located at the end of the DMC. Silverwood Lake is connected to the end of the Aqueduct's East Branch. Pyramid Lake concludes the West Branch. Silverwood Lake can store up to 73,000 acre-feet of water; deeper Pyramid Lake can store up to 171,200 acre-feet.

5.2.5 Aqueduct Gate Operations

The function of the gates at the check structures throughout the aqueduct system is to control the flow while maintaining the water surface elevation in each pool within an acceptable range. In reality, the gates open and close with changes in flow, providing a variable orifice area through which the water flows. The gates are operated based on mathematical relationships and the experience of the operators. Operators make subtle changes in gate operations, often shifting operations of several gates at once in order to control the flow and meet stage objectives in the system.

The DSM2 model is limited in its ability to handle such complex operations. Pilot tests were conducted with DSM2 to determine the best way to simulate the operations of the gates. It was determined that if weirs were specified at each of the check structures, the invert elevation of the weir could control the minimum elevation in a check, and the width of the weir and thus the cross sectional area through which the flow travels, could limit the rise in water surface elevation with increased flow to acceptable levels. Results of this implementation are discussed in Section 6, and presented in Figure 6-5.

5.2.6 San Luis Reservoir and O'Neill Forebay Mixing

Releases from San Luis are considerably greater than flows at Banks during the summer months, therefore, the ability to predict EC downstream of O'Neill Forebay is affected by the ability to correctly predict EC in San Luis Reservoir. The standard representation of reservoirs in DSM2 is that of a vertical walled, completely mixed body of water. This is an obvious oversimplification of the physical system.

A pilot test was conducted implementing a hypothesis that San Luis Reservoir could be modeled as two reservoirs connected by object-to-object flows in DSM2. The first reservoir would represent the effective mixing volume, and the second reservoir would represent a buffer volume. EC in the first reservoir would more closely match the EC in O'Neill Forebay, and the buffer reservoir would show less variation.

Several assumptions were required to implement such a strategy, including the relative size of each of the reservoirs, and the flows between the reservoirs. Considering the magnitude of outflows from San Luis in the summer months, the first reservoir has to have a large enough volume or there has to be a sufficient exchange flow with the buffer reservoir or the first reservoir will dry up. The iterative preprocessing simulations required to specify the flows representing the exchange between the first reservoir and the buffer reservoir are time consuming.

Although the multiple reservoir concept shows promise, it was abandoned for the initial calibration effort. Future investigations could address this issue as a means of improving the models predictive capability in San Luis Reservoir.

5.3 Conversion of Geometric Data to DSM2 Format

5.3.1 Cross Section Geometry

The channel lengths and canal geometry are input to an EXCEL-based tool developed to generate ASCII files depicting irregular (non-rectangular) cross sections for use in DSM2. The tool references a table of cross section parameters obtained from the SWP Data Handbook (DWR, 1997 and 2003), namely base width, side slope, height, and invert elevation, and then constructs two cross section files for each channel in the model domain. The computed cross sections are located at 5 percent and 95 percent of the channel lengths. Channels are defined such that the cross section geometry is constant for the entire channel length. Figure 5-3 presents a screen capture of the cross section generating tool.

Because the Aqueduct contains increases in elevation head due to pumping plants, the Aqueducts' actual invert elevation does not follow a constant declining energy grade line. DSM2 does not have a method for adding head to the system, therefore the downstream invert elevation at Silverwood Lake, taken as the system datum and canal invert slopes from the Data Handbook, are used to calculate upstream channel invert elevations. This is automated in the EXCEL-based tool. A comparison of actual Aqueduct canal inverts and modeled channel inverts is presented in Figure 5-4.

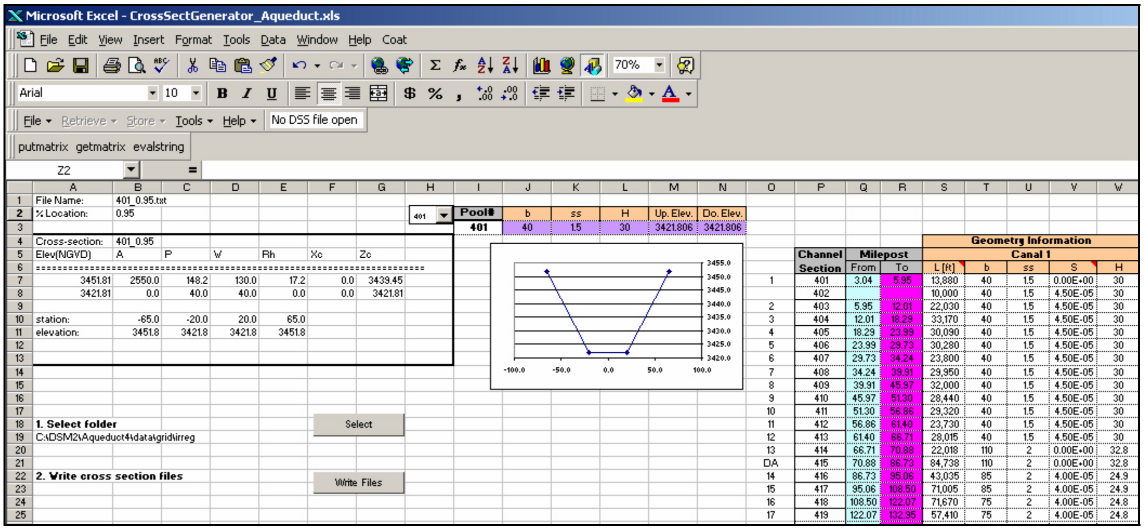

FIGURE 5-3
Cross Section Generating Tool

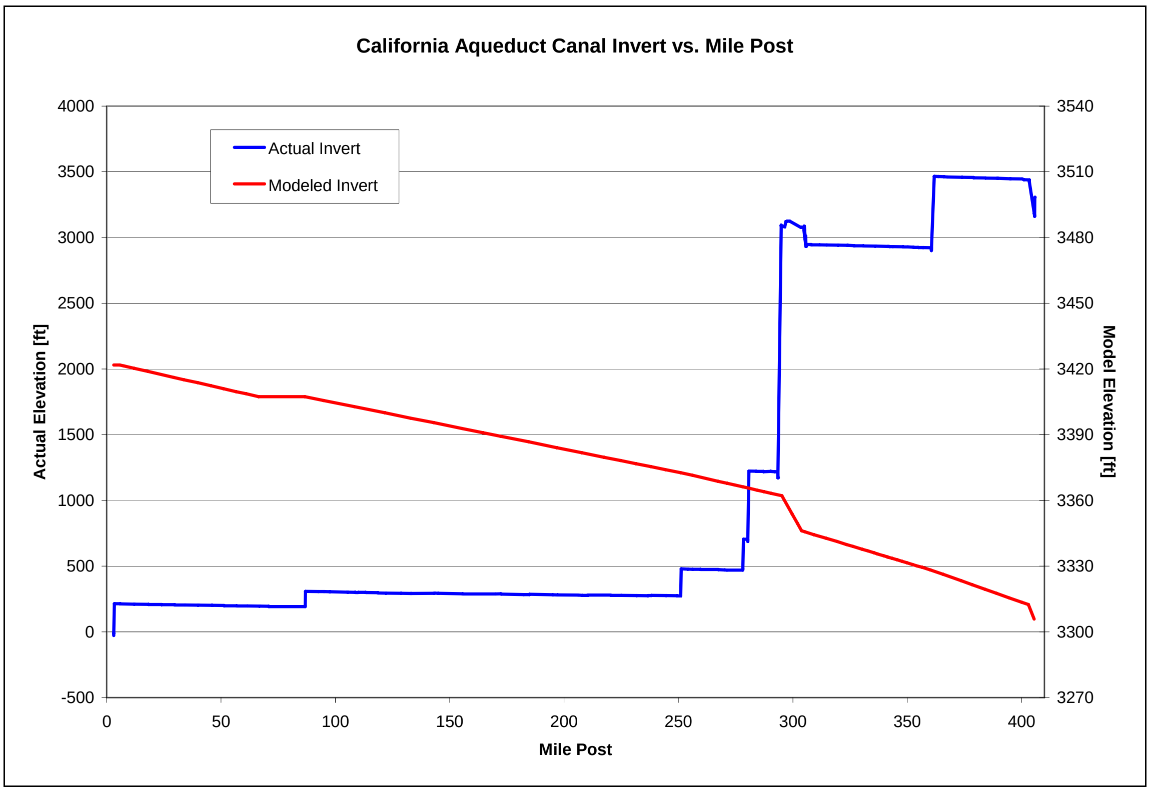

FIGURE 5-4
Comparison of Actual Canal Invert Elevations along the California Aqueduct with Calculated Canal Invert Elevations Used in DSM2

5.4 Inflows and Diversions

5.4.1 Pumping Plant Inflows

Daily OCO Banks Pumping Plant flow data were used to compute seven-day averaged flow time series. This is used as the upstream boundary inflow to the first node of the California Aqueduct in the DSM2 model (node 400). Daily and seven-day averaged banks flows are presented in Figure 5-5. A seven-day averaged Tracy Pumping Plant flow time series is used as the boundary flow into the first node on the DMC (node 100). Daily and seven-day averaged Tracy flows are presented in Figure 5-6.

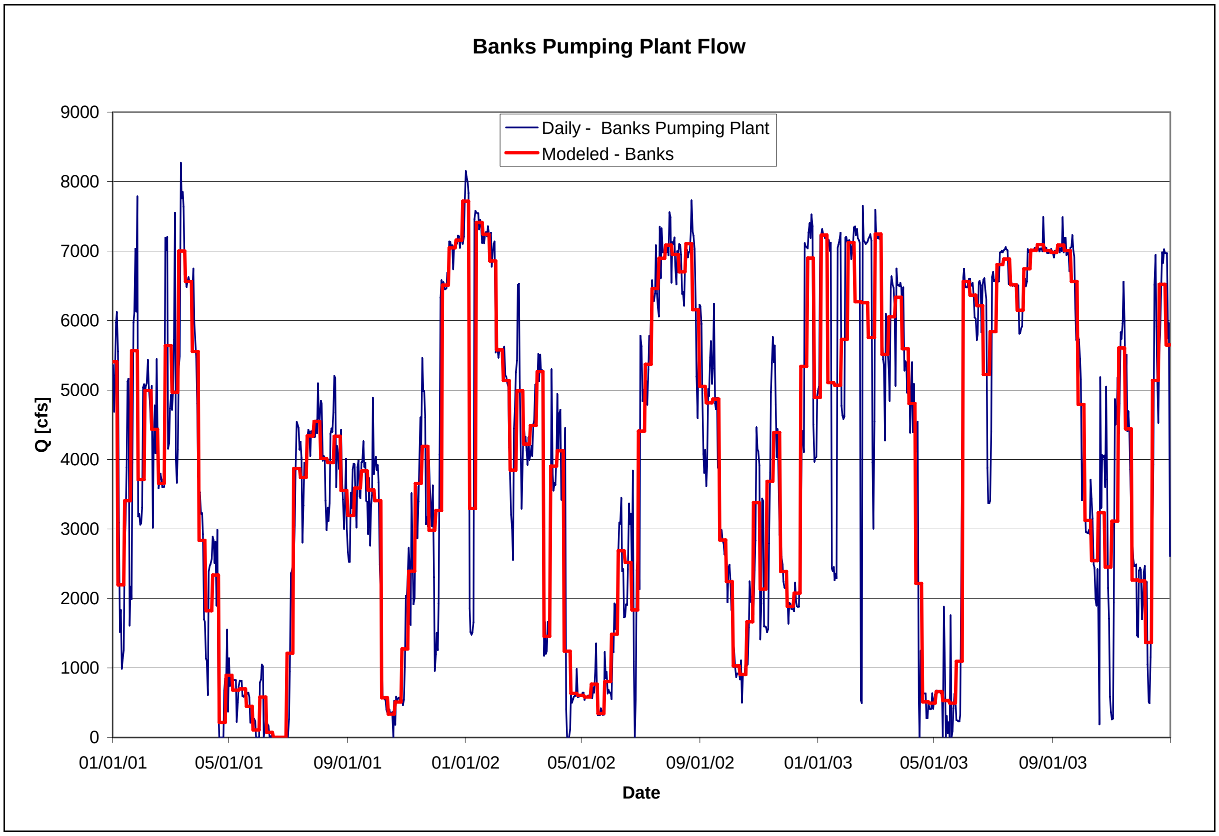

FIGURE 5-5
Banks Pumping Plant Flow Data, Daily and 7-Day Average (DSM2 input)

5.4.2 Floodwater and Groundwater Inflows

Monthly flow data for the Kern River Intertie and floodwater inflows in pools 17-19, and 21 comes from the Monthly OCO reports. The Kern River Intertie flow is applied as an inflow at Check 29. The floodwater inflows are applied at the downstream check for the corresponding pool. Groundwater inflows were deemed negligible and not included in this investigation. Table 5-6 shows the sporadic nature of the recorded inflows over the 3-year simulation period.

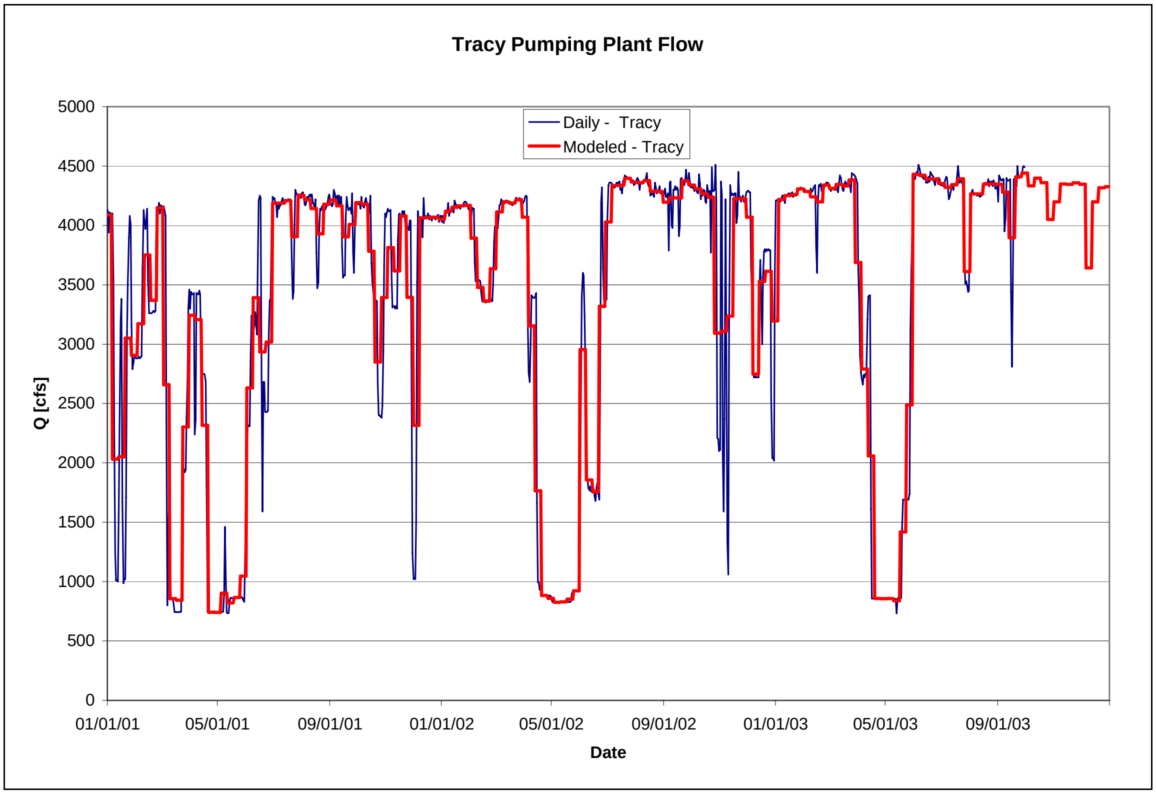

FIGURE 5-6
Tracy Pumping Plant Flow Data, Daily and 7-Day Average (DSM2 input)

TABLE 5-6
Monthly Average Inflows (cfs) in California Aqueduct by Pool
As reported in monthly OCO reports

Month	Pool 17	Pool 18	Pool 19	Pool 21	Pool 29
03/01/01	4.4	29.3	0.2		164.6
04/01/01		0.3			
09/01/01					49.7
01/01/02					114.8
10/01/03					39.2
11/30/03					282.1

5.4.3 Flow Exchanges

Daily flow exchange between San Luis Reservoir and O'Neill Forebay are given in the OCO monthly reports and presented in Figures 5-7 and 5-8. OCO data for the exchange between O'Neill Forebay and the DMC are presented in Figures 5-9 and 5-10. Flow exchanges in DSM2 are handled through separate object-to-object transfers, which are single-direction, instantaneous water transfers that carry water quality information. For water quality purposes both directions of the flow exchange are input into the model rather than just net flow in either direction (i.e. if 100 cfs is pumped into O'Neill from the DMC and 40 cfs is released to the DMC). The object-to-object exchange flows use seven-day averaged OCO flow data.

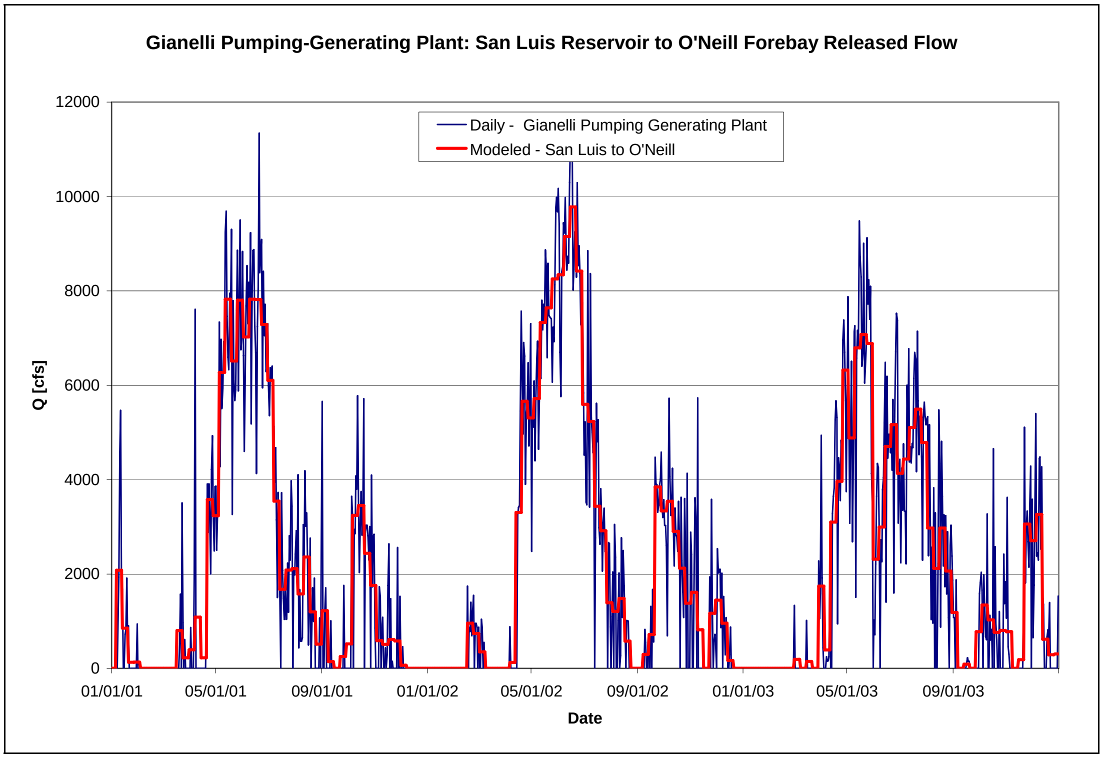

FIGURE 5-7
Gianelli Generating Plant Flow Data, Daily and 7-Day Average (DSM2 input)

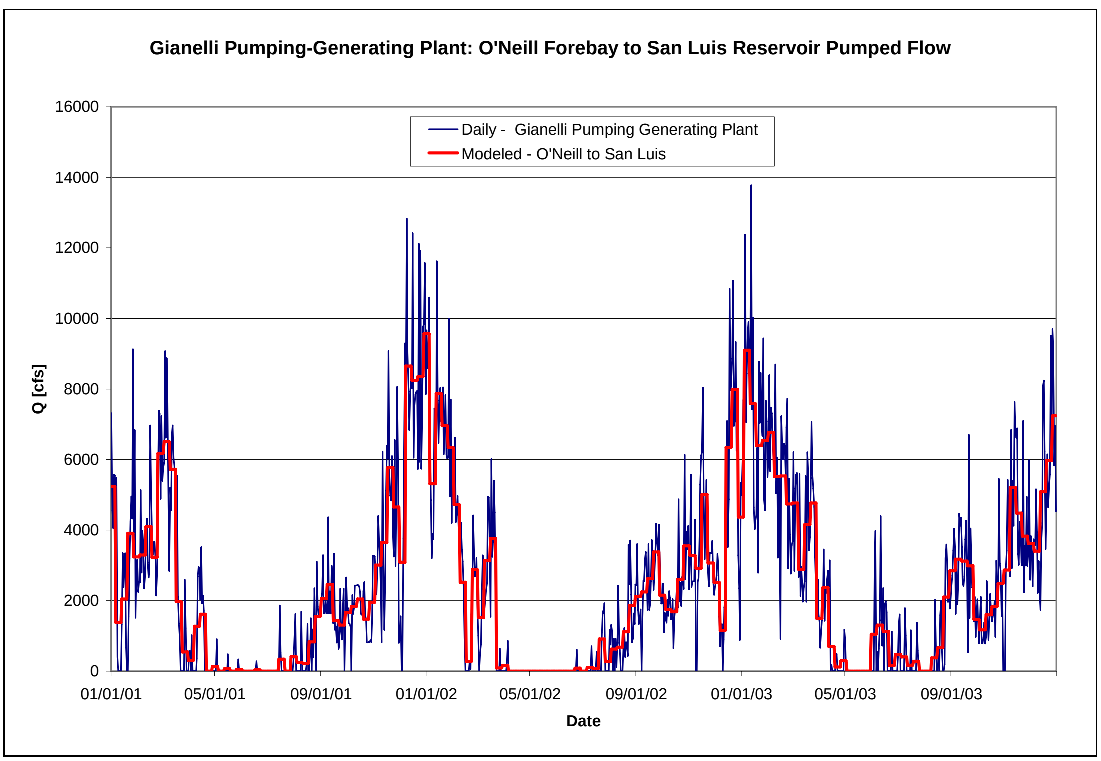

FIGURE 5-8
Gianelli Pumping Plant Flow Data, Daily and 7-Day Average (DSM2 input)

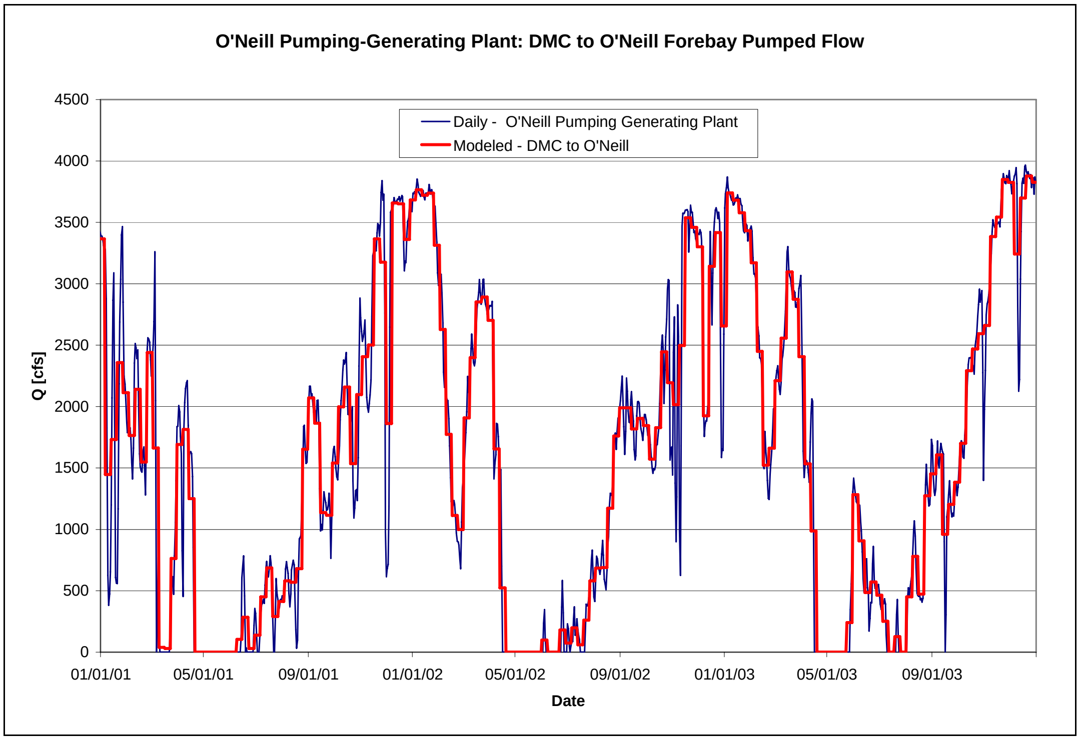

FIGURE 5-9
O'Neill Pumping Plant Flow Data, Daily and 7-Day Average (DSM2 input)

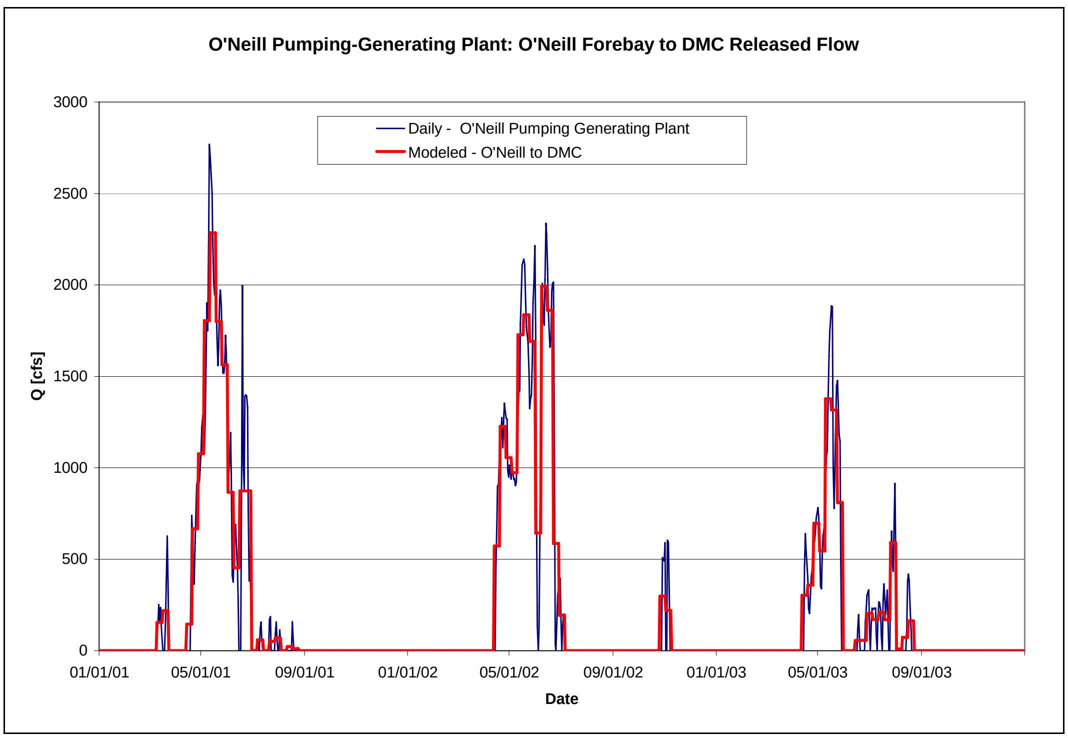

FIGURE 5-10
O'Neill Generating Plant Flow Data, Daily and 7-Day Average (DSM2 input)

Figure 5-11 compares flow measurements taken at various locations along the California Aqueduct, namely Dos Amigos Pumping Plant (Check 13), Check 21, Edmonston Pumping Plant (Check 40), and Oso Pumping Plant (West Branch Diversion). Note the majority of the water pumped through Dos Amigos is delivered before it gets to Edmonston Pumping Plant.

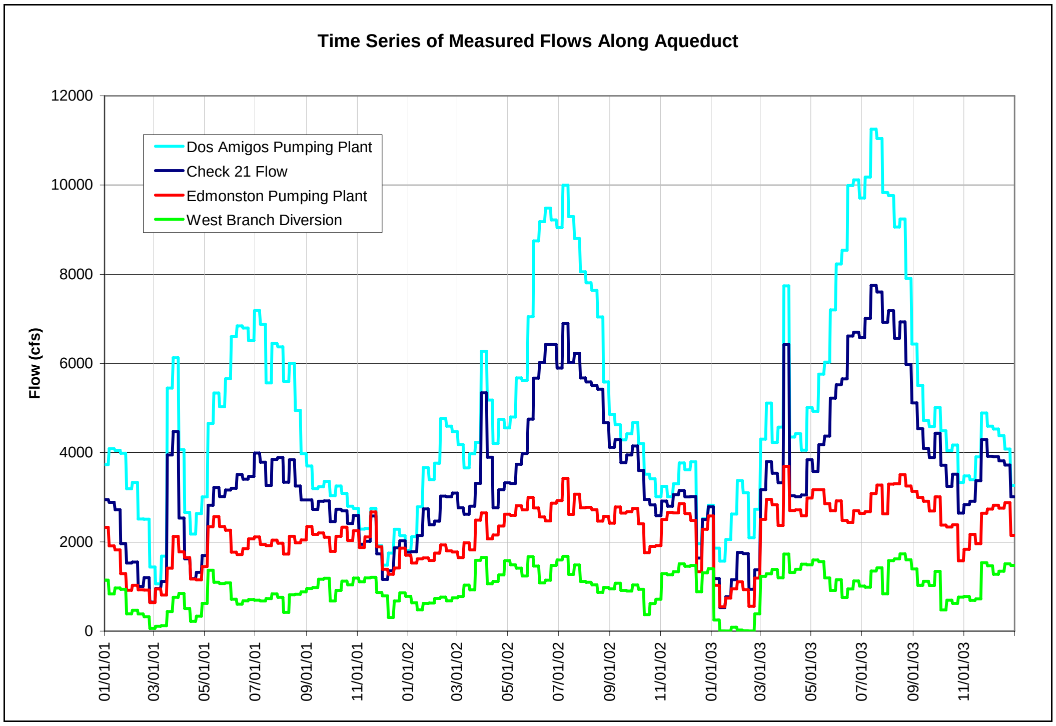

FIGURE 5-11
Comparison of Internal Flow Measurements in California Aqueduct

5.4.4 Water Diversions

Monthly delivery data for each diversion from the OCO reports are grouped by pool along the Aqueduct. Because some pools are modeled with multiple channels, all diversions within a pool are aggregated and withdrawn at the node corresponding with the pool's downstream check. Major diversions, such as wasteways on the DMC, are included as separate nodes at their actual physical location.

Seven-day averaged South Bay Pumping Plant data from the OCO reports is treated as a diversion from the main stem of the Aqueduct (at Check 1) and as an inflow to the South Bay Aqueduct through an object-to-object transfer. The South Bay Pumping Plant daily and seven-day averaged flow data are presented in Figure 5-12. Note that flow into the South Bay Aqueduct had to be artificially increased to 50 cfs at times when the average flow dropped close to zero in order to prevent drying in the channels.

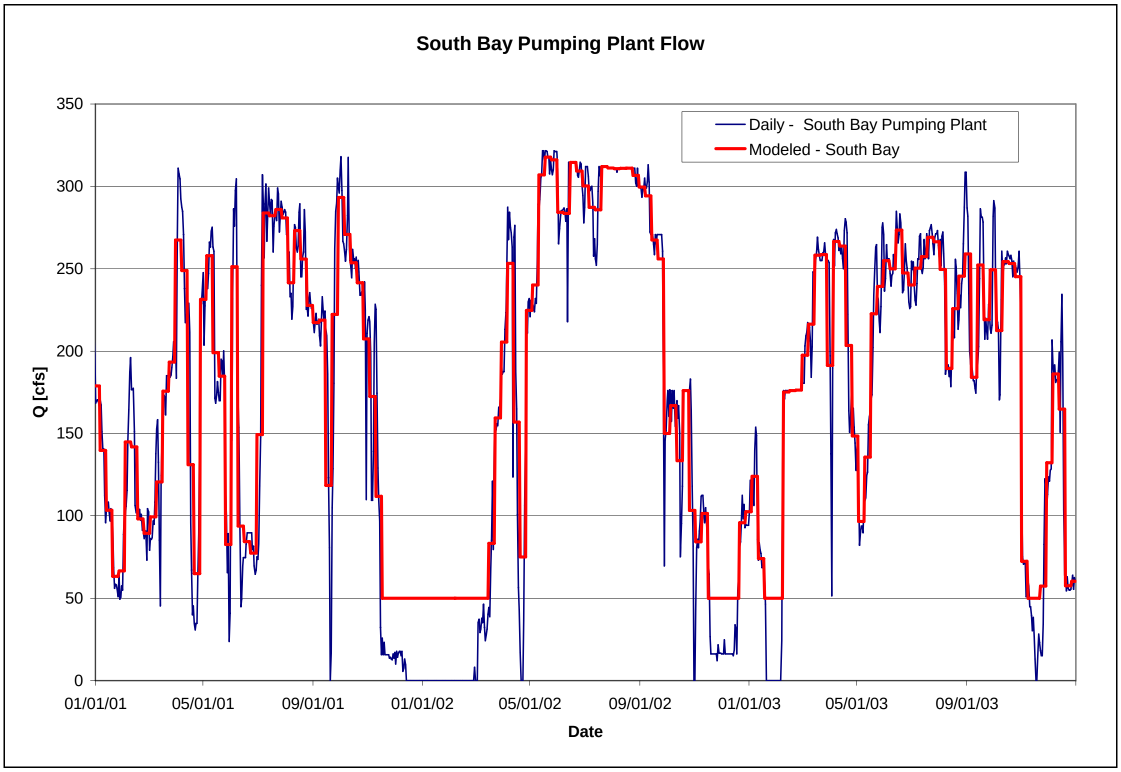

FIGURE 5-12
South Bay Pumping Plant Flow Data, Daily and 7-Day Average (DSM2 input)

O'Neill Forebay is regulated downstream by Check 13, so flow is not allowed to travel freely from O'Neill to the downstream pool in DSM2. An object-to-object transfer is used to carry water from O'Neill to the upstream node of the downstream channel (node 414, channel 415). The transfer is calculated as the flow through Dos Amigos Pumping Plant plus any diversions in pool 13 (there are no inflows to pool 13). In this way, the balance from O'Neill through Dos Amigos Pumping Plant is maintained.

Monthly delivery data from CVO delivery reports are also grouped by pool along the DMC. Multiple deliveries within a pool are aggregated and summed into a single delivery and withdrawn from the pool's downstream check, similar to the deliveries along the Aqueduct.

Monthly averaged daily delivery data for the Pacheco Tunnel is treated as a San Luis Reservoir diversion. Seven-day averaged Oso Pumping Plant data from the OCO reports is treated as a diversion from the main stem of the Aqueduct (at Check 42) and as an inflow to the West Branch through an object-to-object transfer. Figure 5-13 compares the net diversions (delivery minus inflow) in each of four major sections of the California Aqueduct. The majority of the diversions occur between Dos Amigos and Edmonston Pumping Plant.

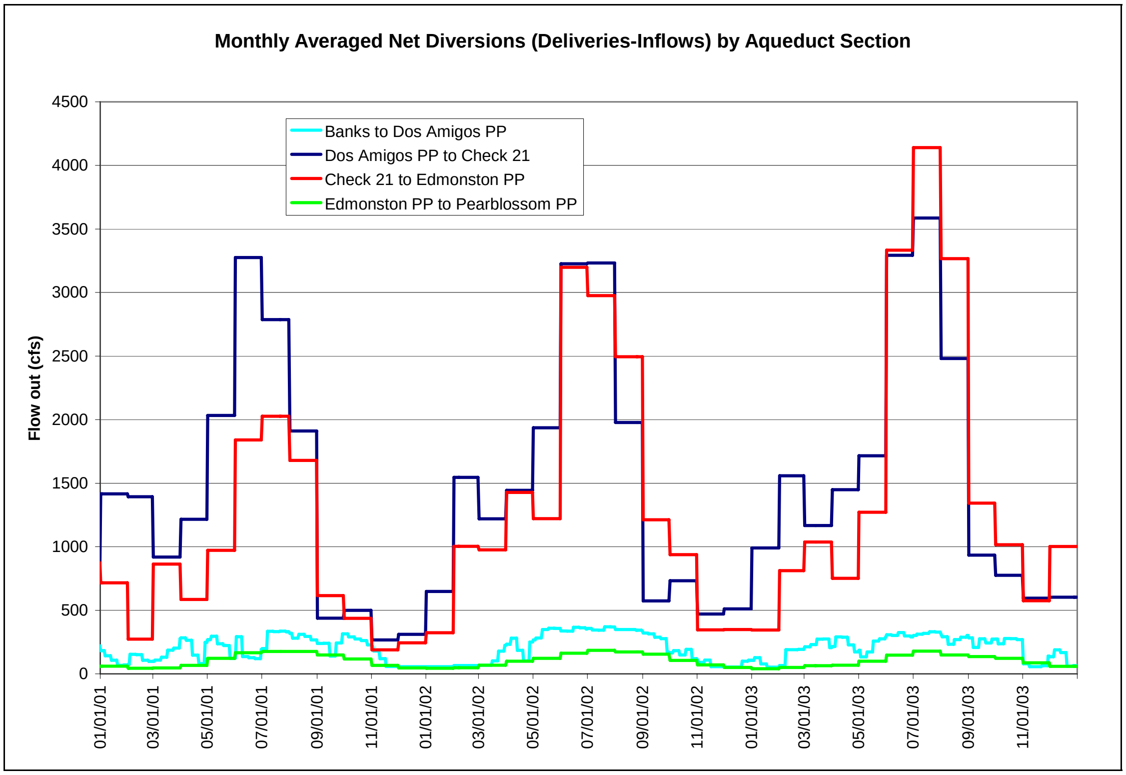

FIGURE 5-13
Comparison of Total Net Diversions by Aqueduct Section

5.5 Water Balance and Required Closure Terms

Water balance calculations were performed on the Aqueduct system as a whole as well as on specific sections of the system. The terms in the mass balance were the measured daily flows throughout the system, and all inflows and diversions as reported in the monthly OCO and CVO reports. The mass balance assumed that all data provided are valid, and that there is no change in storage in the section of the aqueduct over which the balance is conducted. Daily flow data was averaged over 7 days for use in the mass balance calculations. Monthly diversions were assumed to be a constant flow rate for the month. It is recognized that there may be significant weekly or daily variation in the actual diversions that is not represented in the monthly values. For example, a water balance was conducted for the section bounded by Check 21 and the Edmonston Pumping Plant. Data used in the mass balance included daily flow reported at Check 21 and Edmonston Pumping Plant, and monthly averaged diversions and inflows for Pools 22 through 40 as reported in the monthly OCO reports. The net water balance error term is calculated as the difference between all inflows and outflows. Error terms are calculated for four sections along the Aqueduct main stem (Pools 1 through 67). These four sections are defined as follows:

- Reach A runs from pool 1 through Dos Amigos Pumping Plant, using Banks Pumping Plant flow as the inflow and Dos Amigos flow as the outflow
- Reach B starts in pool 14 and runs through Check 21, using Dos Amigos flow as the inflow and Check 21 flow as the outflow

- Reach C starts in pool 22 and runs through Edmonston Pumping Plant (Check 40), using Check 21 flow as the inflow and Edmonston flow as the outflow
- Reach D starts in pool 41 and runs through Pearblossom Pumping Plant (Check 58), using Edmonston flow as the inflow and Pearblossom flow as the outflow

The water balance calculations indicate there are often major inconsistencies in the published data that cause errors in the water balance. Figure 5-14 presents the results of the seven-day average mass balance calculations for the four sections of the main Aqueduct. There are errors topping 1,000 cfs in the first three reaches. However, there are no distinct seasonal patterns in the error balances and no drastic differences between reaches except for the reach between Edmonston and Pearblossom pumping plants. In this final reach, the flows are smallest, so errors are expected to be smallest on an absolute basis. The random distribution of the errors both spatially and temporally indicates no single variable responsible for the error and the errors occur on a systemwide basis. A similar analysis of mass errors on a monthly basis reveals considerable scatter as well.

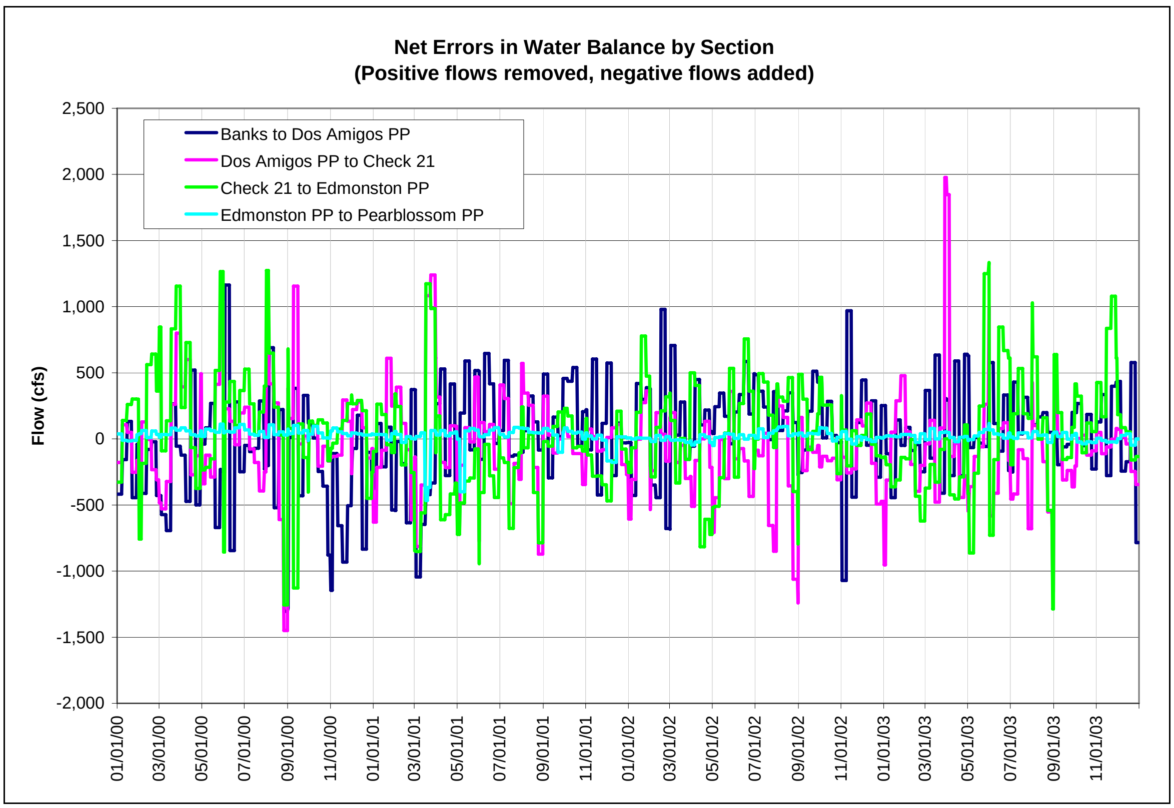

FIGURE 5-14
Comparison of Errors in Water Balance Calculations for Each Section

Figure 5-15 shows the aggregated error in the water balance calculations for the entire Aqueduct from Banks to Pearblossom Pumping Plant (Check 58). The high variability throughout the time period shows that the errors are not seasonal in nature.

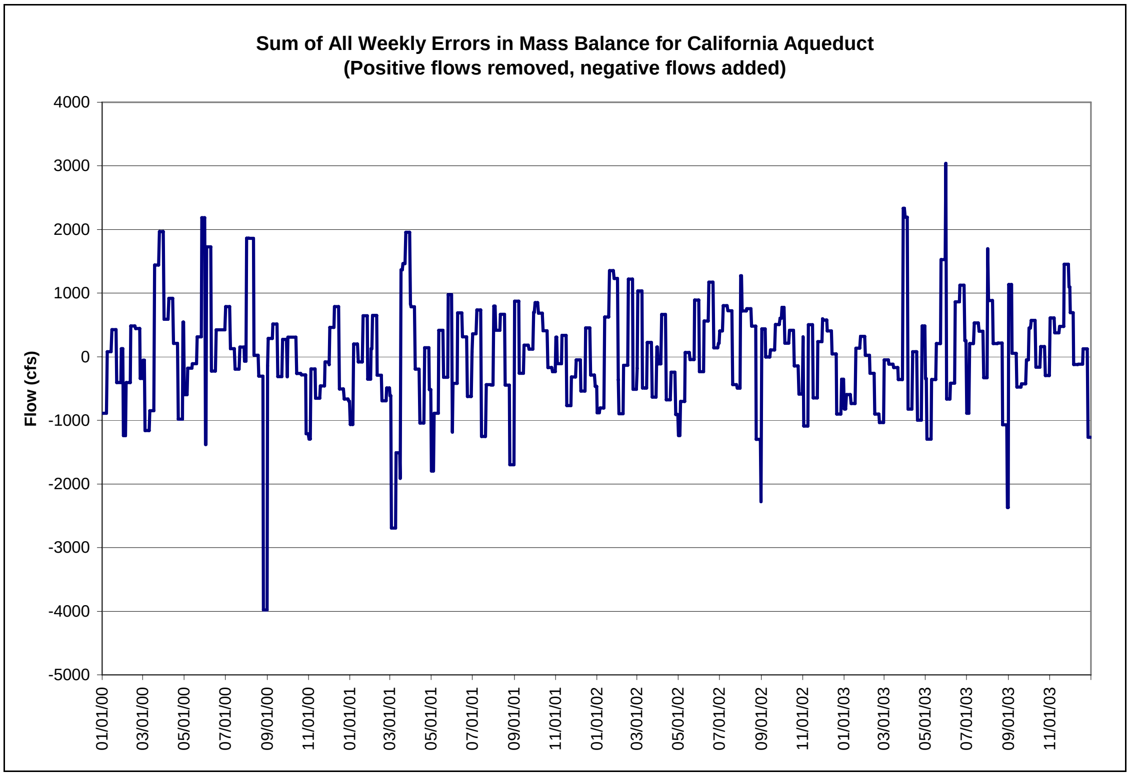

FIGURE 5-15
Time Series of Total Error in Water Balance Calculations for California Aqueduct (Banks to Pearblossom)

Although the system has considerable storage capacity in the individual pools, the magnitude of the required closure terms in the mass balance calculations are beyond this capacity. For example, the surface area of the aqueduct channels along the 121 miles between Check 21 and Edmonston Pumping Plant is approximately 1,800 acres. A flow imbalance of 1000 cfs for 7 days equates to approximately 14,000 acre-feet, which would raise the water level in the aqueduct uniformly over this reach approximately 8 feet. Thus, even allowing for a considerable change in storage, the errors in the mass balance calculations are significant.

- The closure terms to correct for the errors in the water balance are applied in the model at the downstream node of each of the four sections. If the balance for a reach at any point in time is negative (outflow exceeds inflow), an additional inflow was added at the most upstream node of that reach. Conversely, if the balance for a reach at any time was positive (inflow exceeds outflow), an additional diversion was added at the farthest downstream node of the reach. Inflows were added at the upstream node so that water required for deliveries along the reach would be available and prevent the channel from drying out. Diversions were taken from the downstream node to match reported flows.
- In addition, a water balance was calculated for O'Neill Forebay. Table 14 of the monthly OCO reports contains a mass balance for O'Neill Forebay, including the change in storage in the Forebay. The components of the O'Neill Forebay balance were investigated in detail because releases from O'Neill are critical to downstream operations.

Individual components of the water balance are plotted against the calculated error in the balance equation to investigate relationships between the error and a given component. Figure 5-16 presents the error, calculated on a daily basis, against the daily flow released from San Luis Reservoir through the Gianelli Pumping/Generating Plant. The error is the closure term added to the inflow, if positive, and subtracted from the inflow, if negative. Thus, the predominance of large negative closure values presented in Figure 5-16 indicates that either the inflows were overestimated or the outflows were underestimated. The flows have to be adjusted for the model water balance to match the flows reported through Dos Amigos Pumping Plant. A similar correlation exists between the daily error and the flow from O'Neill Forebay to the DMC through the O'Neill Pumping/Generating Plant; however, the errors are three times the flow reported through that facility, indicating that measurement cannot be the only source of error.

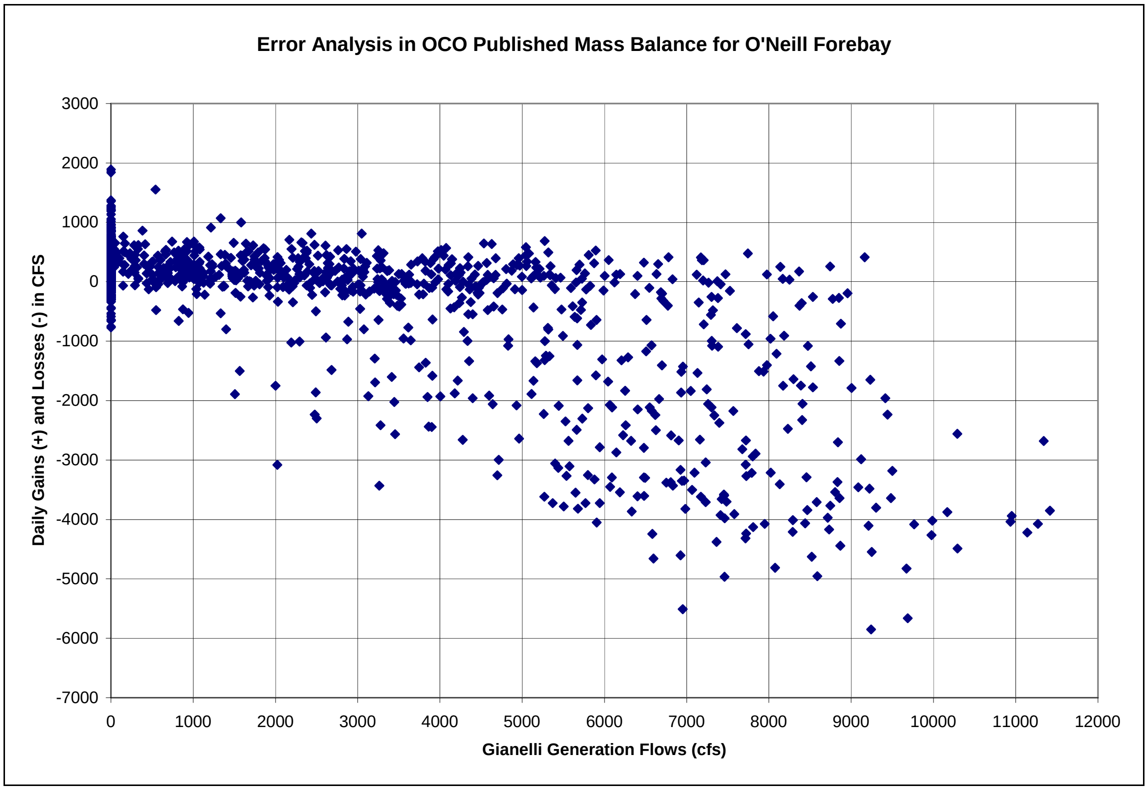

FIGURE 5-16
Error in O'Neill Forebay Water Balance Plotted Against San Luis Reservoir Release

The plot demonstrates that there is a good correlation between high flows from San Luis Reservoir and a high amount of water apparently lost according to the water balance. None of the other components of the mass balance exhibited this behavior. Thus, the largest source of uncertainty in the water balance is the flow released from San Luis Reservoir, and that perhaps the flow release is less than that reported.

Figure 5-17 presents the cumulative mass loss in O'Neill Forebay as published in the OCO monthly reports. The flow through the Gianelli Generating Plant is also included on the plot. The periods of highest mass balance error correlate well with large releases from San Luis Reservoir to O'Neill Forebay.

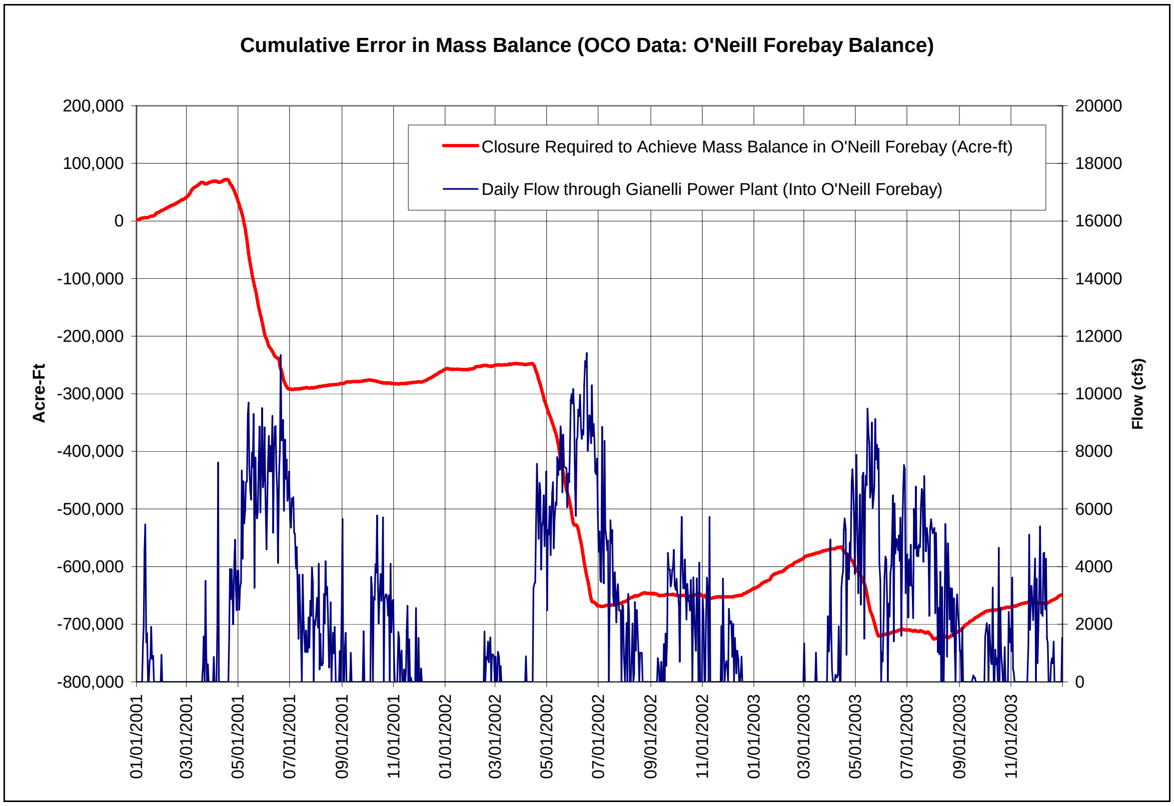

FIGURE 5-17
Cumulative 3-Year Error in O'Neill Forebay Water Balance

O'Neill Forebay has a surface area of approximately 2700 acres. At a yearly evaporation of 60 inches, the total loss to evaporation over three years would be approximately 40,000 acre-ft. Furthermore, since the change in storage at O'Neill Forebay is included in the water balance, the closure error cannot be attributable to evaporative or seepage losses. Thus, the error is likely attributable to either an overestimation of the San Luis Release or an underestimation of the outflow through Dos Amigos Pumping Plant.

5.6 Salinity

In the water quality model (QUAL), all model inflows require specification of the daily EC of the inflow. For the two main system inflows at Tracy and Banks Pumping Plants, EC data was obtained from the CDEC website.

Salinity data is not available for the Kern River Intertie or the floodwater inflows.

O'Neill Forebay was initialized at the start of the model simulation with the Aqueduct Check 13 EC value on January 1, 2001, (581 microSiemens per centimeter [μS/cm]. San Luis Reservoir was initialized with an EC value of 477 μS/cm. This is the value retrieved from

Pacheco Pumping Plant on January 1, 2001. The Mendota Pool was initialized with DMC Check 21 EC data for January 1, 2001 (637 µS /cm). All channels and remaining reservoirs were initialized with the Aqueduct Check 13 EC value (581 µS /cm).

Figure 5-18 compares the daily averaged EC measured at Tracy Pumping Plant to that measured at Banks Pumping Plant for three years beginning January 1, 2001. There are distinct seasonal differences between the two data records; EC at Tracy is higher than Banks, often considerably so, during the months of January through April. The difference in EC between the two locations is smaller during the summer and fall months.

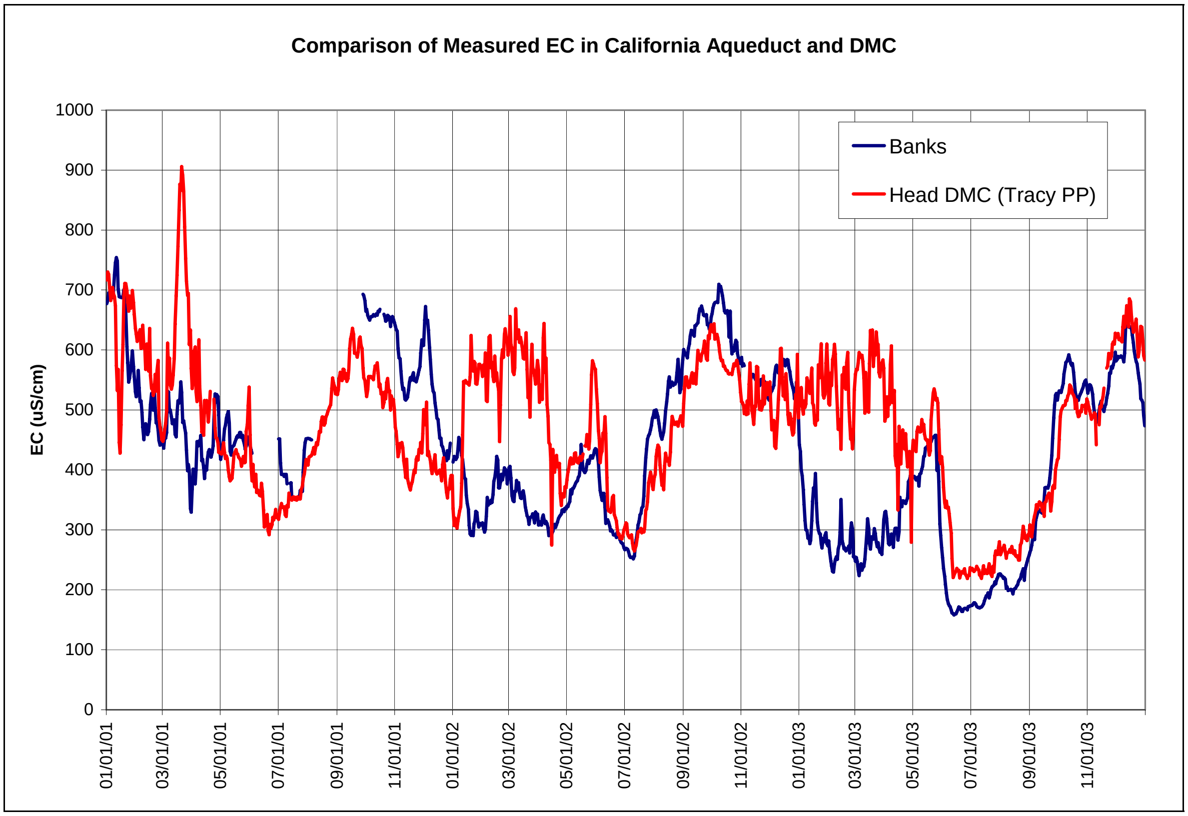

FIGURE 5-18
Comparison of Measured EC at Banks and Tracy Pumping Plants

Figure 5-19 compares the daily averaged EC measured at Tracy Pumping Plant to that measured at the intake of the O'Neill Pumping/Generating Plant on the DMC (Check 13) for three years beginning January 1, 2001. In general, there is a high degree of correlation between these two measurements, as expected, considering the two locations are approximately 66.5 miles apart. The DMC has no major inflows between the two stations aside from storm water influences, which can be considerable. There are over 250 drains into the DMC; the largest are Romero Creek and Quinto Creek.

The three-month period from October through December 2001 indicates that there is a considerable amount of high EC inflow somewhere between the Tracy Pumping Plant and Check 13. This ungaged inflow is not present in the model, and thus the model will not be able to match the observed differences between the Tracy Pumping Plant and the O'Neill Intake during this period.

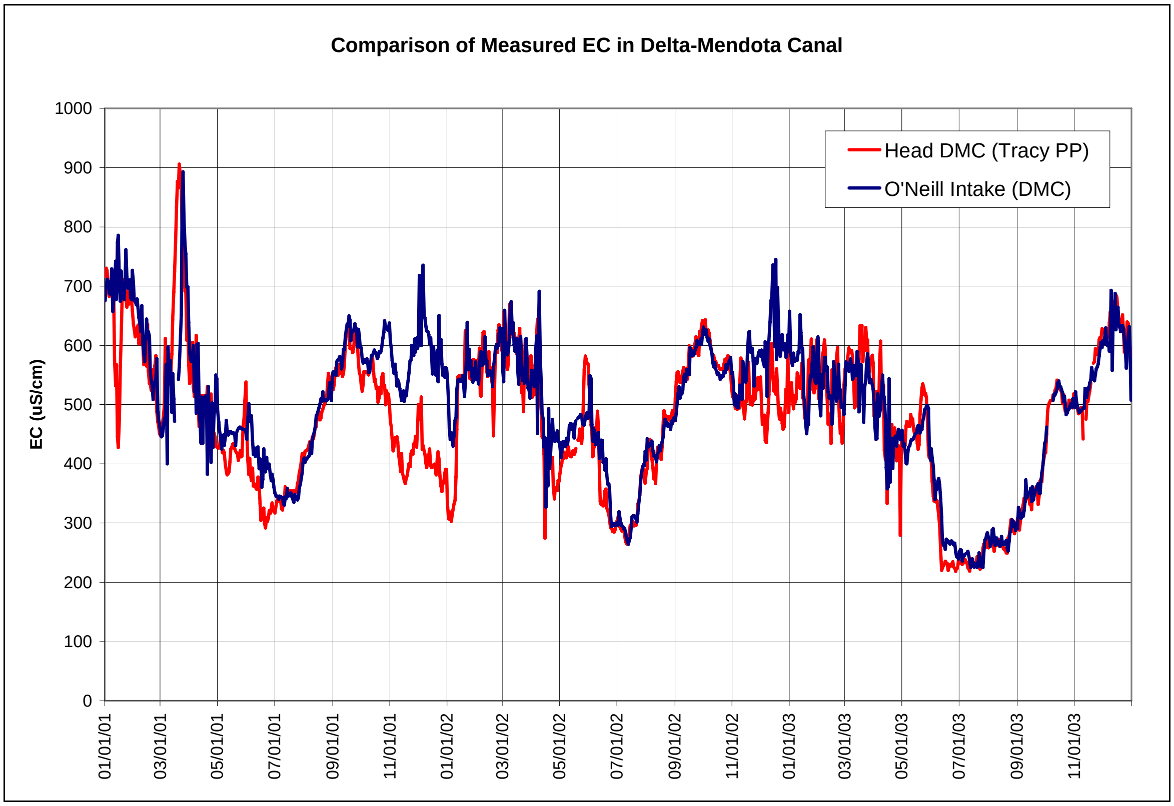

FIGURE 5-19
Comparison of Measured EC at Banks and Tracy Pumping Plants

Figure 5-20 compares the daily averaged EC measured at three locations in the Aqueduct: Check 21, Check 29, and Check 41. As expected, the EC is generally very similar at the three locations, with minor differences for travel time between the stations. There are no major inflows between Check 21 and Check 41, aside from storm water influences.

There are a few notable instances where the EC measured at Check 29 is quite different that that measured at either Check 21 or Check 41. One such instance is the two-month period beginning May 1, 2002. For this period, the EC measured at Check 29 is over 30 percent higher than that measured at the other two checks. This indicates a considerable high EC inflow somewhere between Check 21 and Check 29. However, the OCO monthly reports do not report any inflow into the Aqueduct during these months (Table 5-6 above). Interestingly, Check 41 shows no record of this high EC water being carried downstream. Because there is no reported inflow in the OCO records, the model will not be able to predict the increase in EC observed at Check 29 during this period.

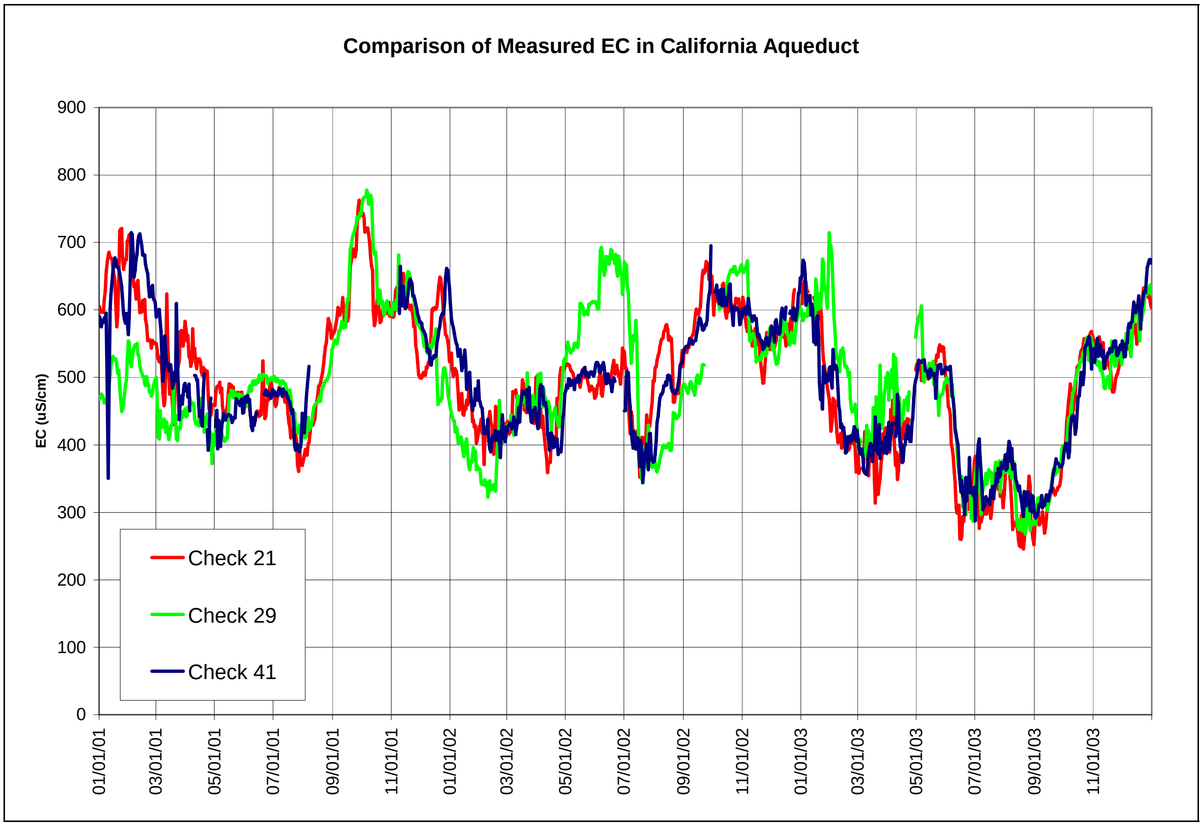

FIGURE 5-20
Comparison of EC Data at Checks 21, 29, and 40 in the California Aqueduct

A salinity value must be assigned to each closure flow added at various locations along the aqueduct to ensure mass balance. Each closure flow was assigned salinity from the closest monitoring station to the location where the closure inflow was added to the system. Daily salinity data for each of the closure inflows were obtained from the CDEC website. Pool 1 closure inflow EC was set equivalent to measured EC at Banks; pool 13 inflow EC was set equivalent to Check 13; pool 22 inflow EC was set equivalent to Check 21 EC; and Pool 41 inflow EC was also set equivalent to Check 21 EC as the data for Check 41 is incomplete. This substitution is reasonable because the closure inflows to pool 41 are relatively small and the effect of these inflows on salinity is negligible.

SECTION 6

Model Calibration, Validation, and Sensitivity Analysis

Model calibration simulations were conducted for a three-year period beginning January 1, 2001 and ending December 31, 2003. The model simulations actually begin one year earlier, and the entire year is used to slowly ramp down water surface elevations at the model boundaries so that the model is in dynamic equilibrium at the beginning of 2001. The model is initiated with no water surface slope, and thus the water depth at the downstream end of the system is greater than 100 feet. The ramp down year (2000) slowly lowers the downstream boundary water surface elevations to appropriate levels. This is required for model stability. Results from 2000 are not presented. This is referred to as the model spinup period.

Model verification includes comparisons between model predictions and known system data for flow, stage (water depth in the channels and reservoirs), and salinity (EC).

6.1 Hydraulics Calibration

6.1.1 Flow

Figures below present results of the final model calibration simulation. Plots of measured and observed flow are presented for the Dos Amigos Pumping Plant (Check 13 on the California Aqueduct), the Edmonston Pumping Plant (Check 40 on the California Aqueduct), and the Pearblossom Pumping Plant (Check 58 on the East Branch of the California Aqueduct). These locations are chosen because of the readily available flow data at the pumping plants. The OCO monthly reports provide daily average flow through all pumping and generating plants in the system.

Final model simulations were conducted with a range of values for Manning's "n". The majority of channels are specified with a friction coefficient of 0.02. Several steeper channels, such as those representing the Tehachapi Tunnel and the Porter Tunnel, required a higher Manning's "n" to maintain model stability. The 0.02 value matches well with previous hydraulic studies of the aqueduct system (DWR, 2004).

Figure 6-1 presents measured and modeled flow at Check 13, the Dos Amigos Pumping Plant. The results here are almost exact, as expected, because the flow out of O'Neill Reservoir was defined as the flow through Dos Amigos Pumping Plant and any deliveries made between the outlet of O'Neill Forebay and Dos Amigos Pumping Plant.

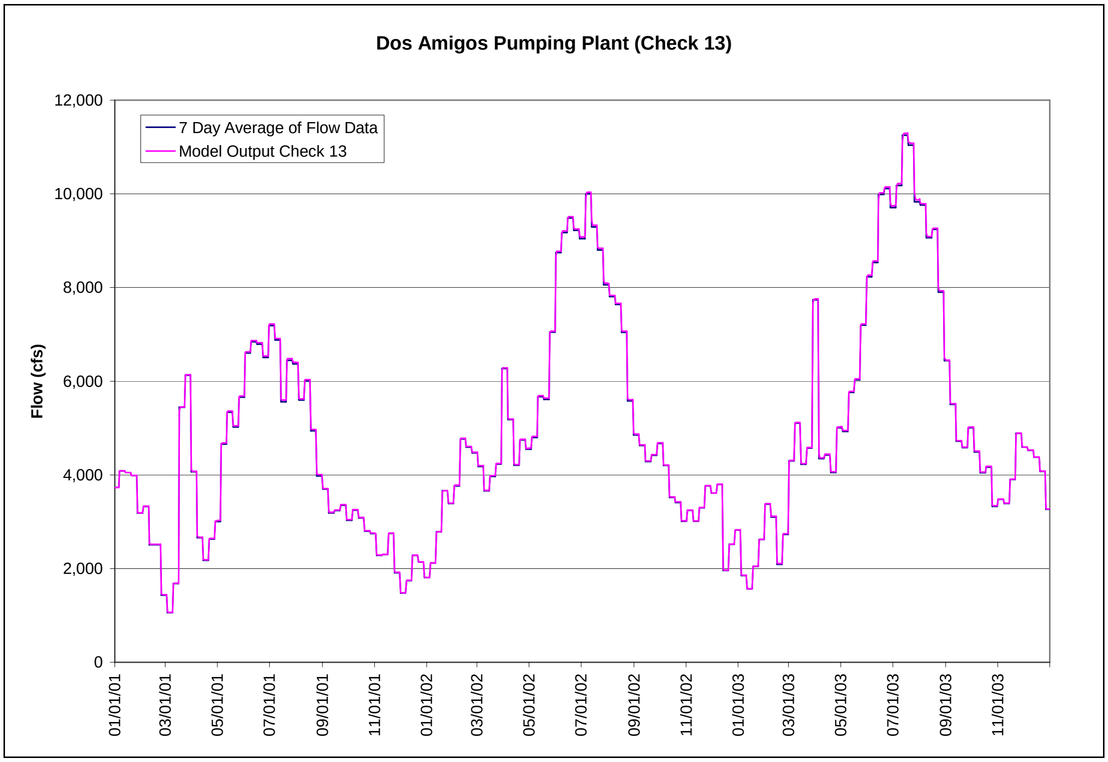

FIGURE 6-1
Comparison of Model Predictions and Observed Data at Dos Amigos

Figure 6-2 compares the model predicted flow and the seven-day average flow calculated from daily flow data provided by the OCO monthly reports for Edmonston Pumping Plant. The flows match very well, as expected considering the application of the water balance closure terms.

As shown in Figure 6-2, there are several periods where there are short term spikes in the model predictions that do not match the observed (averaged) flow data. These spikes have a duration of less than one day, and are associated with the changes in boundary conditions and diversion flows between the seven-day averaged periods. Basically, the mass balance for each section assumes that the flow provided at the upstream end of the channel is available to the channel for the given seven-day period over which the mass balance closure terms are calculated. If there is a large increase in flow into the system, and a similar large increase in diversions from a point near the downstream end of a section, it is possible that the flows provided to meet those diversions have not yet arrived at the diversion location, considering the travel time through the system. Thus, water is being taken out of the system before the increased flow arrives, creating a net loss condition in a particular reach. This quickly draws the water down in a channel, creating a large gradient in the water surface elevation, which, in turn, causes short-term spikes in the flow. When the boundary conditions are averaged on a one-month basis, the spikes are not as frequent, but the longer-period average makes it more difficult to calibrate the model considering the daily variability in aqueduct operations. It should be noted that this issue will not be a problem when the model is applied in a planning or forecasting mode.

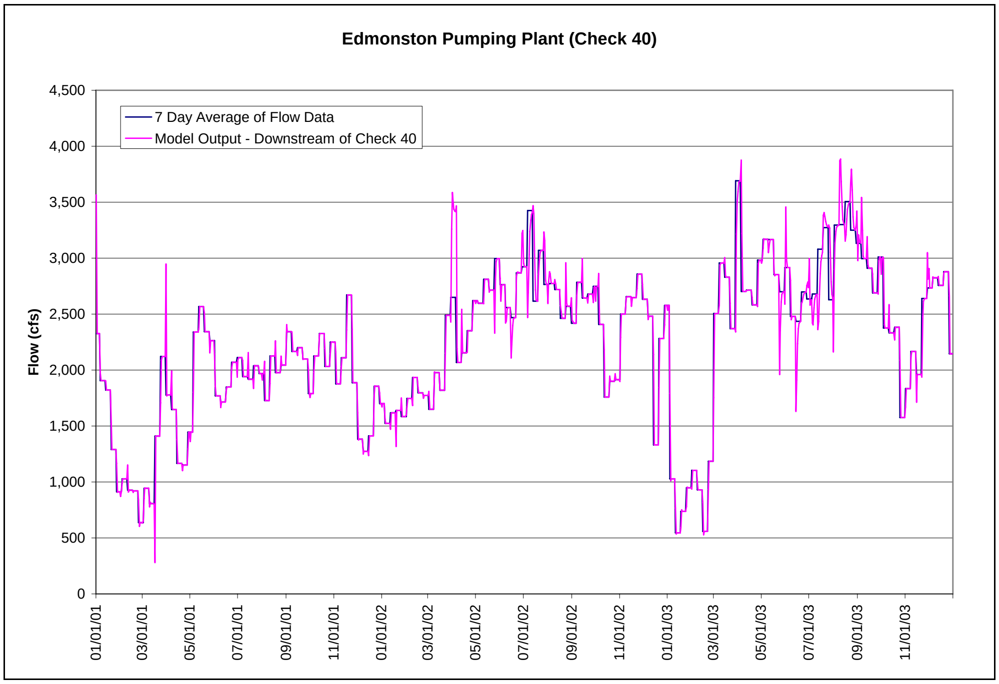

FIGURE 6-2
Comparison of Model Predictions and Observed Data at Edmonston PP

Figure 6-3 compares the model predicted flow and the seven-day average flow calculated from daily flow data provided by the OCO monthly reports for Pearblossom Pumping Plant. Although the model predictions generally follow the trend of the observed data, there are numerous instances, similar to those presented for Edmonston Pumping Plant, where there are short duration spikes in the predicted flows.

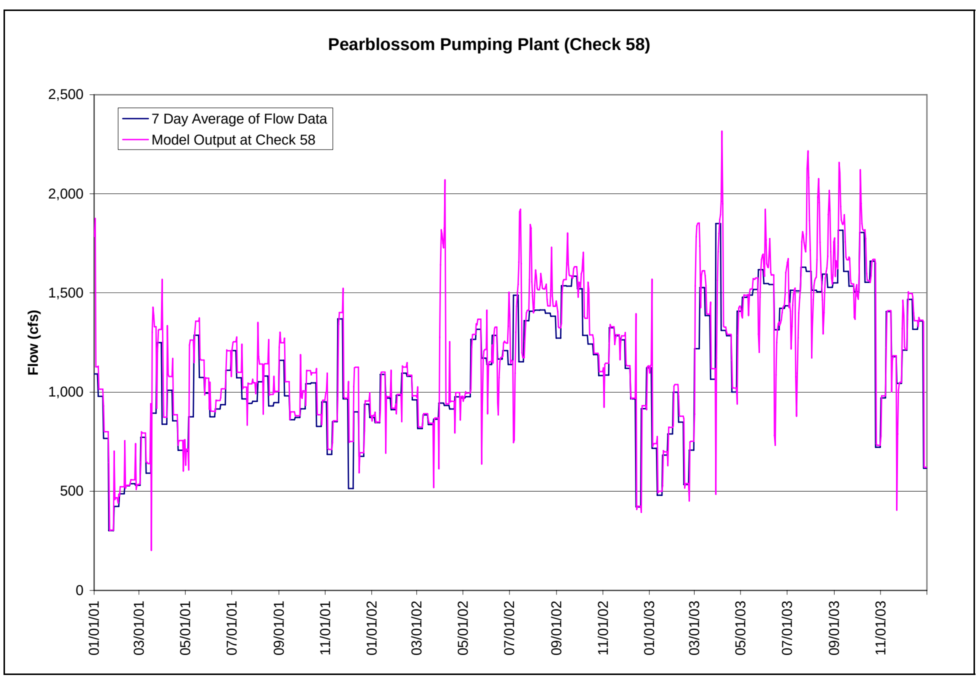

FIGURE 6-3
Comparison of Model Predictions and Observed Data at Pearblossom Pumping Plant

6.1.2 Stage

Model calibration also investigated the predicted stage in the aqueduct channels. The DWR SWP Data Handbook provides tabulations of the operating water levels in the Aqueduct. The Aqueduct pools are generally kept within a narrow operating range, on the order of a few feet, throughout the full range of flows that the system experiences.

Figure 6-4 presents a time series of predicted water depths in three channels in the Aqueduct. These channels are upstream of Checks 12, 19, and 40. Note that the elevations do not range more than a few feet. This was controlled through the use of flow control structures, as described above. The increased water levels upstream of Check 19 occur during elevated flows in the summer months.

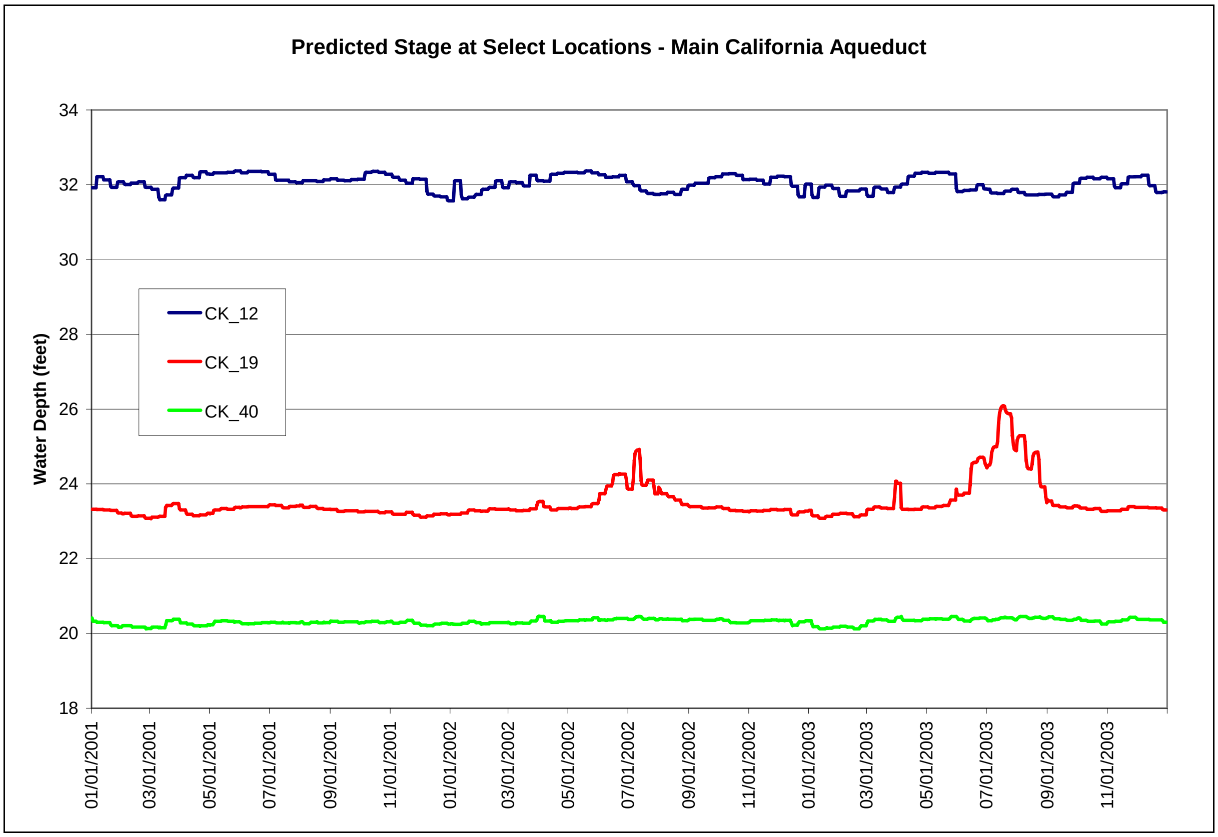

FIGURE 6-4
Comparison of Water Depths at Three Locations along the California Aqueduct

Figure 6-5 summarizes the range in water depths just upstream of each check, as predicted by the model for the entire simulation period. Also included are the ranges as published in the DWR Data Handbook. The model does a very good job of simulating the variation in water level over the appropriate operating range.

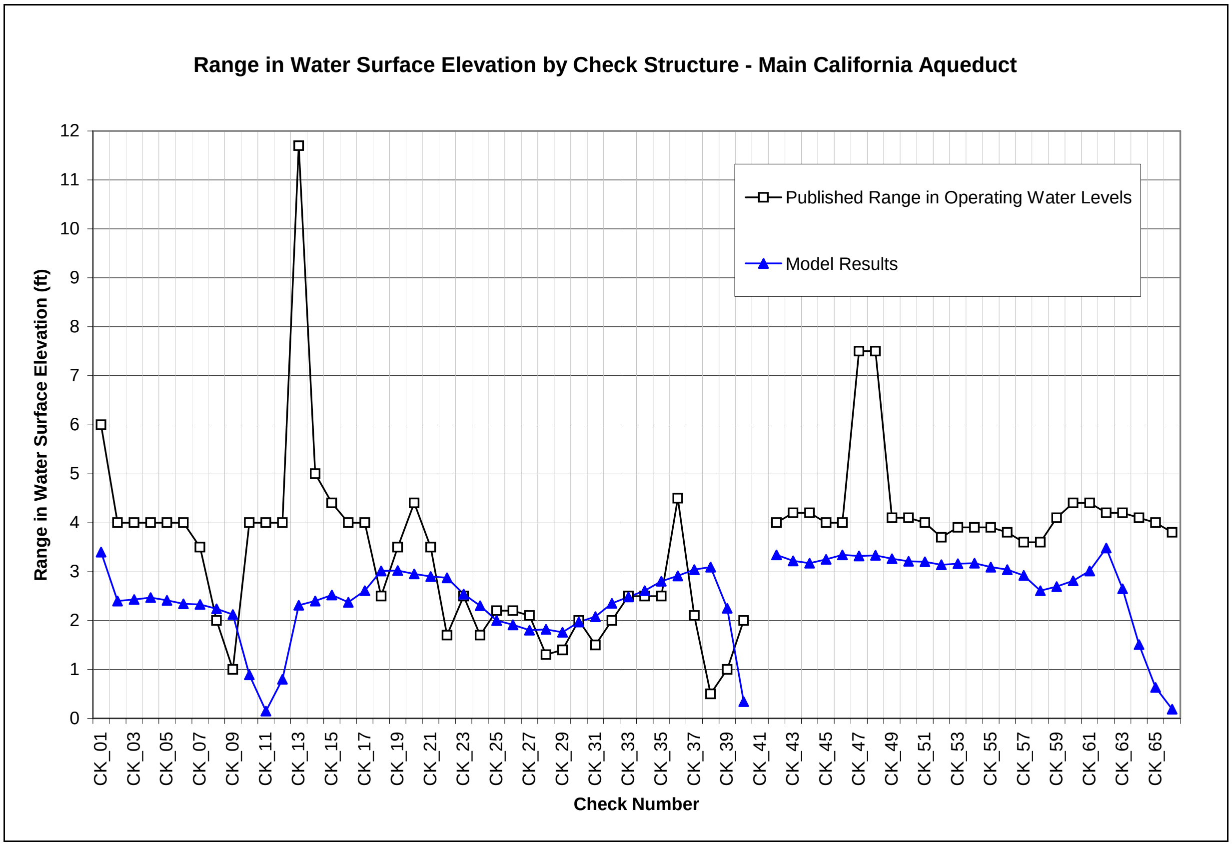

FIGURE 6-5
Summary of Range in Water Surface Elevations in California Aqueduct

Considering the importance of correctly representing the EC in San Luis Reservoir, the calibration effort included comparing the model predictions with the reported storage in San Luis Reservoir. Figure 6-6 presents this comparison, as well as the differences between the two records. Recall that in DSM2, the reservoirs are represented as vertical walled vessels, and thus the surface area is constant. In reality, San Luis Reservoir undergoes a considerable change in surface area throughout the year as the reservoir is drained in the summer months to provide water for deliveries downstream. Considering this limitation, the model provides a reasonable representation of the storage in the reservoir.

6.2 Salinity Calibration

The final parameter investigated during the calibration effort is salinity, or EC. Comparison between predicted EC and measured EC are presented below for various locations throughout the system. Plots are presented in both scatter format and time series format. To assist in the interpretation of model results, flows at certain locations in the system are provided.

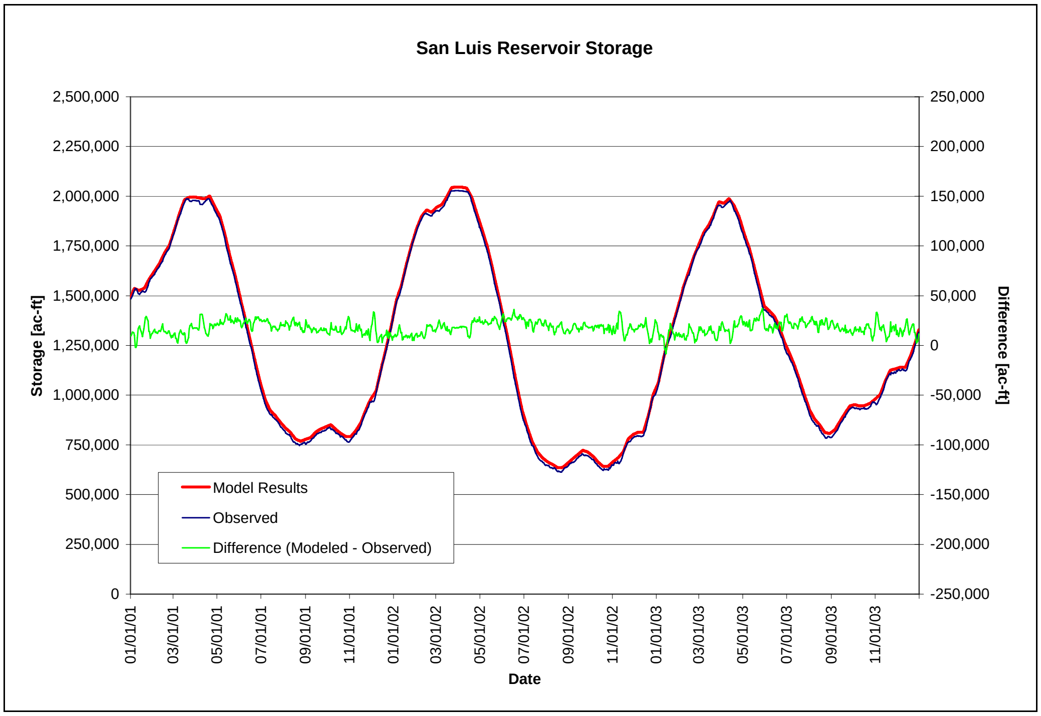

FIGURE 6-6
Comparison of Simulated San Luis Reservoir Storage and Historical Values

Figure 6-7 compares the model predicted EC in the San Luis Reservoir against the daily EC measured at the Pacheco Pumping Plant, which is located on the western (back) side of San Luis Reservoir. Data from the pumping plant is the only long-term data record available characterizing the EC in San Luis Reservoir. For lack of any other data against which to compare predicted EC in San Luis Reservoir, this data set is used. It must be understood that this gage is located in a shallower portion of the reservoir, away from the intake/outlet structure, and is thus not likely to be representative of average EC conditions in the entire reservoir.

In general, the model reproduces the measured trend in EC in San Luis, but tends to underestimate the salinity for the second half of the simulation period. The model begins to deviate from the measured data in June 2002. Interestingly, there is no reported inflow from O'Neill Forebay during this initial increase in measured salinity. Thus, some factor not included in the model is causing the increase in salinity observed in June 2002. By underestimating the EC in San Luis Reservoir, the model will by default underestimate the EC in O'Neill Forebay and the rest of the system downstream during periods when flow is being released from San Luis Reservoir.

Figure 6-7 shows that the model results exhibit less variation than the measured data because the model treats the reservoir as completely and instantaneously mixed, whereas in reality, the reservoir is not completely mixed. There are likely both vertical and lateral differences in salinity in the reservoir. As mentioned above, the measured data was collected in the back of the reservoir, and is thus likely to be more variable than the reservoir-averaged EC.

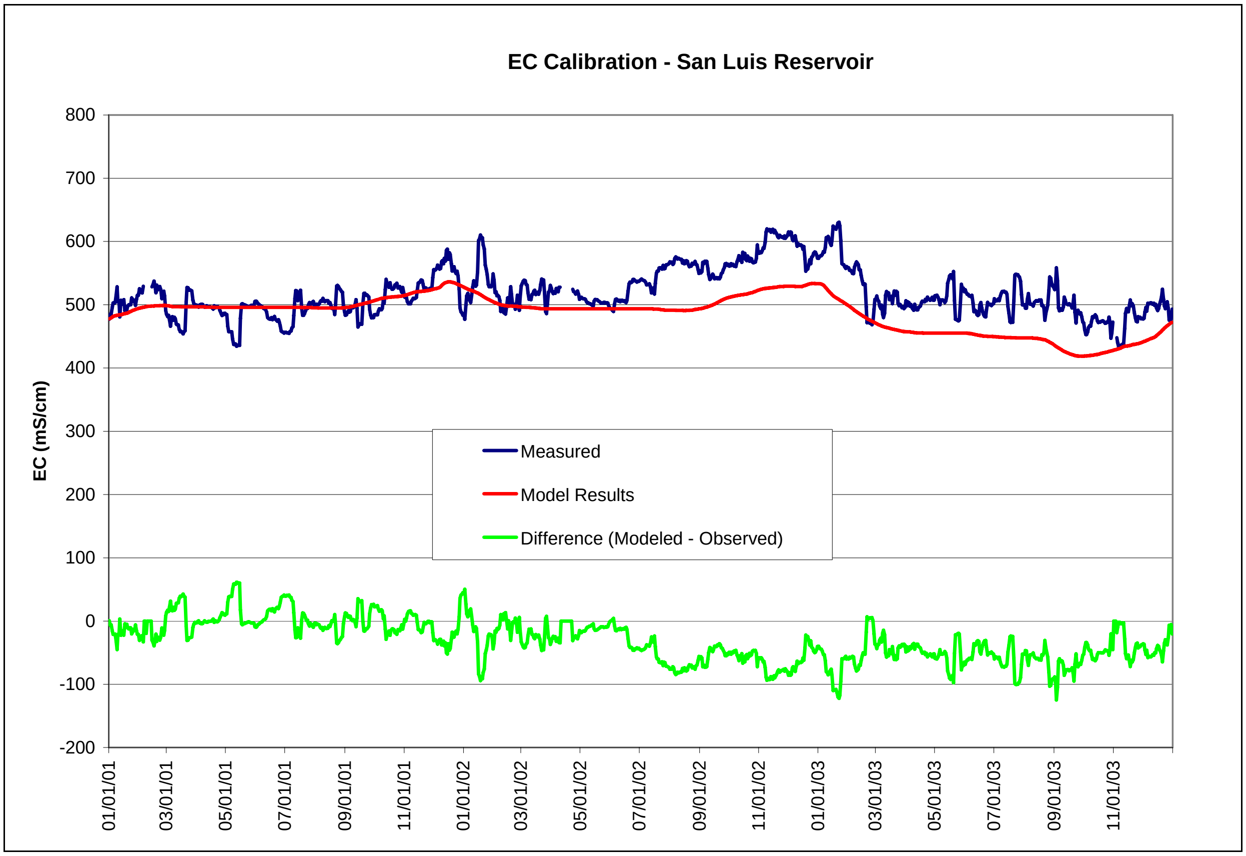

FIGURE 6-7
Comparison of Predicted and Measured EC in San Luis Reservoir

The measured EC often varies on the order of 10 or 20 percent in a few days. The variability in EC of San Luis Reservoir is not just a function of the EC in the water being pumped in from O'Neill Forebay, as demonstrated by Figure 6-8. For example, note the period beginning May 2001 where the inflow is near zero and the EC undergoes a decrease of 10 percent, a rapid increase in EC of 10 percent, and another prolonged decrease. Similar changes in EC without inflow from O'Neill Forebay are visible in the spring of 2002 as well. This supports the fact that there are other controlling influences on the salinity in San Luis Reservoir aside from flows from O'Neill Forebay. Because the current model does not account for the influence of freshwater runoff and evaporation on salinity in San Luis Reservoir, these short-term fluctuations observed at Pacheco Pumping Plant cannot be reproduced by the model.

Figure 6-9 presents the predicted and measured EC at Check 13, just downstream from O'Neill Forebay. Overall, the model does a good job of reproducing the measured EC. It tends to underestimate the higher EC levels in certain instances. The flows from San Luis Reservoir and the DMC into O'Neill Forebay are presented in Figure 6-10 along with the difference between modeled and measured EC. This figure shows periods when the differences between the model predictions and the measured values are evident. Note the correlation between the releases from San Luis Reservoir and differences between model predicted and measured values in April and May of 2003.

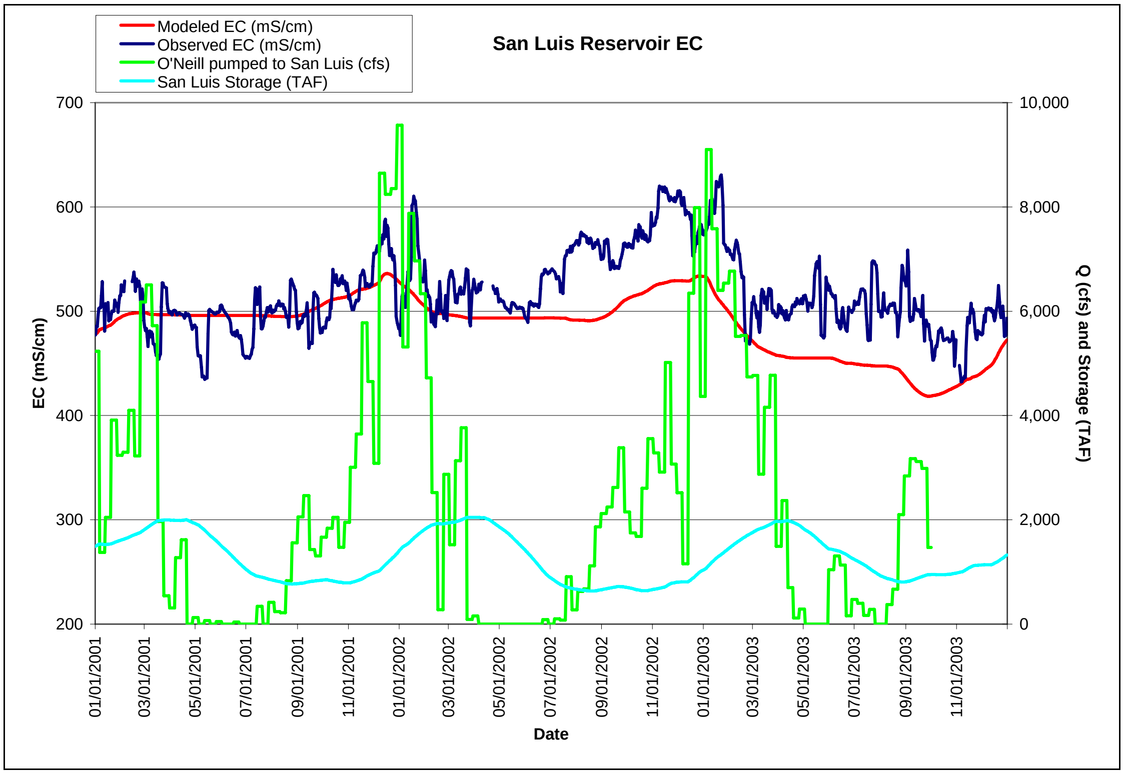

FIGURE 6-8
Comparison of Predicted and Measured EC at Check 13, Below O'Neill Forebay

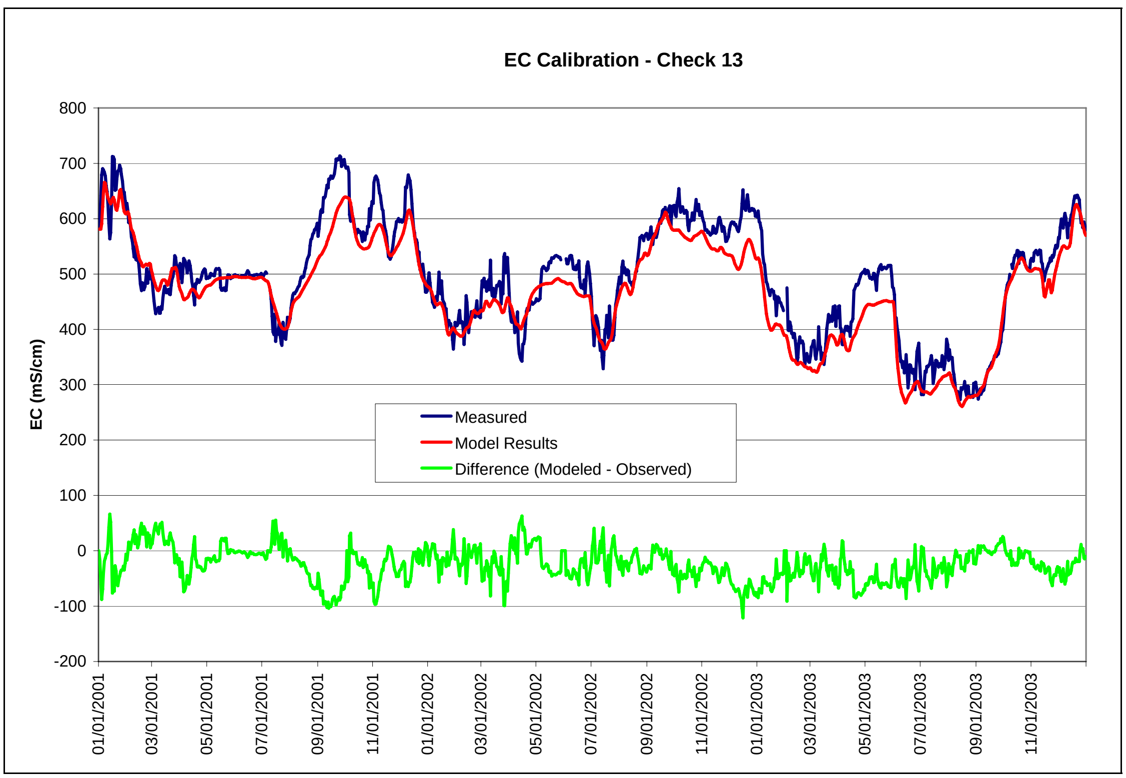

FIGURE 6-9
San Luis EC, Inflows, and Storage

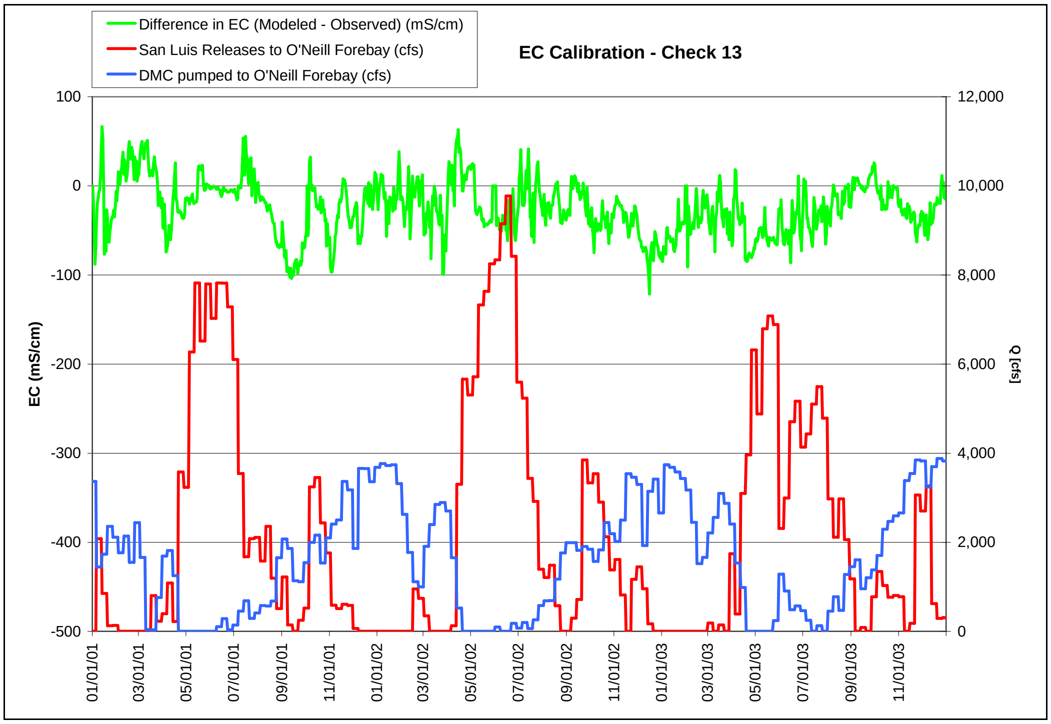

FIGURE 6-10
Comparison of Difference between Predicted and Measured EC at Check 13, Below O'Neill Forebay, to inflows to O'Neill Forebay from San Luis Reservoir and the DMC

Figure 6-11 presents the predicted and measured EC at Check 41. The plot is very similar to Figure 6-9, in that the model underestimates the predicted EC on average, and especially at the higher EC values.

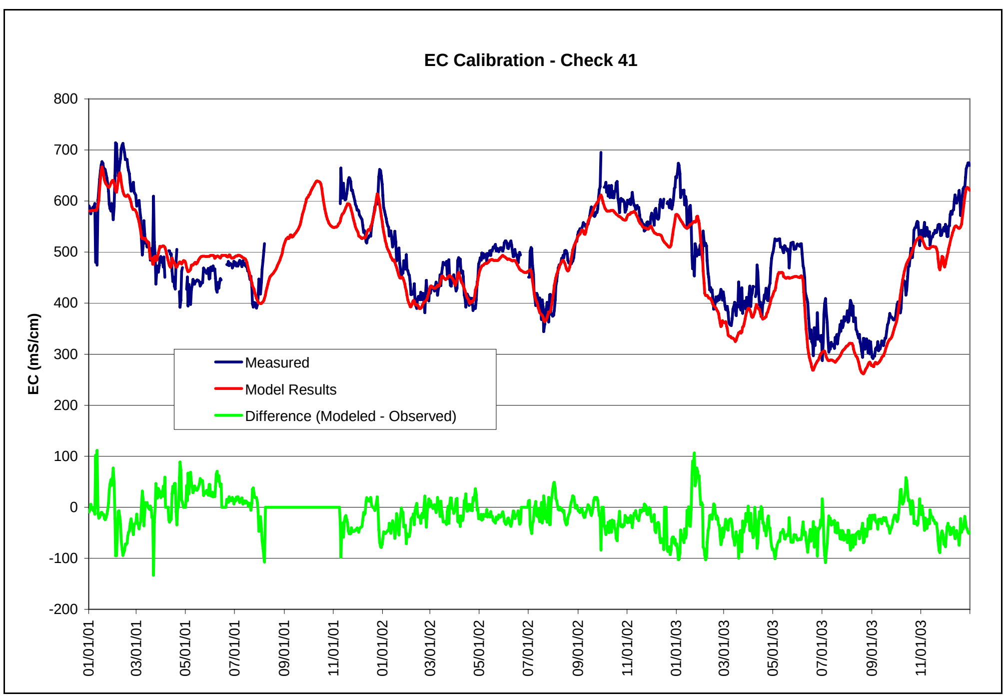

FIGURE 6-11
Comparison of Predicted and Measured EC at Check 41

Figure 6-12 presents the predicted and measured EC at Check 7 in the South Bay Aqueduct. The data quality for the observed EC is questionable in places, but the model does a good job of reproducing the overall trend of the measured data.

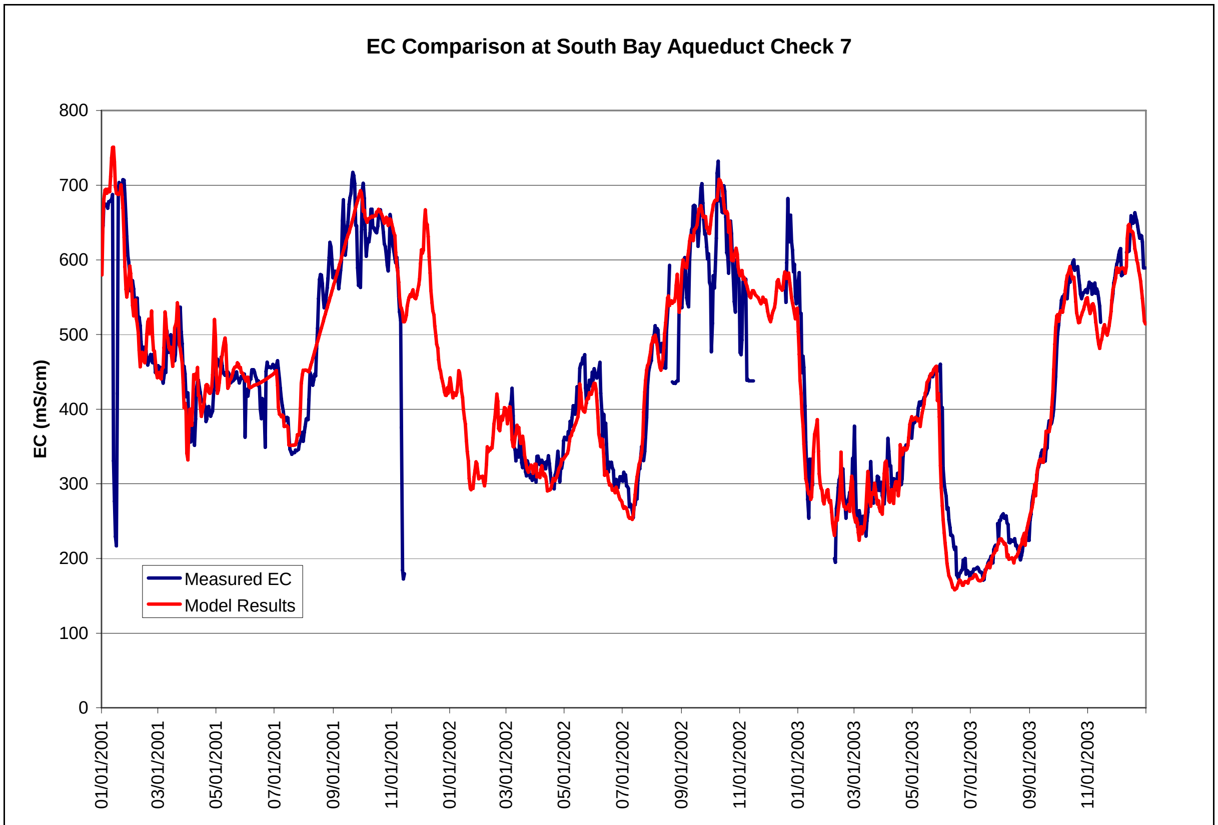

FIGURE 6-12
Comparison of Predicted and Measured EC at South Bay Aqueduct, Check 7

Figures 6-13 and 6-14 present scatter plots of predicted and measured EC at Check 13 and Check 41, respectively. Linear trend lines have been added to the plots to gage the quality of the calibration. The slope of the best-fit trend line provides a measure of the quality of the fit.

The slopes of both of the best fit lines are less than 1.0 indicating a slight bias in the model predictions. On average, the model predicted EC at Checks 13 and 41 is lower than the measured values. This bias is caused by the model's under prediction of EC in San Luis Reservoir and its effect on downstream aqueduct water quality.

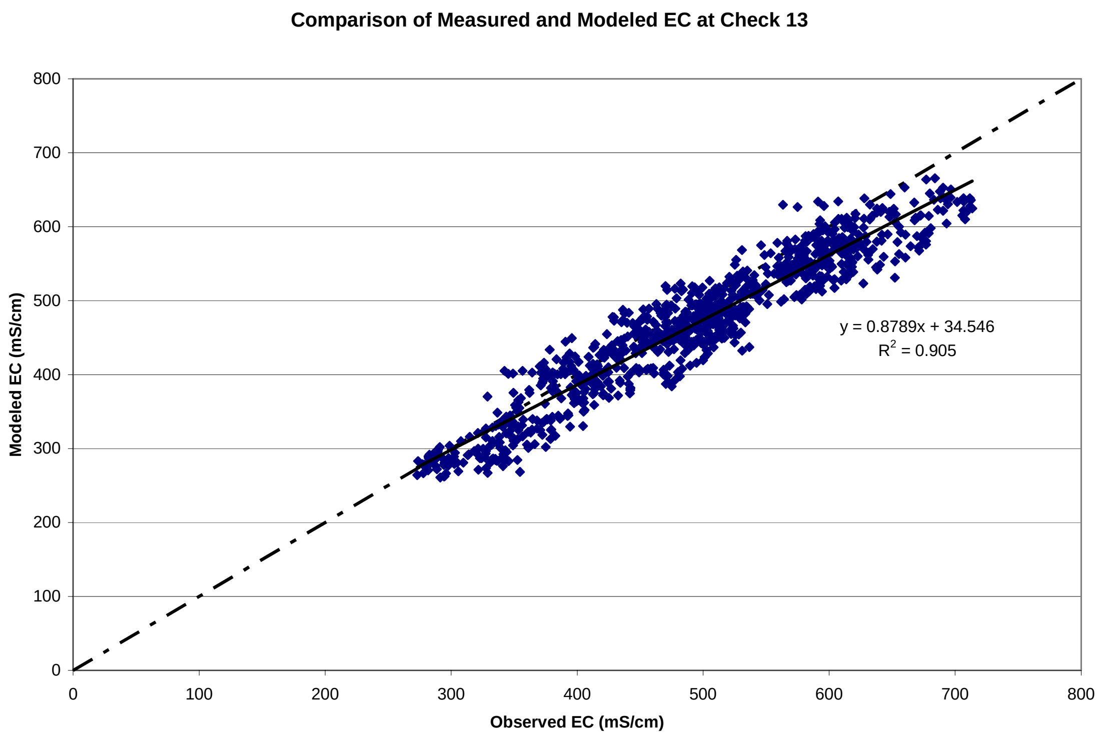

FIGURE 6-13
Scatter Plot of Predicted and Observed EC at Check 13 (daily)

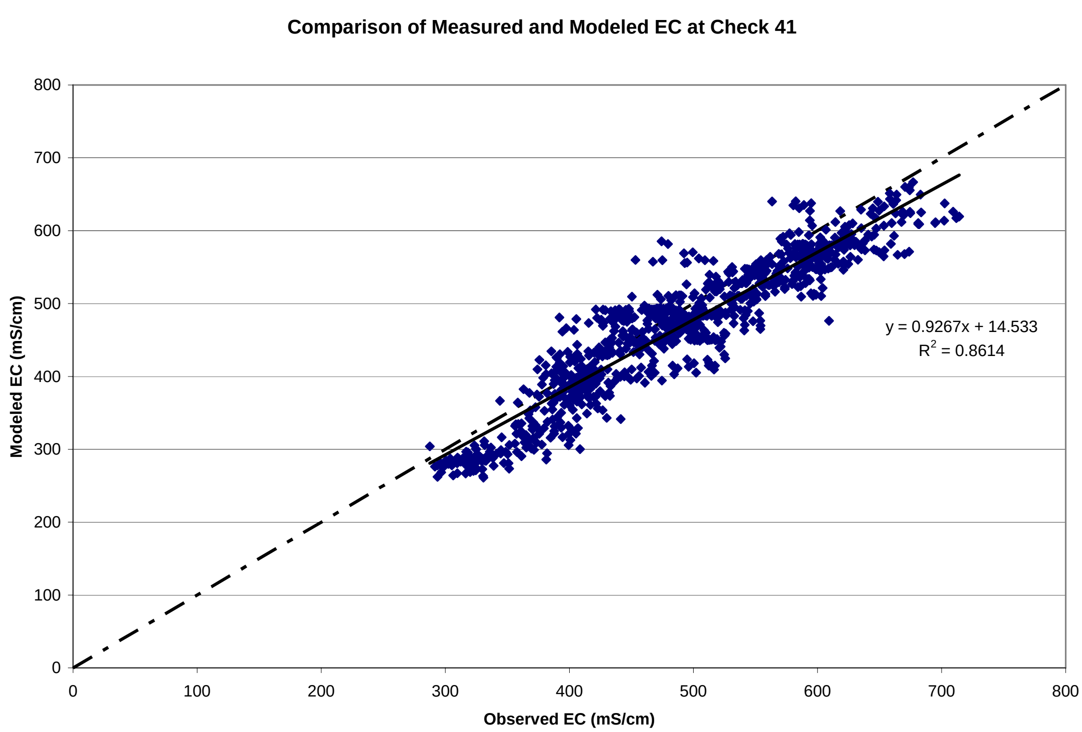

FIGURE 6-14
Scatter Plot of Predicted and Observed EC at Check 41 (daily)

6.3 Model Validation

This project did not conduct a model validation using a separate input set for a time period different from the calibration time period. Because of the limited data available, the entire dataset was used to conduct the model calibration. A wide range of expected flows and salinities is included in the three year simulation period. An alternative approach would have been to conduct two separate simulations instead of a single simulation. For example, the model could have been calibrated on 2002 data and then verified on 2003 data. It is a better use of the limited available data set and a stronger measure of model performance to run the calibration simulations for the three year continuous period.

6.4 Model Sensitivity Analysis

Several tests on model sensitivity were conducted in the process of developing the final calibration simulation. Tests were conducted to evaluate a range of gate specifications, namely weir length and weir crest elevation, and Manning's friction coefficients. Tests were also run to determine the model's sensitivity to the dispersion value. Results show little difference (<1 percent) for a tenfold change in the dispersion coefficient. This is reasonable considering the system is dominated by advection. The dispersion value used uniformly throughout the model is the same value used by DWR in the DSM2 Delta model. The quality of the salinity calibrations indicates appropriate use of the dispersion coefficients.

DSM2 is more applicable to advection dominated systems because the model allows for dispersion between model nodes, but does not allow for dispersive transport across a model node, only advective transport.

The model is quite sensitive to Manning's value. Initial model runs had a Manning's "n" value of 0.03 for the majority of the channels. The stage results for these simulations showed a range in elevation of up to 6 feet in certain locations. A Manning's "n" value of 0.02 showed improved results and maintains water elevations in a reasonable operating range. In certain channels, particularly those representing steeply sloping pipes, the Manning's value had to be increased to maintain model stability.

SECTION 7

Model Limitations

Several of the limitations that affect model calibration are a function of available measured data quality. These limitations will be less important when the model is run in planning and forecasting modes, where the system inflows and diversions will be specified and inherent data measurement errors associated with monitored values will not be a problem.

7.1 Water Balance

The data provided in the OCO monthly operations reports are used to construct a water balance for the system. Results of the water balance indicate probable measurement errors in some of the reported data. Closure terms were calculated to force the modeled system inflows and outflows to balance. These closure values are quite random in both time and location. The closure terms are assigned an EC concentration for the water quality simulations. This is considered a source of error because the closure flows are large enough at times to influence the predicted EC. This is an issue for the model calibration, but will not be an issue for the model when applied in either planning or forecasting mode.

7.2 Diversion Timing

The data quantifying diversions from the system are aggregated on a monthly basis. These data were used to specify the diversions in the model, and were assumed to remain constant over the month at a rate equal to the monthly total diversion converted into a flow rate. It is possible that the diversions are variable during the month. This is considered a limitation in the calibration, but would not affect planning and forecasting model applications.

Sometimes the timing of the diversions creates spurious spikes in model predicted flow, as discussed above. This is visible in calibration plots of flow in the southern portion of the aqueduct (i.e. Pearblossom Pumping Plant, Check 58). Again, this is considered more of an issue in model calibration, and could be eliminated by adjusting the timing of diversions and system flows to coincide more closely.

7.3 Reservoir Operations

The water quality in San Luis Reservoir has a controlling influence on the water quality in the Aqueduct below San Luis Reservoir when flows are being released from San Luis Reservoir. The ability to correctly reproduce water quality in San Luis Reservoir is very important. Currently, DSM2 treats reservoirs as completely mixed, vertical-walled bodies of water. This is considered a limitation in the current implementation and there is a need for further investigation into how to best represent San Luis operations.

7.4 Gate Operations

The gate operations currently in the model are simplistic. The check structures are modeled as broad-crested weirs, with the invert elevations fixed to control the minimum operating water surface elevation in each pool. Although this seems to work reasonably well for this application, the adoption of the new gate operations capabilities present in the yet-to-be-released database version of DSM2 will undoubtedly improve the ability of the model to simulate the flow through the check structures and resulting water surface elevation.

SECTION 8

Conclusions and Recommendations

8.1 Conclusions

A DSM2 model has been developed and calibrated for the California Aqueduct system, including the DMC, the South Bay Aqueduct, and the West Branch. The various branches of the model terminate at Silverwood Lake (East Branch), Pyramid Lake (West Branch), Mendota Pool (DMC), and the Santa Clara Tank (South Bay Aqueduct). 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, and the lack of data for stormwater and other episodic inflows to the system. The closure terms required to ensure a water balance, given the flow and delivery data provided, would not be required if the model were to be run in forecasting mode. In that case, all boundary conditions would be specified and no closure terms to correct for data inconsistencies would be required.

The other major limitation is the DSM2 representation of San Luis Reservoir as a completely mixed water body. It is clear from an analysis of the measured EC at the Pacheco Pumping Plant, along with the flows into San Luis Reservoir, that the system is quite complex. Further development of the treatment of San Luis Reservoir would be the first step in improving model performance.

8.2 Recommendations

There are several proposed recommendations to build on the capabilities of this newly developed modeling tool. These are described briefly below.

8.2.1 Gate Operations

DWR is currently testing a new version of DSM2, referred to as the Database version, which will have certain capabilities beneficial to the California Aqueduct applications. Chief among these capabilities is the ability to adjust gate operations based on the value of a variable in the system. For example, the new version of DSM2 will allow the flow through a gate to change if the water level upstream of the gate increases past a certain level. This simulation of gate operations will more closely mimic the actual system than the treatment of gates in the present application.

8.2.2 Link with Existing DSM2 Applications

The new Aqueduct model can be combined with the standard Sacramento/San Joaquin River Delta model and the recently constructed San Joaquin River extension model to provide a single model capable of modeling the impacts of recirculation operations on salinity in the Delta.

8.2.3 Tracer Tests for Determination of Travel Time

The calibration effort matched both flow and stage to either observed data or known operational constraints (stage). With both of these variables reproduced, and a proper representation of the physical channel geometry, the flow velocity must be correct as well. A series of model simulations could be used to determine the actual travel time of a tracer slug through the system for a variety of flow rates. A tracer slug could be added to the model at Banks, or at any other location through the system, and the time to reach various locations could be tabulated for a variety of flow rates. This could provide useful information for planning purposes or for reactions to spill scenarios.

8.2.4 Analysis of San Luis Reservoir Operations

It is recognized that the representation of San Luis Reservoir is very simplified in the current model. Future investigations could improve the predictive capability in San Luis reservoir by accounting for rainfall and evaporation and their impacts on salinity in the reservoir. Once the predictive ability is improved, model simulations can investigate potential changes in operations of San Luis Reservoir with the specific goal of lowering the annual average salinity in the reservoir.

8.2.5 Develop Planning Mode

The capacity to run the model in planning mode with CALSIM boundary conditions could be developed. This would entail the direct use of CALSIM output for the specification of boundary conditions, and would avoid the problems associated with the required use of closure terms and measured data. A preprocessor would have to be developed that disaggregates CALSIM's representation of diversions from the California Aqueduct and DMC and assigns them to appropriate nodes in DSM2.

8.2.6 Develop Forecasting Mode

A practical application of the DSM2 model of the California Aqueduct is to run the model in forecasting mode. This could provide estimates of water quality conditions throughout the system on a short term or long term basis. Forecasting simulations should be coordinated with current forecasting simulations by DWR for the Delta system.

The development of the forecasting tool would require a centralized manner in which to collect and process data required to run the DSM2 model. DWR has such a system in place to assist in running the DSM2 Delta model in forecasting mode. This system is comprised of instruments that record data specifying conditions at the boundaries of the model as well as current conditions throughout the delta, and telemeter the data to DRW for compilation, QA/QC, and formatting to match DSM2 input requirements.

In order to run the model in forecasting mode, several pieces of information are required, including:

- Specification of pumping plant inflows to the California Aqueduct and DMC systems
- Specification of diversions from the systems

- Specification of San Luis / O'Neill Operations
- Specification of water quality at Tracy and Banks
- Specification of any groundwater or other pump-ins to the system
- Specification of current conditions from which to initiate the model simulation

SECTION 9

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U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region, Central Valley Operations Office. (http://www.usbr.gov/mp/cvo/deliv.html).

APPENDIX A

Model Schematic

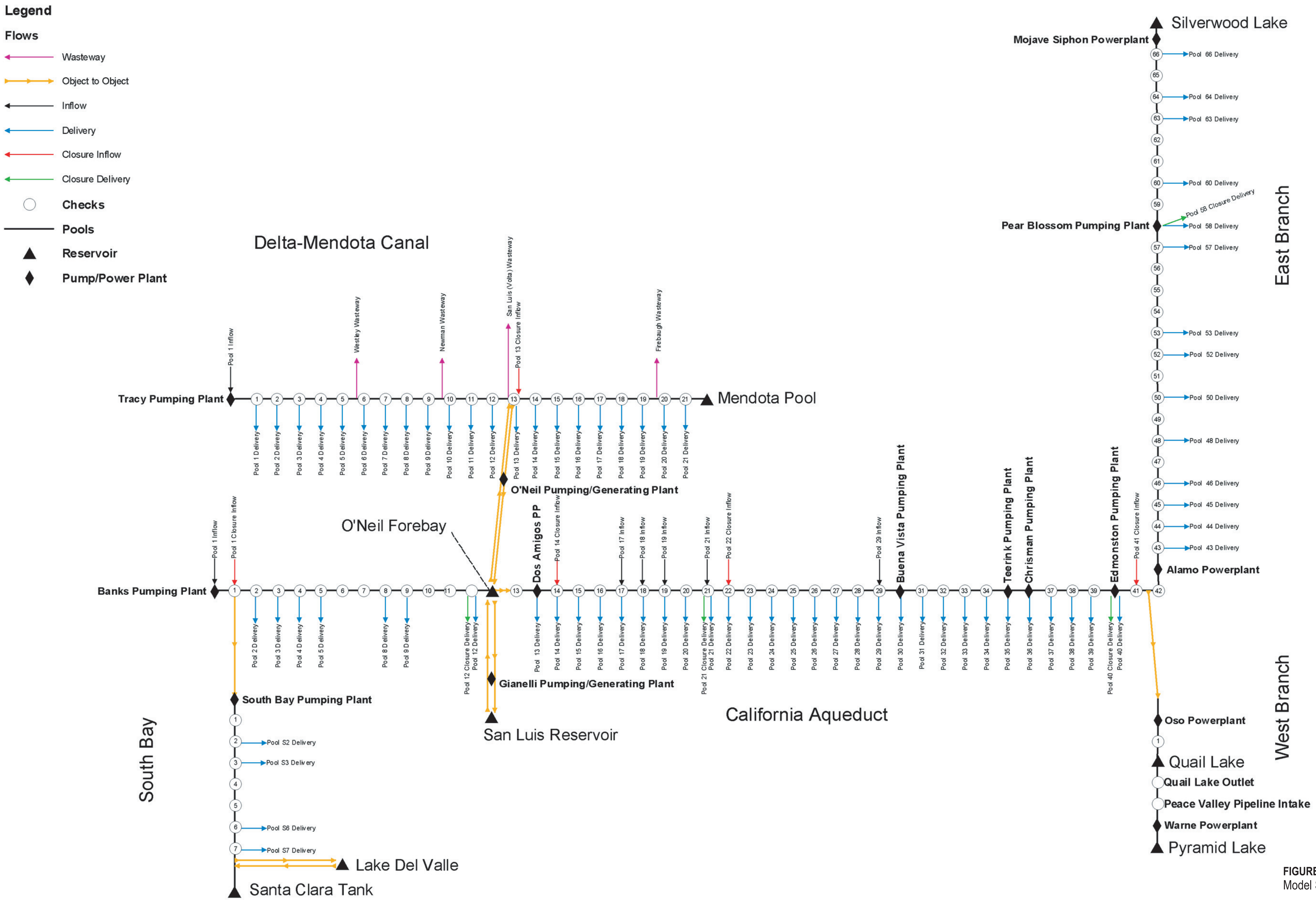

FIGURE A-1
Model Schematic

CH2MHILL

APPENDIX B

Aqueduct Channel Aggregation

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
1	400	Banks Pumping Plant	3.04	-28	100		
1		Discharge Lines	3.06	-12	1,370		
1		Canal	3.32	213.4	6,200		
1		Bethany Reservoir	4.49	213.4	7,400		
1	401	Check 1	5.95	214	280	13,880	401
2		Canal	5.98	211.9	31,840		
2	403	Check 2	12.01	210.5	190	32,030	402-403
3		Canal	12.04	210.4	32,980		
3	404	Check 3	18.29	208.7	190	33,170	404
4		Canal	18.33	208.6	29,900		
4	405	Check 4	23.99	207.2	190	30,090	405
5		Canal	24.03	207.1	30,090		
5	406	Check 5	29.73	205.6	190	30,280	406
6		Canal	29.76	205.5	23,610		
6	407	Check 6	34.24	204.4	190	23,800	407
7		Canal	34.27	204.3	29,760		
7	408	Check 7	39.91	203	190	29,950	408
8		Canal	39.94	202.9	31,810		
8	409	Check 8	45.97	201.4	190	32,000	409
8		End Delta Field Division	46				
9		Canal	46	201.3	27,920		
9	410	Check 9 / Orestimba Creek Siphon	51.3	200	520	28,440	410
10		Canal	51.39	199.4	28,870		
10	411	Check 10	56.86	198.1	450	29,320	411
11		Canal	56.94	197.7	23,540		
11	412	Check 11	61.4	196.7	190	23,730	412
12		Canal	61.44	196.6	27,730		
12	413	Check 12	66.71	195.3	285	28,015	413
12		End of Check 12	66.74				
13		O'Neill Forebay	66.74	195.3	21,390		
13		O'Neill Forebay Outlet	70.85	194.5	590		
13		Canal	70.9	192.2	83,221		
13		Forebay	86.67	192.2	259		
13	415	Dos Amigos Pumping Plant / Check 13	86.73	192.2	126	106,756	414-415
14		Discharge Lines	86.74	202	1,170		
14		Canal	86.96	308.7	29,570		
14		Lining Rise Transition	92.56	307.3	45		
14		Canal	92.57	307.3	13,140		
14	416	Check 14	95.06	306.7	280	43,035	416
15		Canal	95.11	306.6	12,700		
15		Lining Rise Transition	97.52	305.5	50		
15		Canal	97.53	305.5	40,650		
15		Lining Rise Transition	105.22	302.1	105		
15		Canal	105.25	302	17,190		
15	417	Check 15	108.5	300.5	310	71,005	417
16		Canal	108.56	300.5	820		
16		Panoche Creek Siphon	108.71	300.5	810		
16		Canal	108.87	299.6	5,470		
16		Invert Rise Transition	109.9	299.2	1,000		
16		Canal	110.09	301.2	16,290		
16		Invert Drop Transition	113.17	300.2	1,000		
16		Canal	113.36	298.9	27,800		
16		Lining Drop Transition	118.63	297.2	200		
16		Canal	118.67	296.4	17,980		
16	418	Check 16	122.07	295.2	300	71,670	418

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
17		Canal	122.13	295.1	34,820		
17		Lining Drop Transition	128.73	292.9	200		
17		Canal	128.76	292.9	22,100		
17	419	Check 17	132.95	291.4	290	57,410	419
18		Canal	133	291.3	54,010		
18	420	Check 18	143.23	293.1	310	54,320	420
19		Canal	143.33	293.9	9,100		
19		Lining Rise Transition	145.01	293.3	200		
19		Canal	145.05	293.3	55,900		
19	421	Check 19	155.64	289.5	320	65,520	421
20		Canal	155.7	289.3	47,450		
20	422	Check 20	164.69	288.4	280	47,730	422
21		Canal	164.74	288.2	28,170		
21		Lining Drop Transition	170.07	289.2	200		
21		Canal	170.11	289.2	12,060		
21	423	Check 21	172.4	289.6	240	40,670	423
21		End of Joint-Use Facilities	172.44				
22		Canal	172.44	286.5	52,533		
22		Lining Rise Transition	182.39	284.2	9,887		
22		Avenal Gap Siphon	184.27	284.2	360		
22		Canal	184.34	284.2	1,540		
22		Coastal Branch Junction	184.63	284.1			
22		Canal	184.63	284.1	1,016		
22	424	Check 22	184.82	284.1	160	65,496	424
23		Canal	184.84	285.3	53,305		
23		Lining Rise Transition	194.94	281.8	11,115		
23	425	Check 23	197.05	280.5	160	64,580	425
24		Canal	197.07	280.9	47,625		
24		Lining Rise Transition	206.1	278.7	9,715		
24	426	Check 24	207.94	278.3	160	57,500	426
25		Canal	207.96	278.2	12,400		
25		Transition	210.31	278.1	21		
25		Canal	210.31	279.2	39,420		
25	427	Check 25	217.79	278.8	160	52,001	427
26		Canal	217.81	279.5	13,030		
26		Temblor Creek Siphon	220.27	279	430		
26		Canal	220.36	278.5	24,040		
26	428	Check 26	224.92	277.7	160	37,660	428
27		Canal	224.94	277.6	35,800		
27	429	Check 27	231.73	276.4	160	35,960	429
28		Canal	231.75	276.3	25,900		
28		Transition	236.66	275.3	100		
28		Canal	236.67	276.6	7,520		
28	430	Check 28	238.11	276.4	180	33,700	430
29		Canal	238.13	277.3	33,760		
29	431	Check 29	244.54	276.1	180	33,940	431
30		Canal	244.56	276.1	25,790		
30		Transition	249.45	275.3	100		
30		Canal	249.46	273.1	7,660		
30		Forebay	250.92	273	390		
30	433	Buena Vista Pumping Plant / Check 30	250.99	279.5	124	34,984	432-433
31		Discharge Lines	251.01	273	920		
31		Canal	251.18	478.3	15,350		
31		Sandy Creek Siphon	254.09	477.2	300		
31		Canal	254.15	476.9	10,570		
31	434	Check 31	256.14	476.1	141	27,281	434
32		Canal	256.18	475.6	18,190		
32		Sunset RR Siphon	259.62	475.4	508		
32		Canal	259.72	474.9	10,440		
32	435	Check 32 Santiago Creek Siphon	261.72	474.8	390	29,528	435

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
33		Canal	261.77	474.8	13,690		
33		Los Lobos Siphon	264.36	474.4	340		
33		Canal	264.43	474.1	15,500		
33	436	Check 33 San Emigdio Creek Siphon	267.36	473.6	371	29,901	436
34		Canal	267.43	473.3	14,300		
34		Old River Road Siphon	270.14	471.1	394		
34		Canal	270.22	470.8	5,520		
34	437	Check 34 Pleitito Creek Siphon	271.27	469.9	343	20,557	437
35		Canal	271.33	469.6	35,500		
35		Forebay	278.05	470.3	380		
35	439	Teerink Pumping Plant / Check 35	278.13	480.9	124	37,504	438-439
36		Discharge Lines	278.15	474.8	1,500		
36		Canal	278.43	703.4	9,800		
36		Forebay	280.29	703.7	312		
36	440	Chrisman Pumping Plant / Check 36	280.36	703.7	143	12,335	440
37		Discharge Lines	280.37	686.7	2,080		
37		Canal	280.77	1223.5	16,750		
37	441	Check 37 Salt Creek Siphon	283.95	1221.1	387	19,217	441
38		Canal	284.01	1220.9	8,840		
38		Lining Drop Transition	285.69	1220.6	100		
38		Canal	285.71	1220.6	7,280		
38	442	Check 38 Grapevine Creek Siphon	287.09	1220.4	316	16,536	442
39		Canal	287.14	1219.2	16,140		
39	443	Check 39	290.21	1219.6	130	16,270	443
40		Canal	290.23	1219.5	9,920		
40		Pastoria Creek Siphon	292.1	1219.3	340		
40		Canal	292.16	1219.1	6,430		
40		Forebay	293.38	1218.9	380		
40	444	Edmonston Pumping Plant / Check 40	293.45	1171.2	400	25,170	444
41		Discharge Tunnels	293.46	1172	7,700		
41		Surge Tank	294.92	3094	50		
41		End of Surge Tank	294.93				
41		Tehachapi Tunnel No. 1	294.93	3090	7,930		
41		Siphon No. 1	296.43	3080.6	242		
41		Tehachapi Tunnel No. 2	296.47	3082.6	2,810		
41		Transition	297	3122	130		
41		Pastoria Siphon	297.03	3122	2,580		
41		Tehachapi Tunnel No. 3	297.52	3124	5,710		
41		Beartrap Access Structure	298.6	3124.5	315		
41		Porter Tunnel	298.66	3124.5	25,070		
41	447	Check 41 Tehachapi Control Structure	303.41	3078	210	45,047	445-447
42		Tehachapi Afterbay	303.45	3078	2,480		
42		Bifurcation, Begin West Branch	304.04	3078			
42		Canal	303.92	3078	5,650		
42	448	Check 42	304.99	3077.7	70	8,200	448
		Alamo Powerplant					
43		Intake and Penstocks	304.82	3057	4,780		
43		Alamo Powerplant	305.73	2932.5	141		
43		Afterbay	305.75	2932.8	1,380		
		Cottonwood Chutes					
43		Cottonwood Chute No. 1	305	3086.5	570		
43		Canal	305.11	3011.3	1,780		
43		Cottonwood Siphon	305.45	3011	354		
43		Canal	305.52	3010.5	709		
43		Cottonwood Chute No. 2	305.65	3010.4	530		
43		Canal	305.75	2946.6	12,500		
43		Box Siphon 1	308.12	2945.8	335		
43		Canal	308.18	2945.7	8,000		
43	450	Check 43	309.7	2945.2	140	20,975	449-450

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
44		Canal	309.73	2945.1	1,120		
44		Box Siphon 2	309.94	2945.1	185		
44		Canal	309.97	2945	9,170		
44		Box Siphon 3	311.72	2944.4	215		
44		Canal	311.75	2944.3	16,160		
44	451	Check 44	314.81	2943.4	140	26,990	451
45		Canal	314.84	2943.3	25,860		
45	452	Check 45	319.74	2941.7	140	26,000	452
46	453	Canal	319.76	2941.6	21,500	21,500	453
46		Check 46 Myrick Siphon	323.84	2940.4	1,175		
47		Canal	324.06	2939.8	14,326		
47	454	Check 47				15,501	454
		Willow Springs Siphon	326.77	2938.9	1,026		
48		Canal	326.95	2938.1	20,336		
48	455	Check 48				21,362	455
		Johnson Creek Siphon	330.82	2936.9	740		
49		Canal	330.96	2936.3	26,250		
49	457	Check 49	335.93	2934.8	113	27,103	456-457
50		Canal	335.95	2934.8	29,340		
50	460	Check 50				29,340	458-460
		Ritter Creek Siphon	341.51	2933.1	1,140		
51		Canal	341.71	2932.3	1,820		
51	461	Check 51				2,960	461
		Leona Creek Siphon	342.07	2932.2	1,940		
52		Canal	342.44	2931.9	6,898		
52	462	Check 52	343.74	2931.5	146	8,984	462
53		Canal	343.77	2931.3	23,241		
53	464	Check 53				23,241	463-464
		Soledad Siphon	348.17	2929.9	1,643		
54		Canal 21	348.48	2928.8	9,340		
54	465	Check 54	350.25	2928.2	146	11,129	465
55		Canal	350.27	2928	12,820		
55	466	Check 55				12,820	466
		Cheseboro Siphon	352.7	2927.2	1,020		
56		Canal	352.9	2925.6	9,850		
56	467	Check 56				10,870	467
		Littlerock Creek Siphon	354.76	2925	980		
57		Canal	354.95	2924.4	10,430		
57	468	Check 57	356.93	2923.7	113	11,523	468
58		Canal	356.94	2923.5	19,020		
58		Forebay	360.53	2922.4	280		
58	469	Pearblossom Pumping Plant / Check 58	360.61	2922	124	19,424	469
59		Discharge Lines	360.62	2900.5	6,780		
59		Canal	361.89	3465	8,570		
59		Tejon Siphon	363.51	3464.4	660		
59		Canal	363.66	3463.6	12,800		
59	470	Check 59				28,810	470
		Big Rock Creek Siphon	366.09	3462.7	7,690		
60		Canal	367.54	3460.7	33,760		
60	471	Check 60	373.94	3458.1	342	41,792	471
61		Canal	374.02	3457.8	26,375		
61	472	Check 61	379	3455.9	125	26,500	472
62		Canal	379.06	3455.3	27,650		
62	473	Check 62	384.26	3453.4	125	27,775	473
63		Canal	384.29	3452.7	27,540		
63	474	Check 63	389.5	3450.8	125	27,665	474
64	475	Canal	389.51	3450.1	29,440	29,440	475
64		Check 64 Siphon	395.1	3448	420		
65		Canal	395.18	3447.3	27,130		
65	476	Check 65				27,550	476

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
		Antelope Siphon	400.32	3445.4	3,870		
66		Canal	401.05	3439.4	12,440		
66	477	Check 66				16,310	477
		Mojave Siphon	403.41	3438.5	161		
66		Check 66	403.41	3438.5			
		Mojave Siphon Powerplant					
67		Penstocks	403.44	3423.6	11,600		
67		Mojave Siphon Powerplant	405.65	3182	105		
67		Discharge Line	405.67	3160.5	582		
67		Tunnel	405.78	3301.5	764		
67		Slide Gate-Portal	405.92	3305.3	95		
67	478	Silverwood Lake	405.94	3305.8		13,307	478
		South Bay					
		Bethany Reservoir					
S1		South Bay Pumping Plant	0	220	64		
S1		Discharge Lines	0.01	242.8	4,040		
S1	601	Surge Tanks	0.78	728	17	4,121	601
S1		Brushy Creek Pipelines	0.78	740	13,073		
S1	602	Back Surge Pool	3.26	763.9	93	13,166	602
S1		Dyer Canal	3.28	778.3	3,360		
S1		Dyer Check Siphon 1	3.91	777	86		
S2		Dyer Canal	3.93	776.6	68		
S2	603	Dyer Altamont Check Siphon 2	5.21	773.8	16	3,530	603
S3		Altamont Pipeline	5.21	773.8	11,300		
S3	604	Highway 580 Tunnel	7.35	705.7	950	12,250	604
S3		Livermore Canal	7.53	706	10,329		
S3	605	Patterson Check 3	9.49	704	36	10,365	605
S4		Alameda Canal	9.49	703.9	1,393		
S4		Patterson Pass Road Siphon	9.76	703.7	171		
S4		Alameda Canal	9.79	702.9	4,649		
S4	606	Lupin Check 4	10.68	702	60	6,273	606
S5		Alameda Canal	10.69	702	8,481		
S5	607	Arroyo Seco Check Siphon 5	12.29	700.3	410	8,891	607
S6		Alameda Canal	12.36	699.1	1,476		
S6		Tesla Road Siphon	12.64	698.8	121		
S6		Alameda Canal	12.67	698.1	10,455		
S6	608	Arroyo Mocho Check Siphon 6	14.65	696	935	12,987	608
S7		Alameda Canal	14.82	693.8	8,190		
S7	609	Del Valle Check 7	16.38	692.2	60	8,250	609
S8		Del Valle Pipeline	16.39	472.5	11,860		
S8		Arroyo Road Meter	18.16	513.5	—		
S8	610	Del Valle Branch Junction	18.63	475.5	—	11,860	610
S8		Del Valle Pipeline	18.63	475.5	7,020		
S8	611	La Costa Tunnel	19.96	656.7	5,380	12,400	611
S8		Sunol Pipeline	20.98	648	36,300		
S8	612	Mission Tunnel	27.86	593.1	3,510	39,810	612
S8		Santa Clara Pipeline	28.52	589.3	38,730		
S8		Santa Clara Meter	35.86	444.4	—		
S8	613	Santa Clara Pipeline	35.86	444.4	29,180	67,910	613
S8	614	Terminal Pipeline	41.38	186	4,530	4,530	614
S8		Santa Clara Terminal Reservoir	42.24	458	160		
		West Branch					
42		Bifurcation	304.04				
42		Oso Canal	0	3078	2,560		
42		Oso Siphon	0.49	3082.6	420		
42		Oso Canal	0.57	3082.6	4,680		
42		Forebay	1.45	3082.3	238		
42	701	Oso Pumping Plant	1.49	3082.3	107	8,005	701

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
W1		Discharge Lines	1.52	3072.5	2,036		
W1		Quail Canal	1.9	3309.5	14,460		
W1	702	Quail Lake Inlet 1	4.64	3308.6	206	16,702	702
W2		Quail Lake	4.68	3287.2	7,344		
W2	703	Quail Lake Outlet	6.07	3288.3	747	8,091	703
W2	704	Lower Quail Canal	6.21	3286.7	10,760	10,760	704
W2		Peace Valley Pipeline Inlet	8.25	3286.7	394		
W2		Peace Valley Pipeline	8.33	3264.8	28,880		
W2		Penstock	13.79	2633.7	1,460		
W2	705	Warne Powerplant 2	14.07	2586	140	30,874	705
W3	707	Pyramid Lake	14.1	2555.5	25,300	25,300	706-707
		Delta Mendota Canal					
1	100	End of Pipes	3.50	176.83			
1	101		4.45	176.58	5000	5000	101
1	102		5.39	176.33	5000	5000	102
1	103		6.34	176.08	5000	5000	103
1	104		7.29	175.83	5000	5000	104
1	105		8.23	175.58	5000	5000	105
1	106		9.18	175.33	5000	5000	106
1	107		10.13	175.08	5000	5000	107
1	108		11.08	174.83	5000	5000	108
1	109	Check 1	11.35	174.76	1448	1448	109
2	110		12.30	174.51	5000	5000	110
2	111		13.24	174.26	5000	5000	111
2	112		13.70	174.14	2408	2408	112
2	113		14.65	173.89	5000	5000	113
2	114		15.59	173.64	5000	5000	114
2	115	Check 2	16.19	173.48	3147	3147	115
3	116		17.14	173.23	5000	5000	116
3	117		18.08	172.98	5000	5000	117
3	118		19.03	172.73	5000	5000	118
3	119		19.98	172.48	5000	5000	119
3	120	Check 3	20.63	172.31	3443	3443	120
4	121		21.58	172.06	5000	5000	121
4	122		22.52	171.81	5000	5000	122
4	123		23.47	171.56	5000	5000	123
4	124	Check 4	24.43	171.3	5064	5064	124
5	125		25.38	171.05	5000	5000	125
5	126		26.32	170.8	5000	5000	126
5	127		27.27	170.55	5000	5000	127
5	128		28.22	170.3	5000	5000	128
5	129		29.16	170.05	5000	5000	129
5	130	Check 5	29.82	169.88	3459	3459	130
6	131		30.77	169.63	5000	5000	131
6	132		31.71	169.38	5000	5000	132
6	133		32.66	169.13	5000	5000	133
6	134		33.61	168.88	5000	5000	134
6	240	Westley Wasteway	34.23	168.72	3288	3288	240
6	135	Check 6	34.42	168.67	1000	1000	135
7	136		35.37	168.42	5000	5000	136
7	137		36.31	168.17	5000	5000	137
7	138		37.26	167.92	5000	5000	138
7	139		38.21	167.67	5000	5000	139
7	140	Check 7	38.68	167.54	2493	2493	140
8	141		39.63	167.29	5000	5000	141
8	142		40.57	167.04	5000	5000	142
8	143		41.52	166.79	5000	5000	143
8	144		42.47	166.54	5000	5000	144
8	145		43.41	166.29	5000	5000	145

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
8	146	Check 8	44.26	166.07	4462	4462	146
9	147		45.21	165.82	5000	5000	147
9	148		46.15	165.57	5000	5000	148
9	149		47.10	165.32	5000	5000	149
9	150		48.05	165.07	5000	5000	150
9	151	Check 9	48.62	164.92	3021	3021	151
10	152		49.57	164.67	5000	5000	152
10	153		50.51	164.42	5000	5000	153
10	154		51.46	164.17	5000	5000	154
10	155		52.41	163.92	5000	5000	155
10	156		53.35	163.67	5000	5000	156
10	260	Newman Wasteway	54.22	163.44	4571	4571	260
10	157	Check 10	54.41	163.39	1000	1000	157
11	158		55.36	163.14	5000	5000	158
11	159		56.30	162.89	5000	5000	159
11	160		57.25	162.64	5000	5000	160
11	161		57.77	162.5	2717	2717	161
11	162	Check 11	58.28	162.37	2717	2717	162
12	163		59.23	162.12	5000	5000	163
12	164		60.17	161.87	5000	5000	164
12	165		61.12	161.62	5000	5000	165
12	166		62.07	161.37	5000	5000	166
12	167		63.01	161.12	5000	5000	167
12	168		63.50	160.99	2574	2574	168
12	169	Check 12	63.99	160.86	2574	2574	169
13	170		64.94	160.61	5000	5000	170
13	171		65.88	160.36	5000	5000	171
13	172		66.83	160.11	5000	5000	172
13	173		67.78	159.86	5000	5000	173
13	174		68.72	159.61	5000	5000	174
13	175		69.00	159.54	1453	1453	175
13	176		69.25	159.47	1320	1320	176
13	280	San Luis (Volta) Wasteway	69.82	159.32	3013	3013	280
13	177	Check 13	70.01	159.27	1000	1000	177
14	178		70.96	159.02	5000	5000	178
14	179		71.90	158.77	5000	5000	179
14	180		72.85	158.52	5000	5000	180
14	181		73.80	158.27	5000	5000	181
14	182	Check 14	74.40	158.11	3179	3179	182
15	183		75.35	157.86	5000	5000	183
15	184		76.29	157.61	5000	5000	184
15	185		77.24	157.36	5000	5000	185
15	186		78.19	157.11	5000	5000	186
15	187		79.13	156.86	5000	5000	187
15	188	Check 15	79.64	156.73	2667	2667	188
16	189		80.59	156.48	5000	5000	189
16	190		81.53	156.23	5000	5000	190
16	191		82.48	155.98	5000	5000	191
16	192		83.43	155.73	5000	5000	192
16	193		84.37	155.48	5000	5000	193
16	194	Check 16	85.09	155.29	3776	3776	194
17	195		86.04	155.04	5000	5000	195
17	196		86.98	154.79	5000	5000	196
17	197		87.93	154.54	5000	5000	197
17	198		88.88	154.29	5000	5000	198
17	199		89.82	154.04	5000	5000	199
17	200	Check 17	90.54	153.85	3776	3776	200
18	201		91.49	153.6	5000	5000	201
18	202		92.43	153.35	5000	5000	202
18	203		93.38	153.1	5000	5000	203
18	204		94.33	152.85	5000	5000	204
18	205		95.27	152.6	5000	5000	205
18	206		96.22	152.35	5000	5000	206

Appendix B
Aqueduct Conveyance Facilities Table 1

Pool No.	DSM2 Node	Feature	Mile Post	Invert Elev. (ft)	L	Canal L [ft]	DSM2 Channel
		CA Aqueduct Main Stem					
18	207	Check 18	96.81	152.2	3106	3106	207
19	208		97.76	151.95	5000	5000	208
19	209		98.62	151.72	4557	4557	209
19	210		99.57	151.47	5000	5000	210
19	211		100.51	151.22	5000	5000	211
19	212		101.46	150.97	5000	5000	212
19	213		102.41	150.72	5000	5000	213
19	214		103.35	150.47	5000	5000	214
19	215		104.30	150.22	5000	5000	215
19	216	Check 19	105.06	150.02	4003	4003	216
20	217		106.01	149.77	5000	5000	217
20	218		106.95	149.52	5000	5000	218
20	219		107.90	149.27	5000	5000	219
20	220		108.85	149.02	5000	5000	220
20	221		109.79	148.77	5000	5000	221
20	222		110.74	148.52	5000	5000	222
20	300	Firebaugh Wasteway	111.07	148.43	1736	1736	300
20	223	Check 20	111.26	148.38	1000	1000	223
21	224		111.55	148.3	1531	1531	224
21	225		112.50	148.05	5000	5000	225
21	226		113.44	147.8	5000	5000	226
21	227		114.05	147.64	3200	3200	227
21	228		115.00	147.39	5000	5000	228
21	229		115.94	147.14	5000	5000	229
21	230	Check 21	116.48	147	2830	2830	230

APPENDIX C

Previous Deliverables and Meeting Notes

Delta Simulation Model II: California Aqueduct and Delta Mendota Canal Extension

Project Kickoff Meeting March 9, 2004

ATTENDEES:	Tara Smith (DWR) Parviz Nader (DWR) Rob Tull (CH2M HILL) C.Dee Dillion (SWC) Paul Hutton (MWDSC) Armin Munevar (CH2M HILL)	Robert Leaf (CH2M HILL) Rich Breuer (DWR) Kyle Winslow (CH2M HILL) Sanjay Pahuja (CH2M HILL) Rob DuVall (DWR)
PHONE PARTICIPANTS:	Tony Ludzius (MWDSC) Rich Losee (MWDSC)	Karen Murphy (MWDSC) Lisa Holm (CCWD)

Introduction

Paul Hutton gave a brief description of the history and the context for this project. The project is a part of the Real-Time Data and Forecasting (RTDF) initiative that is being implemented by the State Water Contractors (SWC)/Metropolitan Water District (MWD), with the objective of developing programs for monitoring, forecasting, and dissemination of data pertaining to water supply and water quality.

In view of their increased reliance on the State Water Project, the SWC realize the importance of developing forecasting capabilities in regards to the water supply from the California Aqueduct. The California Aqueduct model currently used by MWD has amply demonstrated the utility of a forecasting tool for short- and long-term operations and planning. The objective of this specific project is to develop a DSM2-based model for the California Aqueduct and the Delta Mendota Canal. This model could be integrated with the DSM2 model for the San Francisco Bay Delta, and will also provide a platform for development of the various monitoring and forecasting capabilities envisaged in the RTDF initiative.

The project is being funded by the SWC. For budgetary reasons, the project will be executed in two phases: Phase I (through the end of the current financial year: March – end of June), and Phase II (July – end of October).

Availability of DSM2-Database Version (DSM2-DB)

Rob Tull enquired about the availability of the DSM2-DB version for this project. Tara Smith said that DWR is currently using the DSM2-DB version internally and is in the process of conducting quality assurance tests. Gate triggering capabilities are functional in DSM2-DB, although some other features that may be required for this project (pump lifts, for example) are not functional yet. The DB version could be provided to CH2MHILL within a period of two weeks. This version is based on the FireBird relational database system, and would require an installation of this system. The DSM2-DB version may be ready for public release by the end of 2004.

Tara Smith expressed DWR's preference that this project be executed with the DSM2-DB version. She also clarified that this version is based on the same computational engine as the current DSM2 model.

Rob Tull expressed concern that working with the Beta version of DSM2-DB may result in unforeseen delays to the project schedule. Paul Hutton and Dee Dillon confirmed that they are cognizant of the possibility of such delays and noted that there is flexibility in the existing schedule if the application of the new Beta version were to delay model development.

Technical Approach

Kyle Winslow gave an overview of the technical approach, and described the major issues in the hydrodynamic and water quality modeling of the California Aqueduct. He noted that the current DSM2 version doesn't have the capability to model the gate operations on the California Aqueduct, and the significant potential benefit of the gate triggering capabilities of the DSM2-DB version. He also outlined the various possible approaches for modeling the San Luis and O'Neill Forebay reservoirs in the model, and solicited input from the group on this subject. Paul Hutton and Rich Breuer suggested that the results from the reservoir models previously developed for MWD could indicate the required level of detail in modeling the reservoirs. Rich Losee could be approached for information in this regard. Paul Hutton also indicated that a screening-level modeling of the reservoirs would be acceptable in view of the limited scope and schedule of the current project. Tony Liudzius offered to provide the report on the modeling of San Luis reservoir.

Parviz Nader stressed the importance of understanding the California Aqueduct system and operations, before deciding on the appropriate modeling approach. He also suggested examining the availability of data that could be used for the calibration and validation of the model, before deciding on the appropriate level of modeling detail.

Tara Smith and Rob Leaf pointed out that access to the required data in certain cases might be hampered by the increasing security concerns. It was suggested that requesting data directly from the field divisions might be more fruitful than making an official request to the agencies

Armin Munevar asked Tony Liudzius, about the applicability of the calibration approaches used for the California Aqueduct model development. Tony responded that neither the calibration runs nor the data used for calibration were available any more.

Paul Hutton recommended that the calibration and validation for the model closely follow the methodologies and guidelines employed by the DWR for DSM2 calibration in the delta.

Kyle Winslow mentioned that a combination of field and numerical tracer studies would be very useful in validating the system model. Dee Dillon noted that SWC might consider funding such studies in the future.

Information Needs

Sanjay Pahuja enumerated the data needs of this project. The data can be broadly categorized as: physical/systems data; operational criteria and procedures; hydraulic and water quality data. The last category includes time-series data that are required as inputs for the model, such as diversions and inflows to various project reaches, as well as time-series data that would be required for calibration and validation. In addition, the access to the following models and associated documentation would be very helpful: The California Aqueduct Model, the COLOSSUS Model, the FORTARN-based hydraulic model of the California Aqueduct, and the UNET Model developed for the Arroyo Pasajero Project.

The following is a list of contacts (noted by the meeting participants) that may be able to assist with the data needs:

- Art Hinojosa (DWR)
- Curtis Creel (DWR)
- John Lehigh (DWR)
- Craig Trombley (sp?) (DWR-SWAPO)
- Ghassan Alqaser (DWR)
- Alan Stroppini (USBR)
- Lloyd Peterson (USBR)
- Alan Piney (sp?) (USBR)
- Frances Mizuno (SLDMWA)

Publications/Websites

- State Water Project Data Handbook
- California Bulletin 200 (several volumes)
- Milepost at Structure Sites, Delta-Mendota Canal
- CDEC website
- SWP O&M website

Dee Dillon pointed out that there are no standard/codified operating rules and procedures for the California Aqueduct, and that the operations are guided by the experience and the skills of the operators. This underscores the need for the modelers to thoroughly understand the operations, and to devise a simple yet accurate representation for modeling the operations in this project. In view of the substantial size and diversity of the data requirements, it was recommended that the data-collection efforts be initiated as early as possible.

Action Items

Tara Smith – Check on the availability of DSM2 Beta version

Rich Breuer – Check on contacts with DWR-SWAPO and DWR-O&M (Also, locate copy of SWP Facilities Document)

Tony Liudzius – Procure San Luis reservoir modeling report

Progress Report on Data Collection for DSM2 Extension to California Aqueduct

PREPARED FOR: Paul Hutton

PREPARED BY: Kyle Winslow/SDO

COPIES: Rob Tull/SAC
Toshio Kyosai/SFO
Amy Watson/SDO

DATE: July 2, 2004

Introduction

This memo summarizes efforts to date regarding the data collection for the extension of DSM2 down the California Aqueduct and the Delta Mendota Canal. The geometric, operational, and hydraulic data collected and analyzed to date as part of Tasks 1 through 4 is discussed, and a brief summary of the construction of the preliminary model grid is included.

Data Collection

A large amount of data has been collected, summarized, and analyzed for use in this project. The data primarily resides in both EXCEL and ACCESS databases. All time series data will be transferred to HEC DSS databases using tools enabling the direct export of data from EXCEL to DSS format. The data currently in house includes, but is not limited to:

- Geometric data specifying the location of structures along the California Aqueduct and Delta Mendota Canal, including check structures, pumping plants, powerplants, turnouts, turn-ins, etc.
- Hydraulic data summarizing daily pumping through each of the pumping plants in the system (1990-2003)
- Monthly and annual delivery data at each turnout along the California Aqueduct (1990-2003)
- Monthly and annual delivery data at each turnout along the DMC (1993-2002)
- Monthly groundwater pump-in data along the California Aqueduct (from SuperCAMP and limited to 1990-1993)
- Monthly computed losses by Field Division (Table 22 in SWP Operation Data Monthly reports)

Data has been obtained from several sources, including:

- California Aqueduct Strip Maps
- DWR State Water Project Data Handbook (Blue Book)
- Delta Mendota Canal Milepost at Structure Sites

- Discussions with Curtis Creel, Chief Operations Planning Branch, and Terry Dennis, Chief Dispatcher at DWR Operations and Maintenance
- State Water Project Monthly Operations Data Reports
- State Water Project Annual Operations Data Reports
- CVO Operations Monthly Data Reports
- DWR's SCADA (ISR) Database (Sporadic, high resolution data 2001 to 2004)
- SuperCAMP Model Database

Water Balance

The first step in the application of the DSM2 model is to understand all components of the water balance. A complete water balance will be finalized before any DSM2 simulations are performed in order to remove any sources of error from the modeling study associated with improperly specified boundary conditions.

The water balance calculations began with electronic versions of the monthly SWP Operations Data Reports generously provided by Michael Nolasco at DWR. This 14 year database, originally supplied in individual files for each month, was transformed into a time series format for use in the calculations. The individual diversions specified in the reports were aggregated by aqueduct pool, aqueduct reach, and by contractor. The aggregated deliveries will be used as boundary conditions for initial model simulations.

The water balance has been completed for 1996 to 2003. Initial data obtained for years 1990 to 1995 was incomplete, and thus the water balance began in 1996. The missing data was eventually received, but the potential for focusing on the late 1990's for calibration, coupled with the extensive effort required to reformat the data, contributed to the decision to hold off for now on constructing the historic water balance from 1990 to 1995.

Calibration Period

An evaluation of the available data records was conducted to determine the data periods available for the calibration and verification of the model. Consistency with the latest IEP DSM2 calibration is desired. In 2000, the IEP conducted a recalibration of DSM2 for the period 1990 to 1999. The focus of that calibration effort was 1997-1998. The initial thought is that a similar calibration period will be used for the new DSM2 grid. The calibration dataset will use the most recent data practical, as there are constantly changes to the system and increases in the amount and quality of available data.

Model Schematic

A representative DSM2 grid schematic has been developed and is presented in Figure 1. This schematic is preliminary in nature, and presents the overall coverage of the grid. The schematic is not geo-referenced and is not to scale. The grid covers the Delta Mendota Canal from Tracy to the Delta Mendota Pool, the California Aqueduct from Banks to Silverwood Lake on the East Branch and Pyramid Lake on the West Branch, and the South Bay Aqueduct from the South Bay Pumping Plant to the Santa Clara (Terminal) Tank.

The schematic currently has one channel for every aqueduct pool, with the pools defined by check structures, pumping plants, or other major features. The schematic currently represents a single net diversion for each channel. It is not practical to show every diversion on the model schematic, and it is likely that there will be multiple diversions in some of the model channels. The relative amount of each diversion, as compared to the flow in the channel, will be used to determine the appropriateness of aggregating diversions in each particular channel. Aggregations will be made only where doing so would not significantly alter the travel time through that channel. For example, if the Westlands Water district has two large diversions spaced a considerable distance apart in a given channel, the two diversion would not be aggregated in order to maintain each diversion's influence on the velocity of flow in the channel. Theoretically, there will be a change in velocity downstream of each diversion location. The CALSIM schematic was consulted in the development of this grid to insure a seamless connection between CALSIM and DSM2 for use in future planning studies

DSM2 Irregular Cross Sections

An EXCEL-based tool has been developed to automate the generation of ASCII files depicting irregular (non-rectangular) cross sections for use in DSM2. For Delta applications, where geo-referenced bathymetric data is available, the Cross Section Development Program (CSDP) is generally used to generate the ASCII files. For the aqueduct application, the cross sections are trapezoidal in nature, and geo-referenced data is not readily available. The tool references a table of cross section parameters, namely base width, side slope, and height, and then constructs two cross section files for each channel in the model domain. The computed cross sections are located at 5 percent and 95 percent of the channel lengths. Channels are defined such that the cross section geometry is constant for the entire channel length. Figure 2 presents a screen capture of the cross section generating tool.

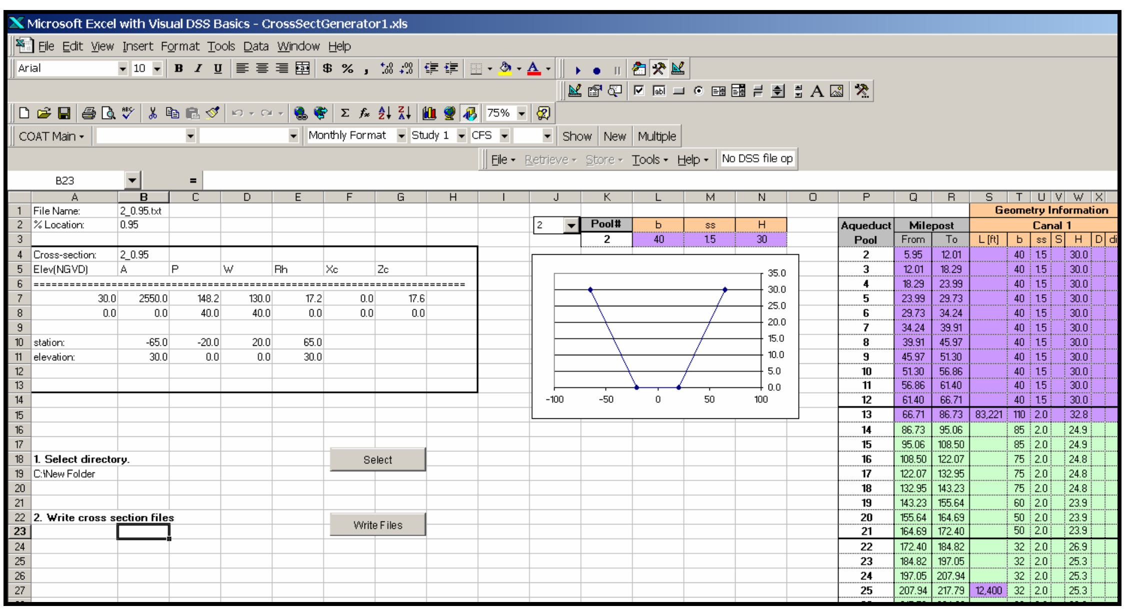

FIGURE 2
Screen Capture of Cross Section Generating Tool

Next Steps

We are working with CVO to set up a meeting as soon as possible to discuss Delta Mendota Canal operations and obtain any additional operations data that is available. We hope to have this meeting by mid-July.

The water balance calculations and thus the boundary specifications for preliminary DSM2 simulations are being reviewed for completeness and consistency. Final checks are being made to compare monthly deliveries by contractor, aggregated on an annual basis and geometrically on a pool and Field Division basis, with published annual deliveries by contractor and field division.

We hope to receive the electronic data files for the South Bay Aqueduct and East Branch models from DWR next week and incorporate this information into the DSM2 model.

Based on whether the DSM2 database version of the model will be available to us in the future, we will need to assess model formulation alternatives for simulation of the check structure, siphon, and pump station operations.

DSM2—California Aqueduct and Delta Mendota Canal Extension Project

Delta Mendota Canal Operations Meeting – July 12, 2004

ATTENDEES:		
	Paul Fujitani/CVO	Paul Hutton/MWD
	Liz Kiteck/CVO	Parviz Nader/DWR
	Joe Martin/SLDMWA	Rob Tull/CH2M HILL
	Graig Grace/CVO	Kyle Winslow/CH2M HILL
	Tom Morstein-Marx/CVO	Toshio Kyosai/CH2M HILL

Introduction

The purpose of this meeting was to meet with the operations staff to collect information on the available data and to develop an understanding of the physical system and its operational criteria.

Project Overview

Paul Hutton gave a contextual overview for the DSM2-California Aqueduct and DMC Extension project. DWR's Municipal Water Quality Investigation (MWQI) program is progressing in the direction of real-time data and forecasting (RTDF) of short- and long-term water quality. For the State Water Contractors, the primary water quality parameters to be simulated by the DSM2 model are bromide and organic carbon. Therefore, the primary interest of this project is to extend the water quality forecasting, which is available with the current DSM2 version, to the California Aqueduct and DMC. A possible future application of this model could include DMC recirculation studies where this model would be connected with the other Delta and San Joaquin DSM2 modules.

O'Neill Forebay and San Luis Reservoir Modeling

After the initial overview of the project by Paul Hutton, Paul Fujitani inquired about the extent of modeling involved in this project regarding the hydrodynamics and water quality of O'Neill Forebay and San Luis Reservoir. Paul Hutton answered that detailed modeling of O'Neil Forebay and San Luis Reservoir will not be the focus of the project. A simplified model may be developed in the future to address these incomplete mixing and short-circuiting issues. Kyle Winslow outlined a potential option to address these issues by modeling the reservoir as two distinct reservoirs, one representing the effective volume and the other representing the passive or ineffective volume.

Current and Potential Future Uses of DSM2 by CVO

Rob Tull asked if DSM2 Delta model results (i.e. stage data, WQ data) are used currently by CVO to assist their operations and planning decisions. Paul Fujitani answered affirmatively and mentioned that it would be valuable if the operators could see the water quality forecast down the California Aqueduct and DMC for a week ahead and evaluate how the operations can be adjusted such as using blending options. Paul Hutton explained that the primary purpose of the project is to assist operations and planning for individual contractors and to be able to forecast the water quality up to 6 months in advance.

Data Collection Progress to Date

Kyle Winslow summarized the DMC data collected to date. (Summarized in the attached handout distributed at the meeting.)

Unmet Outstanding Data Needs

Kyle Winslow explained the data needs that remain unmet to date. (Also summarized in the handout distributed at the meeting.)

DMC Physical Data

Kyle Winslow described the data needs pertaining to channel geometry, specifically channel inverts and changes implemented post-1985. Joe Martin explained that linings were raised in low areas where subsidence had occurred. Subsidence was typically a couple of feet, and the linings were fixed when the canal was dewatered. The last dewatering occurred in 1998. Joe suggested that we should talk with Jim Goodwin in Design and Construction (MP200) to obtain further information.

Wasteways

Kyle Winslow first mentioned that the wasteways would be modeled as diversions from the canal, thus the detailed physical and geometry information would not be necessary. However, Paul Hutton explained that they might have to be explicitly simulated if this model would be used for the recirculation project to provide the connection with San Joaquin module. Joe Martin said that Volta and Firebaugh wasteways are unlined, Westley is lined with 125 cfs capacity, and Newman is partially lined. Information is available on the Design Configuration List.

Discussion of DMC Operations

Velocity

Joe Martin explained that the velocity at the gate is 0.5 fps/unit. The operators need to use check gates to maintain the head below 4 units. The depth of the canal should be maintained at 16.5-17.5 feet. The operators use the Orifice flow equation shown below to calculate the flow rate. Flow rate is a function of the height differentials. A coefficient of 0.75 is used for all the checks. Joe Martin's group keeps historical differential data at each check.

$$Q = CA\sqrt{2gh}$$

The water volumes are measured by SCADA for the first 13 checks and these gates are controlled automatically. The subsequent checks are controlled manually. SCADA records water surface elevation upstream and downstream of each check, flow through the checks, gate position data, and delivery data.

Daily Delivery Data

Joe Martin mentioned that he has an EXCEL spreadsheet with daily delivery data by milepost back to 1975. However, Joe advises against using the data that are more than 10 years old because of subsequent changes, including land use and pump upgrades, and allocation policies.

Kyle Winslow asked about the daily variability of the data. Joe answered that the operation is different day to day. The contractors are mandated to report the amount of water they plan to take each day, which they do not always do.

Kyle Winslow also asked about the data inconsistencies in CVO's operations report regarding district names over the period. Joe Martin explained that data from 10 districts (Davis WD, Foothill WD, Hospital WD, Kern Canon WD, Mustang WD, Orestimba WD, Quinto WD, Romero WD, Salado WD, and Sunflower WD) were combined in May 1995 when the districts merged into Del Puerto WD. Joe will check with Bob Martin (Bob did the last update) at the administration office to obtain the most up-to-date (2 or 3 years old) list of contractors.

Groundwater Pump-ins

For modeling the canals more accurately, it is necessary to know the amount of water entering into the DMC from groundwater sources. Joe Martin mentioned that much groundwater was used in the past, but most pumps have since been shut down due to the tighter water quality regulations. Only three to four wells pump into the canal.

This year pump-ins occurred following the levee break in the Delta. Most of the pump-ins are located in the Mendota pool. When they pump, they record salinity, bromide, EC and TOS data monthly. Last month during the levee break, Del Puerto pumped 100 acre feet into the DMC, and SLWD pumped 166 acre feet. In 2003 (March-Feb calendar year), a total of 765 acre-feet of groundwater was pumped into the DMC.

Losses

Joe Martin explained that losses due to seepage and evaporation along the canal are not explicitly measured. Differences between meter readings and the measured deliveries are used to estimate losses, which average 4,000 – 5,000 acre feet/month. The largest loss in the historic record was about 26,000 acre feet in a single month. June 2004 recorded 8,370 acre feet of loss. These losses are considered to be insignificant compared to the average export of 215,000 acre feet /month.

Occasionally, there are gains of water in winter months, indicating more inflow than losses associated with evaporation and seepage. Usually, low creek flows bypass the system. Conversely, high flows occasionally overshoot, and excess water flows into DMC, typically below check 12 (Salado creek near Patterson).

Travel Time

Joe Martin explained that the travel time from Tracy pumping plant to O'Neill Forebay is approximately 4 hours if the gates are in water from 3 to 4 units levels and about 12 hours if the pools are empty.

Gates at Checks

Joe Martin explained that each check has three gates. These gates measure 20 inches for checks 1-13 and 18 inches for checks 14-23.

O'Neill Forebay and San Luis Operations

Joe Martin and Graig Grace explained that San Luis operations are maintained by Graig's group. Everyday, Joe's group gives Graig's group a projected desired volume of water from San Luis over the following 5 days, and Graig's group adjusts pumping and power generation at San Luis accordingly.

The elevation of O'Neill Forebay is maintained by the SWP in conjunction with Dos Amigos Reservoir. The SWP attempts to maintain the Forebay's elevation between 218 ft and 225 ft, although exceptions occur. This elevation range translates to approximately 6,000 acre feet of water.

DMC Meters

Joe Martin explained that every turnout is metered. Flow verification is performed periodically at check 13 and 1 mile above check 21. Head work flows are measured once a month. USGS also performs checks twice a year. Authority periodically measures flows at check 13 and 21 to validate.

Exchange between CVP and SWP

Tom Morstein-Marx expressed a concern about modeling pumping/generation operations. He explained that there is sometimes exchange of water between the CVP and SWP to help the pumping/generation.

Operation of Large Flow Changes

Joe Martin explained that the gates are operated sequentially during significant flow change over a short period of time, such as during the VAMP period. In these events, gates are usually operated in series with 2 or 3 checks at a time. It takes about 4 hours for the water to travel from Tracy pumping plant to O'Neill Forebay. It takes about 30-35 minutes for Check 1 to see the changes. These operations are usually performed at 7 AM and are completed within 4 hours. He mentioned that their operations can react to flow changes fairly quickly.

Hourly Variation with Tides

Joe Martin explained that pumping capacity at Tracy of each of the 6 Tracy units varies from 800 to 1,000 cfs. There are 3 siphon breakers for the six units, each with a capacity of 50 cfs. Thus, they have an ability to control the flow by up to 150 cfs when all pumps are turned on.

CVO Report of Operations

Liz Kiteck mentioned that the delivery data in "CVO Report of Operations" have errors during September through November period. Grasslands deliveries are reported from both the DMC and the Mendota pool, thus the numbers are counted twice. Liz has been correcting these errors, but has yet to complete the QA. Liz will provide the updated data to Kyle.

Action Items / Data Needs for CH2M HILL

- Joe Martin will provide his EXCEL database containing daily delivery data at turnouts for 1975-present.
- Joe Martin will check with Bob Martin at the administration office about the most up-to-date list of contractors and the most recent structures list.
- Joe Martin will provide historical head differential data for each check.
- CH2MHILL will contact Jim Goodwin in Design and Construction (MP200) to obtain channel geometry information (including the latest channel invert elevations) on DMC as well as information (cross section shape, length) on the four wasteways.
- CH2MHILL will request hourly pumping data from Seth Harris.

DSM2—California Aqueduct and Delta Mendota Canal Extension Project

Project Status Update – July 13, 2004

ATTENDEES:

Paul Hutton/MWD	Rob Tull/CH2M HILL
Tara Smith/DWR	Kyle Winslow/CH2M HILL
Parviz Nader/DWR	Toshio Kyosai/CH2M HILL

Introduction

This memo summarizes the project status update meeting on July 13, 2004. CH2MHILL presented the project status, and the potential approach to calibration and validation periods was discussed. The current status of the DSM2 database version was also discussed. The meeting also included discussion of future direction and schedule.

Progress to Date and Discussions

Physical System Data and Geometry

Kyle Winslow gave an overview of the data that has been collected and processed to date. (Specifics are summarized in the attached handout from the meeting.)

Channel geometry information for the California Aqueduct were taken from the 1997 "State Water Project Data Handbook (bluebook)" since the electronic version of the 2003 bluebook was not available. The data consistency between these two versions will be checked and corrected as necessary. Channel geometry information for the Delta Mendota Canal (DMC) was taken from CVO's "Milepost at Structure Sites: Delta – Mendota Canal - 1985."

Kyle discussed the need to develop an approach to simulating tunnels and siphons, etc. If DSM2 is not capable of specifically modeling these, one possibility would be to use effective velocities through these structures. These siphons can be as large as 18′ diameter barrels as seen in South Bay Aqueduct and in some cases are pressurized as well.

An Excel-based tool was developed by CH2MHILL to automate the generation of ASCII files depicting irregular (non-rectangular) cross sections for use in DSM2.

Hydraulic Data

Kyle Winslow reported that the monthly and annual delivery data at each turnout along the California aqueduct and DMC is available in various formats including contract basis, pool basis and reach basis for the period of 1996-2003. Processing this data was time-consuming due to the variations in data formats provided. CH2M HILL has the data in house to extend these calculations back to 1990 should the need arise.

Instead of concentrating evaporation in only a few locations, it will be back calculated and distributed evenly throughout the pools based on surface area.

DWR assisted CH2MHILL in obtaining SCADA database information including hydraulic information along the California Aqueduct. This data contains both flow and water surface elevations upstream and downstream of every check in the system. The goal is to use this data to develop rating curves for use in DSM2. The head data can also be used to calculate losses through the check structures.

Only a limited amount of information for groundwater pump-ins has been available to date. Groundwater pump-ins will be ignored in the initial calibration and verification.

Grid Schematic

Kyle Winslow distributed and presented a representative DSM2 schematic for the California Aqueduct and Delta Mendota Canal. This schematic is preliminary in nature, and presents the overall coverage of the grid. The schematic is not geo-referenced and is not to scale. The schematic currently has one channel for every aqueduct pool, with pools defined by check structures, pumping plants, or other major features. The schematic currently represents a single net diversion for each channel. It is not practical to show every diversion on the model schematic, and it is likely that there will be multiple diversions in some of the model channels. The schematic can be updated easily and quickly.

Kyle Winslow asked Parviz about the capability to have a reservoir as the downstream end to the system (i.e. Pyramid Lake or Silverwood Lake). Parviz suggested that it may be necessary to add an arbitrary channel downstream of the reservoir that has a stage boundary on its downstream end.

Node Numbering Convention

Parviz Nader and Tara Smith suggested that the Aqueduct module conform to the numbering convention used by the DSM2 Delta and San Joaquin modules. The San Joaquin module's numbering starts with a number greater than the largest number in Delta module. Therefore, the Aqueduct module should start with a number greater than the largest number in San Joaquin module.

Parviz mentioned that the array setting in the DSM2 source code might have an upper limit as to the number of nodes it can hold. If the maximum number in the array has to be changed, DSM2 execution file would need to be recompiled. Parviz will check with Eli Ateljevich regarding this.

Parviz also expressed concern that the average distance between two nodes in the proposed schematic of approximately 7 miles may be too large. He explained that the recent Sacramento Deepwater Ship Channel modeling done by CH2MHILL showed oscillation in the initial results because there was not enough information between nodes. He explained that the only information that is passed from Hydro to Qual modules is nodal velocity and elevation contained in the tide file. No intermediate (mid-channel) data is passed from HYDRO to QUAL.

Paul Hutton commented that having node numbers match check numbers as shown in the proposed schematic would be convenient. Parviz added that node numbering sequence has no effect on execution speed, therefore having nodes that correspond to check numbers and having extra nodes in-between that do not necessarily follow the check numbers in order to provide more information is possible. (For example: **1**-1001-1002-1003-**2**-2001-2002-2003-**3**… with 1, 2, 3 being check structure nodes and 1001, 2001, etc being additional information nodes.)

Wasteways

Paul Hutton requested including wasteways in the model. Wasteways do not have to be modeled in detail, but need to provide a connection point with the San Joaquin module for potential future integrated analyses. CH2MHILL will coordinate with DWR regarding the connection with San Joaquin module. Tara Smith does not think the San Joaquin module includes any inlets from wasteways. Rob Tull requested a San Joaquin module schematic from Tara. Upon receipt of geometry information depicting the wasteways, CH2M HILL will add the wasteways to the model.

Check Set Program

Rob Tull mentioned that Curtis Creel's group would provide the new logic being developed for the gates operations in California Aqueduct.

Model Calibration and Validation Period

Kyle Winslow recommended choosing one year for calibration/validation from recent history rather than using data from 1990-1993, which has traditionally been used for DSM2 Delta Module calibration/validation. The rationale behind favoring more recent data is that there are constantly changes to the system and increases in the amount and quality of data available. Data quality should be taken into account when setting the calibration / validation periods. Currently, the dataset for 1996-2001 has been collected and processed and more data could be processed if necessary to extend the data period back to 1990-1993.

The goal of the project is to correctly reproduce travel time through the system for the full range of inflow conditions. With regard to the adequate time period that would capture a full range of hydrodynamic and water quality conditions, Kyle mentioned that one year could be chosen that covers the majority of conditions expected in the system. Unlike the Delta region where the mixing and tidal influences are complex, the Aqueduct is relatively simple in the sense that the water pumped from the Delta simply flows down the canals one-dimensionally. Preceding conditions are also not as important in the Aqueduct as compared to the Delta, except for San Luis Reservoir and O'Neill Forebay.

To demonstrate this, Kyle compared the EC data for the 1986-1995 period (from SuperCAMP model input dataset) and for the 2001-2004 period (from California Data Exchange Center (CDEC) data). During these periods, January 1990-June 1993 and January 2001-June 2004 were focused on for discussion. The range of EC from upstream to downstream along the canal is generally small for both periods. The various fluctuations seen in the 1990-1993 period can be captured by the 2001-2004 period although the 2001-2004 period showed slightly lower EC values.

Paul Hutton expressed concern over not using a similar data period to what was used for the original DSM2 Delta module calibration and validation (1990-1994). He explained that in order to gain acceptance from the general public it might be necessary to test the Aqueduct model over the same period the Delta model was tested.

Parviz Nader and Tara Smith suggested using periods where EC is transitioning (ramping up or down) for calibration/validation. Parviz recommended verifying the travel time, Manning's coefficient, losses, and other sources of water entering the canal if the model results do not match closely with the recorded data. He also suggested using the boundary conditions at the upstream and downstream, by introducing a dummy channel at the lower end to provide this boundary. Tara added that the object-to-object technique in DSM2 could be used to represent this dummy channel. This technique will allow a certain volume of water to travel from one node to another instantaneously.

Rob Tull said that CH2MHILL would compile a recommendation describing a proposed period for calibration/verification, available data set during the period, and the reasons for selecting the period.

DSM2 Database Version Status Update

Tara Smith provided an update on the status of DSM2 database version development. The DSM2 database version is now being converted from a Firebird to an Access database. Its performance is now being evaluated against the Delta historical condition. The model will have the capability to adjust gate operations based on stage elevation. The DSM2 database version is still being tested for the public release. Staffing issues are slowing down progress on the model, as Jamie Andersen is on maternity leave and Bijaya is committed to other projects.

Kyle Winslow inquired about the capability of DSM2 to reproduce the gate logic using a rating curve or in a piece-wise manner. Parviz explained that the gate logic now being implemented in the DSM2 database version allows users to specify a trigger condition to open/close a gate. The trigger condition can reference stage, flow, or velocity anywhere in the network. Flow calculation through gates uses an orifice equation, and Parviz does not think it can be replaced by another equation. With the current version of DSM2, the coefficient for the orifice equation has to be pre-determined before the model execution and does not have the capability to adapt to changes in the system during the simulation.

Rob Tull expressed concern about the oscillation problem, which can be caused by having gates open and closed. The Colossal model developed by Curtis Creel had a similar problem. Rob said he might gain more understanding of the system and its operation in the meeting with Terry Becker planned for the next day. Parviz will inquire about the specifics of the gate logic implementation in the DSM2 database version.

Schedule

Future direction was discussed regarding whether to wait for the release of the DSM2 database version or to use the text version. Rob Tull's dilemma is that on one hand, choosing a text version has the risk of being outdated soon if the database version is released. On the other hand, choosing the database version has the risk that it might not provide features that would help the Aqueduct module modeling after all.

Paul Hutton understands the delay of the project is due to difficulties CH2MHILL is having collecting all the necessary information. CH2MHILL plans to finish all the data collection by the end of July, and finish model calibration/verification by the end of the year.

Action Items

- Parviz Nader will check on node number protocol and potential limitations.
- Tara Smith will provide San Joaquin River DSM2 schematic.
- Parviz Nader will ask Eli Ateljevich about the specifics of the gate logic implementation in DSM2 database version.
- Kyle Winslow will assemble check/gate operation examples for Parviz to review.
- CH2MHILL will compile a recommendation describing a proposed period for calibration/verification, available data set during the period, and the reasons for selecting the period.

Existing Numerical Models of California Aqueduct: DWR's East Branch and South Bay Aqueduct Models

July 14, 2004

ATTENDEES: Terry Becker/DWR
Jose Alvarado/DWR
Rob Tull/CH2M HILL
Kyle Winslow/CH2M HILL
Tara Smith/DWR

Introduction

Rob Tull gave an introduction to the project, explaining the goal of extending DWR's DSM2 model down the DMC and the California Aqueduct to provide state water contractors with predictive capabilities of water quality.

Terry Becker gave an overview of the work the Engineering Division has conducted on the South Bay Aqueduct and on the East Branch of the California Aqueduct. Numerical models were constructed for both the East Branch Aqueduct Enlargement Study and the South Bay Aqueduct Improvement and Enlargement Study.

East Branch Aqueduct Enlargement Study

Terry Becker discussed the history of the East Branch expansion project. The project began after MWD requested a 1500 cfs (about 1 million acre-ft/year) enlargement of the East Branch. The project was proposed as two phased effort, with each phase adding 750 cfs in capacity to Pearblossom Pumping Plant. Two 375 cfs units have been added to Pearblossom. Phase 2 calls for the addition of two more 375 cfs units. The EIR for the East Branch Enlargement Project was supposed to start 6 months ago. Estimates for the expansion project are $325 million.

Currently the pumping capacity at Pearblossom is 2525 cfs. The channel capacity downstream from Pearblossom, however, is 2150 cfs. There are problems maintaining the required freeboard at flows above 2150 cfs. The canal needs to be enlarged.

Extensive flow tests were conducted in the East Branch to determine hydraulic properties and flow capacities. Water level gauges were installed upstream and downstream of each check structure. The gates were supposed to be fully opened (or nearly opened), but the data doesn't reflect this. According to the data, it wasn't really a full flow test. One gate had to be closed partially because of a siphon that had a large flow capacity. For the last two hours of the test, the system was operating at near steady state.

Diversions were stopped where possible during the flow test. Deliveries were held constant and metered when they could not be stopped for the duration of the test. The test tried to stabilize the flow for a 24 hour period

Data collection took place between 8 am and 10 am. The last of the gate adjustments were made around the previous midnight, so the assumption of steady state was achieved. Operations and Maintenance staff calibrated the instruments before the flow test. Water surface elevations varied on the order of hundredths of a foot during the data acquisition, demonstrating the constant volume control.

Jose Alvarado has developed Excel-based models that contain the East Branch geometry, head losses through each check structure, "effective" Manning's "n" coefficients for each channel, and expansion and contraction coefficients for each structure, and other parameters. The hydraulic model used the blue book and the design drawings for geometric data. Friction values were found to vary by pool. Structure losses were determined by starting with the known water surface slopes and backing out effective friction and loss terms. Both the energy equation and Manning's equations were utilized.

Joe DeVries (UC Davis), who used to work for DWR, used HEC-RAS as a check on the hydraulic model developed by DWR. (DeVries was a key person in the programming of the California Aqueduct operations model). DeVries had a difficult time modeling the flows through the gates.

Sedimentation in the California Aqueduct is a known concern. DWR has looked at dredging, but there are complications. The clay materials have compacted over time and thus suction dredges are not adequate for dredging the aqueduct. Dredging was attempted in the 1980's with a suction dredge, and the dredge didn't work.

The possible sources of the sediment include upstream loading, wind transport, and stormwater runoff. There are approximately 30 pipes in the vicinity of Hesperia that drain to the canal.

South Bay Aqueduct Improvement and Enlargement Study

Terry Becker provided some history and general information on the South Bay Aqueduct:

Capacity of the South Bay Aqueduct is approximately 300 cfs. Zone 7 has requested an additional 130 cfs in capacity. Zone 7 put up the money for studies. They hope to have construction completed in 2008. There are problems with the pumps at South Bay PP (pumps are 40 years old and are approaching their useful life).

There are three main contractors on the south Bay Aqueduct: Zone 7 of the Alameda County Flood Control and Water Conservation District, Alameda County Water District, and Santa Clara Valley Water District.

The South Bay Pumping Plant has 5 45 cfs units, three 30 cfs units, and one 15 cfs unit for a total of 330 cfs capacity. The practical capacity is 310 cfs. There are no spare units should one go offline. Also, the channel has less than one foot of freeboard in the Dyer Canal at flows above 260 cfs. Limited freeboard occurs in other reaches at flows above 270 cfs. Thus, the South Bay Aqueduct cannot currently deliver its capacity. The loss of capacity from the design capacity could be because of age or silt. The enlargement project would add four 45 cfs units. Channel capacity has to be increased. The final channel will have 1.5 feet of lined and an additional 1.5 feet of unlined freeboard.

One purpose of the study was to investigate the potential for off-peak pumping at the South Bay Pumping Plant. This would require a reservoir downstream of the pumping plant to provide water for delivery when the pumps were not operating.

A new reservoir (Dyer Reservoir) is being proposed for the South Bay Aqueduct. Zone 7 originally asked for a reservoir with 100 ac-ft of storage to go along with a planned treatment plant to allow for deliveries that exceeded the capacity of the Dyer Canal or when the canal was not operational for maintenance reasons. Talk of the new reservoir peaked interest for the potential for off-peak pumping to save operational costs. Zone 7 also asked for a cost of a 200 acre-ft reservoir, saying that 100 acre-ft was the minimum allowable size. Current size of the reservoir is 500 acre-ft, 200 for Zone 7 and 300 for the off-peak pumping alternative.

Montgomery Harza is investigating treatment plants off the SBA. They are concerned with turbidity issues, algal blooms, mixing in reservoir, and controls for water surface depth. There are large short term variations in turbidity and in temperature. A ten degree change in temperature drastically changes the chemicals needed for treatment.

Sedimentation in Bethany – soundings show that sedimentation reaches 6 feet deep in places in Bethany Reservoir. There were two dredging episodes in the 1980's.

Terry said some DWR staff (located on 32nd and S?) have collected samples in the sediment to determine grain size distribution. Toxic materials may also be of concern.

As part of the South Bay project, all drains to the system will be eliminated to improve water quality.

There are also known concerns with Clifton Court Forebay. The forebay is silting in, and the decrease in average depth affects temperature, algal blooms, turbidity, weed problems, and loss of capacity. There is talk of dredging a portion of the forebay and using another portion for dredge spoils.

Action Items

DWR provided CH2M HILL with electronic and hard copies of the South Bay Aqueduct Improvement and Enlargement Study Report and the East Branch Aqueduct Enlargement Study Report, as well as electronic copies of the spreadsheet hydraulic models developed for these systems.

Progress Report on DSM2 Extension to California Aqueduct

PREPARED FOR: Paul Hutton

PREPARED BY: Kyle Winslow/SDO

COPIES: Rob Tull/SAC
Toshio Kyosai/SFO
Amy Watson/SDO

DATE: December 3, 2004

Introduction

This memo summarizes progress completed since the July 2, 2004 update memorandum regarding model development for the extension of DSM2 down the California Aqueduct and the Delta Mendota Canal. Primary efforts have been directed at understanding gate operations in the aqueduct, working with DWR so that they understand our needs with respect to DSM2's ability to model the gate operations, investigating DSM2 limitations to modeling terminal reservoirs, and completing the sub-model of the Delta Mendota Canal.

California Aqueduct Gate Operations:

We obtained SCADA data from DWR detailing flow through the gates and water surface elevations upstream and downstream of the gates. Discussions with Ed Trevino and analysis of the SCADA data showed that the flow through the check structures is a function of both head difference across the gate and the position of the gate itself. Theoretically, there is a "Rating curve" relating flow to head difference for each distinct gate position.

We built a spreadsheet tool comprised of a simple two pool system joined by a gate. We have investigated various hydrographs, including slowly varying flows and flows that rise and fall relatively rapidly. We have manually controlled gate operations in order to maintain the proper water surface elevations in the channels. We found that for the largest expected increases and decreases in flow in the aqueduct, we were able to control the water surface elevations sufficiently by opening or closing the gates once every hour. Our gate movements were confined to whole-foot increments, but not limited to one foot at a time. For example, when flows were increasing from 2000 cfs to 8000 cfs, we opened the gates by 6 feet an hour to pass the flow.

Figures 1 and 2 demonstrate the results of one of our simulations. A hydrograph (Figure 1) consisting of a rapid rise in flow (2000 cfs to 10,000 cfs in 8 hours) followed by an equally rapid decrease in flow was sent through the gate. Flow through the gate was calculated with the standard orifice flow equation (as coded in DSM2),

$$Q_g = C w_g d_g \sqrt{2g\Delta h} \qquad \text{Eq. 1}$$

where C is a friction coefficient, w_g is the width of the gate, d_g is the operating depth of the gates, g is acceleration due to gravity, and Δh is the change in head:

$$\Delta h = h_u - h_d \qquad \text{Eq. 2}$$

where h_u is the upstream head and h_d is the downstream head.

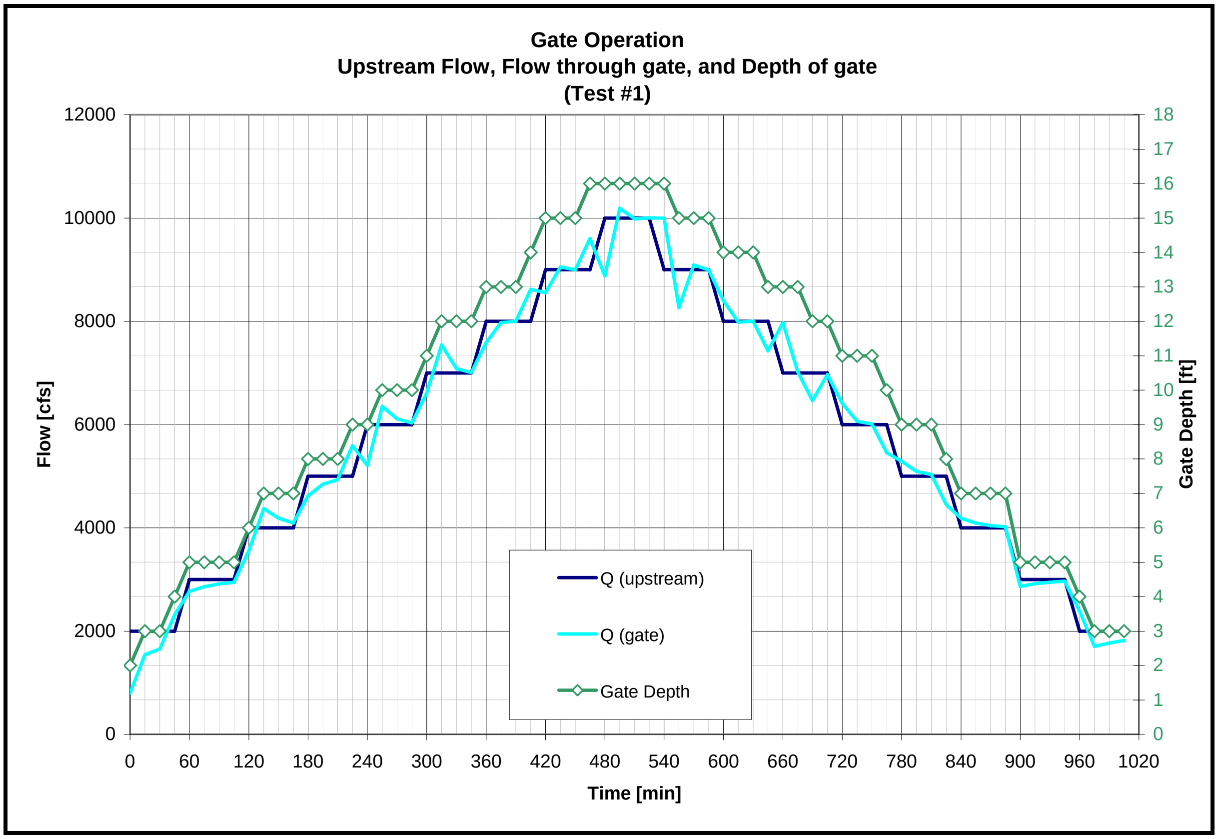

FIGURE1
Test 1: Upstream flow, flow through the gate, and depth of gate versus time.

Results (Figure 2) demonstrate that the water surface elevations could be maintained within a very narrow range (0.5 feet) through adjustment of the gate position on an hourly basis. Subsequent results demonstrated that water surface elevations could be reasonably controlled (1 foot range) when gate operations were constrained to hourly adjustments.

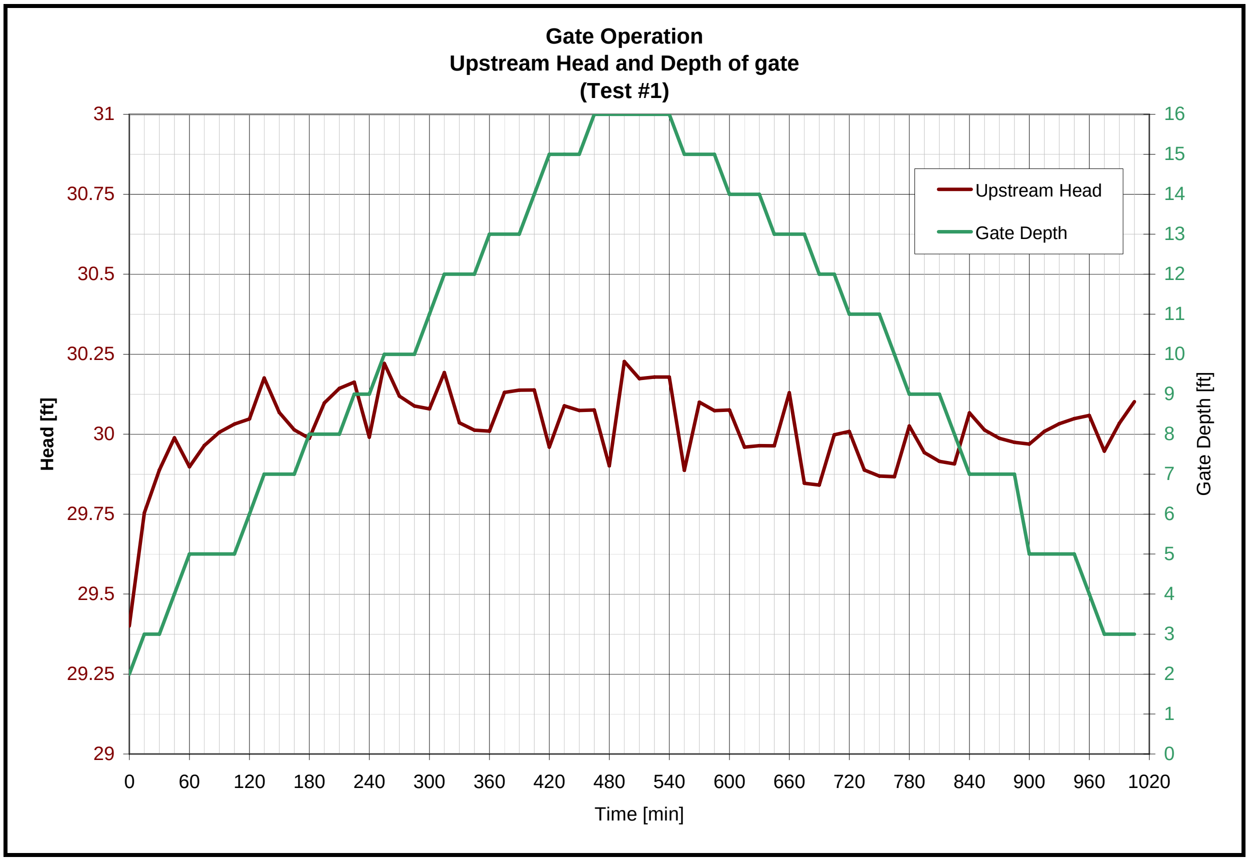

FIGURE 2
Test 1: Upstream head and depth of gate versus time.

The investigation allowed the precise definition of what we would need from DSM2 as far as gate operations are concerned. The best scenario for us would be to have DSM2 provide the ability to change the gate flow as a function of water surface elevation upstream of the gate, such that the upstream water surface elevation remains in a pre-defined range. For example, the range might be a water surface of 29 to 31 feet. When the water level rises to a pre-defined elevation, say 30.75 feet, the gates should open incrementally to lower the water surface elevation. Conversely, when the water surface is dropping and approaches 29.25 feet, the gates should close incrementally in order to raise the water surface elevation.

The change would likely be to the weir crest elevation. If possible, the weir crest elevation could be defined as an integer number of feet, and if the water surface was rising towards the upper limit, the crest elevation would be lowered by one foot to represent the gate opening (rising) by one foot. Conversely, the weir crest could be raised by one foot to mimic the gate closing by one foot when the upstream water surface elevation was approaching the channel minimum.

A memorandum presenting the results of our investigation was written and delivered to DWR on 10/01/2004 (Tara Smith, Parviz Nader) for determination of the capabilities of the yet-to-be-released revised DSM2 code to model flow through the gates. Parviz Nader, after reading the memorandum, believes that DSM2 will have the capability to model flow through the gates via temporal variability in gate parameters (i.e. weir elevations or flow coefficients).

Representation of Pipelines with Channels in DSM2:

We investigated the use of channels to model pipelines along South Bay Aqueduct and California Aqueduct. DSM2 uses open channels for conveyance, and there are a considerable number of pipe sections in the Aqueduct system, mainly in the South Bay branch. A spreadsheet tool was developed to calculate velocities for a given flow through both a trapezoidal channel and a pipe. The channel geometry was varied until the variation of velocity with flow matched that calculated for the pipe. (Velocities and flows were calculated using Manning's equation.)

Delta Mendota Canal Application:

We obtained updated electronic versions of the DMC Structures List from Bob Martin (SLDMWA) on 10/05/2004. We contacted Sheryl Carter (USBR) regarding questions with deliveries to wildlife refuges. Contacted Valerie Ungvari (USBR) who provided electronic versions of certain data presented in the CVO Monthly Operations reports including daily data for three years beginning 1/1/2001 of:

- O'Neill Forebay Operations data including reservoir stage, reservoir storage, pumping flows, generating flows, reservoir gains (losses), deliveries from O'Neill Forebay (San Luis WD and O'Neill Wildlife Delivery), and flow out of O'Neill through Check 12 in the California Aqueduct.
- Pumping Plant flows at Tracy, Banks, and Dos Amigos
- San Luis Reservoir Data including reservoir elevation, reservoir storage, evaporation losses, other gains or losses, Pacheco pumping, generation release, pumping from O'Neill, spill release, and federal components of storage, pumping, and generation release.

We obtained hard copies of daily diversion data aggregated by pool from Joe Martin, Watermaster (SLDMWA) for September 2003 through September, 2004. We entered data into EXCEL and compared with data presented in CVO Monthly Data reports. We determined that certain discrepancies existed, but that cumulative deliveries along the DMC generally agreed to within 10 percent. We compiled monthly averaged data for Tracy inflows, flows to and from O'Neill Forebay, DMC deliveries, and deliveries to the Mendota Pool into DSS format for use in DSM2 application.

We contacted Alan Stroppini (USBR) who provided engineering plans for the four wasteways connected to the DMC. The wasteways vary in length from approximately 1.2 miles (Firebaugh) to 11.9 miles (San Luis). Complete plans showing the invert elevations along the entire channel were available for the Firebaugh and Westley Wasteways, but not for the San Luis or Newman Wasteways. Placeholder elevations were estimated where data were lacking based on the most downstream channel slope information available.

Water surface elevation data in the San Joaquin River were obtained from CDEC internet resources at Vernalis, Patterson, Newman, Stevinson, and Mendota. This data was compared to the calculated invert elevations in the wasteways where they reached the

San Joaquin River. Boundary (downstream) water surface elevations for the wasteways were compiled from the CDEC data for use in DSM2.

We obtained a copy model grid for DSM2 San Joaquin River extension from Michael Mierzwa at DWR.

We investigated DSM2 capabilities of modeling reservoirs (i.e. O'Neill, San Luis, Delta-Mendota Pool, etc.) We were concerned with how DSM2 would handle terminal reservoirs like the Delta Mendota Pool. We constructed a series of pilot studies with variations in channel/reservoir connections.

Figure 3 presents the downstream portion of one of our pilot tests. This schematic shows reservoir [R] connected to Nodes 20 and 21. Channel 20 is necessary for the model to run. We could not get the model to run with Channel 20 removed. Apparently, if a reservoir is connected to a node, that node must be connected to two channels. This critical realization will be kept in mind when developing the O'Neill and San Luis reservoirs. Undocumented "rules" such as this inherent to the DSM2 grid structure repeatedly arose. The current application is definitely implementing geometric features (multiple downstream heads, terminal reservoirs, steep sloped channels, etc) that are not seen in the standard DSM2 grid of the Delta.

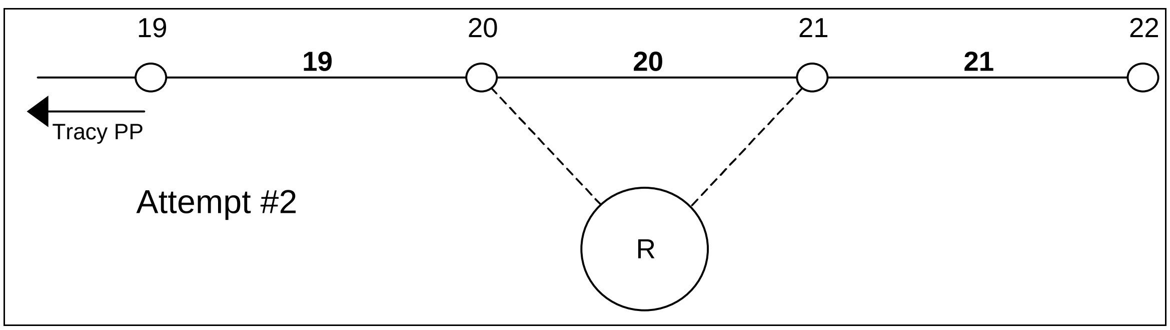

FIGURE 3
Terminal Reservoir with "Dummy Channels" (20 and 21)

Channel 21 is added so that the downstream head boundary condition can be applied at Node 22, away from the reservoir (another "rule"). In order to force flow into the reservoir, we added a gate to Channel 20 at the upstream end. The model would not run with this configuration. After much investigation, it was determined that by simply moving the gate to the downstream end of Channel 20 would allow the model to run. Repeated dealings with unexplainable model reactions to reasonable or even negligible changes in model geometry were not anticipated.

We have constructed a refined DSM2 model of the DMC comprised of 136 channels along the main stem of the DMC. Channels were constructed with maximum lengths of 5000 feet to allow for precise location of diversions. Initial model simulations were conducted with constant upstream flow and constant downstream head to insure no geometric problems existed in the construction of the model grid. Model predictions matched water surface elevations calculated with the step method.

We added channels representing the Westley, Newman, San Luis (Volta), and Firebaugh Wasteways. Significant effort was undertaken to get DSM2 to run with the wasteways included. Currently, the Firebaugh and San Luis Wasteways have been successfully added to the DMC grid. The Westley and Newman Wasteways are causing problems in DSM2 because there are portions of these wasteways that are relatively steep, with slopes well above 1:100 (vertical to horizontal). The drop structures in these two wasteways complicate the application of DSM2. It is likely that the flow regime in these steep reaches is supercritical, which violates assumptions inherent to the application of DSM2. Thus, it may not be possible to model the entire wasteways simply because they are too steep in places. DSM2 will crash if a channel dries up.

For the purposes of this study, it may not be necessary to specifically include the actual geometry representing the wasteways. The primary concern is to have some connection between the DMC and the San Joaquin River such that the model could be used to represent flushing flows directed down the wasteways towards the San Joaquin River with the travel time down the wasteways correctly reproduced.

The wasteways range in length from 1 to 12 miles. The travel time through the wasteways is likely on the order of hours, considering how steep they are. Thus, if the travel time down the wasteways was neglected, it would likely not compromise the model results.

One way to handle the wasteways would be to use the “object-to-object” capability in DSM2, which allows for the specification of flows from one portion of the DSM2 model grid to another portion of the grid. Flows could be removed from the DMC at the proper location and added (and likely even lagged if necessary) at the proper location in the San Joaquin River. The object-to-object capability runs seamlessly with the water quality portion of DSM2 as well.

If somehow it were possible to construct the DSM2 grid in a way to faithfully represent the wasteway geometry and the travel time between the DMC and the San Joaquin River, the flows into the wasteways would have to be controlled by gates, the operation of which would have to be preprocessed. Thus, the preprocessing of the object-to-object flows would not add any considerable effort since the gate operations would have to be preprocessed anyway.

We applied monthly averaged inflows, diversions, and delivery data to the constructed model grid. We have successfully run DSM2 (DMC) with a daily time step for a three year period beginning 1/1/2001.

We have investigated Object to Object flows and have begun testing this capability on the DMC with pre-processed flows depicting O’Neill Forebay operations.

Next Steps

- Merge DMC grid with Aqueduct Grid
- Implement Object to Object flows for San Luis Reservoir Operations
- Investigate capabilities of DSM2 to deal with reservoir mixing