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DEPARTMENT OF WATER RESOURCES

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

34th Annual Progress Report to the
State Water Resources Control Board in
Accordance with Water Right Decisions 1485 and 1641

June 2013

Edmund G. Brown Jr.	**John Laird**	**Mark W. Cowin**
Governor	Secretary for Natural Resources	Director
State of California	California Natural Resources Agency	Department of Water Resources

Foreword

This is the 34th annual progress report of the California Department of Water Resources' San Francisco Bay-Delta Evaluation Program, which is carried out by the Delta Modeling Section. This report is submitted annually by the section to the California State Water Resources Control Board pursuant to its Water Right Decision 1485, Term 9, which is still active pursuant to its Water Right Decision 1641, Term 8.

This report documents progress in the development and enhancement of the Bay-Delta Office's Delta Modeling Section's computer models and reports the latest findings of studies conducted as part of the program. This report was compiled under the direction of Tara Smith, program manager for the Bay-Delta Evaluation Program.

Online versions of previous annual progress reports are available at:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm.

For more information contact:

Tara Smith

Chief, Delta Modeling Section,
Bay-Delta Office,
California Department of Water Resources

tara@water.ca.gov
(916) 653-9885

Edited by

Ralph Finch, Bay Delta Office
See individual chapters for author names

Editorial review, graphics, and report production
Supervisor of Technical Publications
Patricia Cornelius
Frank Keeley, research writer

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Preface

Chapter 1 Temperature Model Development for CalSim

River water temperature is important for the conservation of fishery habitat. Changes of water delivery or construction around water ways may impact of fish mortality by changing river water temperature. Water temperature is highly relevant to fish mortality and also indirectly influences habitat. Current temperature modeling takes flow output from CalSim and then estimates temperature at points of interest. However, when it violates the downstream temperature requirement, there is no way to adjust outflow or storage to lower the impact.

This chapter documents the work on integrating the Sacramento River Water Quality Model (SRWQM) into CalSim and making reasonably accurate estimates for released water temperature. Through this integration, CalSim can adjust flow or storage to meet river temperature requirements.

Chapter 2 Extension of DSM2 for the South Bay and California Aqueducts and Delta Mendota Canal

This chapter is a summary of the full report that documents work on the DSM2 Aqueduct model: (1) extending the model simulation period from 3 years starting January 1, 2001, to 21 years starting from January 1, 1990; (2) modifying the ways to treat gains and losses of water as a result of seepage, evaporation, rainfall, storm water inflow, meter reading errors, etc.; (3) enhancing the model's capability of calculating water quality by adding two more constituents, dissolved organic carbon (DOC) and Bromide; and (4) incorporating inflows from ground water and storm water.

Chapter 3 DSM2 Version 8.1 Calibration with NAVD88 Datum

A new calibration has been performed for Version 8.1 of DSM2, which incorporates the latest improvements to the DSM2 code. The main differences in DSM2 version 8.1 include: DSM2-Qual model formulation change to improve model; modifications to the DSM2-Hydro program source code that improve channel geometry calculation; datum conversion to NAVD88; and Martinez EC boundary correction. Since these changes affect results both in DSM2 Hydro and Qual, a new calibration is needed. This chapter documents the calibration effort done by adjusting Manning's coefficient values in Hydro and dispersion coefficients in Qual. Further improvements involving other changes, e.g. new bathymetry and grid change, may come in future releases.

Chapter 4 Adding Salmon Route Selection Behavior to DSM2 Particle Tracking Model

DSM2 Particle Tracking Model (PTM) simulates the transport and fate of individual neutrally buoyant particles through the Sacramento – San Joaquin Delta. Since its initial development in 1993, the model has been updated. New features, such as attaching fish-like behaviors to particles, have been added to the model. Although the model itself has been calibrated and validated using a field dye study, the adequacy of the model for simulating fish migration has never been quantitatively evaluated due to the lack of field fish monitoring data. Recent developments in the field monitoring, especially in acoustic telemetry fish tag studies, have made it possible for evaluating the adequacy of applying PTM to simulating fish behaviors. This chapter describes the implementation of fish route selection behavior in PTM and the results of the implementation. The approach for using PTM to simulate fish behaviors and the improvements needed for PTM to better simulate fish behaviors are also discussed.

Chapter 5 Particle Filter for DSM2-PTM

This chapter documents the development of a PTM module feature which simulates directing/blocking particles without affecting flows. One of the major applications of this particle filter is to simulate fish screens and non-physical barriers, which could prevent fish from entering some water area. Another application is to provide an option to keep fish from entering agricultural diversions, seepage to groundwater, and water transfer facilities.

Chapter 6 DSM2-PTM Improvements

This chapter describes bug fixes and related tests of DSM2-PTM, with a focus on convergence tests for different PTM time steps. Bugs discovered are:

1. Missing advection: in the loop through the sub-time steps within one PTM time step, the last sub-time cycle is usually missed. This can delay particle motion and the error accumulated can be significant.
2. First time-step error: PTM reads hydrodynamics information from tide file; the first time-step has an initial calculation error. This leads to erroneous results, when particles are released at the beginning of PTM simulation start time.
3. Time interpolation factor (θ) inconsistence: two different weighting average factors between the current and the previous time step are inconsistent for flow, depth, cross-section area, and stage.
4. Missing dispersion: when a particle arrives at the end of a channel, the random motion in y and z direction is missed for the last sub-time step. This leads to erroneous results, especially in a grid system with many connected channels such as Delta.
5. Error warning for transfer: an error exists in the function that checks flow balance for nodes connecting transfers and reservoirs. This doesn’t affect the calculated value but will slow down the module running when the grid has this kind of waterbody combination.

Chapter 7 DSM2-PTM Standard Test Suite Design and Automation

The DSM2-PTM Module is undergoing development for new features and bug fixes. It is essential to have its tests standardized and automated for the changes to the code and input data. This chapter describes the PTM standard test suite design, including several DSM2 test grids, their respective key configuration variables, and design purpose. Scenario runs and plots generation can be batch processed for every version of DSM2-PTM. This batch automation is implemented by Python scripts.

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Chapter 1
Temperature Model Development for CalSim

Authors: En-Ching Hsu and Prabhjot Sandhu,
Delta Modeling Section,
Bay-Delta Office,
California Department of Water Resources

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1 Temperature Model Development for CalSim

1.1 Abstract

River water temperature is important for the conservation of fishery habitat. Changes of water delivery or construction around waterways may impact fish mortality by changing river water temperature. Water temperature is highly relevant to fish mortality and also indirectly influences habitat. Current temperature modeling takes flow output from CalSim[1] and then estimates temperature at points of interest. However, when the downstream temperature requirement is violated, there is no way to adjust outflow or storage to lower the impact.

The purpose of this study is to integrate the Sacramento River Water Quality Model (SRWQM) into CalSim and make reasonable accurate estimates for released water temperature. Artificial Neural Network (ANN) technology is used to capture the behavior of SRWQM by training datasets. A simple system with inflow, storage and outflow is set up around Shasta Lake. The reservoir itself is divided into four layers (top, middle, penstock and lower) and layer temperature is estimated based on given inputs (air temperature, solar radiation, storage, and inflow). Temperature Control Devices (TCDs) were installed in Shasta Lake in 1997 and allow water released from different combination of layers to meet the target downstream river temperature. Through this integration, CalSim can adjust flow or storage to meet river temperature requirements.

1.2 Background

The SRWQM was developed using the HEC-5Q model to simulate mean daily reservoir and river temperature (using 6-hour meteorology data) at Shasta, Trinity, Lewiston, Whiskeytown, Keswick and Black Butte Reservoir and Trinity River, Clear Creek and the upper Sacramento River from Shasta to Knights Landing and Stony Creek. SRWQM simulates flows with TCDs so the released flow is a mixture of water from top, middle, penstock or lower layers of reservoir. SRWQM takes CalSim outputs (flow and storage) as inputs. Temperature outputs from SRWQM are further used in fish mortality models, such as SALMOD[2] and the Reclamation Temperature Model.[3]

1.2.1 Assumptions

1) In CalSim, a simple system is simulated around Lake Shasta (Figure 1-1).
2) The delineation of top, middle, penstock and lower layers for Shasta Reservoir is defined in Figure 1-2. The elevation and storage values are approximations from SRWQM.
3) SRWQM is a daily time-step model. To mimic SRWQM as close as possible, a daily time-step is used for ANN training.
4) Since CalSim uses a monthly time-step, it is necessary to convert from monthly to daily values to use ANN training results. Data from CalSim are reservoir inflow and storage. These are assumed

[1] CalSim is the model used to simulate California State Water Project (SWP)/Central Valley Project (CVP) operations (California Dept. of Water Resources).

[2] SALMOD is the model used to simulate the dynamics of freshwater salmonid population (U.S. Geologocal Survey).

[3] U.S. Bureau of Reclamation Temperature Model simulates monthly mean vertical temperature profiles and release temperatures (U.S. Bureau of Reclamation).

constant for all daily data points. This avoids the possible violation of mass conservation from spline fitting.

5) In SRWQM, Shasta TCDs operate by the rules defined in four Tier operations based on end-of-May Shasta storage (Table 1-1). Monthly target temperatures are calculated at each CalSim time-step so that CalSim can mimic the operation in SRWQM.

6) Water temperature downstream of Shasta Reservoir is assumed to be the mixture from the four layers as shown. Water leakages or seepages from reservoir are ignored because of its relatively small amount and having less impact of downstream water temperature.

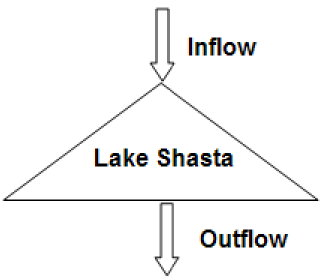

Figure 1-1 CalSim treatment of Shasta Reservoir

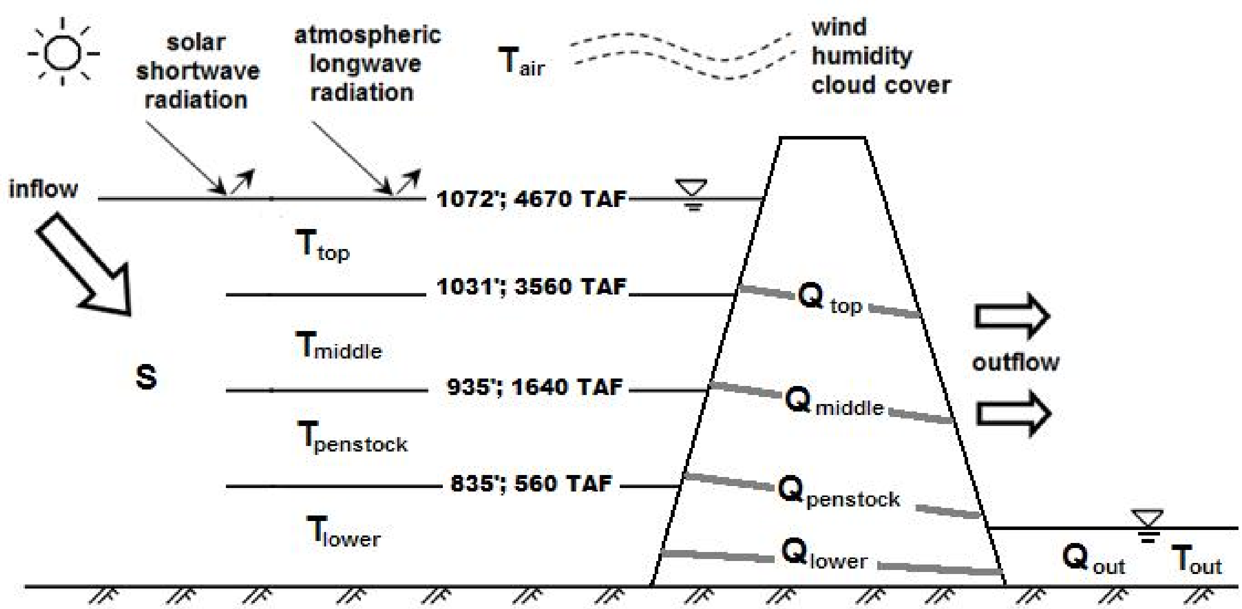

Figure 1-2 Schematic of layer definition in Shasta Reservoir

Table 1-1 Definition of tiers and corresponding temperature schedules for Shasta releases (cited from OCAP BA Appendix H, August 2008 (U.S. Bureau of Reclamation))

Tier	End of May Shasta Storage (TAF)	Target Temperatures	
		Date	Temperature (F)
Tier I	< 3100	1 Jan	60.8
		7 Apr	53.6
		31 Jul	48.2
		7 Dec	60.8
Tier II	< 3500	1 Jan	60.8
		7 Apr	53.6
		7 Jul	48.2
		7 Dec	60.8
Tier III	< 4100	1 Jan	60.8
		7 Apr	53.6
		14 Jun	48.2
		15 Sep	44.6
		7 Dec	60.8
Tier IV	> 4100	1 Jan	60.8
		7 Apr	53.6
		10 May	48.2
		15 Sep	41.0
		7 Dec	60.8

1.2.2 SRWQM ANN Training Framework and Linkage to CalSim

Our goal is to estimate water temperature without actually running the SRWQM model. Input and output results from SRWQM are known to us so it is possible to derive a relationship among them. Inputs of SRWQM are Shasta storage, inflow, reservoir outflow, solar radiation and air temperature. Outputs from SRWQM are the amount of water released and the temperature at each layer (top, middle, penstock and lower). The interactions among those variables cannot be captured by simple linear regression. Mathworks, developers of the mathematical and graphing software MATLAB, has a Neural Network Training package which covers all functionalities and can be simply implemented by scripting (The Mathworks, Inc.). This tool is utilized in this study for ANN training.

Since the ultimate goal is providing ANN training results to CalSim, the linkage between CalSim and SRWQM training results is an important part of this development. There are many approaches to link those two models and it depends on how ANN training results are exported. CalSim and CalLite[4] run on the WRIMS2[5] engine which is written in Java. This allows external functions written in Java to easily interface with them. For this reason, the neural network results are coded as Java functions. The framework schematic is shown in Figure 1-3. The details will be addressed later.

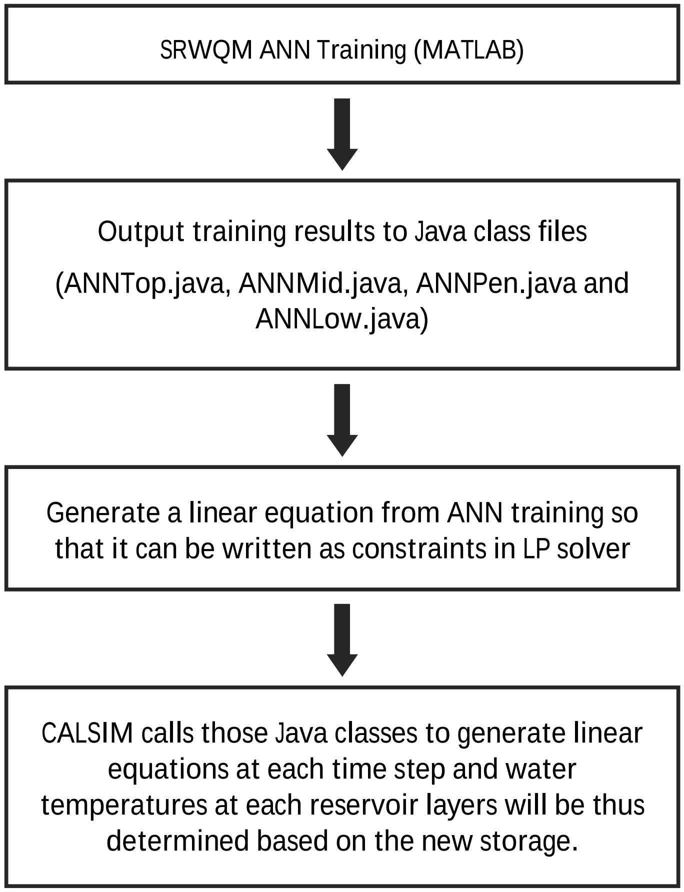

Figure 1-3 SRWQM ANN training framework and linkage to CalSim

1.2.3 Problem Setup

From SRWQM temperature model outputs, daily water temperatures in each reservoir layer are available as input. Measured daily air temperature and interpolated reservoir storage are also accessible as inputs. With this information, it is necessary to find a relationship among those variables. Linear regression was the first attempt, but it is not powerful enough to handle a complex, multivariate problem. Artificial Neural Network (ANN) is a mathematical model that is usually used to model complex relationships between inputs and outputs or to find patterns in data. It is an adaptive system that

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[4] CalLite is a screening model for planning and management of the State Water Project and Central Valley Project in California, developed by the Department of Water Resources and US Bureau of Reclamation Mid-Pacific Region (California Dept. of Water Resources).

[5] The Water Resource Integrated Modeling System (WRIMS model engine or WRIMS) is a generalized water resources modeling system for evaluating operational alternatives of large, complex river basins (California Dept. of Water Resources).

changes its structure based on external or internal information that flows through the networks during the learning phase. For time series data analysis, it is important to consider past data that may carry their influence for current time-step, that is, the system may have memory.

The testing setup uses SRWQM temperature model results from a baseline planning study. The simulation period of SRWQM is from October 1, 1921 to September 30, 2003. Since the first few years initialize the simulation and are not considered valid model output, the ANN training period is from October 1, 1925 to September 30, 2003. Before the evaluation of input variables, some results from adjusting ANN training parameters are shown to have a good sense of how ANN behaves. Inputs use up to the previous four weeks air temperature and previous two weeks Shasta storage.

SRWQM is a physically-based model that accounts for mass, heat balance, and transfer. It requires meteorological data and hydrological data for each time-step to perform complex computation. Shasta Reservoir is a strongly stratified reservoir; temperature control devices (TCD) were installed in 1997 to withdraw water from different layers. This structure allows operators to access water at multiple elevations in order to maintain cool water releases without bypassing power generators. With the operation of TCDs, the water mixing inside reservoir becomes more complicated and hard to estimate. Mass balance may be straightforward but heat balance is difficult to calculate with simple models. We provide water release from each layer as input in the ANN so that the ANN can implicitly consider heat balance and mixing. Without understanding physical interaction, the ANN searches for the best relationship between input and outputs. Once the relationship is obtained, the output can be easily calculated from matrix multiplication. As Figure 1-4 shows, ANN is used to replace complex computation and the physical-based model, yielding results consistent with SRWQM. The release water temperature below Shasta (*T*) is calculated by Equation 1.

$$T = \left(Q_{top}T_{top} + Q_{mid}T_{mid} + Q_{pen}T_{pen} + Q_{low}T_{low}\right)/\left(Q_{top} + Q_{mid} + Q_{pen} + Q_{low}\right) \qquad \text{Eq.1}$$

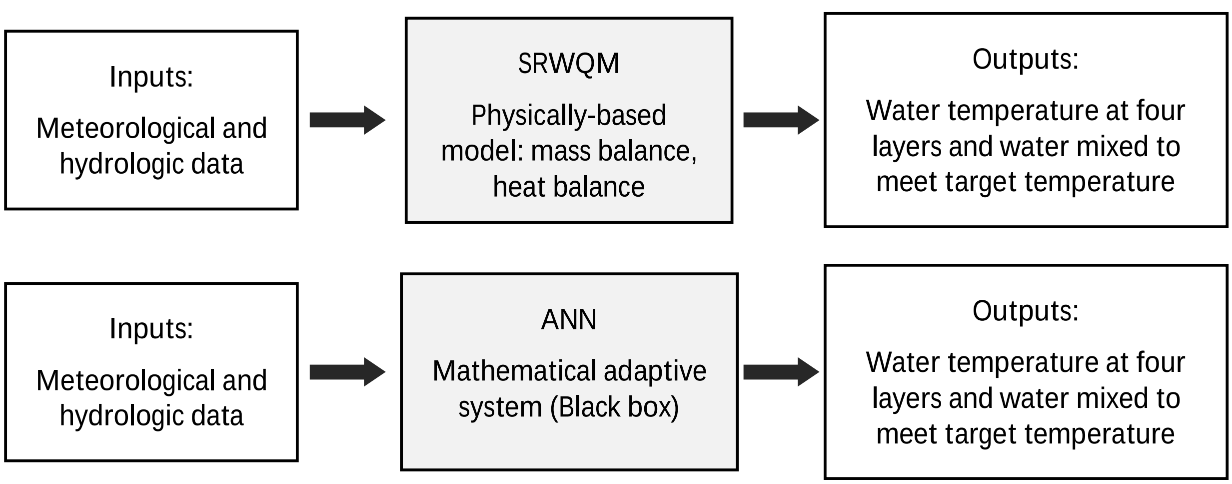

Figure 1-4 SRWQM versus ANN

1.3 ANN Training

1.3.1 Comparison of ANN Network Parameter Setup

An ANN simulation has many different possible configurations, and it is not obvious beforehand which will yield the best results. Some tests have been carried out to observe the sensitivity of ANN parameter changes. The ANN parameters used for this study are:

1) 500 epochs (training iterations) appears acceptable. Validation checks usually stop the training before reaching this number.
2) Three layers of artificial neuron networks are used for this ANN, with 10 neurons in the first layer, 3 neurons in the second layer and 1 neuron in the third layer.
3) 80% of data will be used to train the network while 20% of data will be used to validate the training. Validation data are sampled randomly from the entire data set.
4) All input variables (air temperature, storage, inflow, outflow, etc.) and output temperatures are scaled to dimensionless values between 0.1 and 0.9.

1.3.2 Selection of Input Variables

Our goal is to estimate water temperature in each reservoir layer. We need to consider factors that may impact water temperature profile. Those factors are from a physical mass balance and heat balance point of view: reservoir storage, air temperature, Julian day, inflow, total outflow, outflows from each layer, outflow temperature, etc. Data for inflow temperature is not available but may be close to air temperature, so we assume it has been covered. Outflow temperature from each layer is the training target.

We tested many combinations of input valuables. Input available as time series data for SRWQM are air temperature, short wave radiation, wind speed, and heat exchange rates. Wind speed and exchange rate are noisy and do not have significant impact on output performance, so only air temperature and solar radiation are included as inputs. A final set of inputs, based on performance improvements, are: air temperature, solar radiation, storage, inflow, outflow from top layer, outflow from middle layer, outflow from penstock, and outflow from lower layer. Output targets are outflow temperatures from top, middle, penstock, and lower layers.

In Table 1-2, the results of several test cases are summarized. The coefficient of determination, R^2, is one way to evaluate the improvement from one scenario to another. This is calculated for the training and validation set as used by the neural network training algorithm.

Table 1-2 Comparison of combinations of inputs

Input Combination	R-Square Values			
	Top	Middle	Penstock	Lower
9S	0.877	0.941	0.958	0.919
9T9S	0.942	0.974	0.981	0.920
9T9S9R	0.952	0.981	0.987	0.973
9T9S9I9R	0.972	0.992	0.987	0.980
9T9S9I9TO9MO9PO9LO9R	0.992	0.994	0.996	0.993

We started with the hypothesis that temperature in any layer is related to inputs in the past. Each input is represented as a time series and in order to provide a “memory” to the input, the previous time-steps’ input was represented. For example, today’s water temperature can be influenced by the previous week’s or month’s air temperature. This is explicitly provided as input as a moving average of previous time-steps. These are sampled as current time *t*, *t* -7days, *t* -21, *t* -35, *t* -49, *t* -63, *t* -77, *t* -91, *t* -105, *t* -119, etc. All values are 7-day moving averages.

Each input variable is abbreviated with simple notation. For example, 9T9S9I9TO9MO9PO9LO9R stands for 9 prior weekly (as defined above) air temperatures (T, T_{t-7}, T_{t-21}, ..., T_{t-105}), 9 storages (S), 9 inflows (I), 9 outflows from the top layer (TO), the middle layer (MO), the penstock layer (PO), the lower layer (LO), and 9 solar radiations (R).

From Table 1-2, the results make sense: higher R^2 values are seen with more inputs to the ANN. Besides looking at R^2 values, we also investigated the results through time series plots in order to help us view the effects of the inputs in more detail.

1) With storage alone, the water temperature profile in each layer can be roughly captured with R^2 > 0.88.
2) There is a significant improvement from 9S to 9T9S (R^2 0.92-0.98). Therefore, air temperature plays an important role for reservoir heat balance. Air temperature and solar radiation have high correlations. Solar radiation preserves some extra details, such as length of daylight and sun declination. Adding solar radiation brings R^2 to 0.95-0.987. We believe that having both as inputs helps capture meteorological changes as confirmed by the improvement in R^2 (Figure 1-5).
3) Adding inflow as input improves R^2 to 0.97-0.99. This input compensates the information we may miss from storage (Figure 1-6).
4) Another improvement happens when the outflow from each layer is added to the set of inputs. These inputs introduce factors that are related in heat balance. Reservoir operations may call for different outflows than what the neural network was trained on, so it is important that the input have a representation of these factors (Figure 1-7).

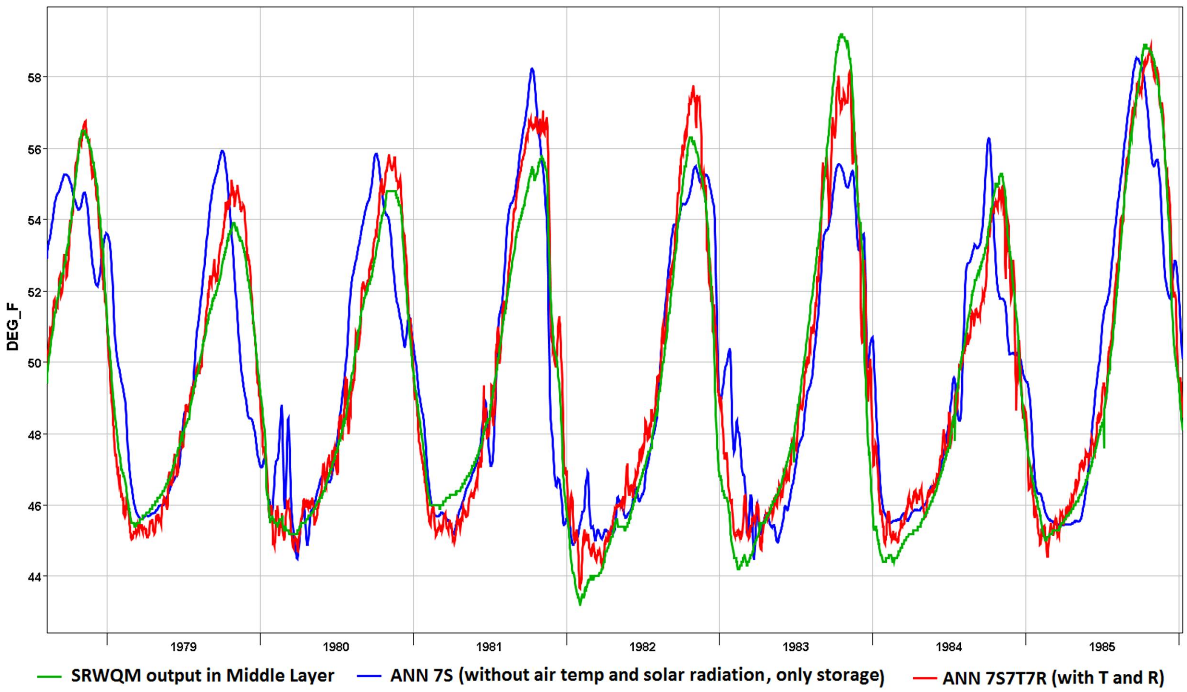

Figure 1-5 Comparison between with and without air temperature and solar radiation

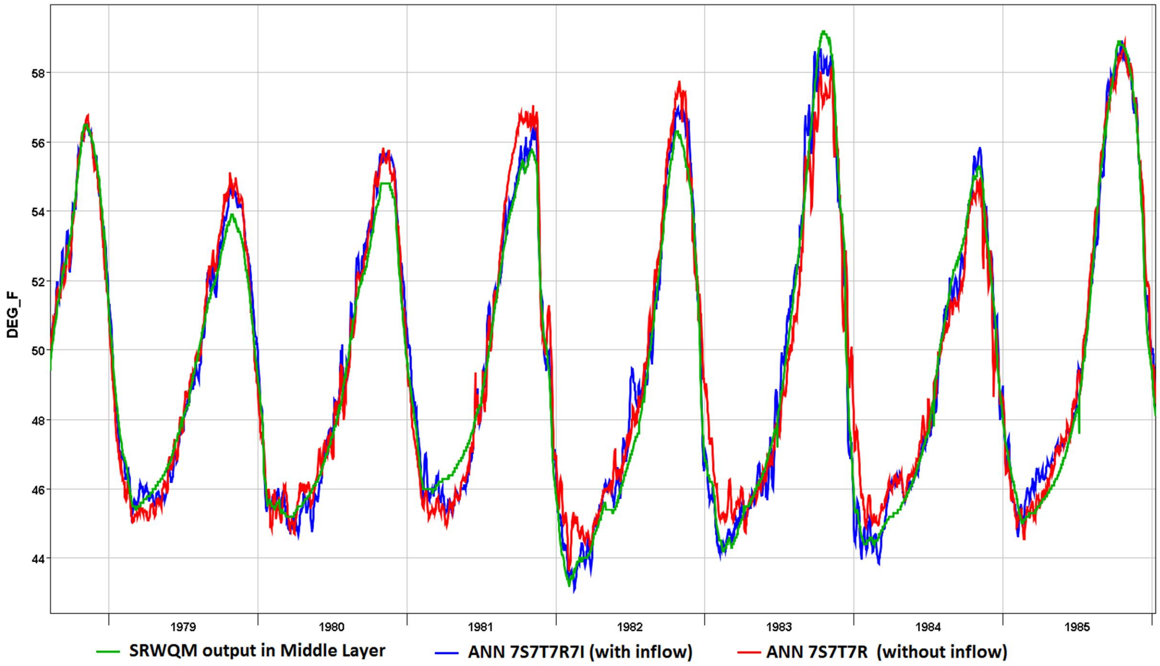

Figure 1-6 Comparison between with and without inflow

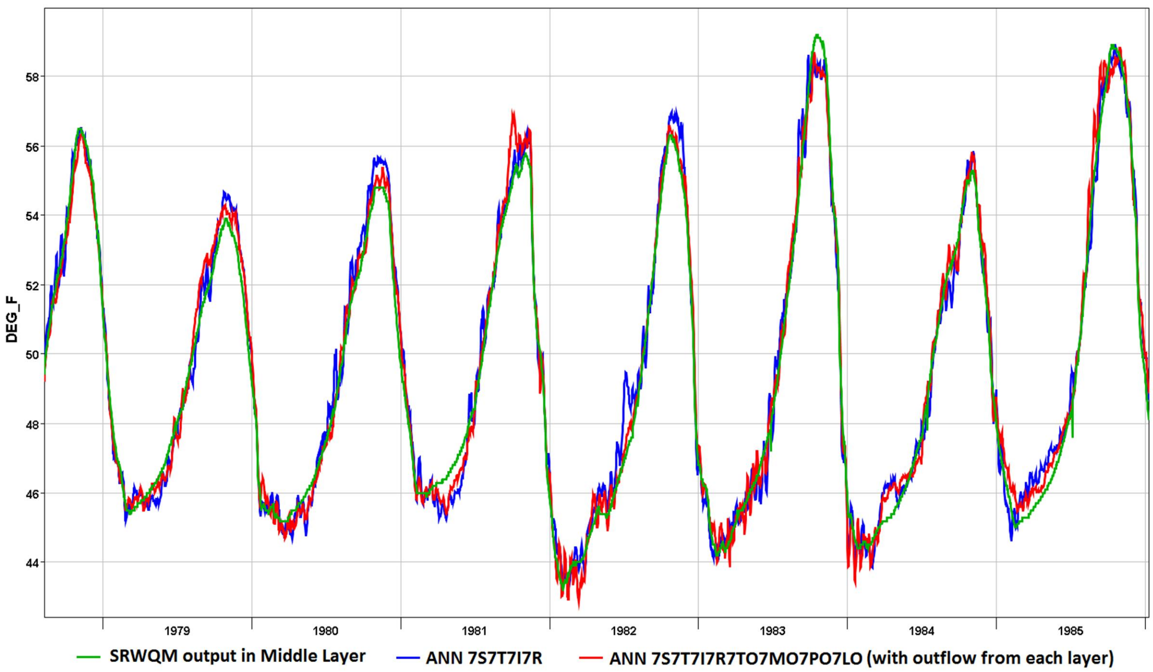

Figure 1-7 Comparison between with and without outflow from each layer

1.3.3 Selection of Input Memory

Previous time-steps are sampled as current time *t*, *t* -7days, *t* -21, *t* -35, *t* -49, *t* -63, *t* -77, *t* -91, *t* -105, *t* -119, etc. A comparison of different input memory length is summarized in Table 1-3. Increasing length of memory does improve goodness-of-fit. As the ANN memory gets longer, the gradient of improvement becomes slower. Time series are plotted from one scenario to another to investigate the improvement because R^2 values are fairly close and are not adequate to make conclusions based only on R^2 values.

Table 1-3 Comparison of different length of data memories

Input Combination	R^2 Values			
	Top	Middle	Penstock	Lower
4T4S4I4TO4MO4PO4LO4R (up to *t*-35)	0.926	0.972	0.982	0.972
5T5S5I5TO5MO5PO5LO5R (up to *t*-49)	0.942	0.977	0.985	0.978
6T6S6I6TO6MO6PO6LO6R (up to *t*-63)	0.956	0.981	0.988	0.982
7T7S7I7TO7MO7PO7LO7R (up to *t*-77)	0.969	0.984	0.990	0.984
8T8S8I8TO8MO8PO8LO8R (up to *t*-91)	0.974	0.986	0.991	0.987
9T9S9I9TO9MO9PO9LO9R (up to *t*-105)	0.992	0.994	0.996	0.993
10T10S10I10TO10MO10PO10LO10R (up to *t*-119)	0.986	0.990	0.993	0.990

In Figure 1-8, we can see the improvement from input length 4 (about a month) to input length 9 (t-105 days, about three months). Usually ANN does an almost perfect estimation for rise and drop segments. The problematic part has always been in peak and trough. As memory increases, we see the peak is correctly estimated and there is less leakage in trough (Figure 1-9). However, when the memory increases to 10 (t-119 days, about 17 weeks), extra memory starts to bias the results, especially the location and amplitude of peak. That may be the cutoff point for input memory.

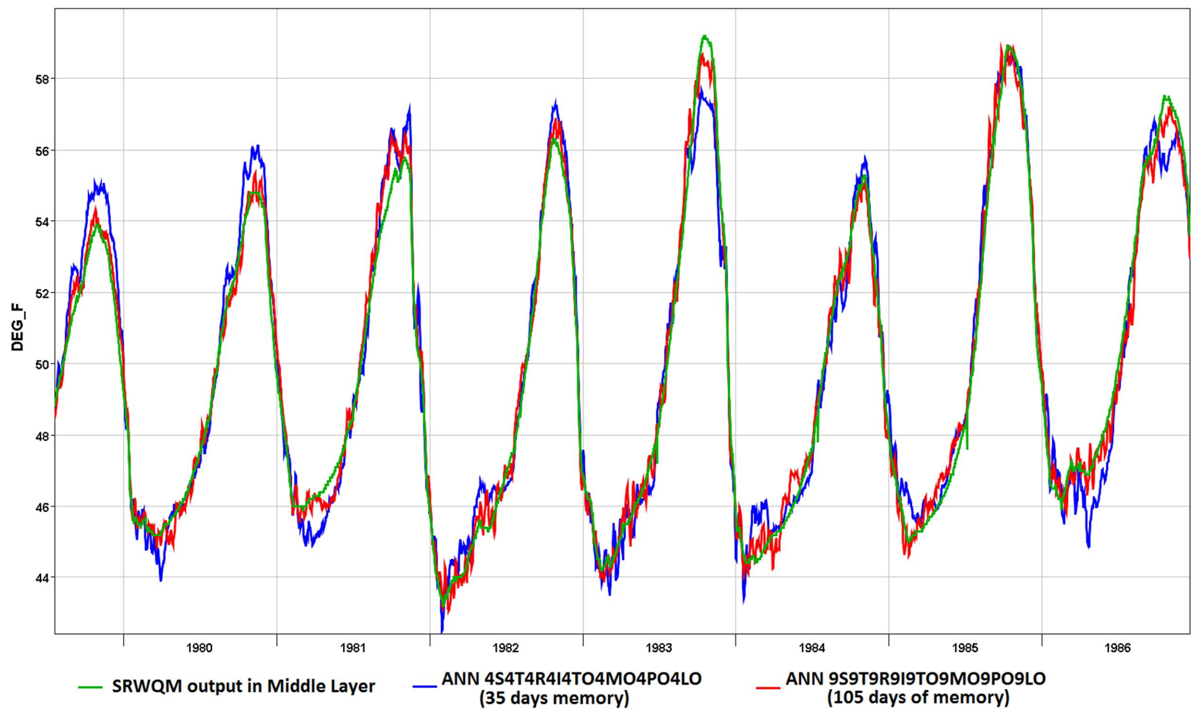

Figure 1-8 Comparison between different length of input memory

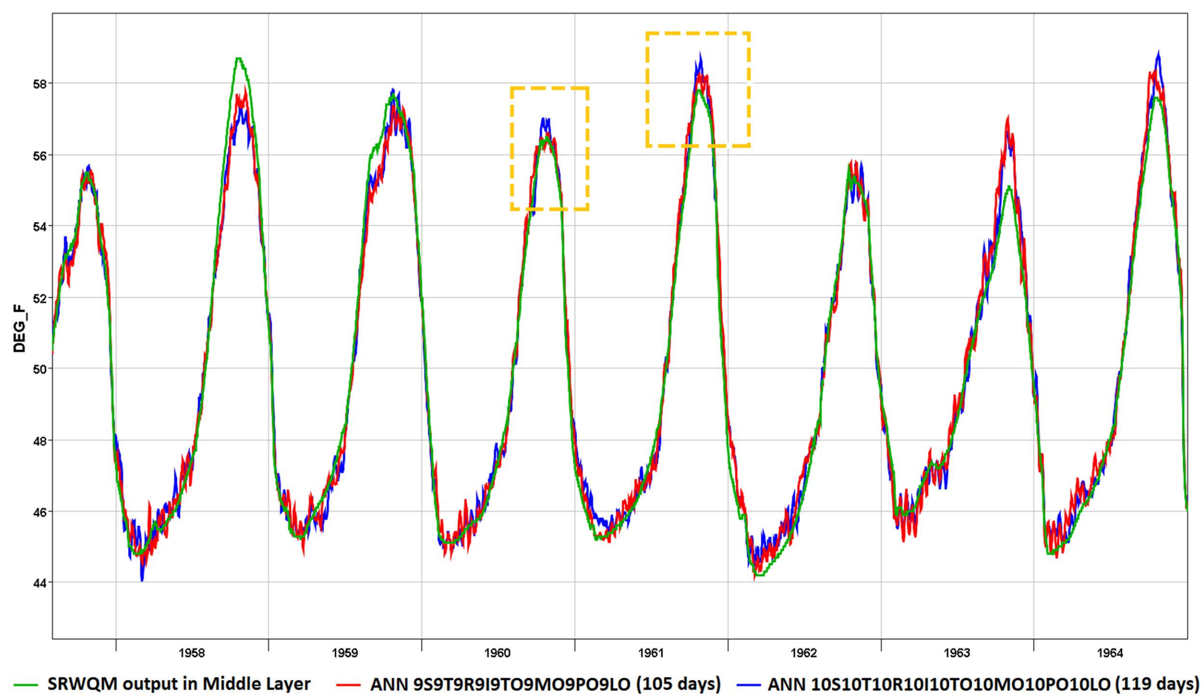

Figure 1-9 Comparison between different length of input memory

1.4 Integration SRWQM ANN to CalLite

1.4.1 Storage of SRWQM ANN Training Results

CalSim and CalLite use the WRIMS2 Engine, which is written in Java, so coding external functions in Java makes direct connections without translation through another computer language. ANN training results for each layer is stored separately in four Java class files.

SRWQM is a daily time-step model, so in order to preserve the model behavior, ANN training is performed for original daily inputs and outputs. However, CalSim is a monthly operation model, so data conversion is necessary. The process is shown in Figure 1-10. Monthly inputs are Shasta storage and inflow. Metrological data, such as solar radiation and air temperature, are read in as daily data since it is independent of CalSim operation.

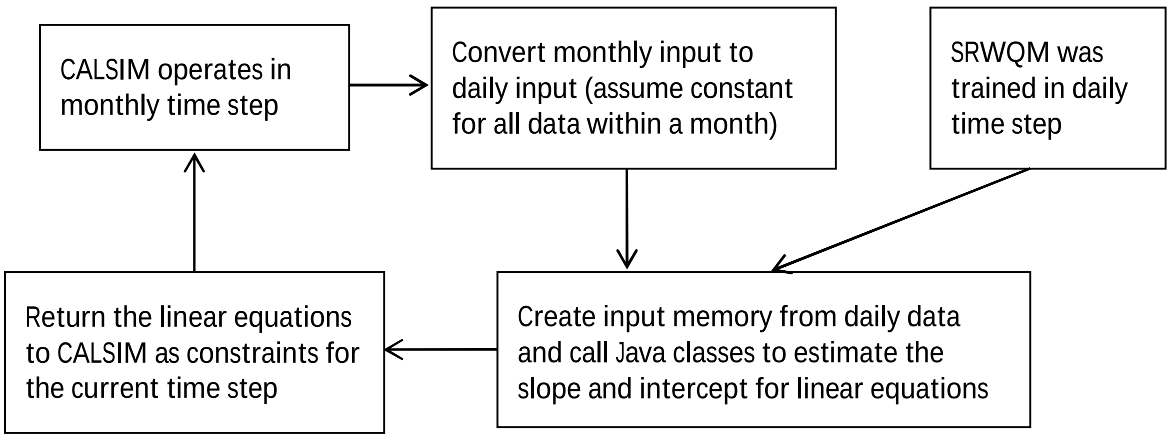

Figure 1-10 SRWQM ANN CalSim integration and its time-step conversion

1.4.2 Linearization of SRWQM ANN Results

There is an additional effort for this integration, the conversion between ANN nonlinearity and LP linear constraints. CalSim and CalLite are programmed in WRESL code which is a simulation language for flexible operational criteria and uses a linear programming (LP) solver to allocate water efficiently. In order to do so, all the constraints must be given in the form of linear equations. If not, the compiler will reject the nonlinearity and not solve the problem. We follow the approach that has been adopted in DSM2 EC ANN training(Seneviratne & Wu, 2007). A contour line of a given constant EC is calculated from EC ANN training which is a function of Sacramento flow and export. Once the contour is calculated, a box is applied (Figure 1-11a) to define the intersecting points so that the contour can be approximated by a straight line. This will provide a linear equation which is recognizable in the LP solver.

From previous SRWQM ANN training evaluations, inputs used to estimate water temperature are air temperature (T), solar radiation (R), inflow (known), Shasta storage (S) and outflows (TO, MO, PO, LO) from each layer (unknown). In the training evaluation, there is about 1% improvement from with-outflow to without-outflow. However, when integrating with CalSim, if outflows from each layer are considered for linearization, there will be five unknowns and it increases the complexity for linearization. The variations of outflows from each layer are high and lots of assumptions need to be made in order to linearize the problem. Those assumptions and trial-and-error guesses introduce unsteady outputs and cumbersome iterations. The error and bias can easily exceed 1% by a significant margin. Therefore, outflows are dropped from linearization to simplify and stabilize the problem.

In SRWQM ANN training, air temperature, solar radiation and inflow are known. The only decision variable is Shasta storage. Therefore, simple linear fitting between water temperature and storage can approximate the relationship (Figure 1-11b). To make a reasonable fitting, the range of sampling points is selected based on the previous time-step Shasta storage and current inflow. This will ensure those points covering the possible range of storage for the current time-step. This line is calculated at each time-step, so it provides a real time relationship between storage and water temperature based on air temperature, solar radiation and inflow happening in that month.

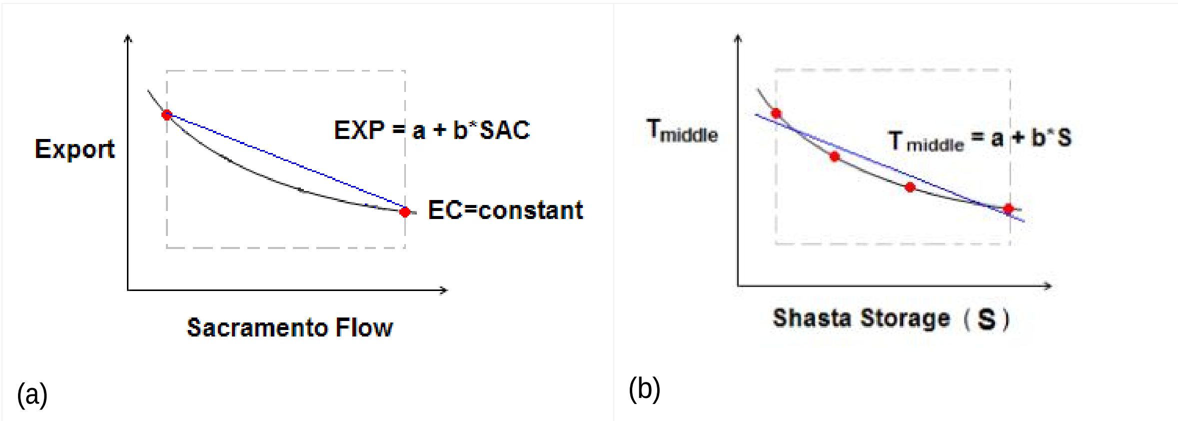

Figure 1-11 Linearization for ANN results

1.4.3 Temperature Estimates from CalLite

Water temperatures at four layers (top, middle, penstock, and lower) are estimated by ANN training results while Shasta storage is determined by CalLite optimization. Shasta Lake has the TCD so it can adjust water released from each layer to meet downstream water temperature requirement.

In this study, we used a baseline planning study for ANN training. The simulation period is from 1921 to 2003. To investigate the performance of CalLite SRWQM-ANN, the most straightforward approach is comparing time series plots. The 82-year runs are presented in Figure 1-12. We divided the entire time series into four plots for more detail. The red line is the Shasta release water temperature from SRWQM daily model and the blue line is the temperature from a simple CalLite setup which is a monthly operation model. Traveling through time, CalLite captures the overall pattern fairly well, especially in rising segments, descending segments and troughs. There are greater differences in peaks. However, the differences rarely exceed 3^oF and in most years it matches surprisingly well in spite of the complexities during the dry seasons.

Scatter plots help us interpret the results in more detail, such as analyzing results based on water year types or months. In Figure 1-13, there are scatter plots for all points and five water year types (wet, above normal, below normal, dry and critical). The X axis is the water temperature from SRWQM while the Y axis is the water temperature from CalLite. A 45 degree line is shown to help visually interpret the goodness-of-fit. Upper and lower 95% confidence intervals are also shown to help us get a good sense of range of estimations.

By looking at water year type (Figure 1-13), the results scatter around the 45 degree line with 95% confidence limit within 1^oF. The only exception is critical water years in which the confidence interval increases to 2^oF and CalLite is more likely to overestimate the water temperature. Overall, release water temperature in wet years ranges from 43 ^oF to 56 ^oF, above normal year from 42 ^oF to 60 ^oF, below normal year from 44 ^oF to 60 ^oF, dry year from 44 ^oF to 62 ^oF and critical year from 44 ^oF to 67 ^oF.

By evaluating the results for individual months, we observe that CalLite is more likely to slightly overestimate the temperature from February to October and underestimate temperature from November to January. Overall, release water temperature in Jan ranges from 44 ^oF to 50 ^oF, Feb from 43 ^oF to 48 ^oF, Mar from 43 ^oF to 48 ^oF, Apr from 44 ^oF to 51 ^oF, May from 45 ^oF to 54 ^oF, Jun from 46 ^oF to 54 ^oF, Jul from 47 ^oF to 60 ^oF, Aug from 48 ^oF to 65 ^oF, Sep from 47 ^oF to 65 ^oF, Oct from 47 ^oF to 62 ^oF, Nov from 50 ^oF to 57 ^oF and Dec from 47 ^oF to 55 ^oF. The high variation (wide confidence intervals) happens in the months of August and September.

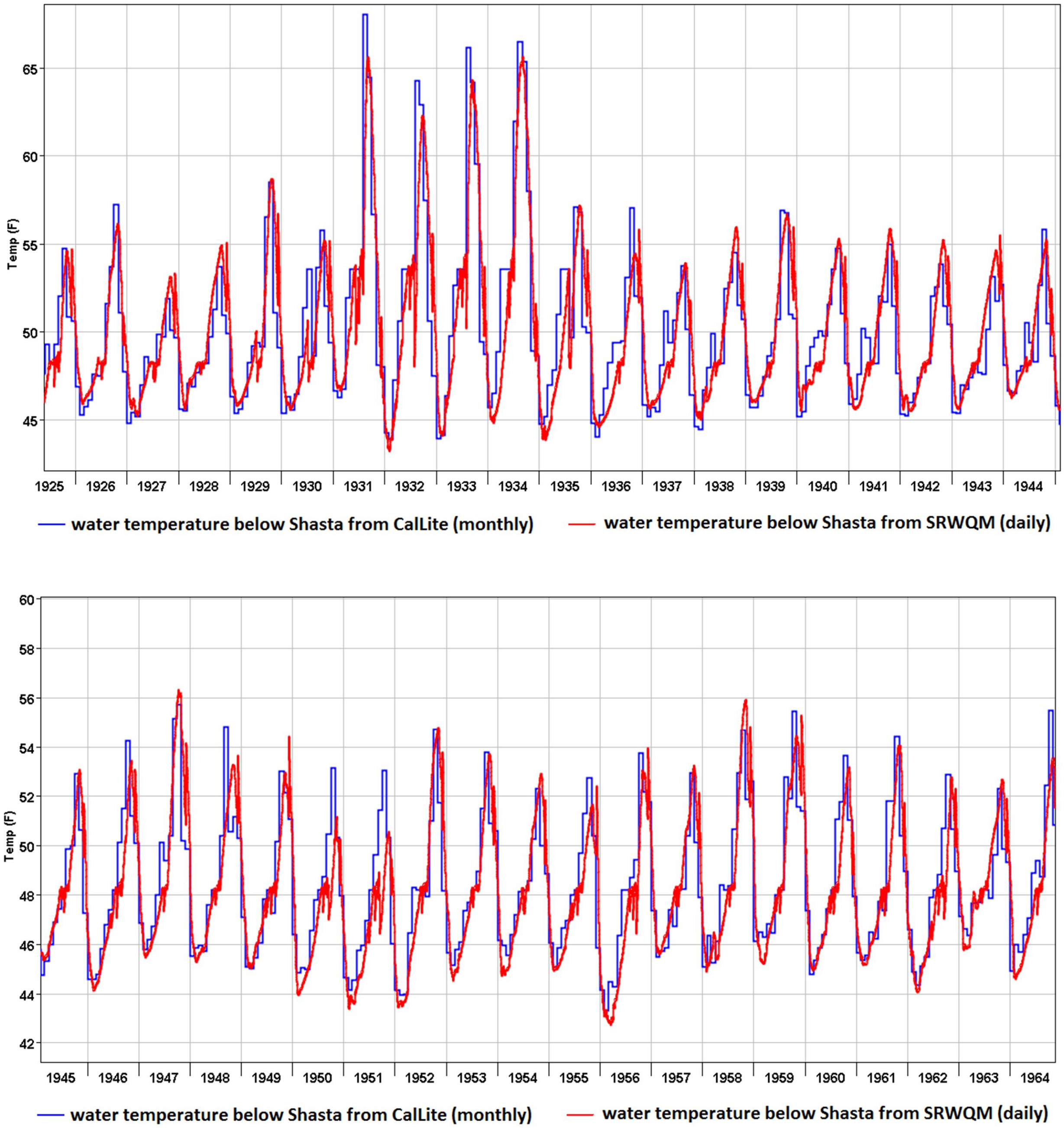

Figure 1-12 Comparison of release water temperature below Shasta for a baseline planning study

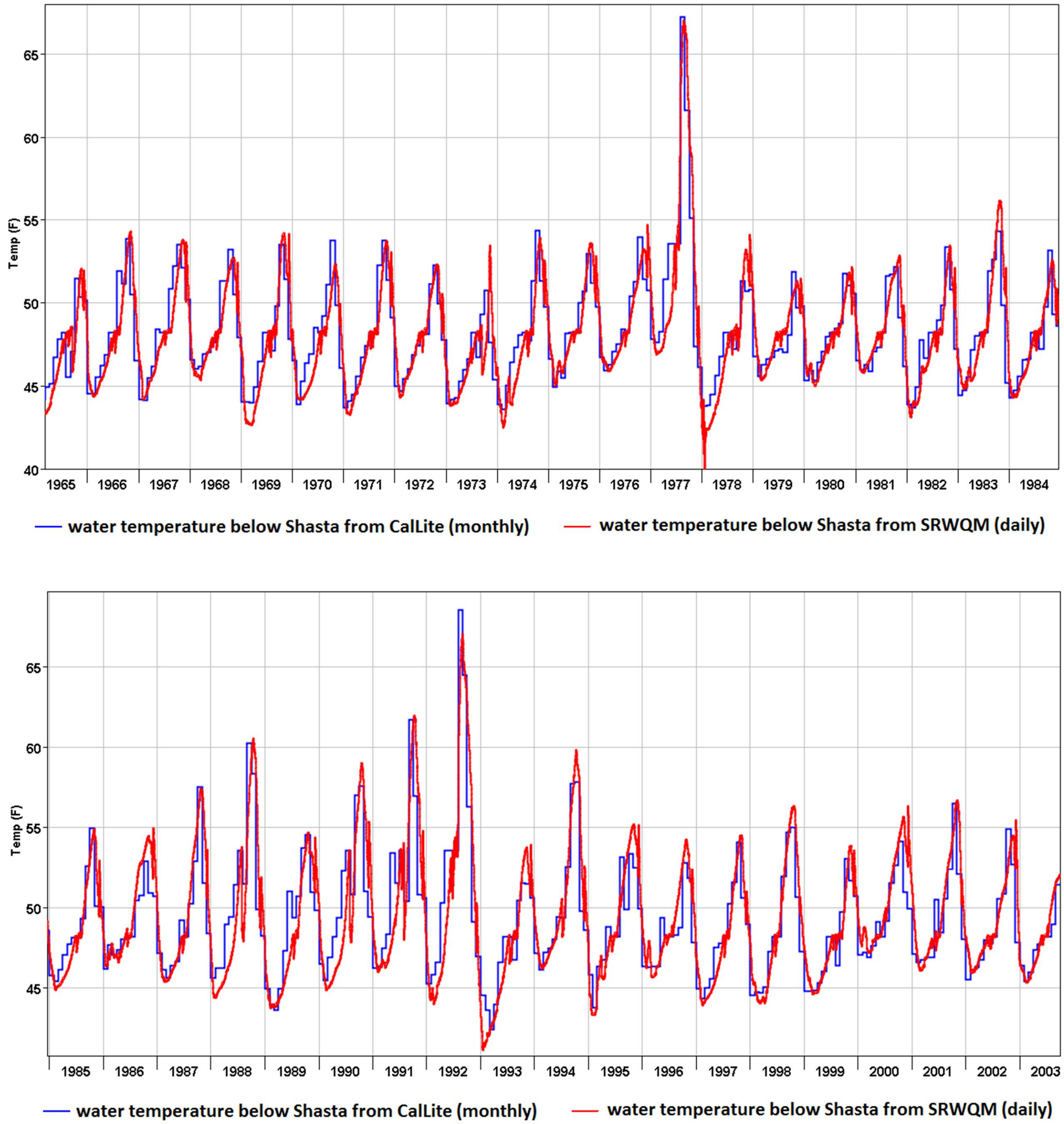

Figure 1-12 (cont.) Comparison of release water temperature below Shasta for a baseline planning study

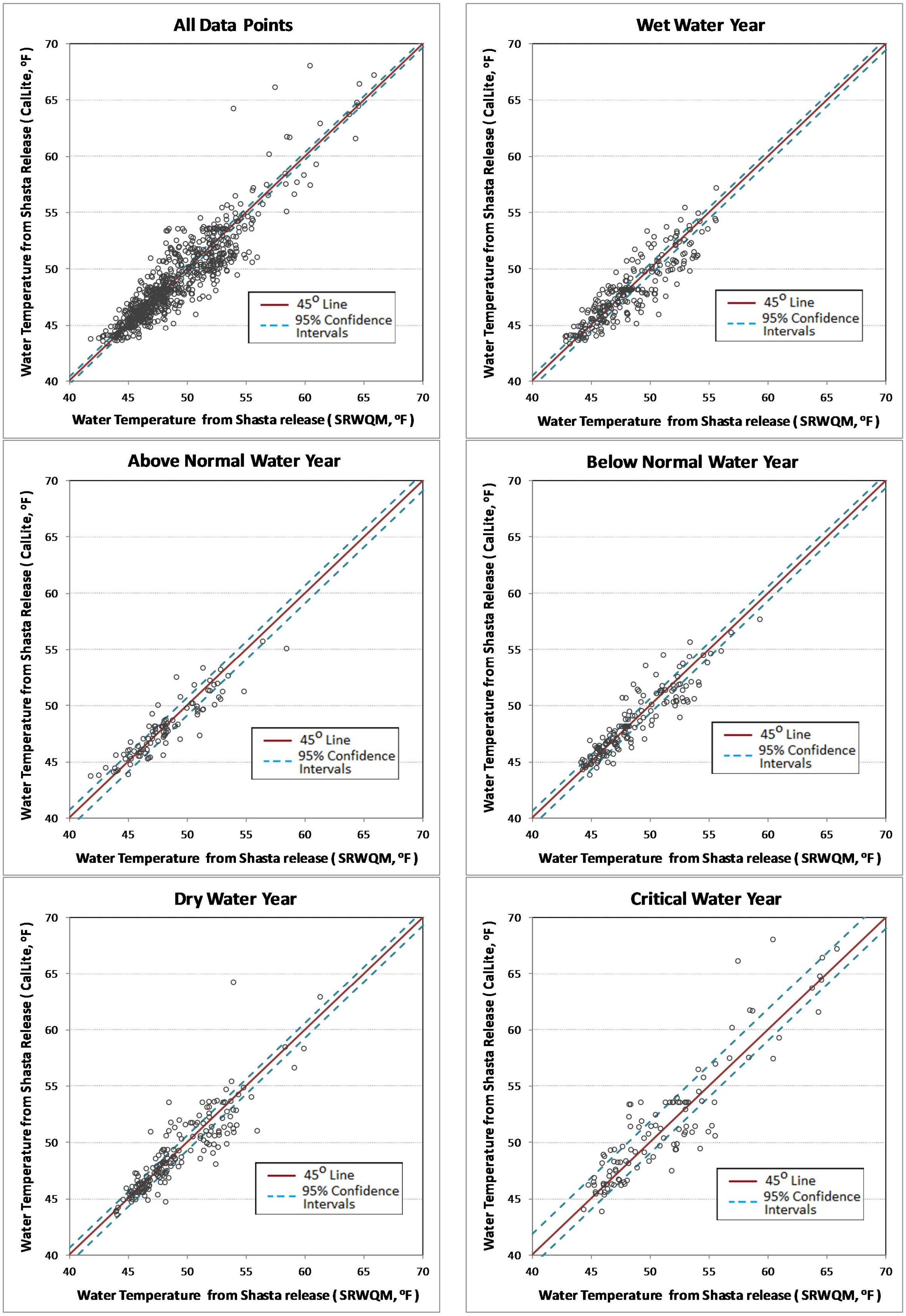

Figure 1-13 Scatter plots by water year type for water temperature from SRWQM and CalLite

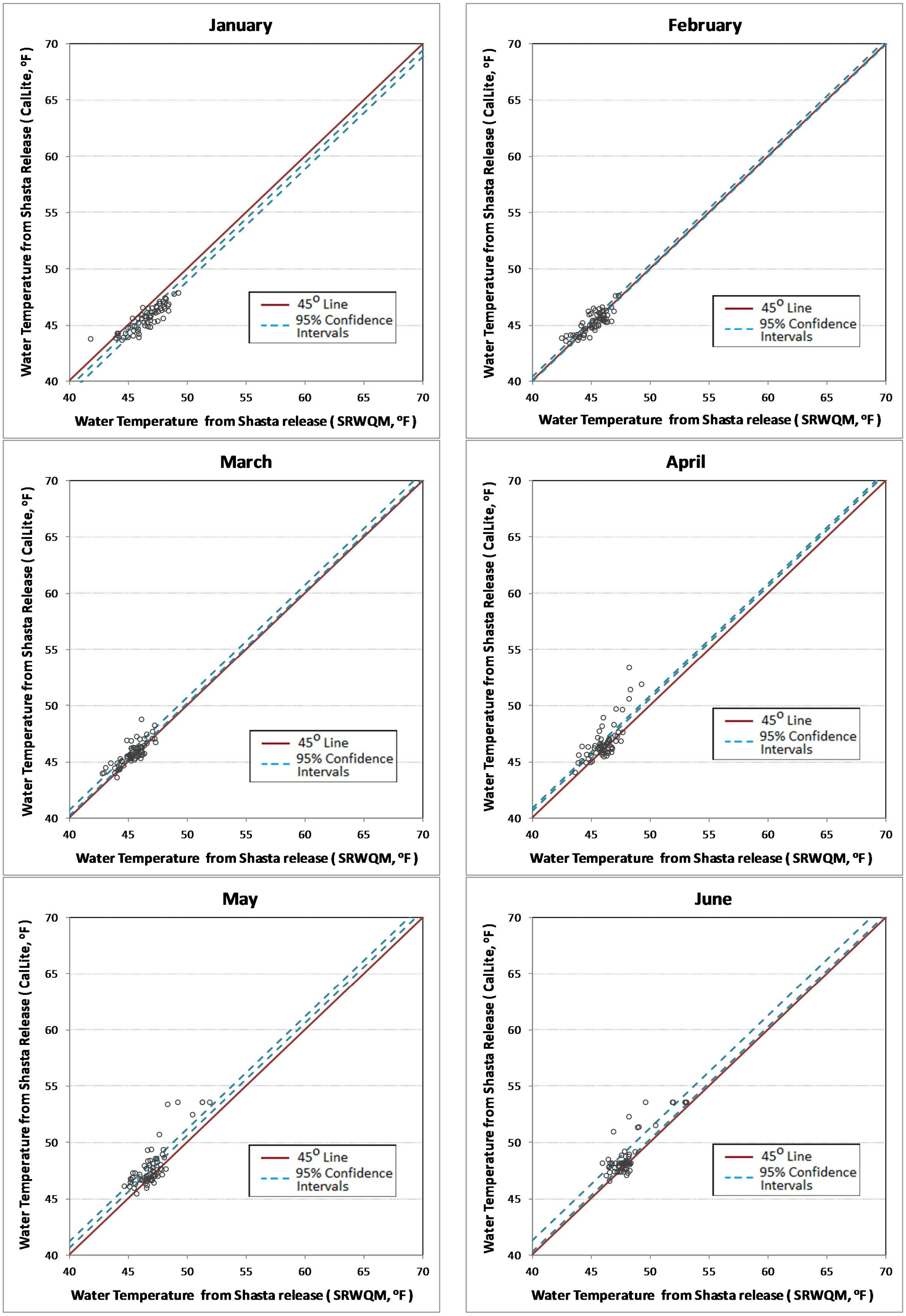

Figure 1-14 Scatter plots by month for water temperature from SRWQM and CalLite

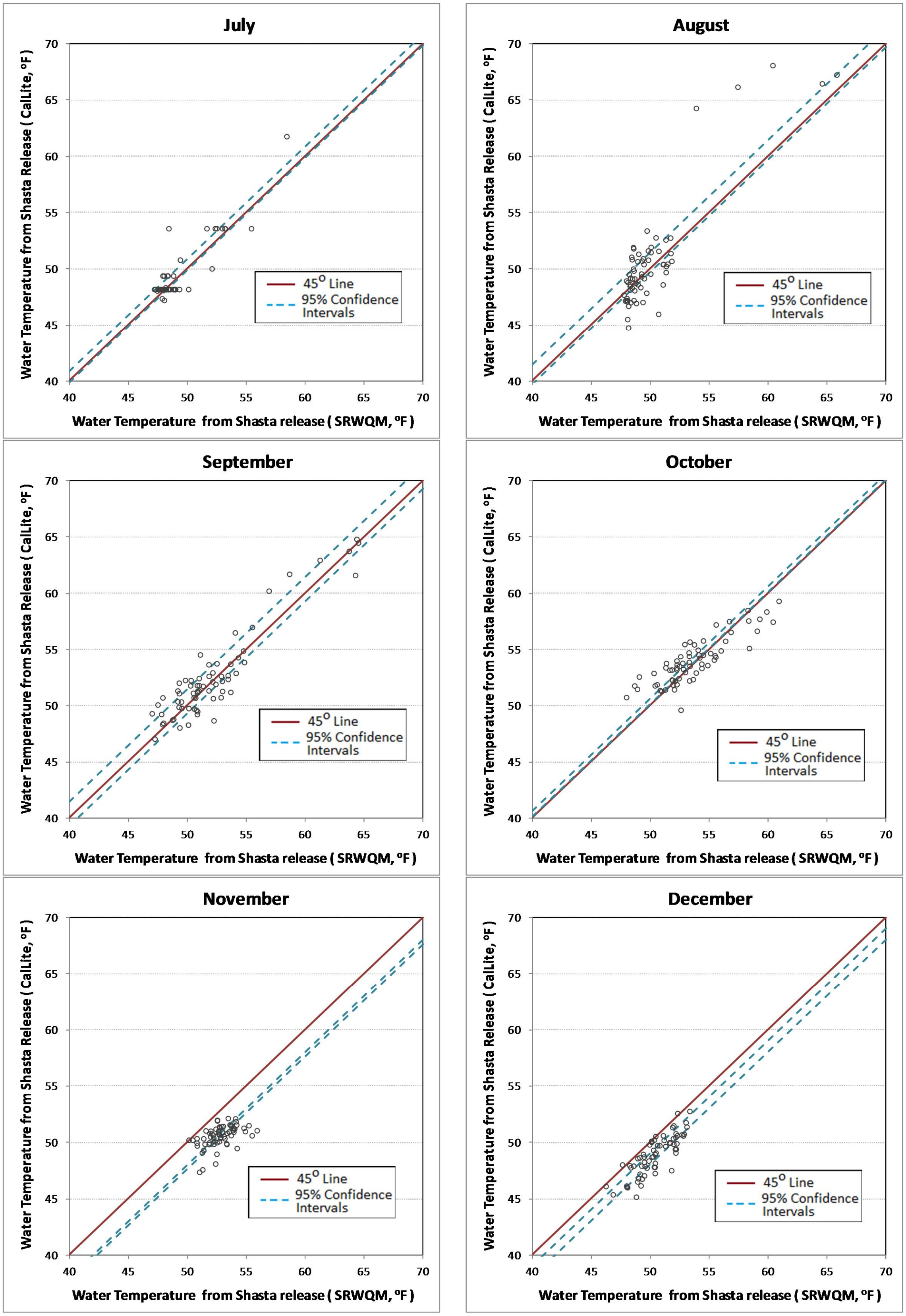

Figure 1-14 (cont.) Scatter plots by month for water temperature from SRWQM and CalLite

1.5 Sensitivity Analysis for SRWQM ANN Training

The sensitivity analysis for this project is studying the effect of changes in input parameter values on output temperature values. In this study we are delivering a proof-of-concept case and we are inviting feedback from various user and expert groups before we invest the substantial effort required to conduct such an analysis.

We would typically study such sensitivity by parameter perturbation. For example we would independently perturb air temperature, inflow and outflow by 10% and run the model to see temperature responds to those changes of each parameter.

We did a preliminary study involving climate change scenarios, named as Early Long Term (ELT) and Late Long Term (LLT). The aim was to see how an ANN trained on this data responds to different input data sets, such as higher or lower outflow and different meteorological data. We were looking for poor estimation or bias which would imply that the training sets are not sufficient to represent model behavior.

The comparison of water temperature below Shasta from CalLite and SRWQM for ELT and LLT are shown in Figure 1-15 and Figure 1-16, respectively. Note that outputs from CalLite are monthly while outputs from SRWQM are daily. Overall, we did not see any major changes in those plots and this implies that the training set is sufficient in capturing these relationships. However, training with wider range data is recommended to precisely quantify the relationship between inputs and outputs.

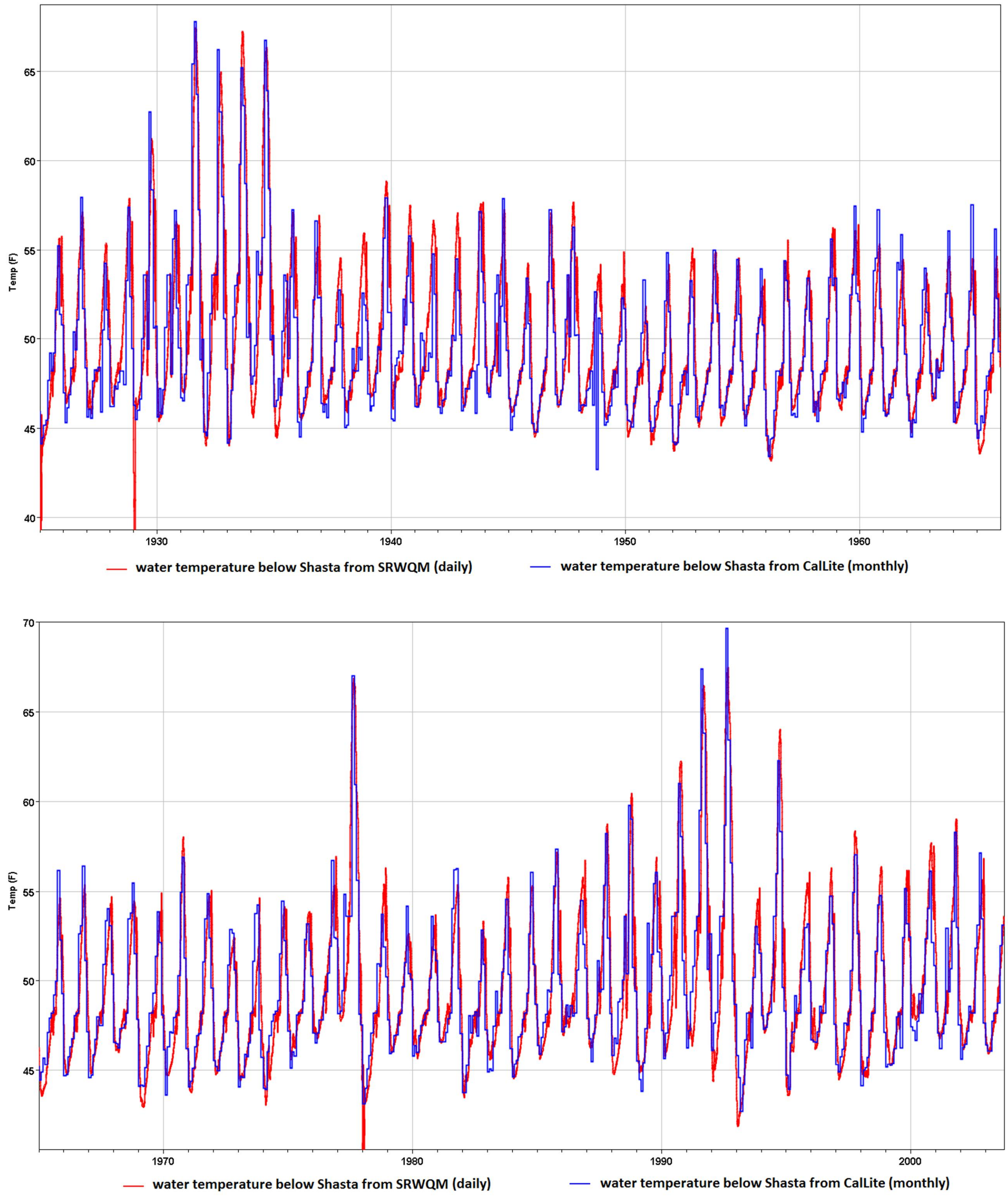

Figure 1-15 Comparison of release water temperatures below Shasta for an ELT climate change study

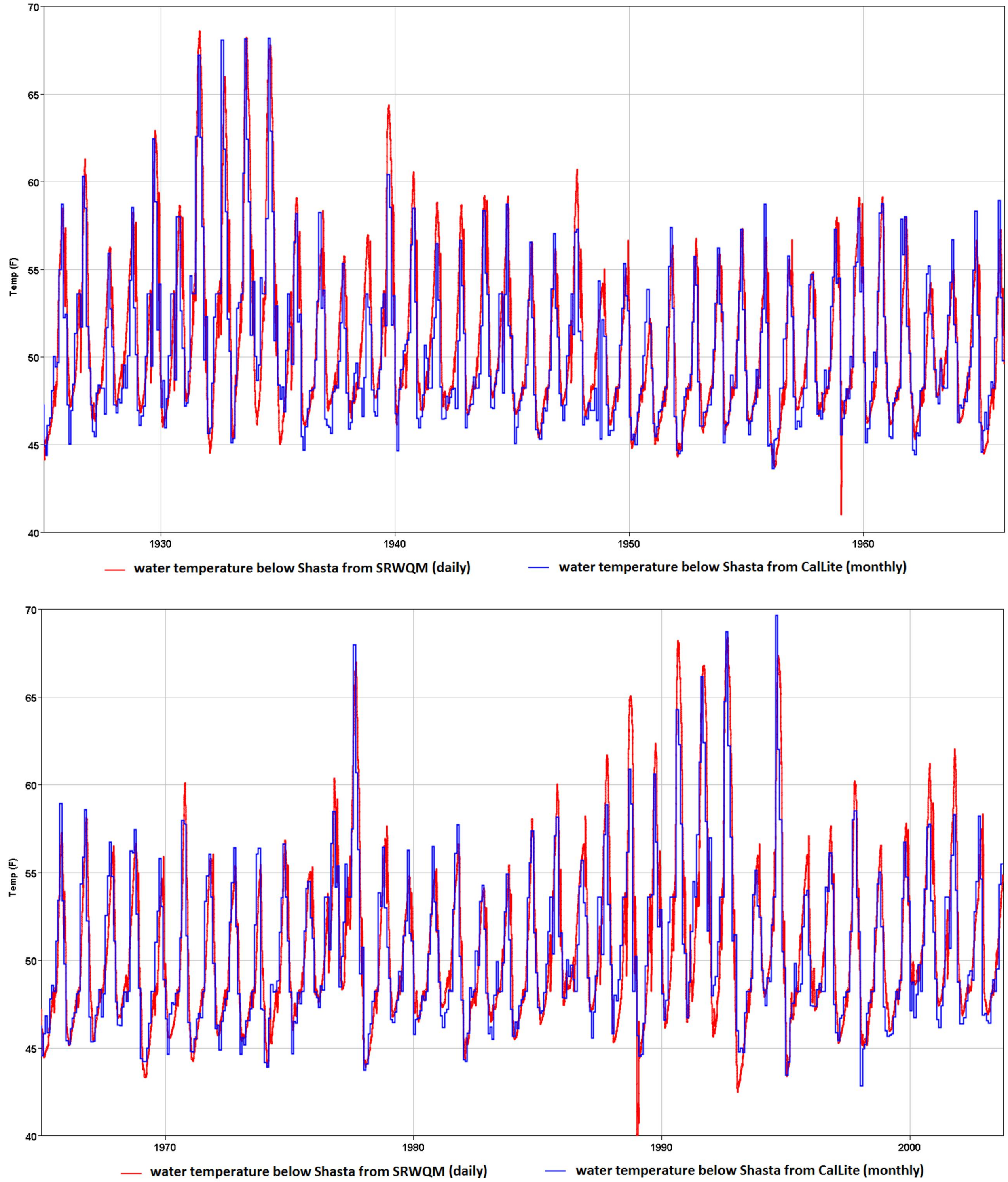

Figure 1-16 Comparison of release water temperatures below Shasta for a LLT climate change study

1.6 Downstream ANN Training for Balls Ferry

The previous ANN training was used to define the water temperature of each layer so that CalSim can decide how to mix water to achieve target temperatures below Shasta. However, biological points of interest often are further downstream. As water travels, its temperature is affected by air temperature, solar radiation, Shasta released water quantity, and tributary water temperatures. The goal is to define the water temperature releases from Shasta in order to meet the temperature requirements at particular downstream locations.

1.6.1 Downstream Water Temperature

The output locations in SRWQM are shown in Figure 1-17. Through the TCD, we are able to decide how to release water to meet target release water temperatures. This may be limited to immediately downstream of Shasta Dam. As water travels further downstream, water temperature is more dominated by air temperature. Taking Figure 1-18 for instance, water temperature below Keswick and Balls Ferry still follow the pattern of water below Shasta Reservoir. However, Shasta water releases do not have much influence on river temperatures near Hamilton City and Knights Landing. Right now we follow the temperature control target in SRWQM which is based on end-of-May Shasta storage. We may need to know locations and temperature requirement so that we can define violation criterion in SRWQM and later in the CalSim operation.

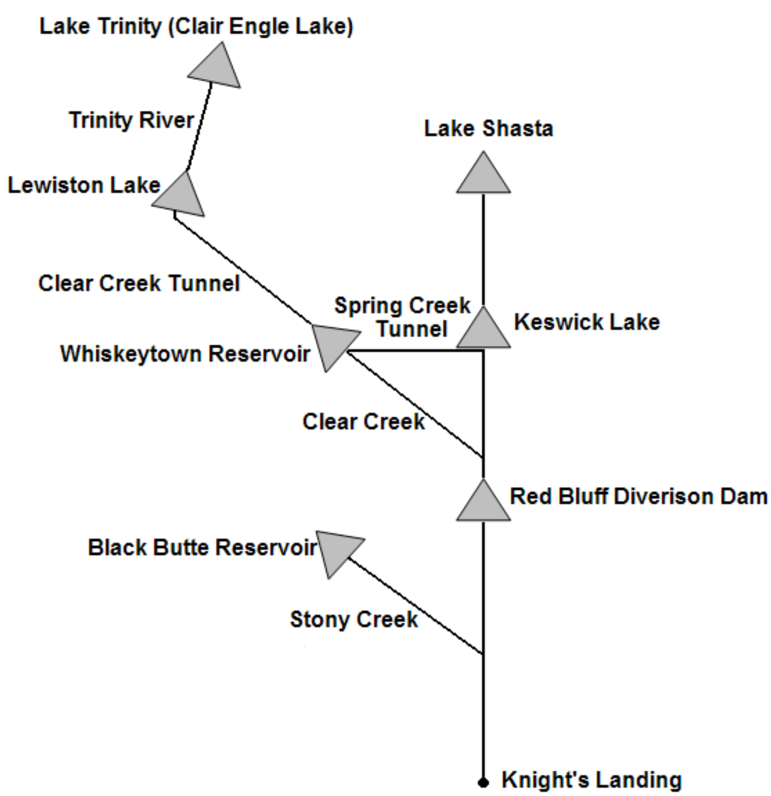

Figure 1-17 Schematic of HEC-5Q Upper Sacramento River Model

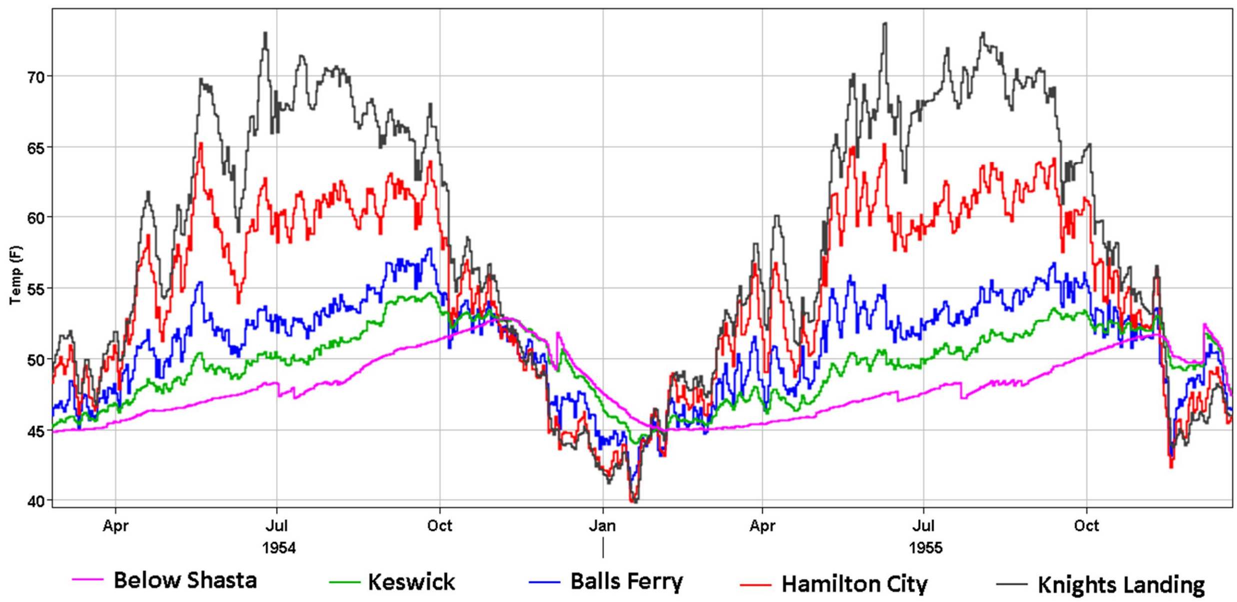

Figure 1-18 Water temperature at locations downstream of Shasta Reservoir

1.6.2 Downstream ANN Training for Balls Ferry

A simple ANN training is set up to derive the relationship between Shasta release temperature and temperature at Balls Ferry. The variables used as inputs are 1) air temperature 2) solar radiation 3) Shasta outflow and 4) Shasta outflow temperature. Daily time series data and five weeks of input memory are used for ANN training. The training result is shown in Figure 1-19. Goodness-to-fit is around 0.95. The red line represents Balls Ferry temperature while the blue line is the estimate from ANN training. Overall, ANN estimates the temperature pattern fairly well.

For SRWQM, multiple seasonal patterns depending on the end-of-May Shasta storage conditions were developed to use the cold water. It provides information on whether the year is wet, dry or critical and defines temperature schedules for Shasta release. Therefore, Shasta release temperature usually stays constant for one operation period unless there is not enough cold water in storage to meet this target. To incorporate downstream temperature requirement to CalLite, we can assume a 56 ^{O}F target temperature at Balls Ferry. Through downstream ANN training, it tells us the desired release temperature from Shasta and then that becomes new target temperature for Shasta TCD operation.

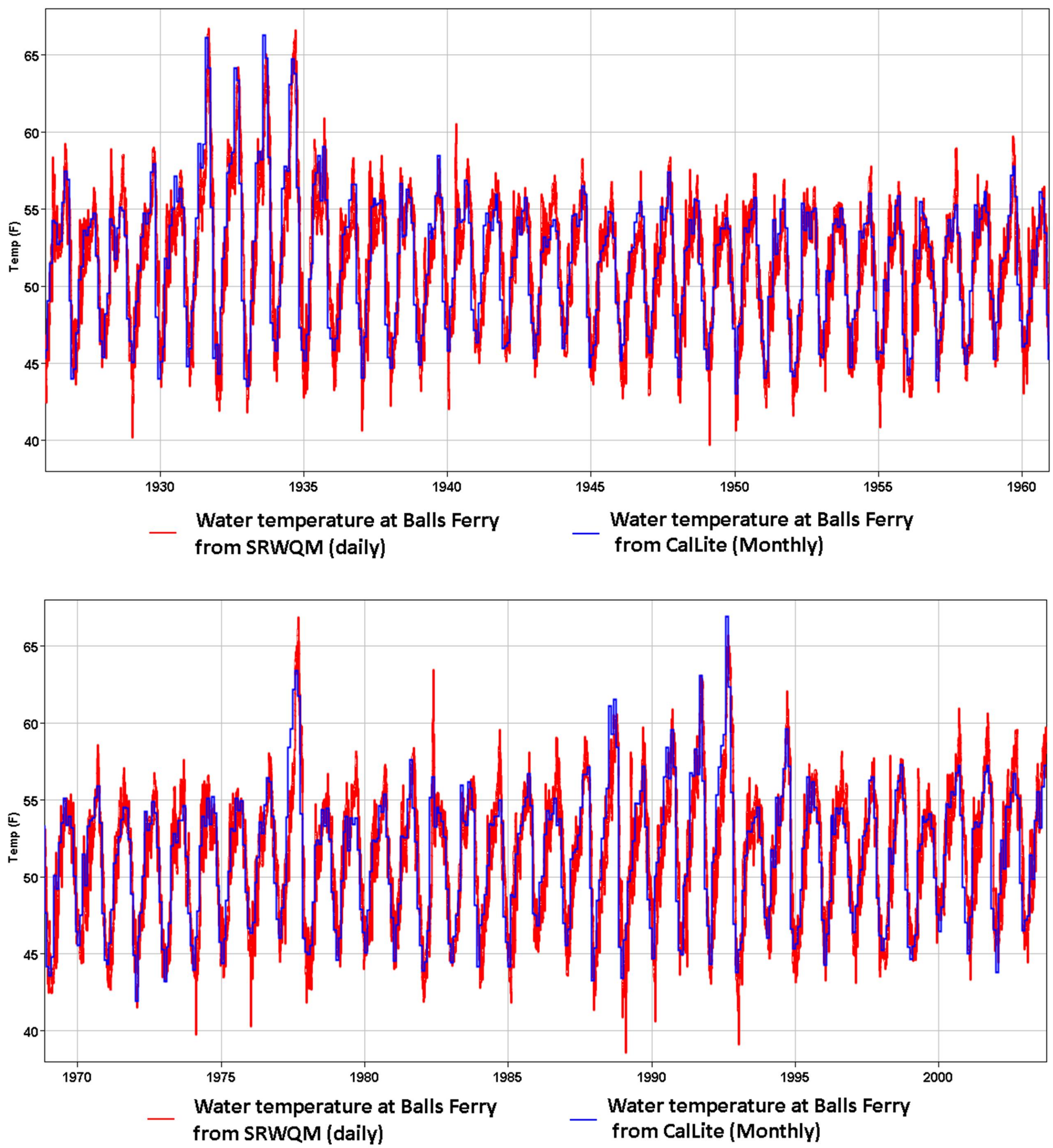

Figure 1-19 Water temperature at Balls Ferry

1.7 Summary

The goal of this study is to estimate water temperature from CalSim/CalLite without actually running the SRWQM temperature model. Having temperature constraints in CalSim allows system operation to control downstream water temperature.

The Sacramento River Water Quality Model (SRWQM) is the temperature model selected for ANN training. It was developed to simulate mean daily reservoir and river temperatures. A single reservoir system around Shasta Lake is set up for testing. The components are inflow, outflow (downstream water demand plus flood control spills) and storage. It is assumed that downstream demand is the same as outflow from Shasta in a baseline study. Shasta Lake is vertically divided into four layers and water temperatures at each layer are available from SRWQM. Artificial Neural Networks (ANNs) can be trained to simulate water temperatures in each layer based on given inputs: air temperature, solar radiation, Shasta storage and inflow. The effect of each input on temperature output can be seen over a period of time. This memory effect is represented by explicitly specifying up to 3 months of past input values.

With given inflow and total outflow, the TCD releases water from different layers to meet downstream temperature requirement. For now, temperature does not control total outflow unless some further constraints are given or CalSim allows back optimizations.

Integration of SRWQM ANN into CalLite WRESL code was done by generating Java classes based on training data. This allows a direct interface with the WRIMS Java Engine.

The relationship from Shasta to downstream locations, such as Balls Ferry, is also derived, based on air temperature, solar radiation, Shasta released flow, and temperature. Further downstream, water temperature is dominated by air temperature.

ANN training is validated with high correlation (R^2 approaching 1) ranging from 0.97 to 0.99. A baseline planning study is used for training and temperatures are evaluated by comparing the results from SRWQM and CalLite. CalLite captures SRWQM quite well.

Detail sensitivity analysis will be done later. For now, other scenarios with climate changes (ELT and LLT) have been tested and ANN performs well.

1.8 Future Directions

1. This study has tested a simple single model around Shasta. To incorporate this additional temperature feature into CalSim and CalLite, ANN training results and codes will be delivered to the CalSim/CalLite team so that they can evaluate this new feature.
2. We assumed outflow is equal to downstream demand, and that water temperatures are determined based on the outflow is a given. With a fixed outflow, TCD releases water from different layers to meet target temperature. If the outflow violates a temperature constraint, a penalty is added to the optimization but this does not change outflow to alter the result. Therefore, temperature has no control for total release outflow as well as storage. Right now, we can only estimate release temperature based on given flows. The decision of outflow and storage changes needs to be evaluated by looking at the entire system.
3. Sensitivity analyses can be done either through ANN training or CalLite problem solving. This will be management's call for timelines and necessary efforts.

1.9 Acknowledgements

Kuo-Cheng Kao and Hao Xie of DWR provided help in CalLite integration.

1.10 References

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Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

34th Annual Progress Report
June 2013

Chapter 2

Extension of DSM2 for the South Bay and California Aqueducts and Delta Mendota Canal

Authors: Siqing Liu, Robert Suits,
Delta Modeling Section,
Bay-Delta Office,
California Department of Water Resources

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2 Extension of DSM2 for the South Bay and California Aqueducts and Delta Mendota Canal

2.1 Introduction

An important part of the California Department of Water Resources (DWR) Municipal Water Quality Investigation (MWQI) program is to develop short- and long-term forecasting simulation capabilities for the California Aqueduct. Similar capabilities for the Delta have been developed in order to provide forecasted quality of inflows at the Banks and Jones Pumping Plants for the California Aqueduct and Delta Mendota Canal (DMC). The short- and long-term forecast for both the Delta and California Aqueduct relies on hydrologic and water quality modeling using DWR's Delta Simulation Model 2 (Bay-Delta Office, California Department of Water Resources). The original DSM2 extension model for the California Aqueduct, South Bay Aqueduct, and Delta Mendota Canal (DSM2 Aqueduct Model) was developed by CH2MHILL in 2005 (CH2MHILL, 2005). Since then a lot of work has been done by the DWR Bay-Delta Office, Operations & Maintenance, and MWQI to verify and improve the DSM2 Aqueduct model. The report will document our work on the DSM2 Aqueduct model which includes: (1) extending the model simulation period from 3 years starting January 1, 2001 to 21 years starting from January 1, 1990; (2) modifying the ways to treat gains and losses of water as a result of seepage, evaporation, rainfall, storm water inflow, meter reading errors, etc.; (3) enhancing the model's capability of calculating water quality by adding two more constituents, dissolved organic carbon (DOC) and Bromide; and (4) incorporating inflows from ground water and storm water.

This chapter is a summary of the full Report of this project, prepared for the MWQI Program (Liu, 2013). Interested readers should refer to the full Report for complete details of the DSM2 Aqueduct Model.

2.1.1 California Aqueduct

The California Aqueduct is the primary conveyance facility for the SWP (Figure 2-1). The section of the California Aqueduct 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 (off-line). Both the South Bay Aqueduct and the West Branch of the California Aqueduct are included in the model. The South Bay Aqueduct, which begins at the South Bay Pumping Plant and ends at the Santa Clara Tank, is comprised of 7 checks, open channels, siphons, and tunnels. The West Branch simulated in the model starts from the bifurcation to the Oso Pumping Plant, and ends at Pyramid Lake. It is composed mostly of open channels and an in-line reservoir, Quail Lake. The Aqueduct is managed by four DWR 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.

Figure 2-1 California Aqueduct / State Water Project

A series of pumping plants on the Aqueduct provides incremental lifts in water head to maintain an average downstream 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 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 is not included in the model.

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.

2.1.2 South Bay Aqueduct

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.

2.1.3 Delta–Mendota Canal

The Delta–Mendota Canal (DMC) is a 117 mi (188 km) aqueduct in central California. It was completed in 1951 and is operated by the United States Bureau of Reclamation (USBR) and the San Luis Delta Mendota Water Authority. The DMC is part of the USBR Central Valley Project and its purpose is to replace the water in the San Joaquin River that is diverted into Madera Canal and Friant-Kern Canal at Friant Dam. The canal begins at the C.W. Bill Jones Pumping Plant, which lifts water 197 ft (60 m) from the Sacramento-San Joaquin Delta. The canal runs south along the western edge of the San Joaquin Valley, parallel to the California Aqueduct for most of its journey, but it diverges to the east after passing San Luis Reservoir, which receives some of its water. The water is pumped from the canal and into O'Neill Forebay, and then it is pumped into San Luis Reservoir by the Gianelli Pumping-Generating Plant. Occasionally, water from O'Neill Forebay is released into the canal. The Delta–Mendota Canal ends at Mendota Pool, on the San Joaquin River near the town of Mendota, 30 mi (48 km) west of Fresno. The Delta–Mendota Canal capacity is 4,600 cu ft/s (130 m^3/s) and gradually decreases to 3,211 cu ft/s (90.9 m^3/s) at its terminus. 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 Introduction to the DSM2 Aqueduct model

The DSM2 model has three separate components: HYDRO, which calculates water velocities and elevations; QUAL, which calculates EC and other constituents throughout the Delta; and PTM, which is a particle tracking model. HYDRO provides hydraulic inputs for QUAL and PTM. The DSM2 Aqueduct model only used HYDRO and QUAL. DSM2 HYDRO relies on an appropriate grid resolution to run with sufficient accuracy and efficiency.

For the extension model, grid nodes are located where inflows and outflows occur, or where channel geometry changes occur (usually where check structures are located). 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 Jones Pumping Plant and the Mendota Pool, and 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, and is modeled with at least 8 channels and 9 nodes. The West Branch contains one check structure and an in-line reservoir, and is modeled with at least 2 channels and 3 nodes in DSM2.

South Bay Pumping Plant flow 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 a DSM2 object-to-object transfer. Likewise, pumping to the West Branch from the OSO Pumping Plant data is treated as a diversion from the main stem of the Aqueduct at DSM2 node 448 through an object-to-object transfer. 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). The water exchange between O'Neill Forebay and San Luis Reservoir and between O'Neill Forebay and DMC is modeled as object-to-object transfer in the model.

The 116 mile Coastal Branch splits from the main line 11.3 mi (18.2 km) south-southeast of Kettleman City transiting Kings County, Kern County, San Luis Obispo County, and Santa Barbara County to deliver water to the coastal cities of San Luis Obispo, Santa Maria, and Santa Barbara. The Costal Branch of the SWP was not modeled directly. Instead, the pumping to the Coastal Branch from the main stem of the Aqueduct through the Las Perillas Pumping Plant is treated as a diversion from the main stem of the Aqueduct at DSM2 Node 424.

The DSM2 Aqueduct model developed by CH2MHILL was based on version 6 of DSM2. The model was calibrated by comparing model-calculated flows, stages, and EC against measured data for a three-year period beginning January 1, 2001. Model validation was not conducted using a separate input set for a time period different from the calibration time period. Many assumptions were made when the DSM2 Aqueduct model was developed, including:

(1) Gains and losses: Results of water balance calculations based on inflow and outflow data from various sources indicate gains and losses must be considered in order to maintain the measured water levels of the Aqueduct.

(2) Reservoir operations: DSM2 treats reservoirs as completely mixed, vertical-walled bodies of water (Continuously Stirred Tank Reactors).

(3) Gate operations: The check structures are modeled as broad-crested weirs, with the invert elevations fixed to control flows.

(4) Diversion data interval: 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.

2.3 Verification of the DSM2 Aqueduct model

The calibration of the original DSM2 Aqueduct model covered a three-year period starting January 1, 2001. The model was not verified using a separate input set for a time period different from the calibration time period. The original model was calibrated to calculate water velocities, stages of water bodies, and EC, a surrogate for salinity. During the verification and improvement period, the model was verified using 21-year data starting January 1, 1990. The three-year calibration period was also included in the verification process since data was collected from more sources, more ground water pump-in and storm water inflows were included in the model, and the model experienced some improvement.

The completion of the verification process was a result of teamwork among three groups in DWR: the Operation Control Office (OCO), the MWQI program and the Bay Delta Office (BDO). OCO was responsible for compiling all the flow and stage data for model verification from different sources. The data includes pumping at major pumping stations which move water into or out of the Aqueduct and DMC, diversions from the California Aqueduct, DMC, or San Luis Reservoir by water contractors, groundwater pump-ins and storm water flow to the modeled system, rainfall, and evaporation. MWQI collected EC, DOC, and Bromide for the model's boundary inflows from three sources, California Data Exchange Center (CDEC), Water Data Library (WDL), and U.S. Bureau of Reclamation. More details about data compilation will be explained in the next chapter. BDO developed a tool to pre-process hydro and water quality data for the DSM2 Aqueduct model. The main tasks that the tool can accomplish include: (1) downloading data from CDEC; (2) converting monthly data to daily data required by the model; (3) conducting calculation of mass balance; (4) filling missing EC and DOC data; (5) calculating Bromide from EC and fingerprinting data; and (6) exporting data to DSS files.

2.3.1 DSM2 Version 8

DSM2 Version 8 (Bay-Delta Office, California Department of Water Resources) is an improvement on DSM2 Version 6. Several bugs found in Version 6 were fixed. Two main enhancements to DSM2 are: (1) some algorithms were changed to reduce the program's run times, and (2) operating rules were introduced in Version 8 so gates and barriers can operate according to specified operating rules. No significant differences were observed when model results from running two versions of the DSM2 model were compared. The verification for the DSM2 Aqueduct model was also done using DSM2 Version 8. Results for flows, stages, EC, Bromide and DOC from both version 6 and version 8 DSM2 Aqueduct models were compared, and no significant differences were observed. For the current version 8 of the DSM2 Aqueduct model, gate operations are treated the same way as in version 6 of the model. BDO has spent limited time on trying to use operation rules for gate operations, but without success. The problem is that the model would not converge for most of the time steps, thus the results cannot be trusted. This issue will be investigated in more detail in the future.

2.4 Hydrologic and Water Quality Data

The DSM2 extension model is driven by a lot of data, which include both hydrologic and water quality data. For the HYDRO part of the extension model, O&M compiled hydrologic data from various sources, and did analysis on gains and losses. MWQI compiled water quality data for the QUAL part of the extension model. The following several sections will cover work done by O&M and MWQI in more details.

2.4.1 Hydrologic data

For the HYDRO part of the DSM2 extension model, several types of data have to be given. Among them are: (1) pumping flows or check flows, (2) meteorological data (rainfall and evaporation) as source or sink point flows, (3) groundwater inflows as source seepage point flows, (4) storm water inflows, (5) diversion flows, and (6) storage changes of the Aqueduct. For the 21-year simulation period starting from January 1, 2010, O&M compiled data from different sources. Table 2-1 is a list of the data sources for the historical data and current data.

The pumping flows at Banks and Jones Pumping plants are treated as boundary inflows in the model. The pumping flows at South Bay Pumping Plant, Oso Pumping Plant, the Las Perillas Pumping Plant, Dos Amigos pumping Plant, and pumping/generating flow for Gianelli Generating Plant and O'Neill

Generating Plant are treated as object-to-object flow transfer. Daily delivery data for the Pacheco Tunnel is treated as a San Luis Reservoir diversion. Flows at SWP Check 21 and pumping flows at Edmonston and Pearblossom Pumping Plants were not directly used in the model; instead, they were used in mass balance calculations, which will be discussed in the next section.

Meteorological data is mainly used as inflows and outflows for San Luis Reservoir. Groundwater and storm water inflows are grouped by pool along the Aqueduct or DMC. Monthly delivery data for each diversion are grouped by pool along the Aqueduct or DMC. 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.

Table 2-1 Sources for hydrologic data

Data	Historical	Current
Evaporation / Precipitation at SWP& DMC	CIMIS http://wwwcimis.water.ca.gov/cimis/welcome.jsp	CIMIS http://wwwcimis.water.ca.gov/cimis/welcome.jsp
Evaporation / Precipitation at San Luis	Prior to 1998, SWP Monthly Operations Data Reports http://www.water.ca.gov/swp/operationscontrol/monthly.cfm	CVP Reservoir Operations Reports http://www.usbr.gov/mp/cvo/reports.html
Pumping data	MAPPER[1]	MAPPER
Pacheco Tunnel and Check 21 Flows	MAPPER	MAPPER
Diversion and Pump-in Flows for the SWP	Prior to 2000, SWP Monthly Operations Data Reports / SWP Annual Reports of Operation http://www.water.ca.gov/swp/operationscontrol/monthly.cfm http://www.water.ca.gov/swp/operationscontrol/annual.cfm	SAP[1]
Diversion and Pump-in Flows for the DMC	San Luis-Delta-Mendota Water Authority	San Luis-Delta-Mendota Water Authority

2.4.2 Gains and Losses

When the extension model was developed by CH2MHILL in 2005, it was found that gains and losses must be considered on some sections of the Aqueduct system in order for the model to run successfully.

[1] For information about MAPPER or SAP data contact the Delta Compliance and Modeling Section (dcm@water.ca.gov) or the Operations Records and Reports Section (ocoweb@water.ca.gov)

The gains and losses were the amount of water that cannot be balanced when known outflows and storage change are deducted from known inflows (Equation 2-1).

$$gain\ or\ loss\ =\ inflow - outflow - storage\ change \qquad (2\text{-}1)$$

Following the similar procedures documented in CH2MHILL's report, gains and losses were calculated using Equation 2-1 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.

For Reach A, other major inflows include water released to O'Neill Forebay from San Luis Reservoir, water pumped to O'Neil Forebay from DMC, and groundwater pump-ins. Other major outflows include water pumped to San Luis Reservoir from O'Neill Forebay, water released to DMC from O'Neill Forebay, and water delivered to contractors between DSM2 node 401 and 415. For Reaches B and C, other major flows include groundwater pump-ins and storm water flows. Other major outflows include water delivered to contractors. There are no other major inflows for Reach D. Other major outflows include water delivered to contractors between DSM2 node 445 and 469, which include water delivered to West Branch.

A number of factors can cause gains and losses. Inaccurate measurements may result in inflows/outflows being higher or lower than actual values. Because seepage and evaporation along the canal are not explicitly measured, they are not included in outflows. At times, high flows overshoot, and excess water flows into SWP or DMC. Since the amount is not known, it is not considered in inflows. Also not considered in inflows is rainfall added to water bodies in the system. Another factor is that both daily and monthly data are used in mass balance calculations. Monthly data such as diversions, groundwater pump-ins, storm water inflows, and storage change were assumed to be a constant flow rate for the month. It is possible that there may be significant weekly or daily variation in the actual inflows/outflows that are not represented in the monthly values.

Figure 2-2 presents the results of the mass balance calculations for the four sections of the main aqueduct.

The magnitude of gains / losses in the first two reaches is higher than the magnitude of gains / losses in the last two reaches. There are no distinct seasonal patterns in the gains / losses. No single factor is solely responsible for the spatially and temporally variation of gains / losses. At first sight, the magnitude of gains / losses is significant, but in fact, it is negligible when compared with primary inflows. To further verify that the gains / losses do exist, Bryant Giorgi of O&M compared his calculation with that of Guy Masier and found that both calculations lead to very close results (Giorgi & Singh, 2011). The minor differences are results that the same data from different sources may be somewhat different.

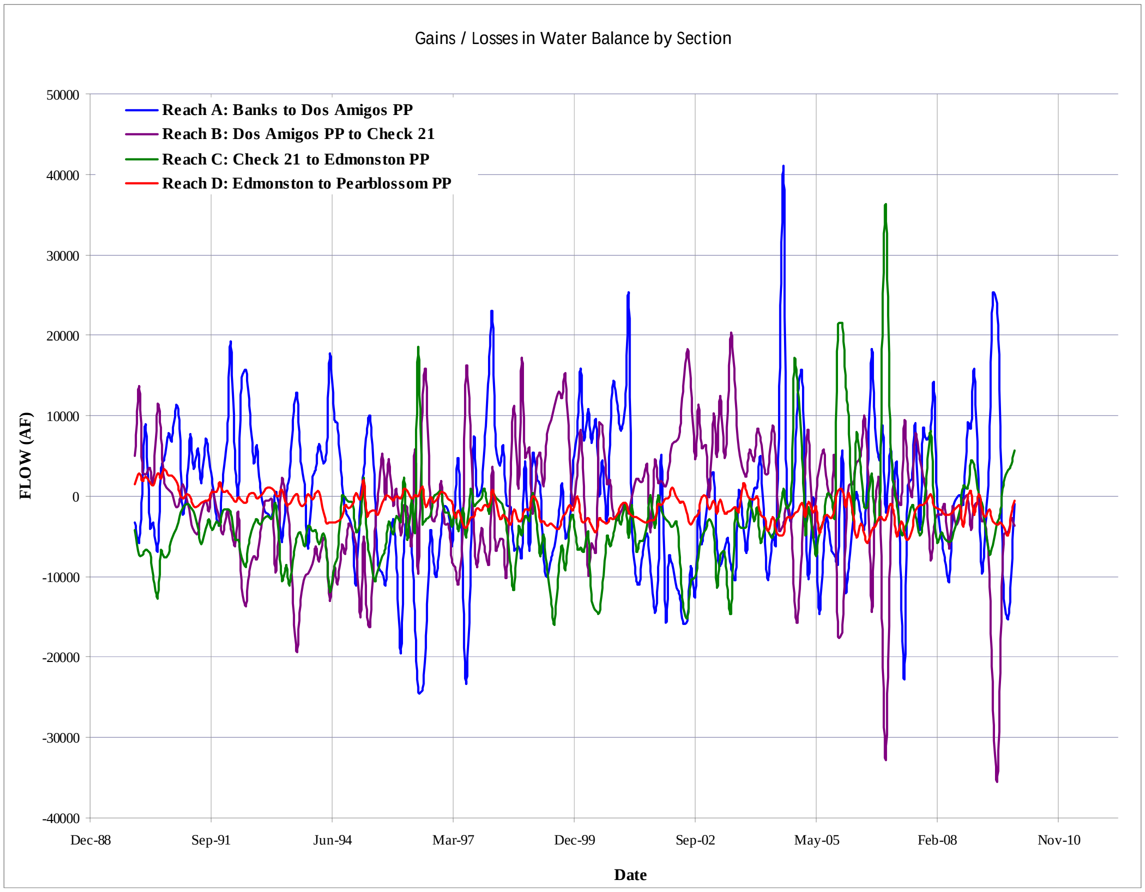


Figure 2-2 Comparison of gains / losses in Water Balance Calculations for Each Section

When CH2MHILL developed the model, closure terms to correct gains and losses were applied in the model at either the upstream or downstream node of each of the four sections. If there is a loss for a reach at any time, an additional inflow was added at the most upstream node of that reach. However, if there is a gain for a reach at any time an additional diversion was added at the farthest downstream node of the reach. Generally there is no problem with this approach except when losses are significant. For a loss, an additional inflow is added to prevent the channel from drying out. For water quality modeling, the water quality for the inflow must be given at each time step. While this is not a problem for Reach A, it is a problem for Reaches B and D, since water quality in those reaches is not known until the model is run. In our approach, when there is a loss in Reach B, C, or D, the loss is deducted proportionally from diversions in that reach to keep mass balanced, so there is no need to specify water quality for inflows used to balance losses. For a gain, it is treated the same way as in the CH2MHILL report.

2.4.3 Water quality data

In the water quality model (QUAL), all model inflows require specification of the daily water quality of the inflow. Even though the model requires daily input, for inflows such as groundwater pump-ins and storm water flows only several grab sample data is available. In this case, constant water quality values were assigned to each location using the data provided to BDO by MWQI.

MWQI worked on several tasks to compile EC, Bromide, and DOC data from different sources, conducted QA/QC for the data and filled in missing data using linear interpolation where data gaps are less than two months. Water quality data collected by MWQI consists of two parts: quality of inflows, used to run the model, and other water quality data, used to verify the model. The Metropolitan Water District of Southern California (MWD) also provided Bromide and DOC data for model verification. The following several paragraphs give more details about how data was collected and processed.

The EC data for the CA Aqueduct and DMC was analyzed using Standard Methods 2510-B (Fong & Aylesworth, 2006), (Clesceri, Greenberg, & Eaton, 1998) and EPA Method 120.1 (U. S. Environmental Protection, 2000). MWQI collected EC data for both surface water inflows and groundwater pump-ins.

Conductivity measurements were taken from 95 stations in the CA Aqueduct. When available, archived continuous-sample data from the California Data Exchange Center (CDEC) was used. When continuous-sample data was not available, grab sample data from the Water Data Library (WDL) was used.

At some stations, salts were measured as Total Dissolved Solids (TDS) instead of EC. In order to convert these measurements to EC, data from the two closest stations with complete EC and TDS datasets were identified. A Mann-Whitney test was used to determine if EC at these 2 stations were similar. If there were no statistical differences, then a regression equation between EC and TDS was derived at one station. Since EC was statistically similar between the 2 stations, it was assumed that the EC-TDS relationship would also be similar for the stations bounded by the stations with the complete datasets and that the same TDS-EC regression line could be used to calculate EC measurements from TDS data.

Conductivity measurements were taken at 59 stations in the DMC. The data for the DMC analyses came from several different sources. When available, daily and hourly data was retrieved from CDEC. Water quality, including both Central Valley Project (CVP) and non CVP data, was provided by the USBR database (U. S. Bureau of Reclamation, 2009). Data for wells pumping groundwater into the DMC between Check 13 and Check 21 data were obtained from a spreadsheet provided to us by USBR personnel.

Bromide measurements were taken at 79 stations in the CA Aqueduct. When available, real time data from the California Data Exchange Center (CDEC) was used. When real-time data was not available, grab sample data from the Water Data Library (WDL) was used. Bromide measurements were taken at 9 stations in the DMC. The data for the DMC analyses came from several different sources. When available, daily and hourly data was retrieved from CDEC. Water quality, including both Central Valley Project (CVP) and non CVP data, was provided by the USBR database (USBR 2009). Data for wells pumping groundwater into the DMC between Check 13 and Check 21 data were obtained from a spreadsheet provided by USBR.

The DOC data for the CA Aqueduct and DMC was analyzed using either the combustion method (EPA Methods 415.1) or the oxidation method (EPA Method 415.3) (U. S. Environmental Protection Agency, 1999) and (U. S. Environmental Protection, 2000). Both methods are considered equivalent by the EPA for measuring DOC. Generally, variability between the 2 methods occurs with measurements of the total organic carbon fraction, not the dissolved fraction; therefore, combining the DOC data generated by these 2 methodologies was considered acceptable for this report.

DOC measurements were taken at 91 stations in the CA Aqueduct. When available, real time data from the California Data Exchange Center (CDEC) was used. When real-time data was not available, grab sample data from the Water Data Library (WDL) was used.

At some stations, carbon was measured as Total Organic Carbon (TOC) instead of Dissolved Organic Carbon (DOC). In order to convert these measurements to DOC, data from the two closest stations with complete TOC and DOC datasets were identified. A Mann-Whitney test was used to determine if DOC at these 2 stations were similar. If there were no statistical differences, then a regression equation between DOC and TOC was calculated at one of these stations. Since DOC was statistically similar between the 2 stations, it was assumed that the DOC-TOC relationship would also be similar for the stations bounded by the stations with the complete datasets and that the same DOC-TOC regression line could be used to calculate TOC measurements from a station's DOC data.

DOC measurements were taken at 9 stations in the DMC. The data for the DMC analyses came from several different sources. Water quality, including both Central Valley Project (CVP) and non CVP data, was provided by the USBR database (USBR 2009). Data for wells pumping groundwater into the DMC between Check 13 and Check 21 data were obtained from a spreadsheet provided to us by USBR personnel.

At the DMC@McCabe Road station near Check 12 (WDL, station ID: DMC06716), carbon was measured as TOC instead of DOC for 27 of the 80 samples. Normally, in order to convert these measurements to DOC, data from the two closest stations with complete TOC and DOC datasets are identified, and a Mann-Whitney test is used to determine if DOC at these 2 stations were similar. However, only the Delta Mendota Canal station at mi 67.15 has enough DOC and TOC measurements to be compared. Therefore, a regression equation between DOC and TOC was calculated for the station Delta Mendota Canal at mi 67.15 without a Mann-Whitney test. The linear correlation coefficient for DOC and TOC was 0.963.

Compared to other inflows, pumping from Banks and Jones PP has more influence on the water quality downstream the Aqueduct. From Table 2-6 it can be seen that water quality data at Banks and Jones PP may have gaps for a long period. A tool, described in the next section, was developed to fill in those gaps in a most reasonable way. For example, there exists no DOC data at Banks PP before October 23, 2003 and at Jones PP before February 25, 2009, and no EC data at Jones PP before August 24, 1999. In this case, EC and DOC outputs from Delta DSM2 Model were used to fill in the gaps. For other EC and DOC gaps that last more than a week, EC and DOC outputs from Delta DSM2 model were not directly used, instead EC and DOC output were adjusted so that the first data just before a gap and the first data just after a gap are the same as measured data of the same day. Data gaps for Bromide were filled in a similar way. The only difference is that at present the Delta-only DSM2 Model does not simulate Bromide, so there is no existing direct output for Bromide. The tool used an expression to calculate Bromide from EC (measured or DSM2 calculated) and Martinez fingerprinting at Banks or Jones PP.

Table 2-2 Available EC, DOC and Bromide Data from CDEC

Station	Constituent	Duration	Data Available
Banks PP	EC	daily	01/01/1986 to present
	DOC	daily	10/23/2003 to present.
	Bromide	daily	01/29/2009 to 02/07/2011
	Bromide	event	10/25/2007 to present
Jones PP	EC	daily	08/24/1999 to present
	EC	hourly	03/31/1988 to present
	DOC	daily	02/25/2009 to present
	Bromide	event	03/05/2011 to present

2.5 Preparing DSM2 for Historical Simulation

It's a very time consuming process to pre-process all input data for the extension model. A tool based on Microsoft Excel VBA was developed to save time and reduce possible mistakes when many raw data are processed for use in the DSM2 Aqueduct model. The tool consists of an interface (Figure 2-3) and related Excel worksheets. On the interface are Excel cells for data input, tabs for worksheets for storing raw and processed data, buttons for executing the 8 steps for pre-processing input data, running the DSM2 Aqueduct model, and post-processing model results.

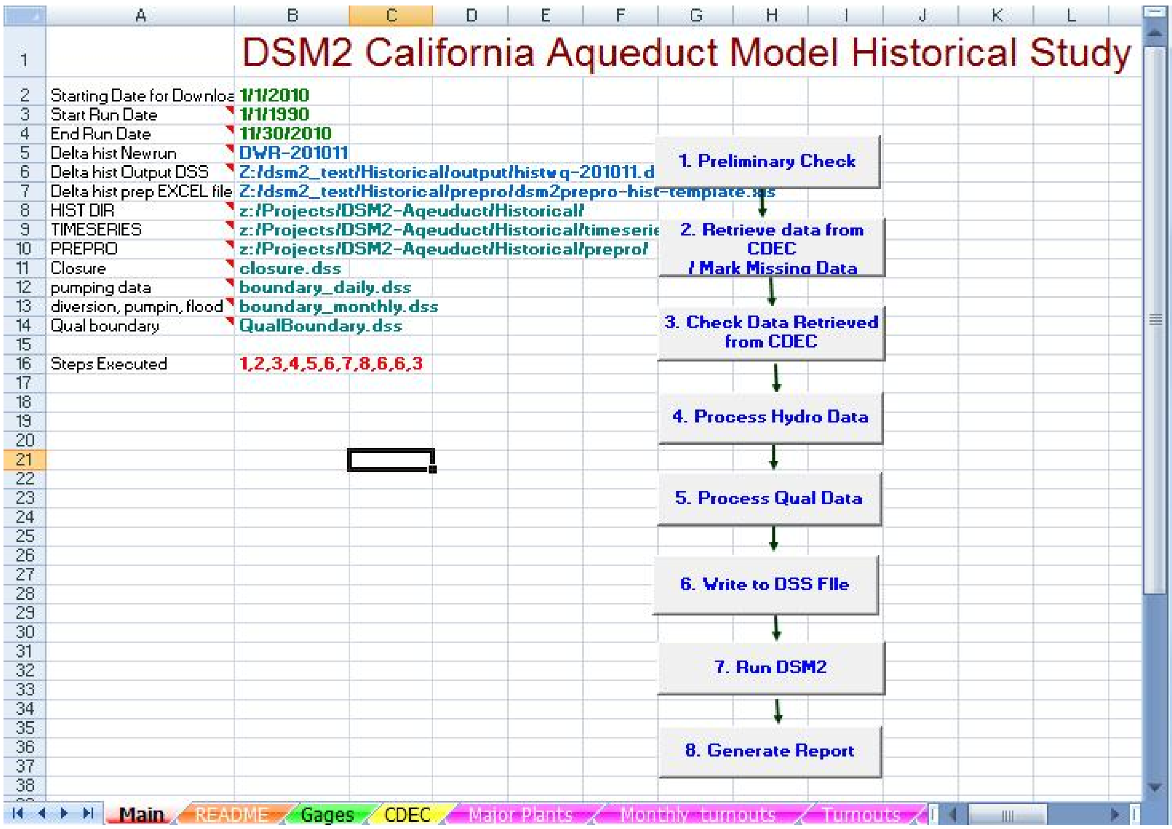


Figure 2-3 Interface of the tool for pre-processing raw data for use in the DSM2 Aqueduct model

Tasks that can be completed by using the tools include: (1) downloading water quality data from CDEC; (2) pre-processing hydraulic and water quality data; (3) calculating water gains and losses for the Aqueduct system; (4) exporting data to DSS file for use by the DSM2extension model; (5) executing the DSM2 Aqueduct model; and (6) post-processing model results. More detailed descriptions of each task are available in the full Report (Liu, 2013).

2.6 Model Verification

The original DSM2 Aqueduct model was calibrated using 3 years of data starting January 1, 2001. There was no verification based on independent data. The original model was calibrated to calculate water velocities, stages of water bodies, and EC. After the model was improved, the model was verified using 21 years of data starting from January 1, 1990. Model verification includes comparisons between model predictions and known system data for not only flow, stage, and salinity (EC), but also two other constituents, Bromide and DOC. The model was run using a warm-start file, which provides the initial conditions for all DSM2 nodes and reservoirs. This is especially important for the San Luis Reservoir, since water residence time for San Luis Reservoir is much longer when compared with the California Aqueduct.

To estimate the predictive power of the model, the Nash–Sutcliffe (N-S) model efficiency coefficient is used. It is defined as:

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q_o}\right)^2}$$

where Q_o is observed values, and Q_m is modeled values. Q_o^t is observed value at time t.

Nash–Sutcliffe efficiencies can range from −∞ to 1. An efficiency of 1 ($E = 1$) corresponds to a perfect match of modeled discharge to the observed data. An efficiency of 0 ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model. Essentially, the closer the model efficiency is to 1, the more accurate the model is.

2.6.1 Verification of Flow and Storage

The DSM2 Aqueduct model can produce flow rates and stages for reservoirs and each node of a channel. Since water balance was conducted for the main section of the California Aqueduct, and gains and losses were enforced to maintain water level of each pool, the verification was conducted only for flows in the Aqueduct and DMC. For the San Luis Reservoir, all inflows and outflows were specified, and no gains/losses were enforced, so the verification was conducted for stages.

Comparison of measured and observed flow are presented for Check 21, the Buena Vista Pumping Plant (Check 30 on the California Aqueduct), the Teerink Pumping Plant (Check 35 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) in the full Report (Liu, 2013). These locations were chosen because of the readily available flow data at the pumping plants. To reduce the length of this summary chapter, only figures for Check 40 and San Luis Reservoir are shown.

The N-S efficiency for each location is listed in Table 2-3. The high N-S model efficiency for each location indicates that the model did well in estimating flows at Checks 21, 30, 35, 40 and 58, and storage at San Luis Reservoir.

Table 2-3 Nash–Sutcliffe (N-S) model efficiency for check flows and reservoir storage

Location	SWP Check 21	SWP Check 30	SWP Check 35	SWP Check 40	SWP Check 58	San Luis Reservoir
variable	Flow	Flow	Flow	Flow	Flow	Storage
N-S	0.94	0.82	0.81	0.78	0.86	0.85

Figure 2-4 shows measured and modeled flow at Check 40, and Figure 2-5 shows the comparison of measured and modeled storage of San Luis Reservoir. Figure 2-7 is a scatter plot with box charts for both measured and modeled flows at Check 40. To examine the difference between measured and modeled flows at different flow ranges, we created Exceedance curves (Figure 2-6) based on flow data for the period between 1990 and 2010. Overall as the Exceedance percentage decreases, the difference between measured and modeled flows also increases. Shown on Figure 2-6 are box-whisker plots for measured and modeled flow. For a box-whisker plot, the bottom and top of the box are flows of the 25th and 75th percentile; the band near the middle of the box is the 50th percentile (median). The ends of the whiskers represent the lowest datum still within 1.5 interquartile range (IQR) of the lower quartile, and the highest datum still within 1.5 IQR of the upper quartile. From the box-whisker plots, we can find that for Checks 21 and 58, August is the month that modeled flows deviate the most from measured flows; for Checks 30, 35 and 40, modeled flows are closer to measured flows for the period between October and December.

Water is pumped uphill into the San Luis reservoir from the O'Neill Forebay when there is surplus water, and is released back into the Forebay to continue downstream along the aqueduct as needed for farm irrigation and municipal uses. Considering the amount of water that is pumped into or released from San Luis reservoir, water quality in the reservoir is important for modeling water quality in the Aqueduct. The verification effort included comparing the model predictions with the reported storage in San Luis Reservoir. Figure 2-5 presents the measured and modeled storage at San Luis Reservoir. In DSM2, the reservoirs are represented as vertical walled vessels, and thus the storage is calculated using a constant surface area. 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.

2.6.2 Verification of EC

As in the calibration period, salinity or EC was also investigated in the verification period. Comparison between modeled EC and measured EC is presented for Aqueduct Checks 12, 13, 18, 21, 29, 41, 66, San Luis Reservoir, DMC Checks 13, 20, and 21, and South Bay Aqueduct Check 7 in the Full report (Liu, 2013). The source of measured EC data at SWP Checks 12, 13, 18, 21, 29, 41, 66, DMC Checks 13, 20, and 21, South Bay Aqueduct Check 7, and San Luis Reservoir was CDEC. Table 2-4 lists the N-S efficiency for each location. Except for DMC Check 20, N-S efficiency for other locations is high enough to prove that model can calculate EC satisfactorily. The low N-S for DMC Check 20 was the result that the model did not do well for two periods. By removing data during the two periods, the N-S coefficient will be increased to 0.53.

Table 2-4 Nash–Sutcliffe (N-S) model efficiency for EC calculation

Location	SWP CK 12	SWP CK 13	SWP CK 18	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 13	DMC CK 20	DMC CK 21	South Bay CK 7	San Luis Reservoir
N-S	0.81	0.89	0.93	0.92	0.56	0.49	0.70	0.88	0.14	0.38	0.87	0.67

Plots are presented in this Chapter in both time series format (Figure 2-9 and Figure 2-13) and scatter format (Figure 2-12 and Figure 2-11) for San Luis Reservoir and Check 41.

Exceedance curves for EC (Figure 2-13 and Figure 2-14) are used to compare modeled and measured EC at Check 41 and San Luis Reservoir, from another perspective. For San Luis Reservoir, the simulated EC values are lower than the observed EC values for the same Exceedance percentage that is above 20%. The simulated EC values are generally greater than the observed EC values for Exceedance percentage below 20%, except for Exceedance percentage below 5%.

The Box-Whisker plots in Figure 2-15 and Figure 2-16 show the comparison of the lower quartile (Q1), median (Q2), upper quartile (Q3) of modeled and observed EC. Overall, the monthly medians of modeled and observed EC at each location are close. However, monthly ranges of box and whisker can sometimes be quite different. For San Luis Reservoir, the monthly mean of modeled EC is equal or less than that of observed EC.

2.6.3 Verification of Bromide

In the calibration period, only salinity or EC was investigated. In the verification period, besides EC, Bromide was also investigated. The model setup for Bromide simulation was exactly the same for EC simulation. The only difference was that the boundary conditions for Bromide simulation were changed. Measured Bromide data is available for Aqueduct Checks 13, 21, 29, 41, 66, DMC Check 12, South Bay Aqueduct Check 7, and San Luis Reservoir. Measured Bromide data is scarce for those locations except for SWP Checks 13, 41, and 66. The sources for measured Bromide include, WDL and MWD ((Liu, 2013) contains more details). Table 2-5 lists the N-S efficiency for each location. Overall the model did well in estimating Bromide at all locations.

Table 2-5 Nash–Sutcliffe (N-S) model efficiency for Bromide calculation

Location	SWP CK 13	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 12	South Bay CK 7	San Luis Reservoir
N-S	0.85	0.79	0.46	0.61	0.78	0.60	0.95	0.83

Much more information about Bromide performance of the DSM2 Aqueduct Model is in (Liu, 2013).

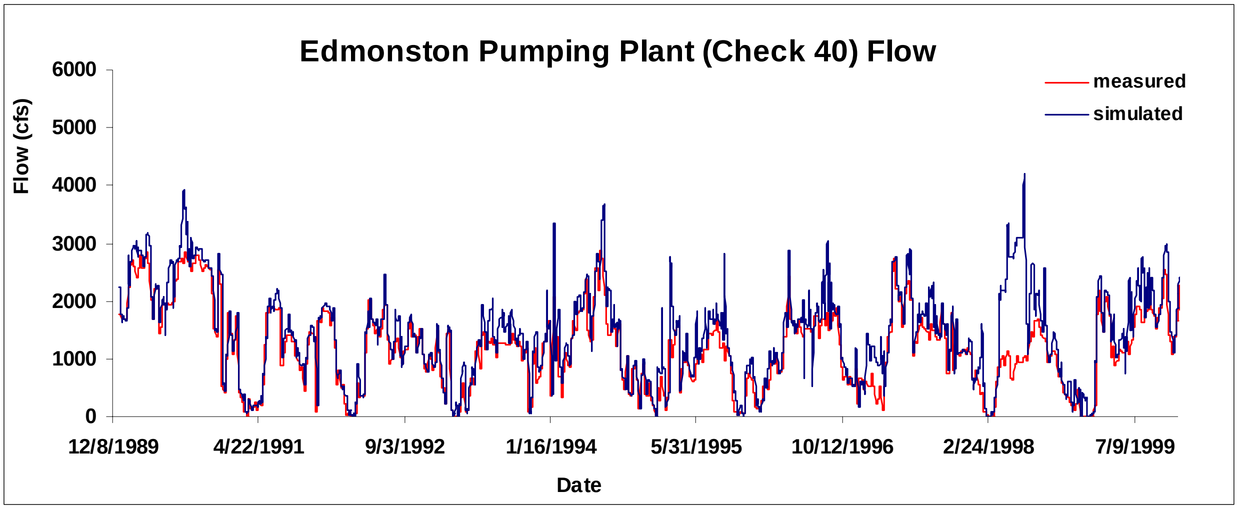
2.6.4 Verification of DOC

In the verification period, the DOC simulation was also investigated. The model setup for DOC simulation was similar to that for EC and Bromide simulation, with the difference that the boundary conditions for DOC simulation were changed. Measured DOC data is available for Aqueduct Checks 12, 13, 21, 29, 41, 66, DMC Check 12, South Bay Aqueduct Check 7, and San Luis Reservoir. Measured DOC data is scarce for those locations except for SWP Checks 13, 41 and 66. The sources for measured DOC include CDEC, WDL, and MWD. Table 2-6 lists the N-S efficiency for each location. Overall the model did a reasonably good job in calculating DOC, but not as good as its calculations for EC and Bromide. It may be that DOC is more subjected to decay during travel.

Table 2-6 Nash–Sutcliffe (N-S) model efficiency for DOC calculation

Location	SWP CK 12	SWP CK 13	SWP CK 21	SWP CK 29	SWP CK 41	SWP CK 66	DMC CK 12	South Bay CK 7	San Luis Reservoir
N-S	0.20	0.79	0.81	0.64	0.56	0.43	0.34	0.61	0.25

Much more information about DOC performance of the DSM2 Aqueduct Model is in (Liu, 2013).



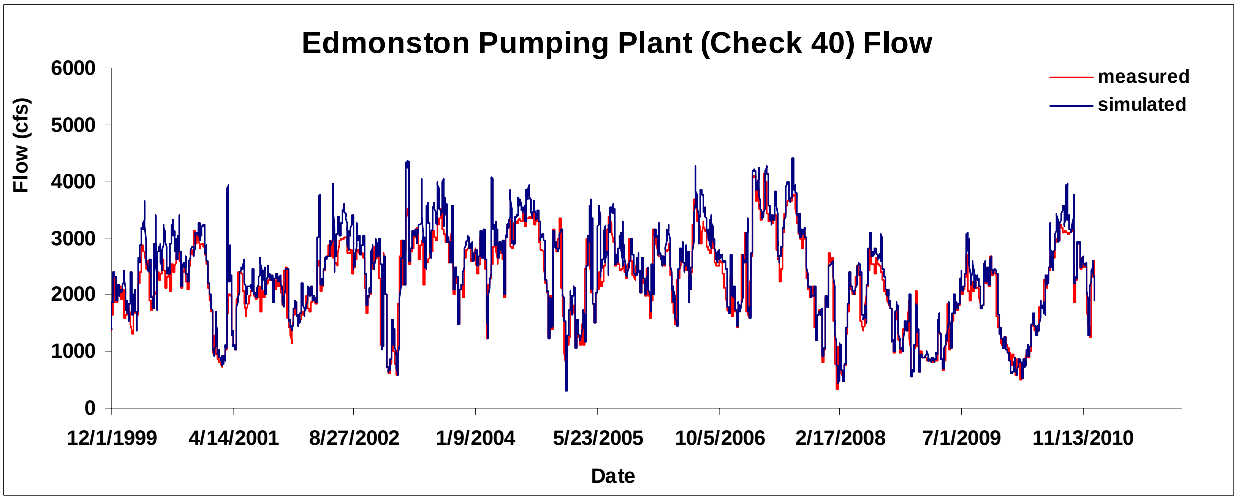
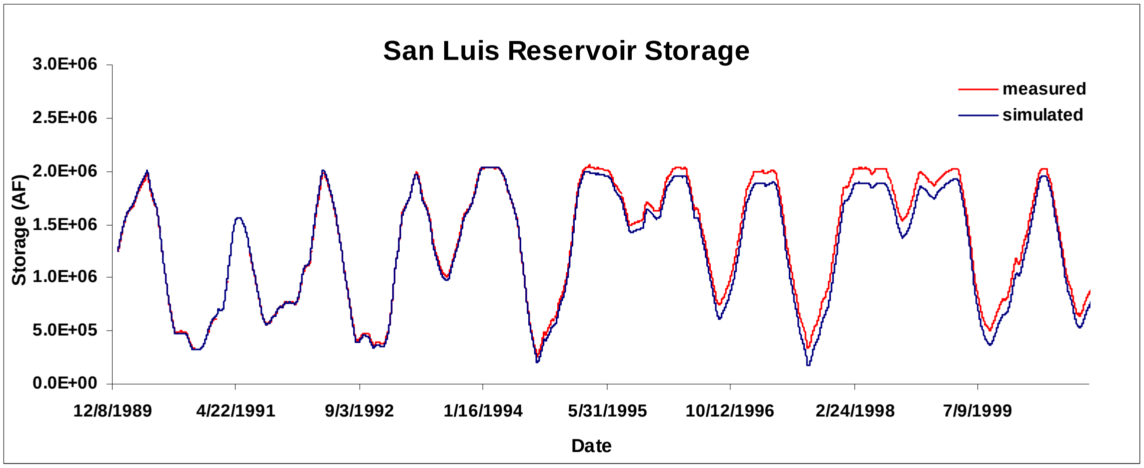


Figure 2-4 Comparison of Measured and Simulated Flow at California Aqueduct Check 40



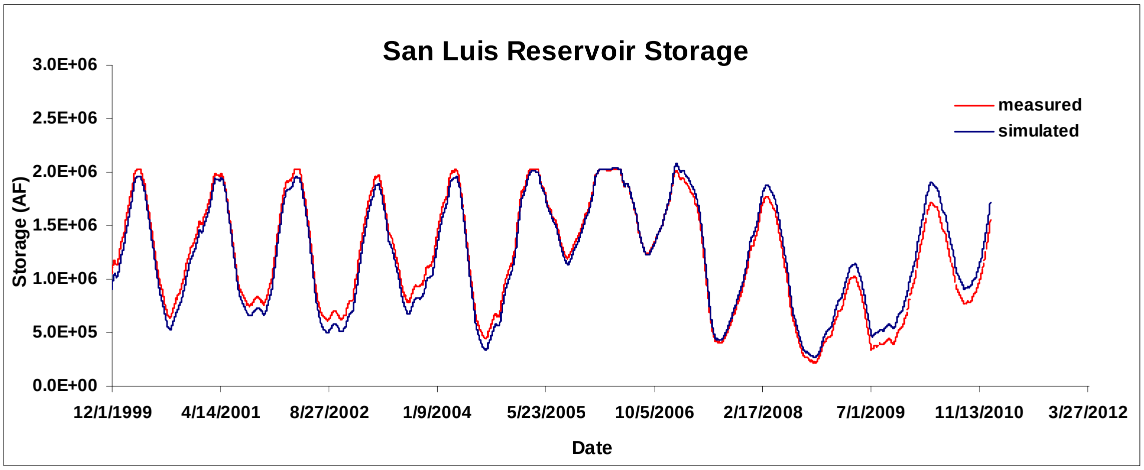


Figure 2-5 Comparison of Measured and Simulated Storage of San Luis Reservoir

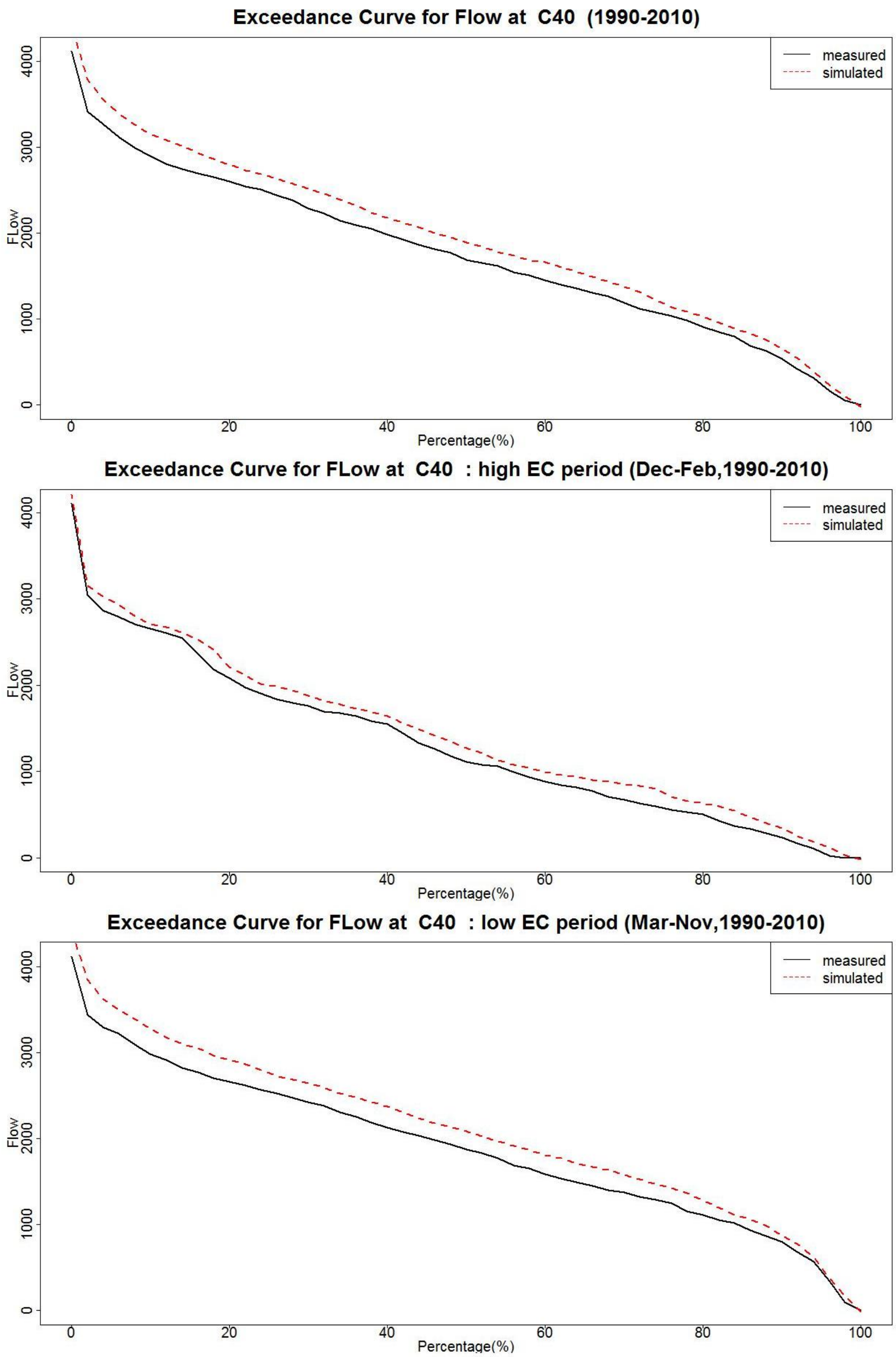


Figure 2-6 Exceedance Curve for Flow at C40

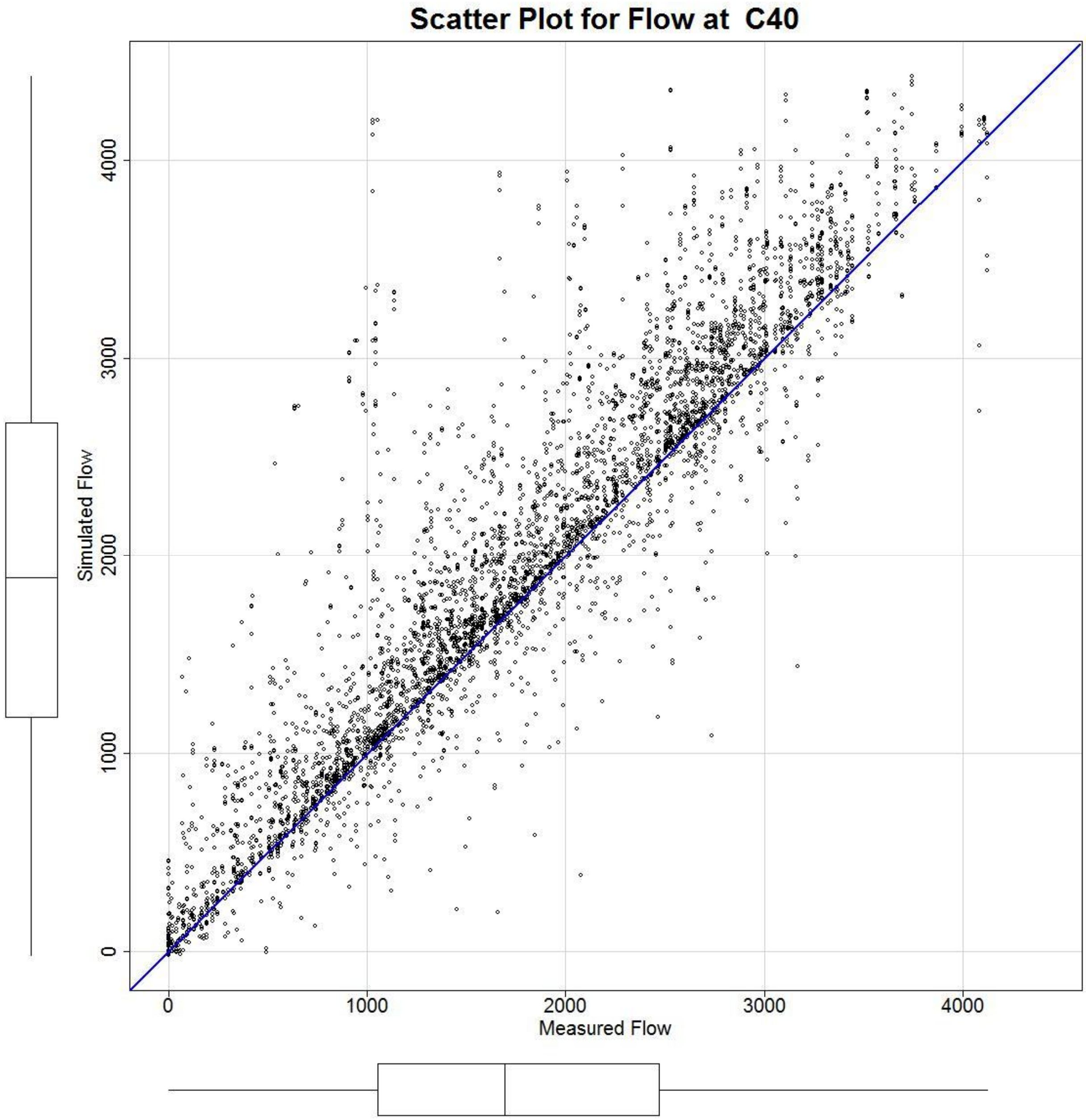


Figure 2-7 Scatter Plot for Flow at California Aqueduct Check 40

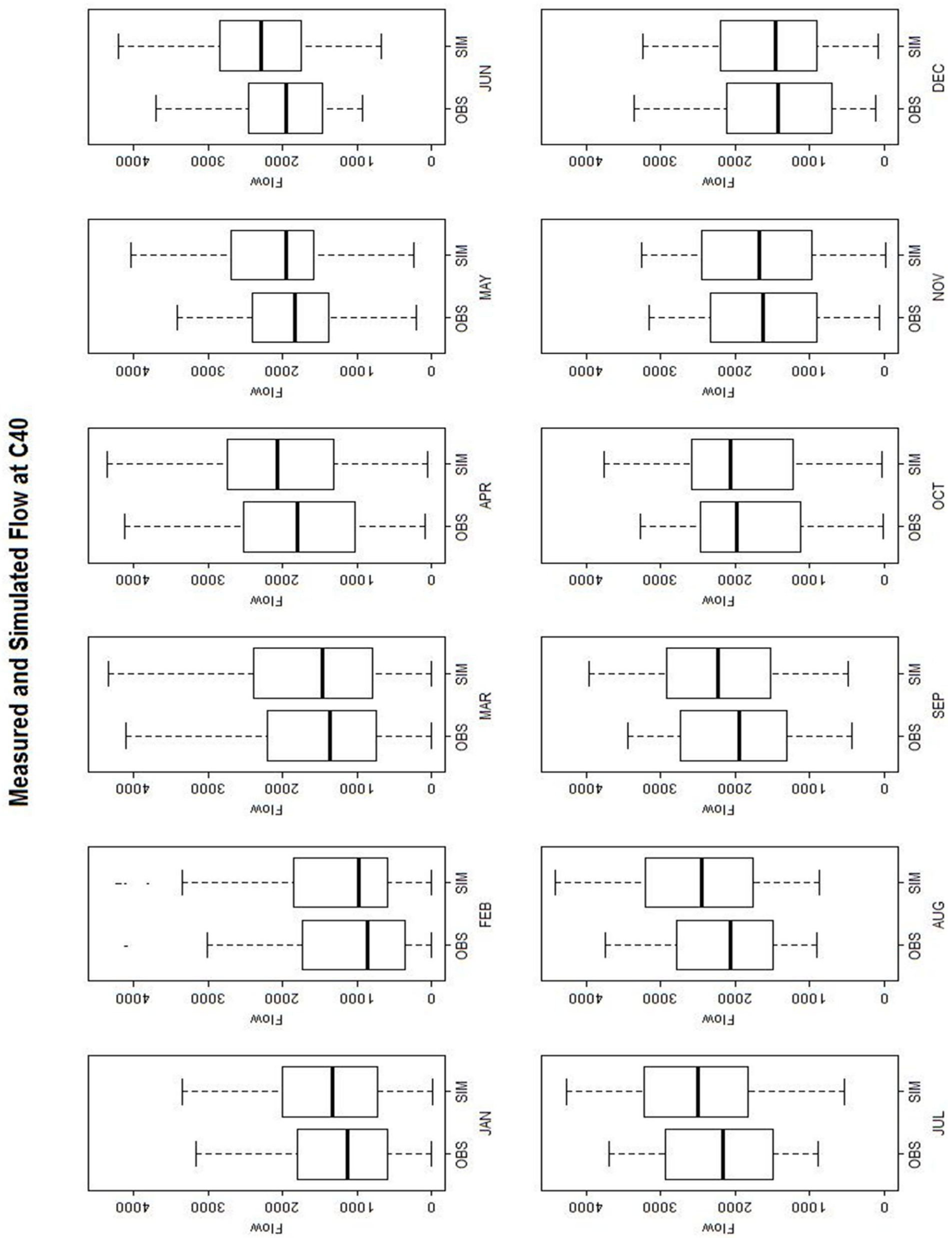
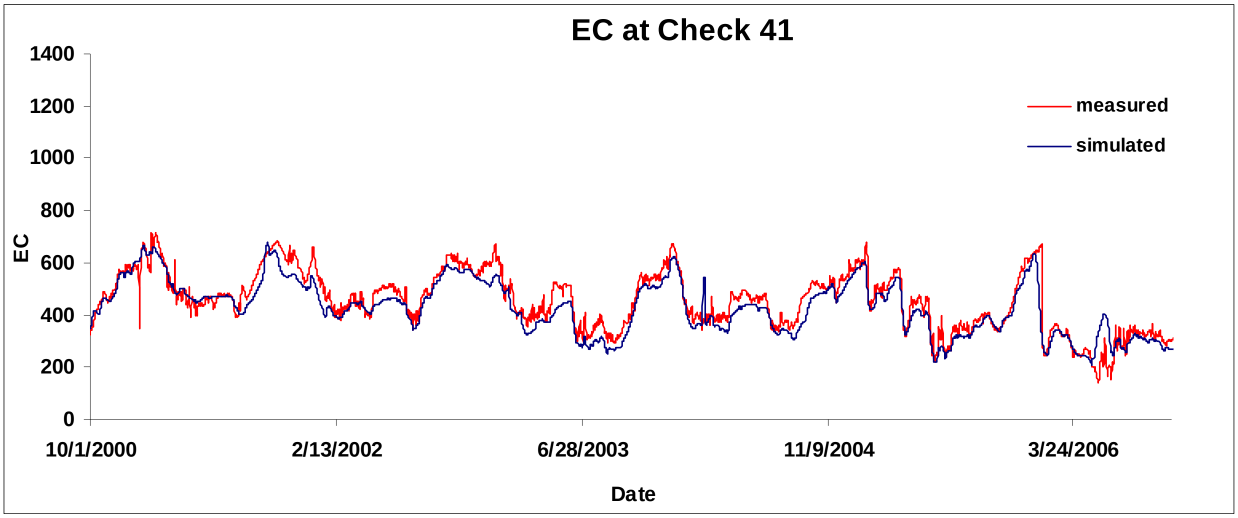


Figure 2-8 Month by Month Comparison of Measured and Simulated Flow at California Aqueduct Check 40



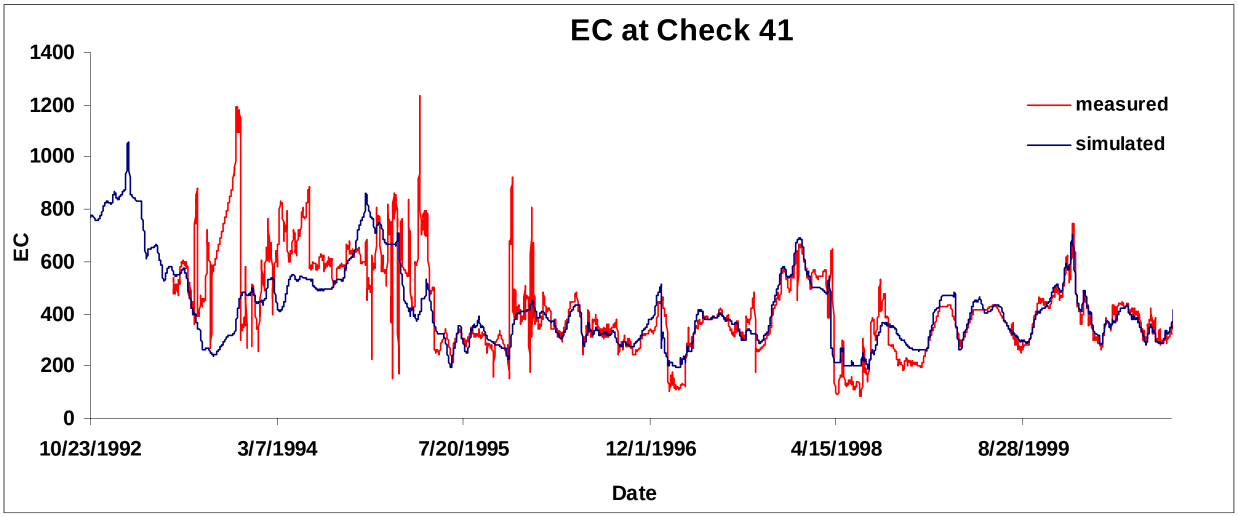
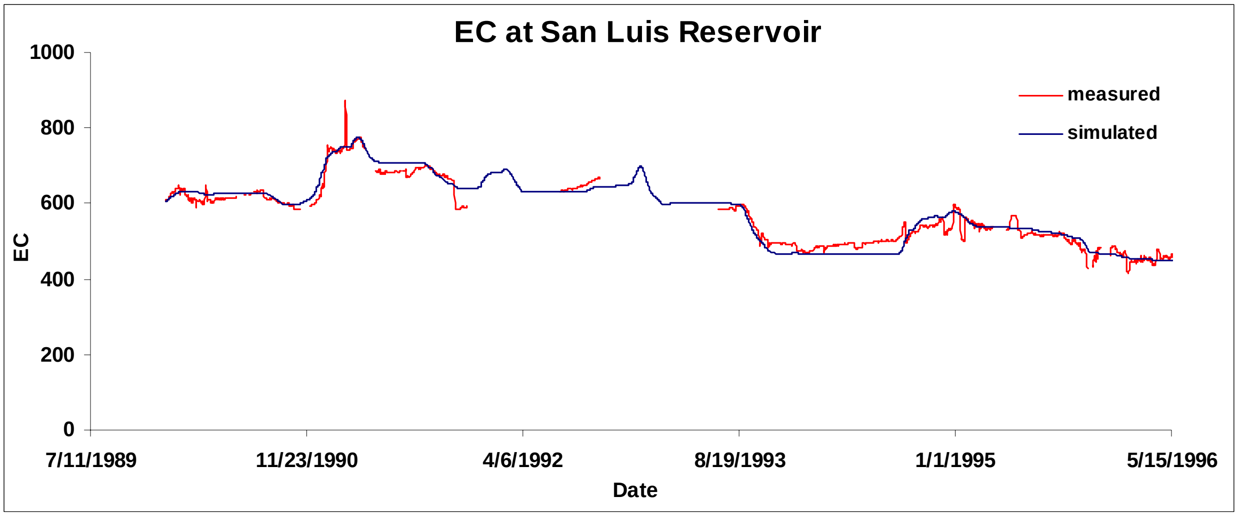


Figure 2-9 Comparison of Measured and Simulated EC at California Aqueduct Check 41



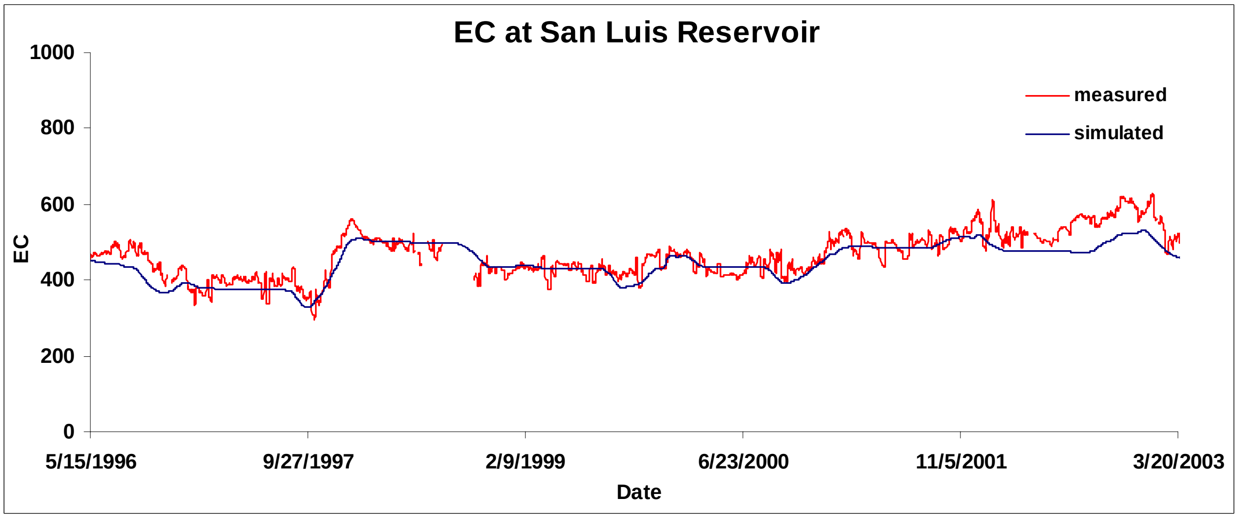


Figure 2-10 Comparison of Measured and Simulated EC at San Luis Reservoir

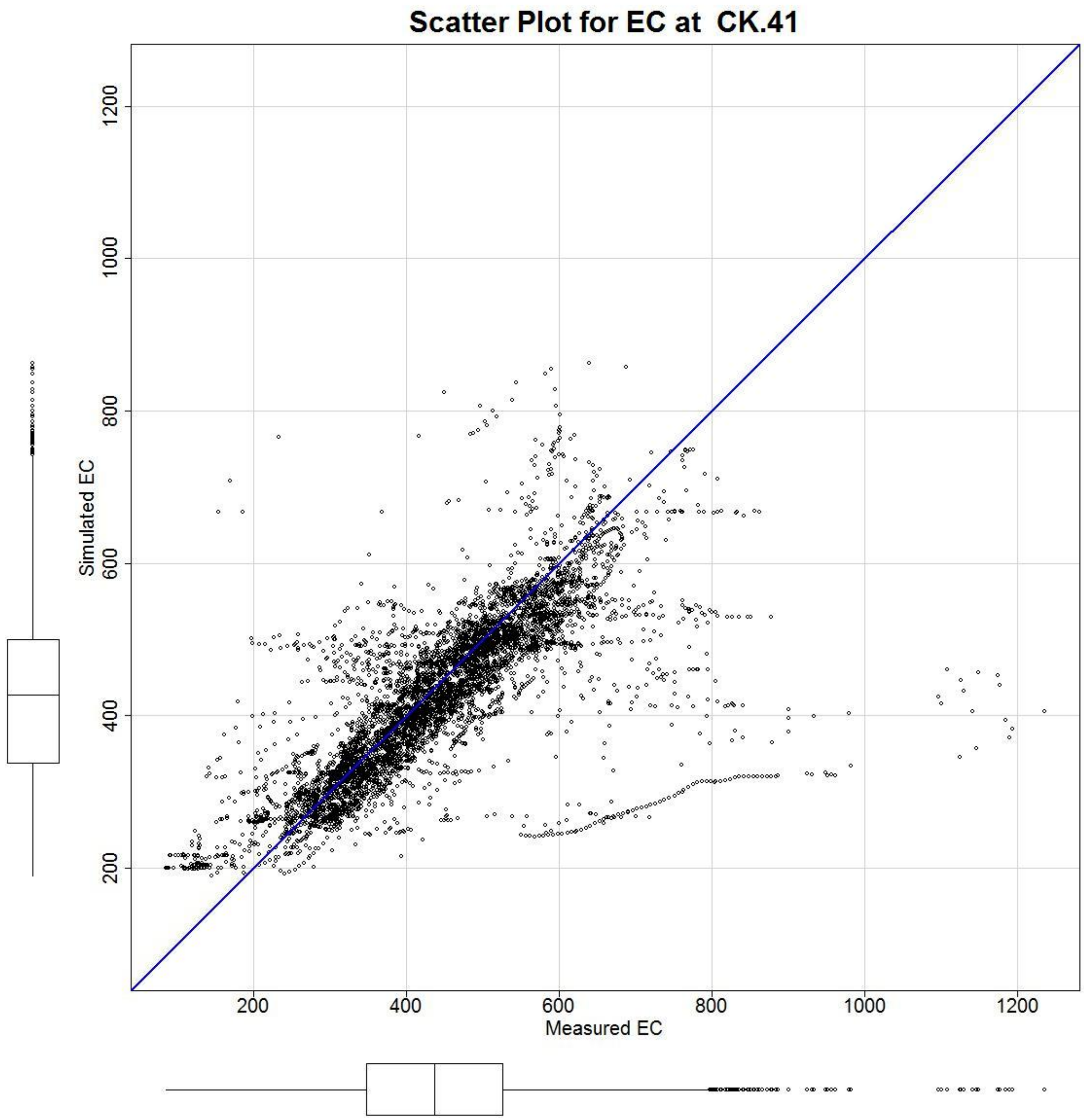


Figure 2-11 Scatter Plot for EC at C41

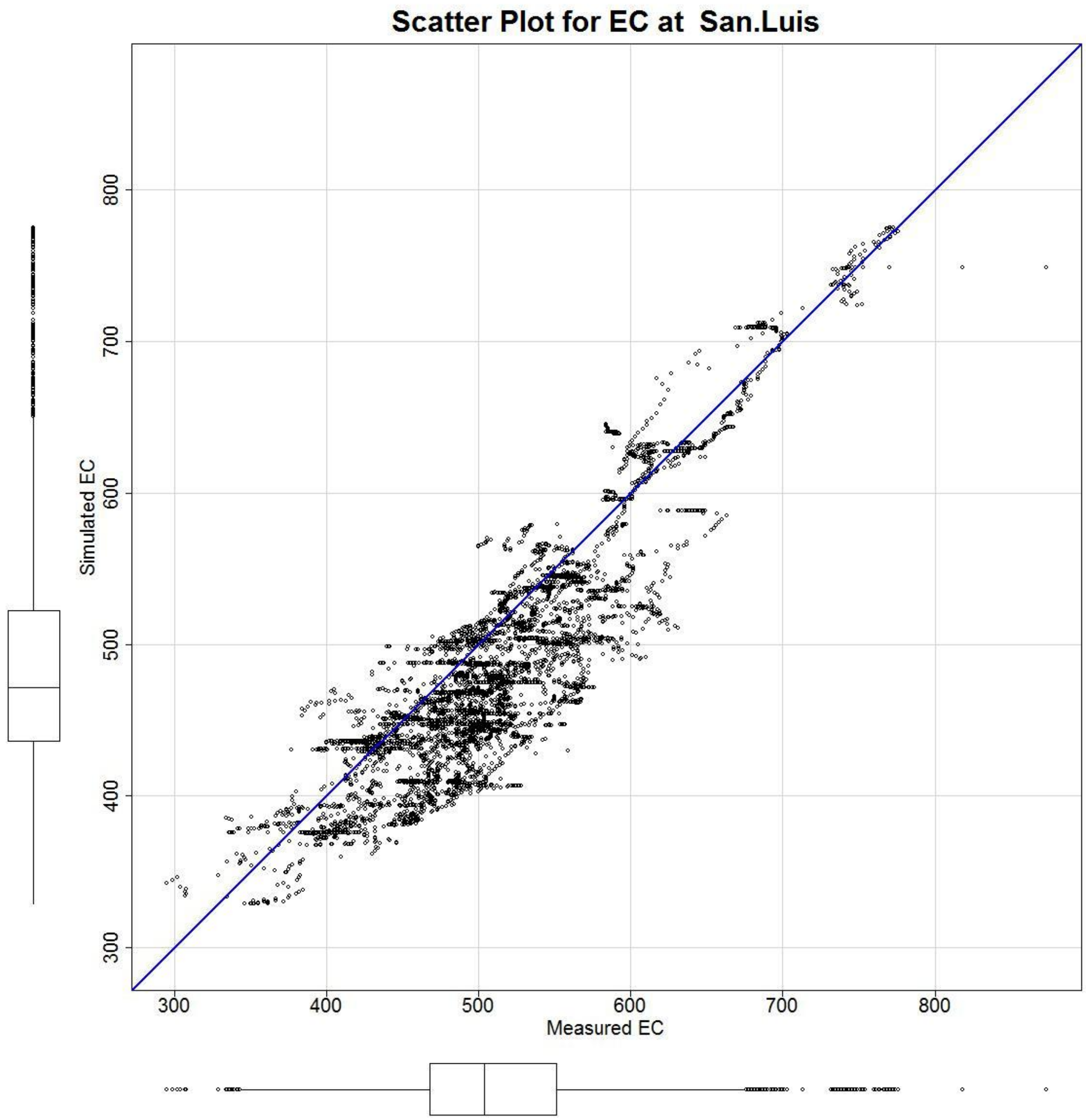


Figure 2-12 Scatter Plot for EC at San Luis Reservoir

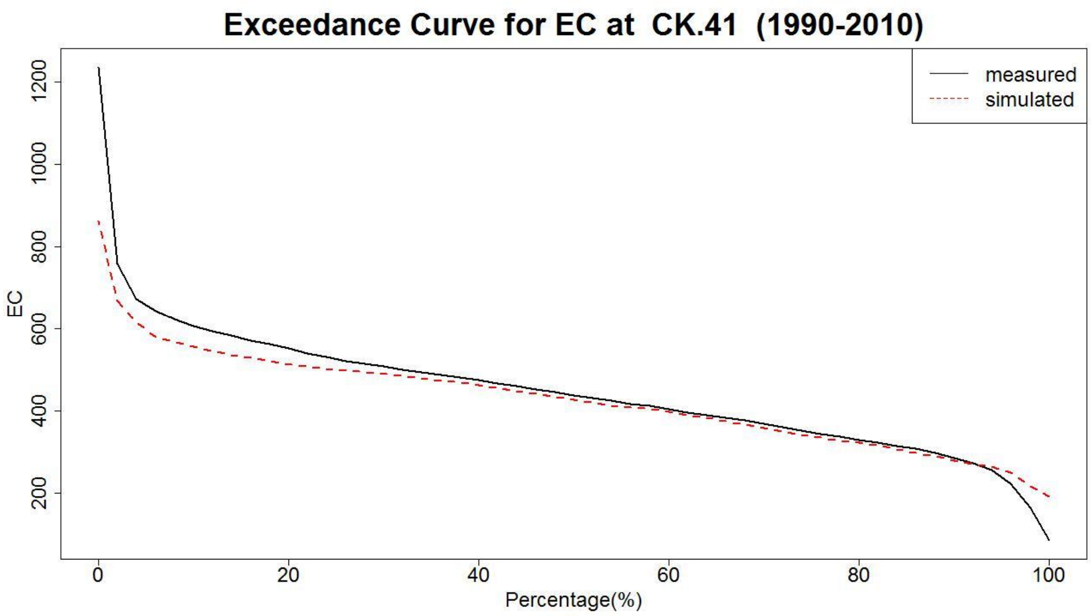


Figure 2-13 Exceedance Curve for EC at California Aqueduct Check 41

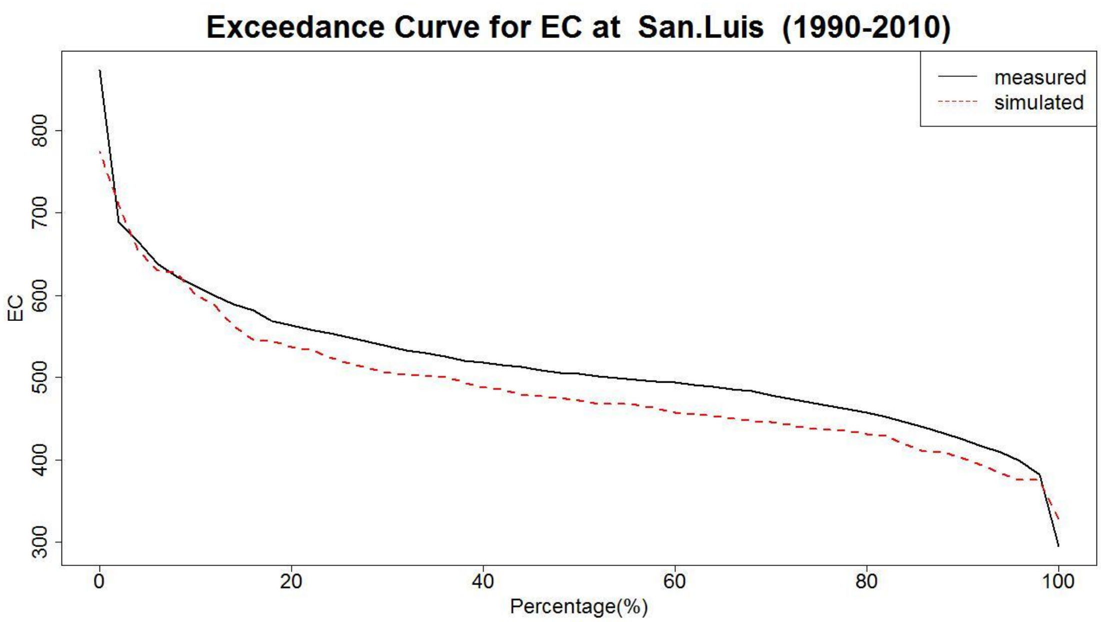


Figure 2-14 Exceedance Curve for EC at San Luis Reservoir

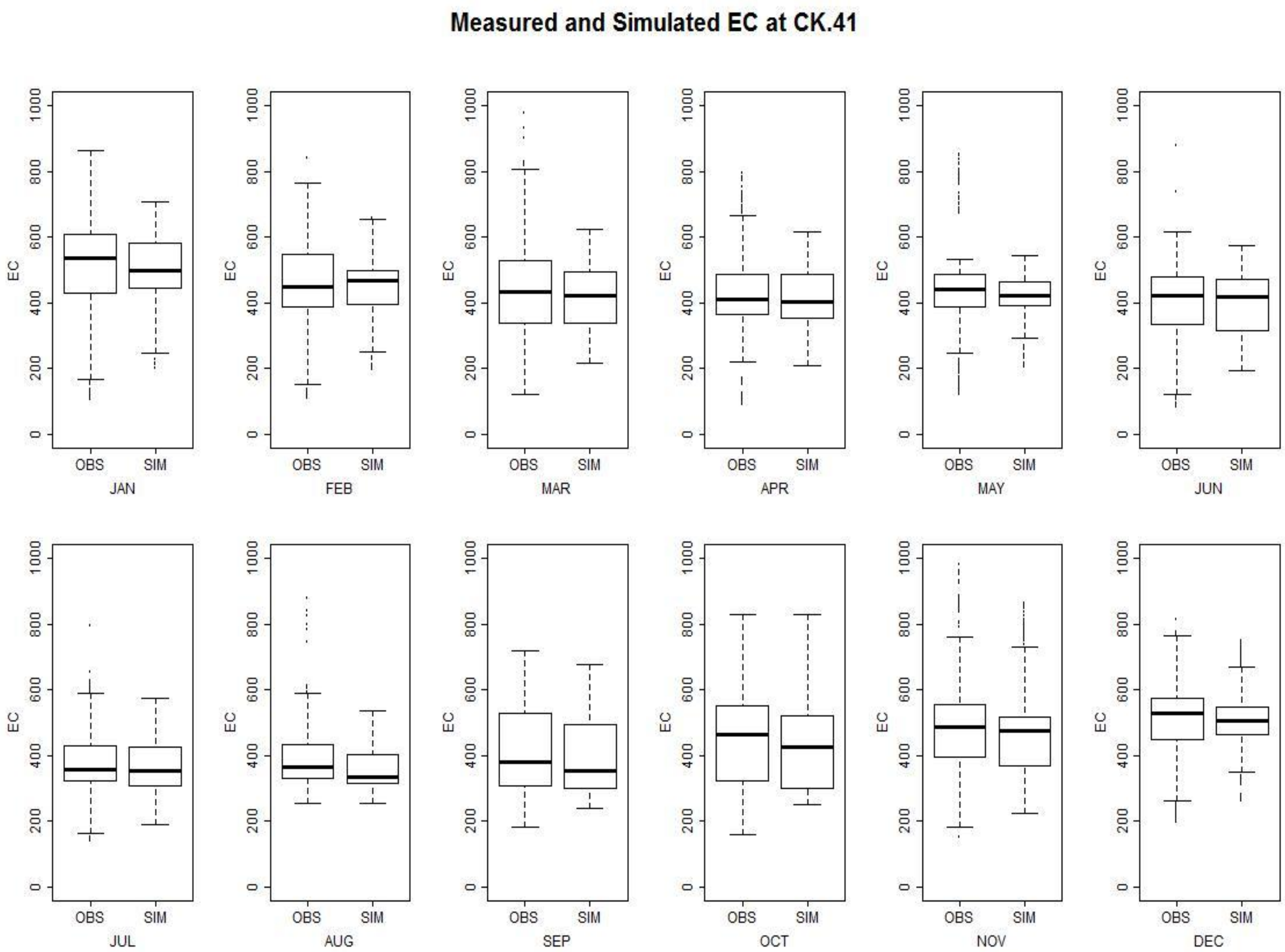


Figure 2-15 Month by Month Comparison of Measured and Simulated EC at California Aqueduct Check 41

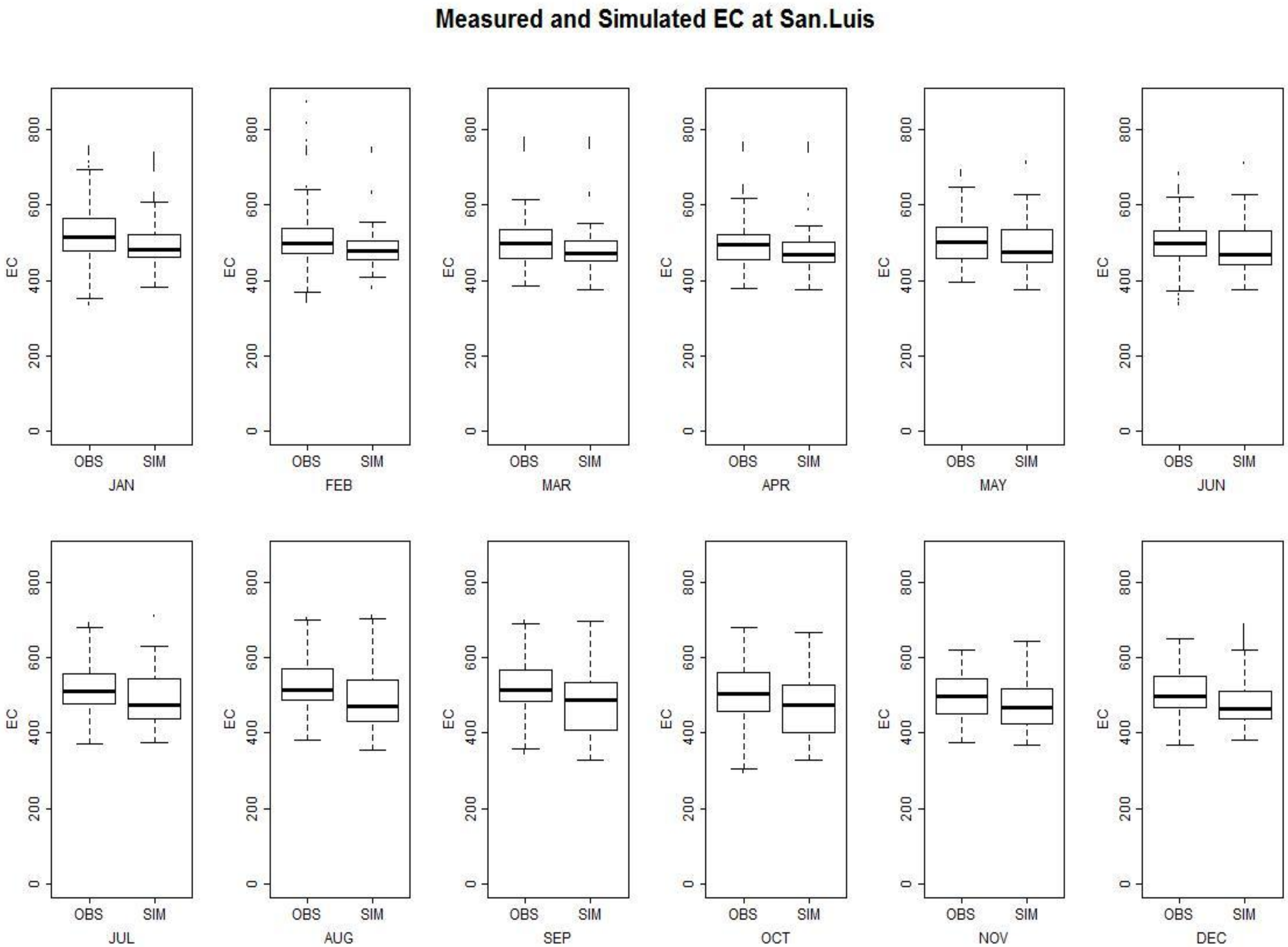


Figure 2-16 Month by Month Comparison of Measured and Simulated EC at San Luis Reservoir

2.7 Model limitations

Like every model of a physical system, the Aqueduct model has its limitations. The model was based on the 1-D DSM2 program. It cannot be used to accurately answer questions that involve more than one dimension. In particular, reservoirs are treated as completely mixed, vertical-walled bodies of water. So for a bay or reservoir, regardless of actual size, there is only one value at a given time of its state variables.

Unlike the Delta-DSM2 model, which has an unlimited water source from the tidal boundary, the water available to the Aqueduct and DMC system is restricted by pumping at Banks and Jones Pumping Plant. Model removed from the system must not exceed water added to the system, so a strict mass balance must be maintained in order for the model to run successfully. This requires that hydrologic inputs, i.e. inflows, outflows, rainfall, evaporation, storage, etc. be consistent. Otherwise, gains and losses are introduced to avoid problems such as channel drying (not enough water), or overbank flow (too much water). The use of gains and losses has an impact on water quality modeling.

In general, the check structures try to maintain a near constant elevation in any given pool. This is the main reason that in the model, the check structures are modeled as broad-crested weirs, with the invert elevations fixed to control flow. DSM2 version 8 allows users to define rules for gate operations. This usually involves specifying flow rates, or stages as conditions for gate operations. BDO staff has spent limited time on trying to use operation rules for gate operations, but without success. The model would not converge for most of the time steps, thus the results cannot be trusted. The reason for this is not clear. Further investigation is needed to find the problem.

There are limitations with diversion flows and some source flows. 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. It is unrealistic to specify daily water quality input for groundwater pump-in and storm water flow. Instead, a constant water quality input is specified for each source flow. In reality, diversions and the quality of groundwater and storm water may have dramatic change from day to day. It is impossible for the model to track the changes because of the limitation of sparse inputs.

2.8 Conclusions

The DSM2 extension model, which was calibrated by CH2MHILL in 2005 to calculate flows and salinity, was verified using 21-year historical hydrologic and water quality data. The model was extended to simulate Bromide and DOC besides EC.

The model can simulate water quality (EC) reasonably well. As expected, the results are less accurate when locations are farther away from boundaries, i.e. Jones and Banks PP. For San Luis Reservoir, simulated EC matched observed EC reasonably well. For the period from 1990 to 2002, and 2010, the model did a good job in estimating EC. For the period from 2003 to 2009, however, the model underestimated EC at San Luis Reservoir by a small amount.

Measured data on Bromide is sparse. Based on limited measured data, the simulated Bromide output matched measured Bromide data well for SWP Checks 13, 21, 29, 339, 41, and 66, DMC Check 12, South Bay Aqueduct Check 7, and San Luis Reservoir. Measured Bromide data shows that Bromide concentration at San Luis Reservoir varied between 0.2 and 0.3 mg/l almost all the time.

The model did not do as well in modeling DOC as it did in modeling EC and Bromide when compared solely with N-S Coefficients. The model underestimated DOC at Checks 41, 66, and DMC Check 12. For San Luis reservoir, the model underestimated DOC for the period between 2004 and 2007; the model simulated DOC reasonably well for the period between 2008 and 2010. DOC decay may play a role in the mismatch between modeled and measured DOC. Another factor may be that DOC was sampled at Pacheco pumping plant rather than at a location near Gianelli Pumping / Generating Plant. Even for locations with low N-S coefficients, the model did a decent job by following trend well. DOC decay from upstream checks to downstream checks is not obvious. No seasonal trend of DOC decay is observed. Models results show that it is reasonable to model DOC as a conservative constituent.

Treating San Luis Reservoir as completely mixed body of water is sufficient for meaningful results. As expected, the magnitude of changes in EC, DOC, and Bromide at San Luis Reservoir is quite small than that of EC, DOC, and Bromide changes at SWP Checks. The model was able to catch the smaller changes.

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Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

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Chapter 3
DSM2 Version 8.1 Calibration with NAVD88 Datum

Authors: Lianwu Liu and Prabhjot Sandhu,
Delta Modeling Section,
Bay-Delta Office,
California Department of Water Resources

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3 DSM2 Version 8.1 Calibration with NAVD88 Datum

3.1 Introduction

A new calibration has been performed for Version 8.1 of DSM2, which incorporates the latest improvements to the DSM2 code. The main differences in DSM2 version 8.1 include: DSM2-Qual model formulation change to improve model convergence (presented at CWEMF 2011 conference and discussed in (Liu & Ateljevich, Improvements to DSM2-Qual: Part 1, 2011)); modifications to the DSM2-Hydro program source code that improve channel geometry calculation (presented at CWEMF 2012 conference and documented in (Liu & Ateljevich, Improved Geometry Interpolation in DSM2-Hydro, 2012)); datum conversion to NAVD88; and Martinez EC boundary correction. Since these changes affect results both in DSM2 Hydro and Qual, a new calibration is needed. This calibration is done by adjusting Manning's coefficient values in Hydro and dispersion coefficients in Qual. Further improvements involving other changes, e.g. new bathymetry and grid change, may come in future releases.

3.2 Hydrodynamics Calibration

This calibration is based on the 2009 BDCP Calibration grid (CH2M Hill, October 2009), and converted to NAVD88. CDEC has been reporting stage data in NAVD88 since 2006. Before then, although stage stations were reported using a common datum (NGVD 1929), in fact individual stage stations had different, unknown local datums. Minor changes were made to some channels and cross sections, e.g., channels 141 and 144 were corrected. Those cross sections having a negative conveyance gradient (dConveyance) were modified. Some corrections were made to Martinez stage and Clifton Court Gate operation data.

Sensitivity tests of model and tidefile time steps were done; the time steps chosen for this calibration were 15, 30, and 15 minutes for Hydro, the tidefile, and Qual, respectively (the tidefile is output by Hydro and contains hydrodynamic data for use in Qual).

The Hydro calibration period was from October 1, 2001 to October 1, 2002 and October 1, 2007 to October 1, 2008, and validation period from October 1, 2006 to October 1, 2007 and October 1, 2009 to October 1, 2009. The calibration stations are listed in Table 3-1 and shown in Figure 3-1.

Table 3-1 Hydrodynamics Calibration Locations

Location	Short Name	CDEC_ID	Flow	Stage
Grant Line Canal at Tracy Bridge	CHGRL009	GCT		x
Victoria Canal near Byron	CHVCT000	VCU	x	*
Cross Channel	DLC	DLC	x	x
False River	FAL	FAL	x	*
Grant Line Canal	GLC	GLC	x	x
Georgiana Slough at Sacramento R	GSS	GSS	x	x
Holland Cut	HOL	HOL	x	*
Miner Slough at Hwy84 Bridge	HWB	HWB	x	x
Little Potato Sough	LPS	LPS	x	*
Mokelumne R at San Joaquin R	MOK	MOK	x	*
Old River at Quimbey	ORQ	ORQ	x	x
Old River at Frank's Tract	OSJ	OSJ	x	x
Middle River near Holt	RMID005	HLT	x	*
Middle River	RMID015	MDM	x	x
Middle River at Tracy Blvd	RMID027	MTB		x
Old River at Bacon Island	ROLD024	OBI	x	x
Old River at hwy4	ROLD034	OH4	x	x
Old River below dam	ROLD046	OBD		x
Old River above dam	ROLD047	OAB	x	x
Old River near Tracy	ROLD059	OLD		x
Old River at Head	ROLD074	OH1	x	x
Martinez	RSAC054	MRZ		x
Rio Vista	RSAC101	SRV	x	x
Sacramento R below Georgiana Sl	RSAC123	GES	x	x
Sacramento R above Cross Ch	RSAC128	SDC	x	x
Freeport	RSAC155	FPT	x	x
San Joaquin at Antioch	RSAN007	ANH		x
Jersey Point	RSAN018	JER	x	x
Prisoner's Point near terminous	RSAN037	PRI	x	*
Rough and Ready Island	RSAN058	RRI	x	x
San Joaquin at Garwood Bridge	RSAN063	SJG	x	x
Brandt Bridge	RSAN072	BDT	x	x
San Joaquin at Mossdale Bridge	RSAN087	MSD	x	
Cache Slough at Ryer Island	RYI	RYI	x	x
San Joaquin near Lathrop	SJL	SJL	x	x
Dutch Sl at Jersey Isle	SLDUT007	DSJ	x	x
Beldon Landing	SLMZU011	BDL		x
Montezuma Slough at National Steel	SLMZU025	NSL	x	x
Threemile Sl at San Joaquin R	SLTRM004	TSL	x	x
Steamboat Slough	SSS	SSS	x	x
Sutter Slough at Courtland	SUT	SUT	x	x
Turner Cut near Holt	TRN	TRN	x	*

*Datum inconsistency at some stations not resolved.

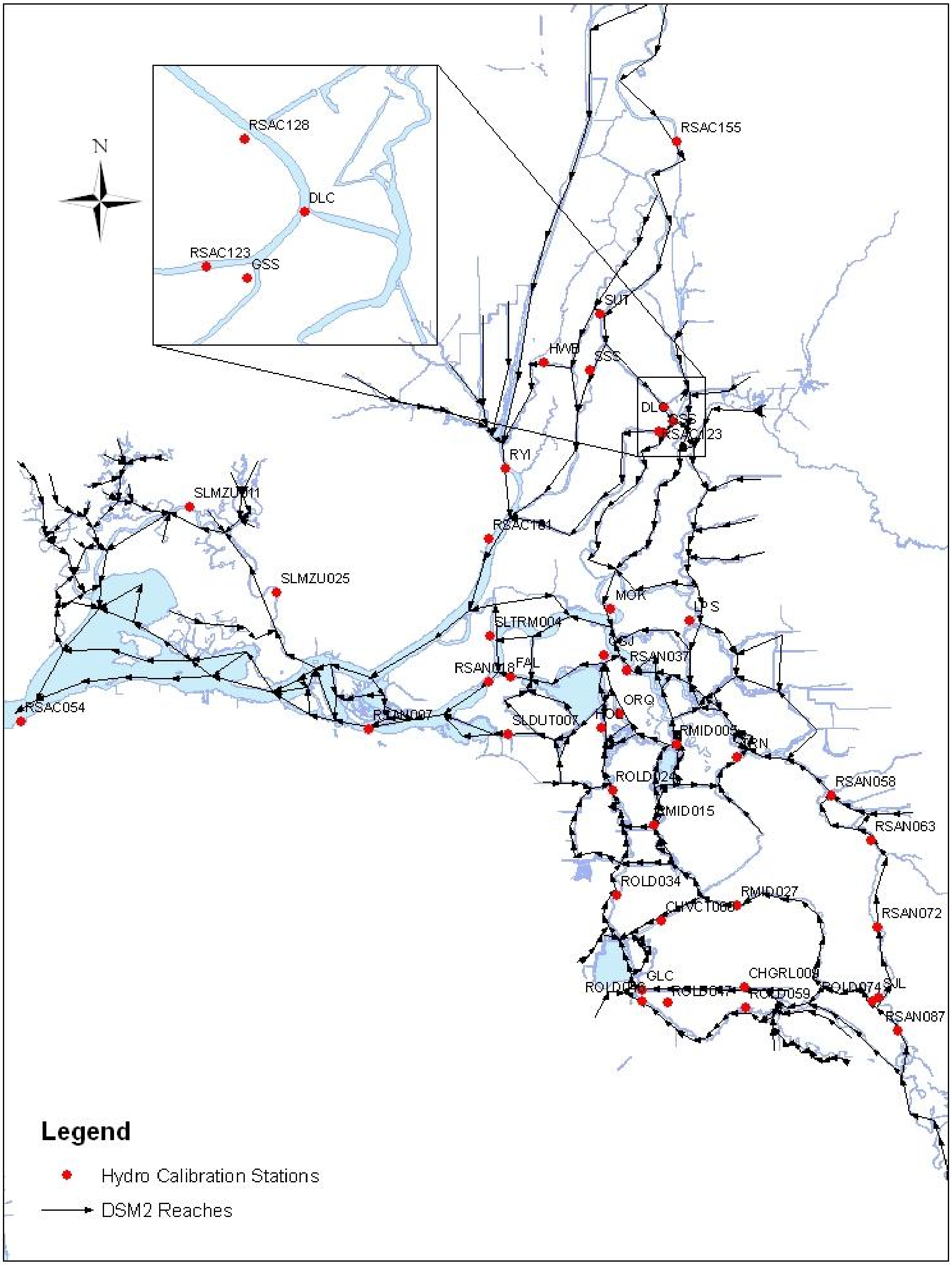

Figure 3-1 Hydro Calibration Stations

The model was primarily calibrated to match observed flows. Manning's coefficient values were adjusted for Hydro calibration. Stage was also compared to observed data in the same format as flow comparison. The calibration metrics are composed of five figures for each station:

- Timeseries comparison of instantaneous flow. This plot compares modeled and observed instantaneous flow. We show only 5 days in order to be able to see the tidal process and comparison clearly.
- Timeseries comparison of tidally-filtered daily-averaged flow. This plot compares modeled and observed tidally averaged flow, or net flow. Net flow is critical for flow distribution and for salt transport.
- Linear regression analysis of tidally-filtered daily-averaged flow. This scatter plot with a linear regression trend line shows statistically the comparison of the simulated vs. observed daily averaged flow. R^2 value gives information about the goodness of fit of the model. The trend line shows over- or under-predicting of the model.
- Linear regression analysis of instantaneous flow. This analysis followed a similar procedure described in the "Flooded Islands Pre-Feasibility Study" report (Resource Management Associates, 2005). The phase difference between the modeled and measured time series was determined using a cross-correlation procedure, and the modeled time series was shifted with the calculated phase lag before doing the regression analysis. The phase difference is noted in the figure. A positive value indicates that the simulated tidal process lags behind the observed record, while a negative value indicates a faster response by the model. The slope of the regression line approximates the amplitude ratio for modeled vs. observed tidal process. R^2 value gives information about the goodness of fit of the model. This plot was generated using data from May 15, 2008 to July 15, 2008. This short period of low flow was selected to better represent the tidal process. It is difficult to use the whole calibration period since the high flow period may have bigger net flow errors, which may be difficult to portray in a figure.
- Daily Maximum, Average, Minimum comparison. This plot compares modeled and observed daily maximum, average, minimum flow over the entire calibration period. It is easy to see how the model is doing overall in the entire calibration period.

Since overall the calibrated flow in 2009 BDCP Calibration matched observed data reasonably well, the 2009 calibration was used as a reference. Manning's n values were adjusted by groups. 26 adjustments and runs were made to reach a satisfactory result.

Due to the bug fixes of channel area interpolation, Manning's n values changed significantly in some areas, as summarized in Table 3-2. For example, in Sutter Slough and Steamboat Slough, Manning's n changed from 0.024 to 0.029; Lower San Joaquin River channels 48 through 51 changed from 0.022 to 0.026; channels in the Montezuma Slough area changed from 0.018 to 0.021.

Table 3-2 Recalibrated Manning's Coefficient

GroupName	Channel Number	2009 BDCP Calibration	Recalibrated
SUTTER_SL	375--382	0.024	0.029
STEAMBOAT_SL	383--387	0.024	0.029
LOWER_SJR	48--53, 282--301	0.019--0.037, most 0.022	0.026
THREE MILE SL	307--310	0.033	0.032
FALSE_RIVER	276--279	0.027	0.025
DUTCH_SL	215, 260, 273--275	0.027	0.025
OLD_RIVER	81--124, 214--278	0.027	0.025
MOK	334-344,348--349	0.019, 0.022	0.028
MONTEZUMA_SL	455--542	0.018	0.021

Flow results at a few locations are shown in Figure 3-2 through Figure 3-7. In summary, stations in the North Delta showed moderately improved results comparing to 2009 BDCP Calibration, e.g. Rio Vista, RSAC123 (Figure 3-2 and Figure 3-3). Stations in the South Delta showed little or no improvement, e.g., ROLD024 (Figure 3-4). A few stations showed dramatic improvements, e.g., RSAN087, LPS, and DLC (Figure 3-5 through Figure 3-7). The flow coefficients of the Delta Cross Channel gate were changed to 2.0, to allow enough flow through the gate.

Stage comparisons at a few selected stations, i.e. CHGRL009, RMID027, and DLC, are shown in Figure 3-8 through Figure 3-10. Simulated stages in this calibration compared with field data are much better than the 2009 calibration results, mainly due to the conversion to NAVD88. Maximum stages in tidal cycles match much better with field record. Minimum stages tend to be lower than observed data (e.g., Figure 3-10 Stage at Delta Cross Channel); as a result, simulated tidal ranges tend to be larger than field data.

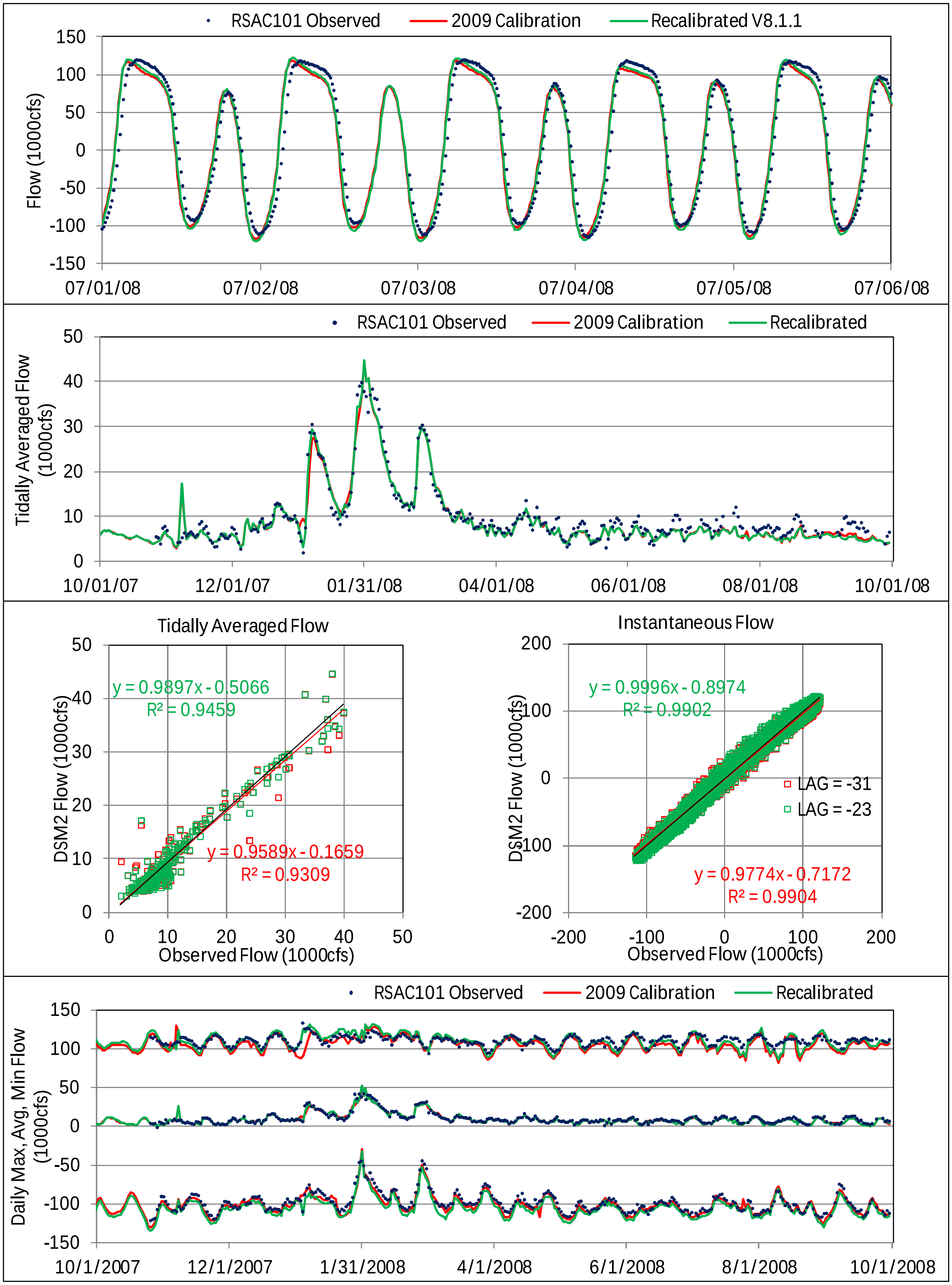

Figure 3-2 Sacramento River at Rio Vista

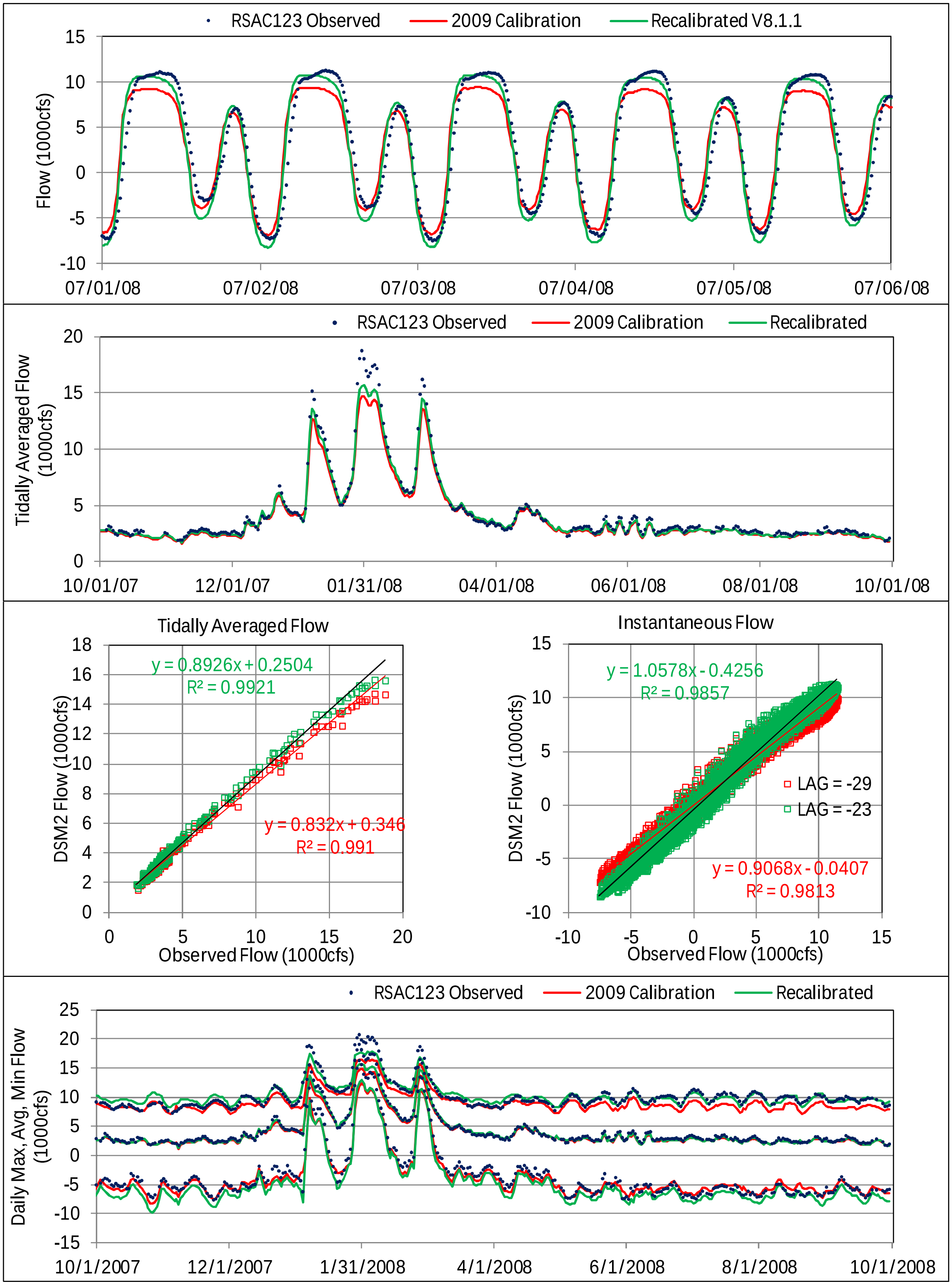

Figure 3-3 Sacramento River downstream of Georgiana Slough

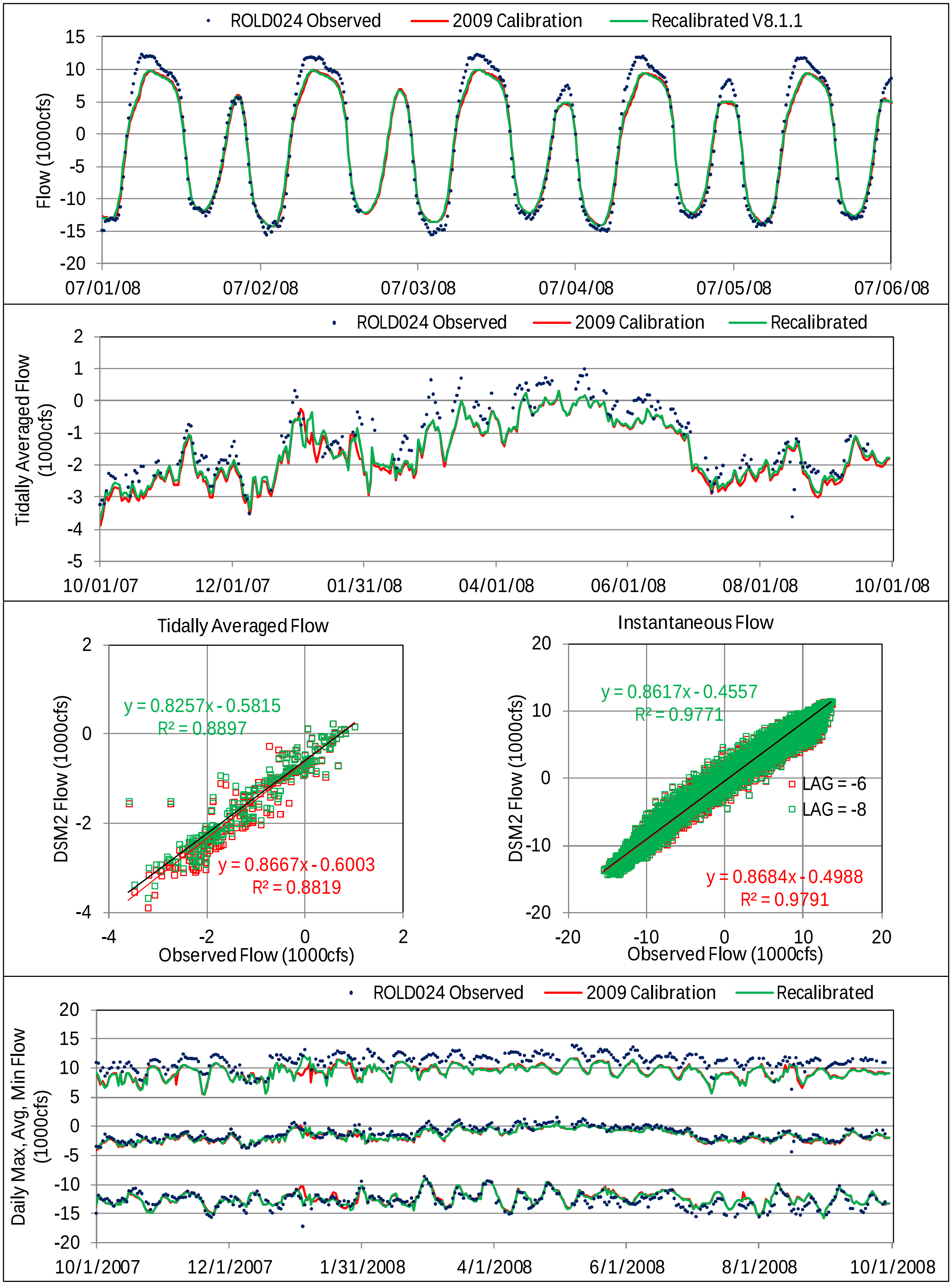

Figure 3-4 Old River at Bacon Island

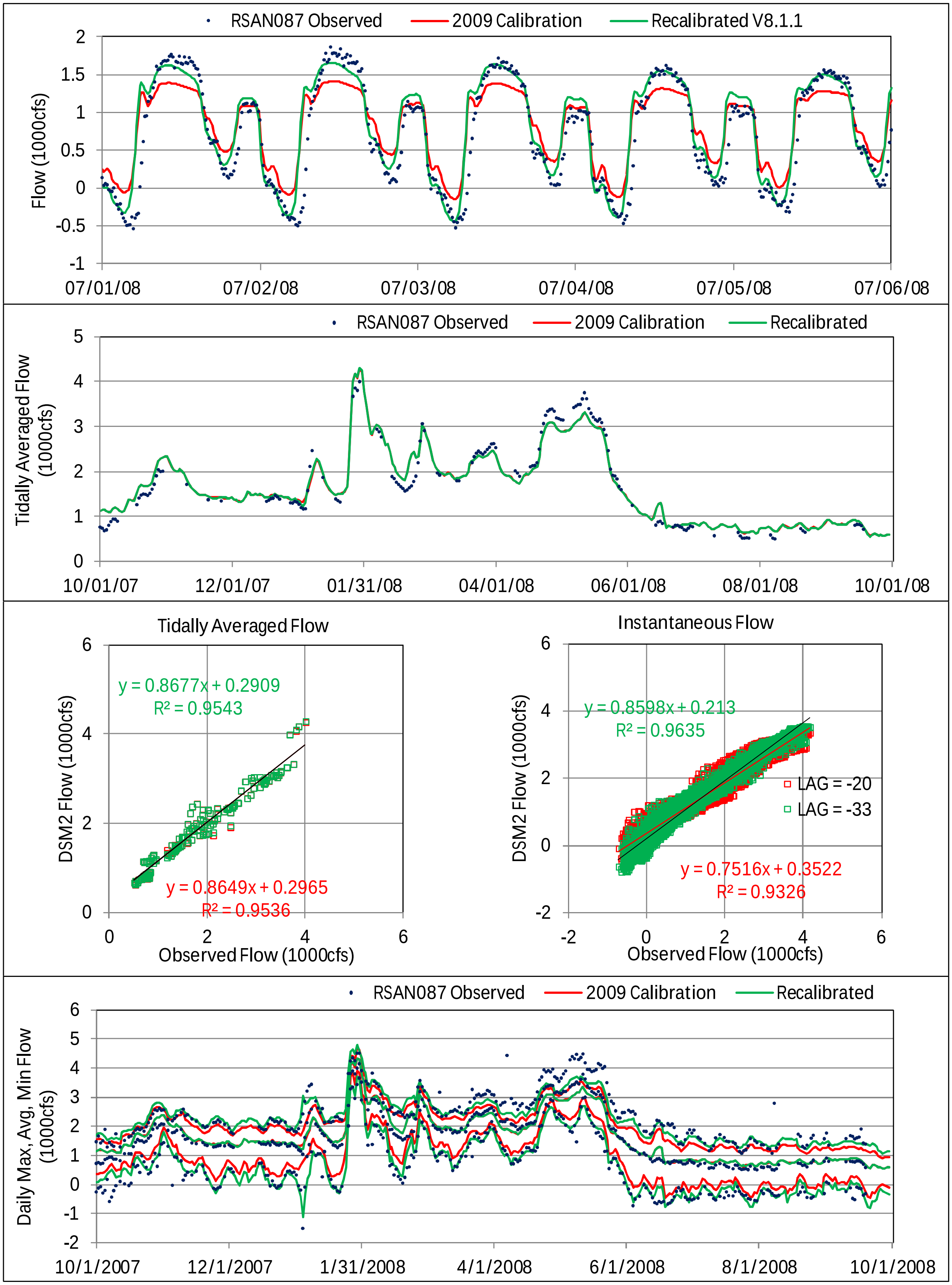

Figure 3-5 San Joaquin River at Mossdale

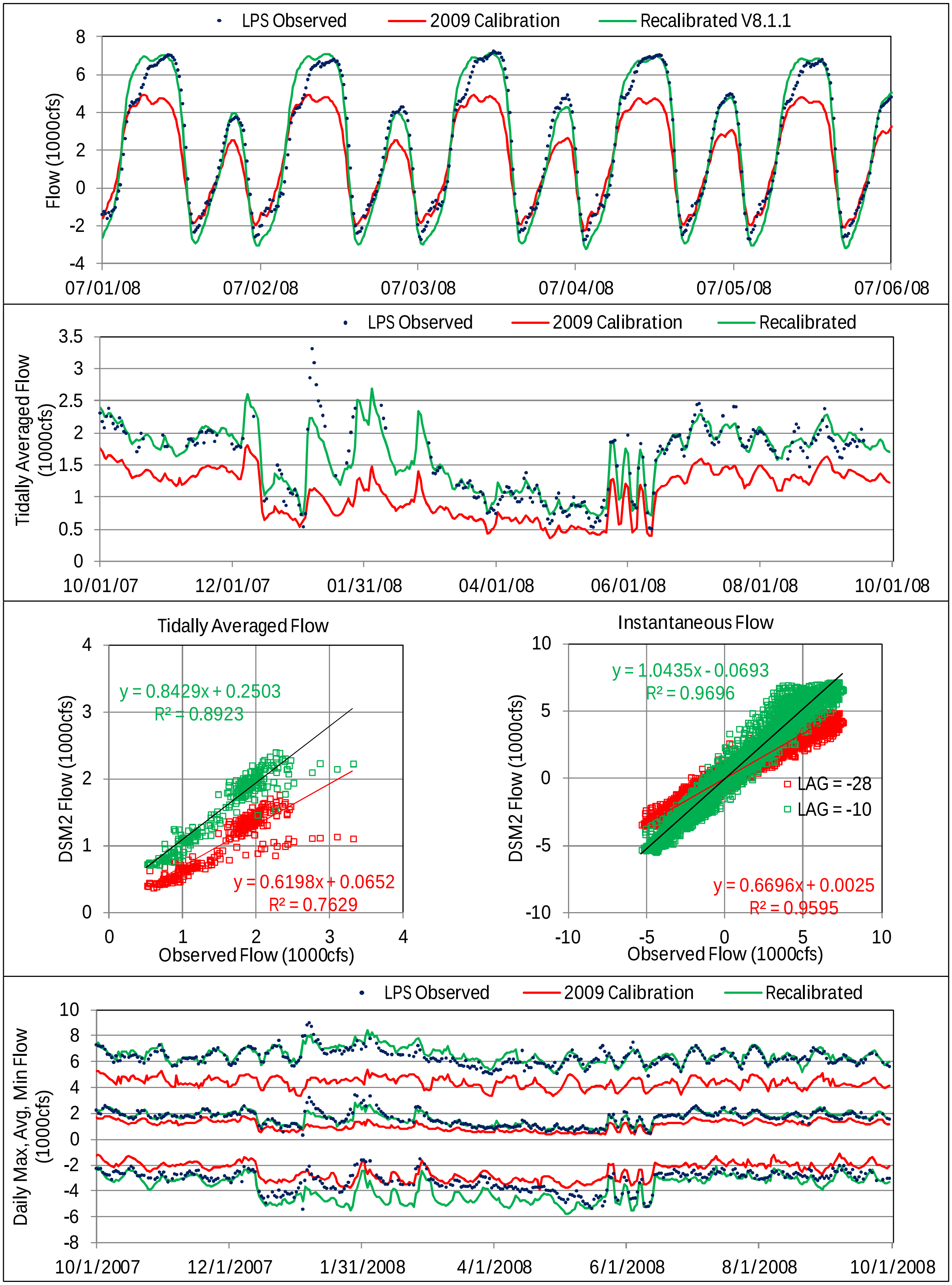

Figure 3-6 Little Potato Slough

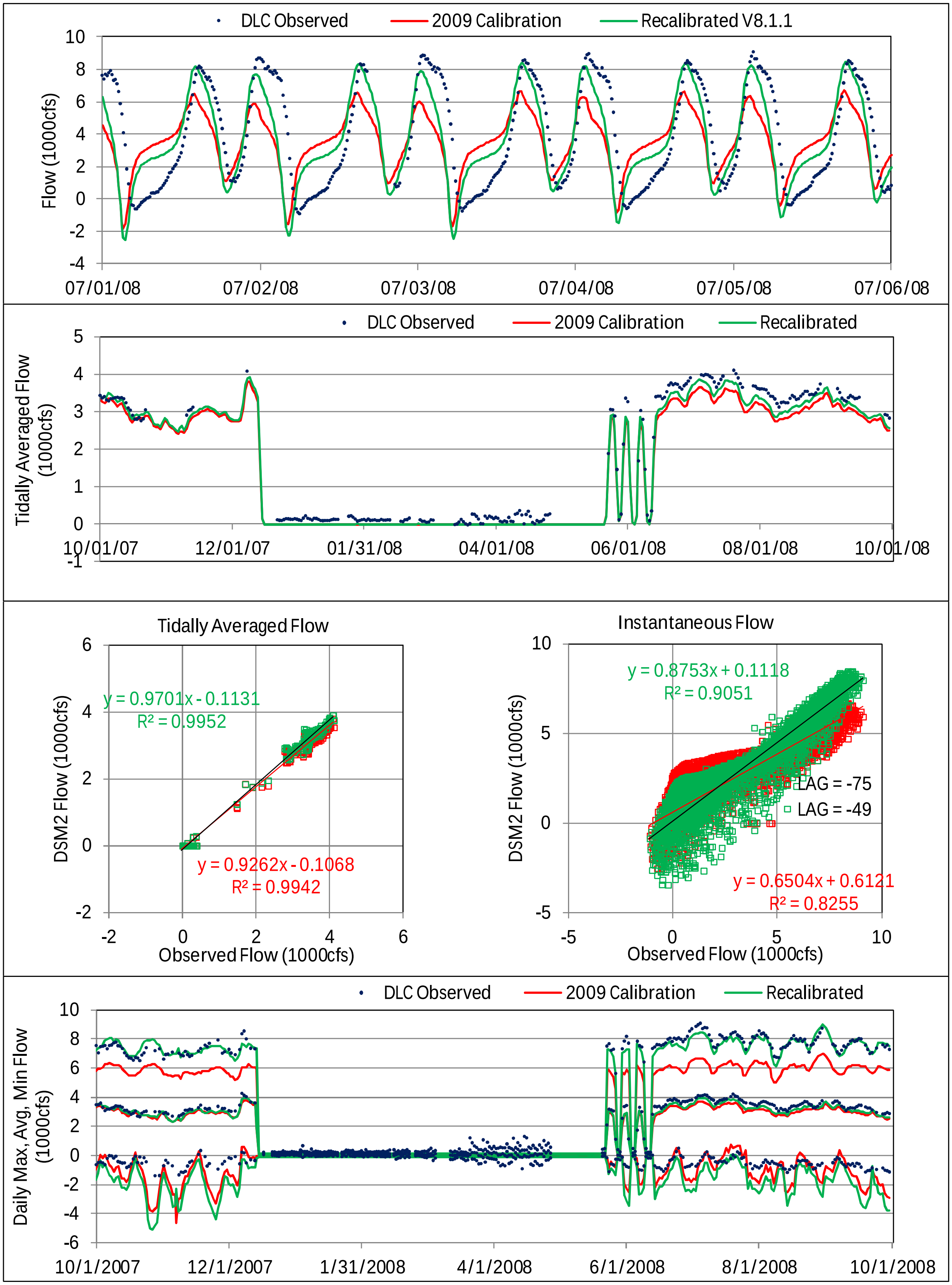

Figure 3-7 Delta Cross Channel

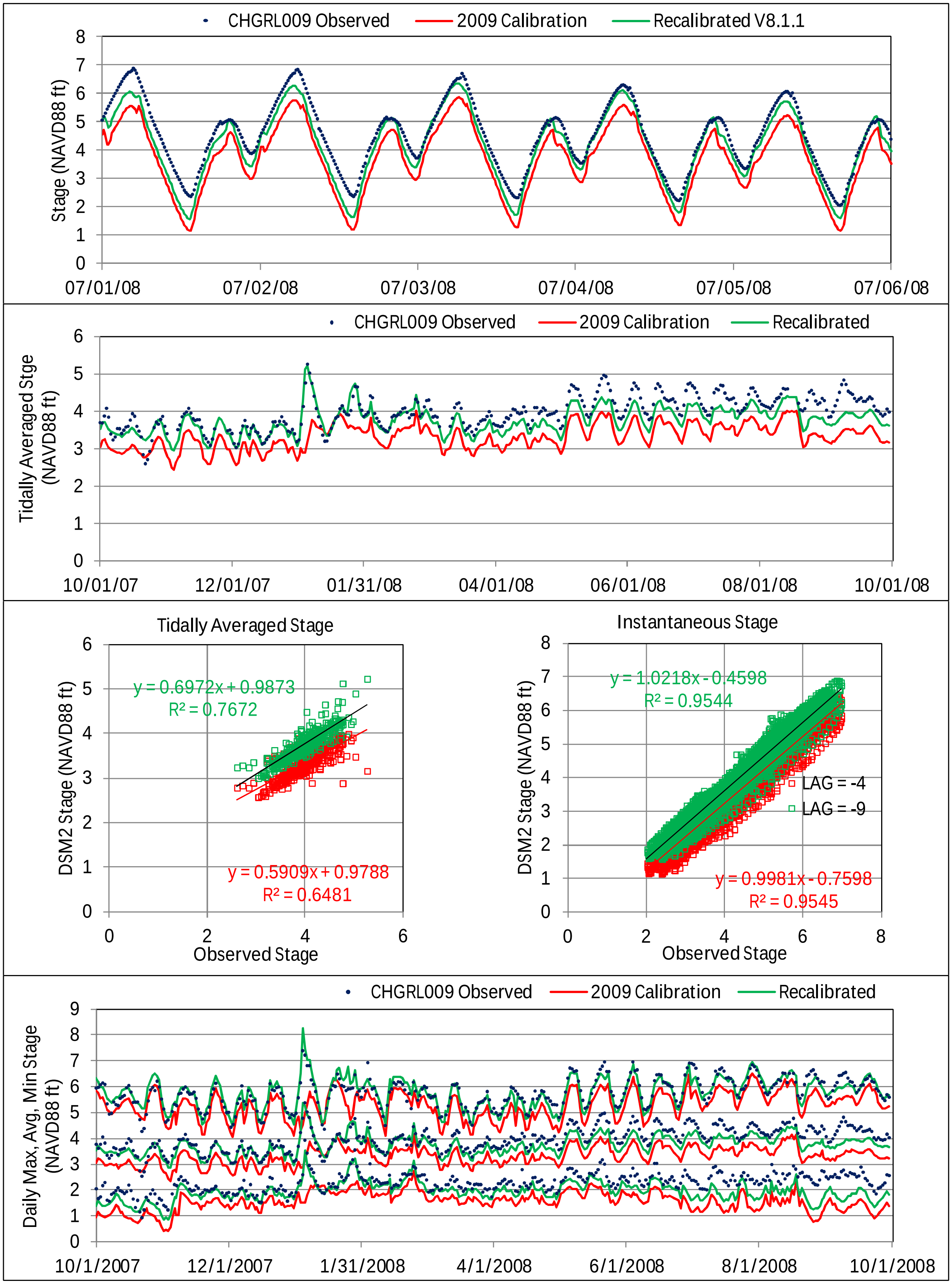

Figure 3-8 Stage at Grant Line Canal

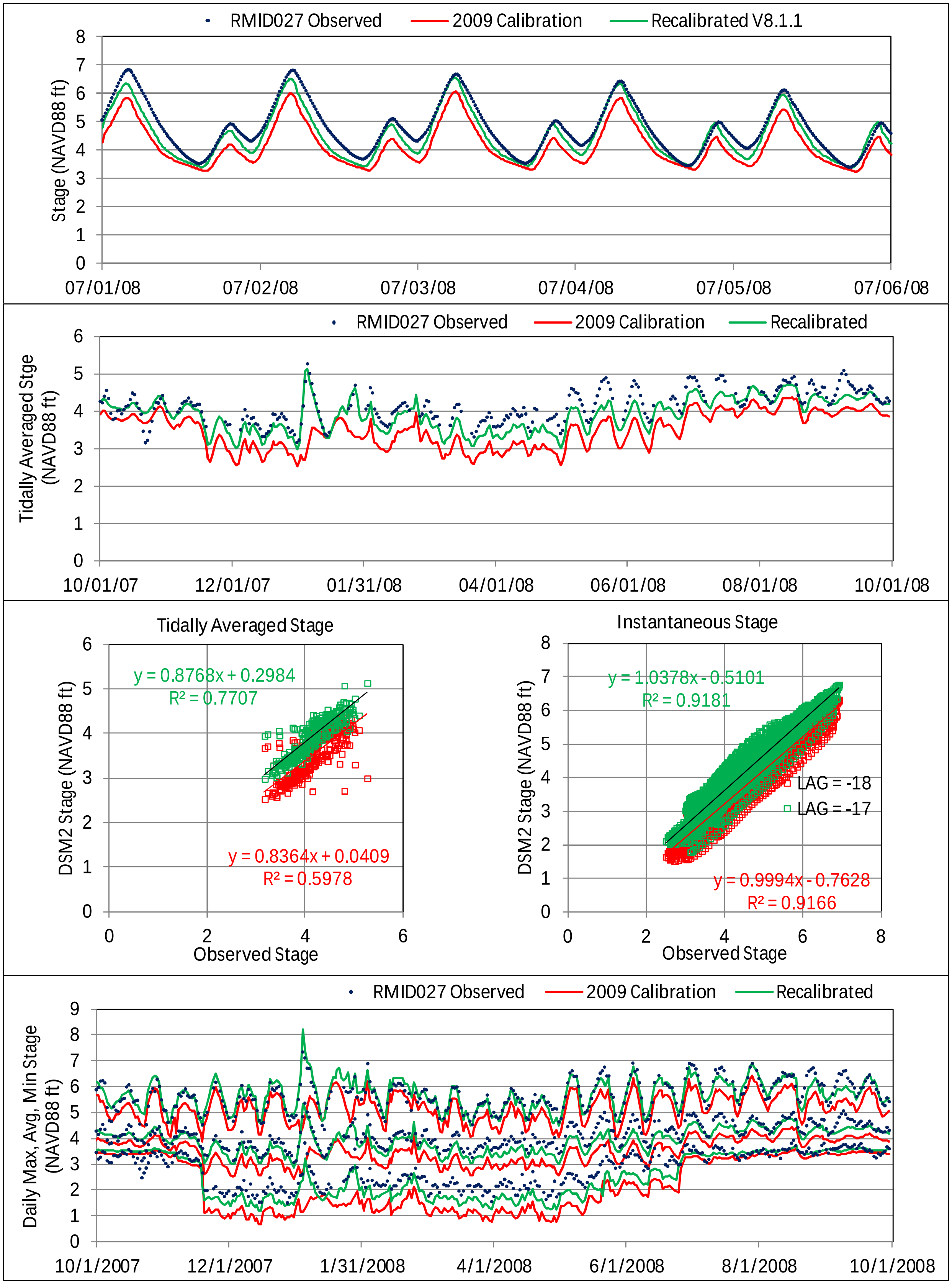

Figure 3-9 Stage at Middle River at Tracy Blvd

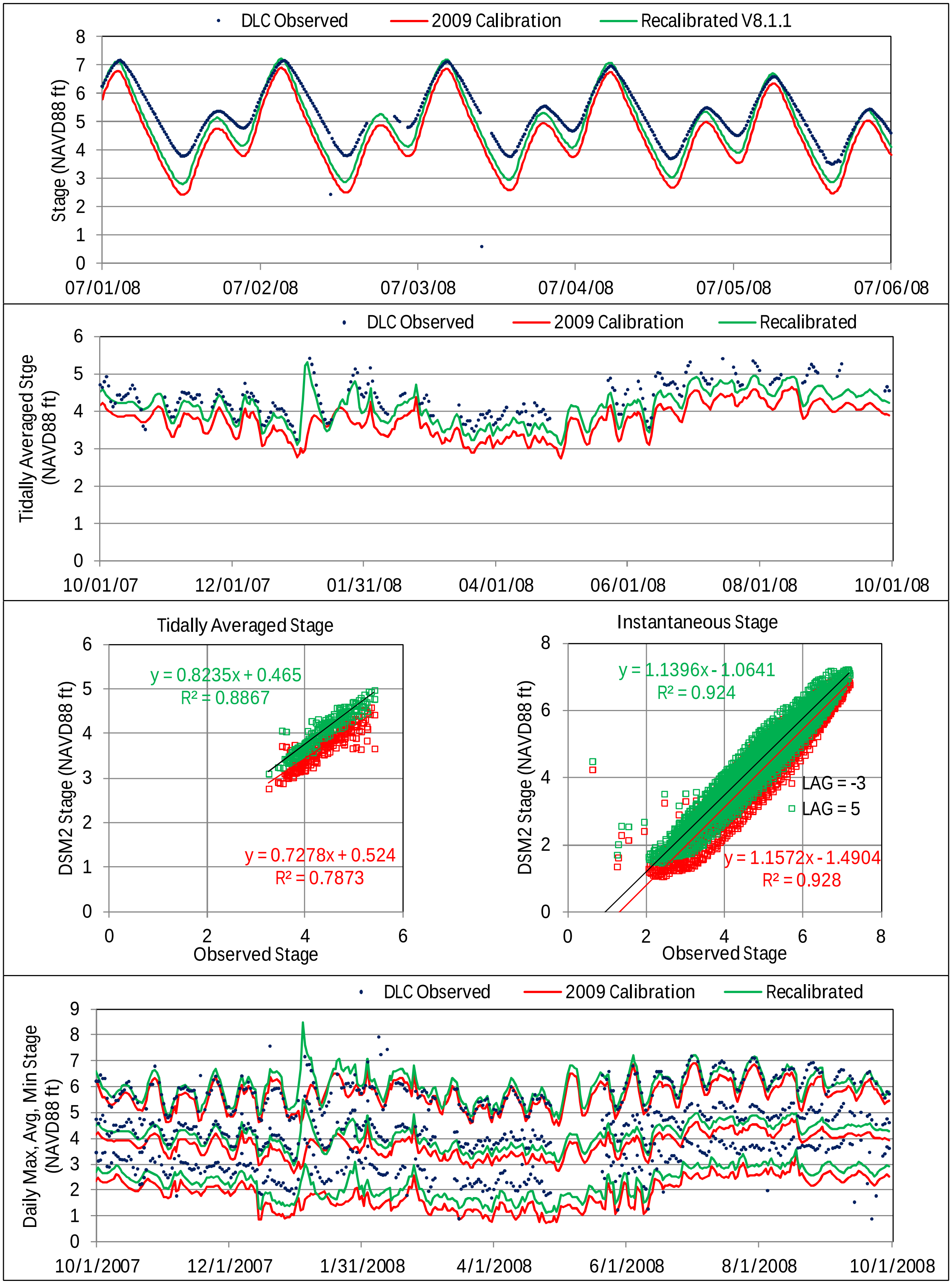

Figure 3-10 Stage at Delta Cross Channel

3.3 EC Calibration

Version 8.1 improved the dispersion formulation for model convergence (Liu & Ateljevich, Improvements to DSM2-Qual: Part 1, 2011). A new dispersion coefficient (DC) was introduced. The calibration period was from October 1, 2000 to October 1, 2008. We try to use all the stations with good data. The calibration stations are listed in Table 3-3, and shown on the map (Figure 3-11).

Some corrections were made for Martinez boundary EC. It was found, before October 1, 2002, the data were from IEP, they were indeed hourly averaged data. But after October 1, 2002, CDEC hourly data were used, which were instantaneously sampled, not hourly averaged. They were converted to hourly averaged values using HEC-DSSVue (US Army Corps of Engineers, Hydrologic Engineering Center), and the property was changed to **PER-AVER**. It is recommended to always use **PER-AVER** data at boundaries for Qual. It is more accurate for Qual to take **PER-AVER** data at boundaries because of the nature of its numerical scheme. If we start to use 15 minute data for Martinez boundary EC, it is still recommended to convert to period average. A sensitivity test showed that the differences between using 15 minute data and 1 hour data for Martinez boundary were around 0.1% in the Delta, so we used hourly-averaged for Martinez EC in this calibration.

The metrics used to evaluate model performance include:

- Linear regression analysis of monthly-averaged EC. This scatter plot with a linear regression trend line shows the simulated vs. observed monthly averaged EC. The intercept is set to zero so that the slope shows the bias of the model for higher EC. The model is over-predicting when the slope is higher than 1, and under-predicting when the slope is smaller than 1. R^2 value gives information about the goodness of fit of the model. A high R^2 value close to 1 means best fit, which usually means high quality data and good model prediction.
- Timeseries comparison of monthly-averaged EC. This plot compares modeled and observed EC month by month, easy to see directly which months the model is doing well or bad.
- Timeseries comparison of daily-averaged EC. This plot compares modeled and observed EC on a daily basis, making it easier to see how the model is doing over all.
- Mean Error (ME) and Percent Mean Error (PME). The mean values of observed and modeled EC for the entire calibration period are calculated. Percent Mean Error is calculated using Mean Error divided by the observed mean and expressed as a percentage. This gives a normalized percentage of how much the model is over-predicting or under-predicting.
- Root Mean Squared Error (RMSE) and Relative RMSE. RMSE is calculated based on daily averaged data. It is a good indicator of model prediction error and representative of the size of a “typical” error. Originally, we proposed the relative RMSE (also called normalized RMSE, or percent RMSE), calculated as RMSE divided by the range of the data and expressed as a percentage. A more mathematically sound parameter called RMSE-observed standard deviation ratio (RSR) may give better scaling and normalization, so we changed to RSR (Moriasi, Arnold, Van Liew, Bingner, Harmel, & Veith, 2007). It was recommended to be satisfactory for RSR ≤ 0.70 for watershed models with a monthly time step, and very good for RSR ≤ 0.5, while Percent Bias (PBIAS, same as PME) is also satisfactory.

Table 3-3 EC Calibration Stations

Location	Short Name	CDEC_ID
Three Mile Slough	3MILE_SL	TMS
DMC Headworks	CHDMC006	DMC
Grant Line Canal at Tracy Bridge	CHGRL009	GCT
Harvey O Banks PP	CLIFTON_C	HBP
Middle River near Holt	RMID005	HLT
Victoria Island	RMID023	VIC
Middle River at Tracy Blvd	RMID027	MTB
Union Island	RMID040	UNI
Holland Cut	ROLD014	HOL
Bacon Island at Old River	ROLD024	BAC
Old River near Tracy	ROLD059	OLD
Martinez	RSAC054	MRZ
Port Chicago	RSAC064	PCT
Mallard Island	RSAC075	MAL
Pittsburg	RSAC077	PTS
Collinsville	RSAC081	CLL
Emmaton	RSAC092	EMM
Rio Vista	RSAC101	RIV
Hood	RSAC139	SRH
San Joaquin at Antioch	RSAN007	ANH
Jersey Point	RSAN018	JER
San Andrea's Landing	RSAN032	SAL
Rough and Ready Island	RSAN058	RRI
San Joaquin at Mossdale Bridge	RSAN087	MSD
Vernalis	RSAN112	SJR
Brandt Bridge	SAN072	BDT
Farrar Park	SLDUT009	FRP
Beldon Landing	SLMZU011	BDL
Montezuma Slough at National Steel	SLMZU025	NSL
Bethel Island	SLPPR003	BET
Threemile Sl at San Joaquin R	SLTRM004	TSL

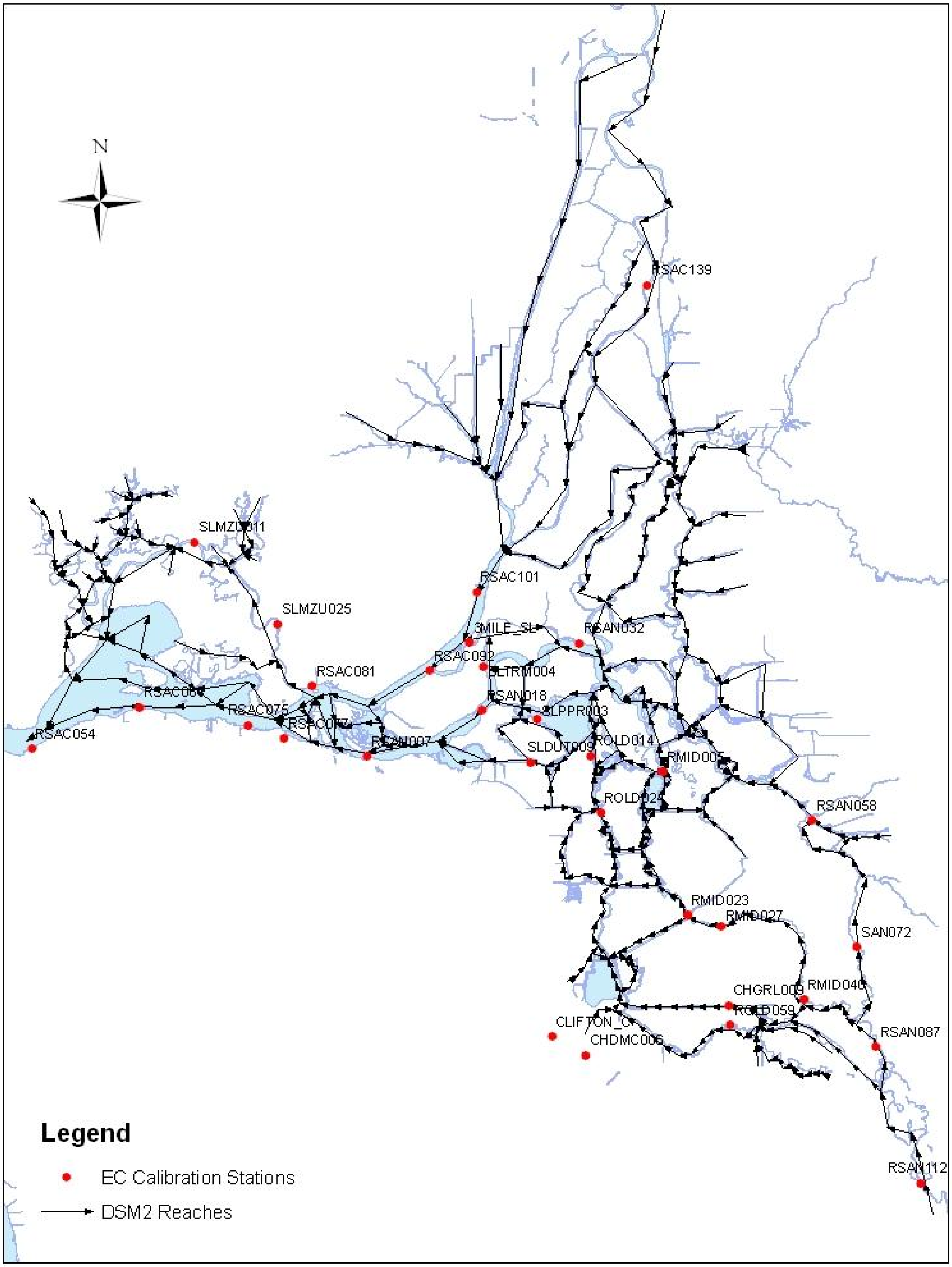

Figure 3-11 EC Comparison Stations

The calibration started by scaling the 2009 BDCP calibration dispersion coefficients by 1200, i.e., $DC = DQQ \times 1200$, where DQQ is the old dispersion coefficient, since previous experience showed this approach gave reasonable results. Then we calibrated the coefficients in groups from the West Delta to the South Delta in the trial runs. 11 adjustments and runs were taken to reach the satisfactory results, as described in the calibration notes.

30 stations with good data were selected and plotted. Mean Error, Percent Mean Error, RMSE and RSR are calculated and listed in Table 3-4 (the same metrics were calculated for 2009 calibration run and listed in Table 3-5 for comparison). Figure 3-12 through Figure 3-17 show the calibration metrics plots (including the 2009 calibration for comparison) at key stations: Collinsville, Emmaton, Jersey Point, Old River at Bacon Island, Clifton Court Forebay, and Montezuma Slough at Beldons. Some outlier data points for monthly EC were taken out for regression analysis for some South Delta stations (Clifton Court, ROLD024, SLDUT009), including December 2000, 2002, 2003, 2004, 2005, and January 2001, when the model failed to predict the EC peaks, as seen in Figure 3-15 and Figure 3-16. The reasons for these missing peaks are not clear. By taking out these outliers, the statistical analyses are more meaningful and represent the model performance in other months better.

From Table 3-4, key stations including Collinsville, Emmaton, Antioch, Jersey Point, and Old River at Bacon Island have the smallest Percent Mean Errors (PME) within 3% and RSR values less than 0.5. The model consistently under-predicts San Joaquin River stations (RSAN072, RSAN058) and South Delta stations (ROLD059, CHGRL009, RMID027, CLIFTON COURT), where the PMEs are larger than -10%. The worst is Old River at Tracy Road (ROLD059) with percent mean error -22%. The RSR values of most of the stations are less than or close to 0.5 except RMID027, ROLD059, RSAC101, and RSAN032, which may need to be further improved. The predicted EC at Montezuma Slough stations (SLMZU011, SLMZU025) are much lower than observed, although the predicted EC matches the timing of salinity intrusion well. These biases are similar to the 2000, 2009 calibrations.

Figure 3-18 shows Martinez EC comparison was improved compared to the 2009 calibration, due to the correction of the Martinez boundary EC input data.

A lot of reasons might contribute to the errors in predicted EC, e.g. bathymetry, DICU, boundary flow and water quality measurement errors, over-simplification of the model formulation, etc. A 1D model such as DSM2 may be inadequate to accurately model areas that are highly two dimensional (e.g., shallow bays, such as Grizzly Bay, Suisun Bay, and Franks Tract) or three dimensional (e.g., stratification in West Delta). Further investigations are needed to improve the model calibration.

Table 3-4 Summary of Error Estimates at Selected Stations

Location	DSM2 Station	CDEC Station	Mean (umhos)				RMSE (umhos)	STDEV	RSR
			Observed	Simulated	Error	%			
Three Mile Sl at Sac River	3MILE_SL	TMS	471	448	-22	-4.7	182	397	0.46
Jones Pumping Plant	CHDMC006	DMC	445	421	-24	-5.4	65	135	0.48
Grant Line Canal at Tracy Blvd Bridge	CHGRL009	GCT	595	522	-74	-12.4	102	243	0.42
Banks Pumping Plant	CLIFTON COURT	HBP	394	362	-32	-8.2	58	136	0.42
Middle River near Holt	RMID005	HLT	314	322	8	2.5	28	79	0.35
Middle River at Borden Hwy	RMID023	VIC	351	342	-9	-2.5	61	110	0.56
Middle River at Tracy Blvd	RMID027	MTB	513	442	-71	-13.9	145	184	0.79
Middle River at Mowery Bridge	RMID040	UNI	615	586	-30	-4.8	76	226	0.33
Old River at Holland Cut	ROLD014	HOL	456	408	-49	-10.6	69	214	0.32
Old River at Bacon Island	ROLD024	BAC	367	357	-10	-2.6	86	173	0.50
Old River at Tracy Road	ROLD059	OLD	640	500	-140	-21.9	173	264	0.65
Martinez	RSAC054	MRZ	17557	16374	-1183	-6.7	1304	8049	0.16
Sac River at Port Chicago	RSAC064	PCT	7856	8950	1095	13.9	3032	5707	0.53
Sac River at Mallard	RSAC075	MAL	4697	4665	-32	-0.7	824	4230	0.19
Sac River at Pittsburg	RSAC077	PTS	4110	4366	256	6.2	1371	3674	0.37
Sac River at Collinsville	RSAC081	CLL	2912	2917	6	0.2	789	2828	0.28
Sac River at Emmaton	RSAC092	EMM	644	637	-7	-1.1	298	705	0.42
Sac River at Rio Vista	RSAC101	RIV	187	201	14	7.6	57	48	1.19
Sac River at Hood	RSAC139	SRH	156	157	1	0.7	13	31	0.42
SJR at Antioch	RSAN007	ANH	1860	1863	2	0.1	568	1839	0.31
SJR at Jersey Point	RSAN018	JER	678	695	17	2.5	229	569	0.40
SJR at San Andreas Landing	RSAN032	SAL	223	252	29	12.9	65	91	0.72
Stockton Ship Channel	RSAN058	RRI	596	529	-67	-11.3	120	204	0.59
SJR at Brandt Bridge	RSAN072	BDT	529	490	-39	-7.3	75	234	0.32
SJR at Mossdale	RSAN087	MSD	527	506	-21	-3.9	69	231	0.30
SJR at Mossdale	RSAN112	SJR	573	573	0	0.0	2	214	0.01
Dutch Slough	SLDUT009	FRP	569	527	-42	-7.4	149	381	0.39
Montezuma Slough at Beldons	SLMZU011	BDL	6856	5122	-1734	-25.3	2130	4712	0.45
Montezuma Slough at National Steel	SLMZU025	NSL	5286	3756	-1530	-28.9	2114	4164	0.51
Piper Slough at Bethel Island	SLPPR003	BET	459	382	-77	-16.7	145	287	0.50

Table 3-5 Summary of Error Estimates Calculated for 2009 Calibration

Location	DSM2 Station	CDEC Station	Mean (umhos)				RMSE (umhos)	STDEV	RSR
			Observed	Simulated	Error	%			
Three Mile Sl at Sac River	3MILE_SL	TMS	471	452	-19	-4.0	188	397	0.47
Jones Pumping Plant	CHDMC006	DMC	445	412	-34	-7.5	67	135	0.50
Grant Line Canal at Tracy Blvd Bridge	CHGRL009	GCT	595	520	-76	-12.7	103	243	0.42
Banks Pumping Plant	CLIFTON COURT	HBP	394	354	-40	-10.2	65	136	0.48
Middle River near Holt	RMID005	HLT	314	331	17	5.4	38	79	0.48
Middle River at Borden Hwy	RMID023	VIC	351	344	-7	-2.1	64	110	0.58
Middle River at Tracy Blvd	RMID027	MTB	513	471	-42	-8.2	159	184	0.87
Middle River at Mowery Bridge	RMID040	UNI	615	586	-30	-4.8	76	226	0.34
Old River at Holland Cut	ROLD014	HOL	456	380	-76	-16.7	96	214	0.45
Old River at Bacon Island	ROLD024	BAC	367	335	-31	-8.6	93	173	0.54
Old River at Tracy Road	ROLD059	OLD	640	498	-142	-22.1	173	264	0.65
Martinez	RSAC054	MRZ	17557	15785	-1771	-10.1	1913	8049	0.24
Sac River at Port Chicago	RSAC064	PCT	7856	8610	754	9.6	2886	5707	0.51
Sac River at Mallard	RSAC075	MAL	4697	4601	-95	-2.0	878	4230	0.21
Sac River at Pittsburg	RSAC077	PTS	4110	4371	261	6.4	1408	3674	0.38
Sac River at Collinsville	RSAC081	CLL	2912	2964	53	1.8	811	2828	0.29
Sac River at Emmaton	RSAC092	EMM	644	592	-52	-8.1	316	705	0.45
Sac River at Rio Vista	RSAC101	RIV	187	190	3	1.4	46	48	0.97
Sac River at Hood	RSAC139	SRH	156	157	1	0.5	8	31	0.25
SJR at Antioch	RSAN007	ANH	1860	1887	27	1.4	598	1839	0.33
SJR at Jersey Point	RSAN018	JER	678	682	4	0.5	251	569	0.44
SJR at San Andreas Landing	RSAN032	SAL	223	252	28	12.6	68	91	0.75
Stockton Ship Channel	RSAN058	RRI	596	541	-55	-9.2	104	204	0.51
SJR at Brandt Bridge	RSAN072	BDT	529	487	-42	-7.9	68	234	0.29
SJR at Mossdale	RSAN087	MSD	527	504	-23	-4.3	84	231	0.36
SJR at Mossdale	RSAN112	SJR	573	573	0	0.0	2	214	0.01
Dutch Slough	SLDUT009	FRP	569	507	-62	-10.8	165	381	0.43
Montezuma Slough at Beldons	SLMZU011	BDL	6856	5227	-1629	-23.8	2049	4712	0.43
Montezuma Slough at National Steel	SLMZU025	NSL	5286	4065	-1222	-23.1	1758	4164	0.42
Piper Slough at Bethel Island	SLPPR003	BET	459	368	-90	-19.7	161	287	0.56

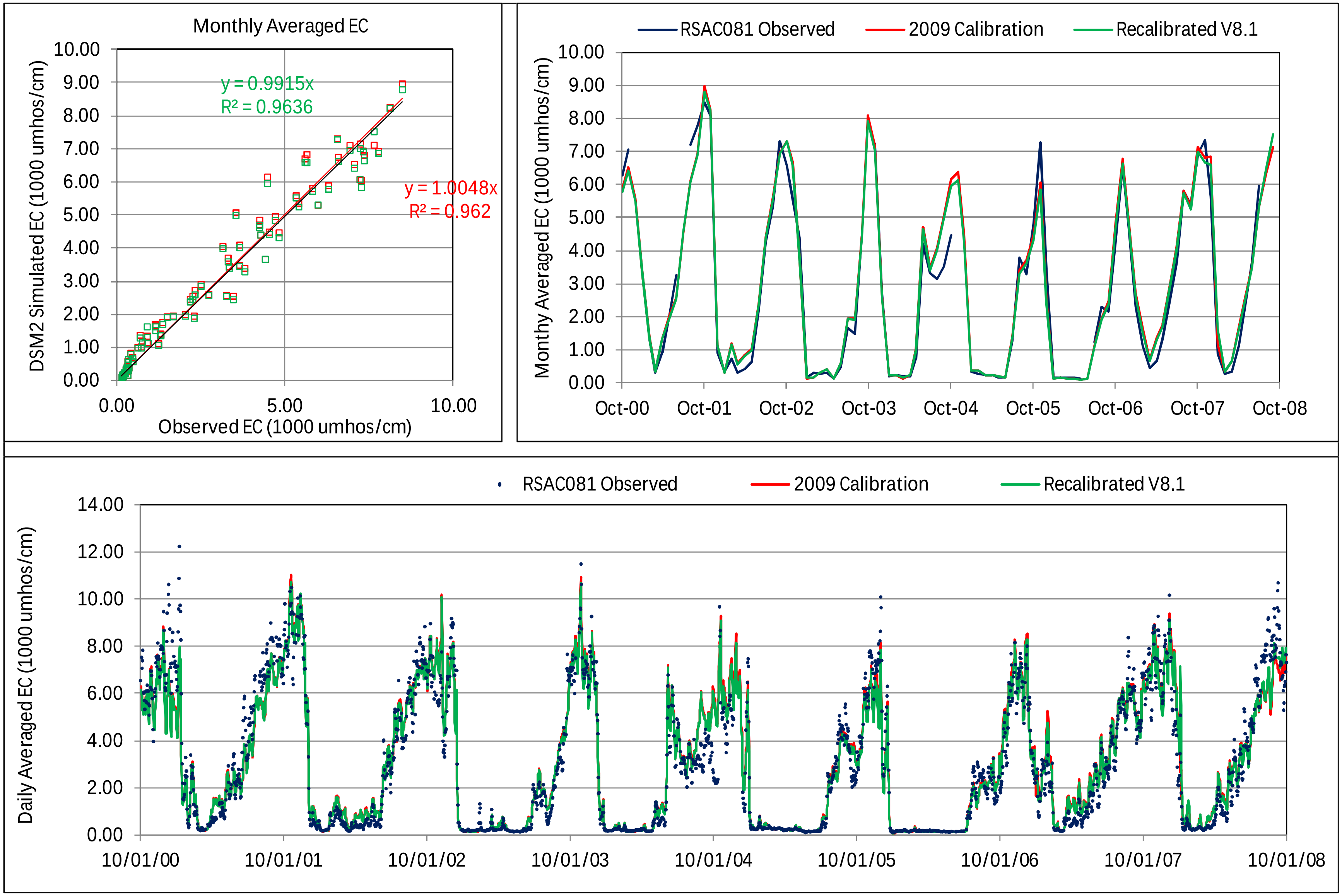

Figure 3-12 Sacramento River at Collinsville (RSAC081)

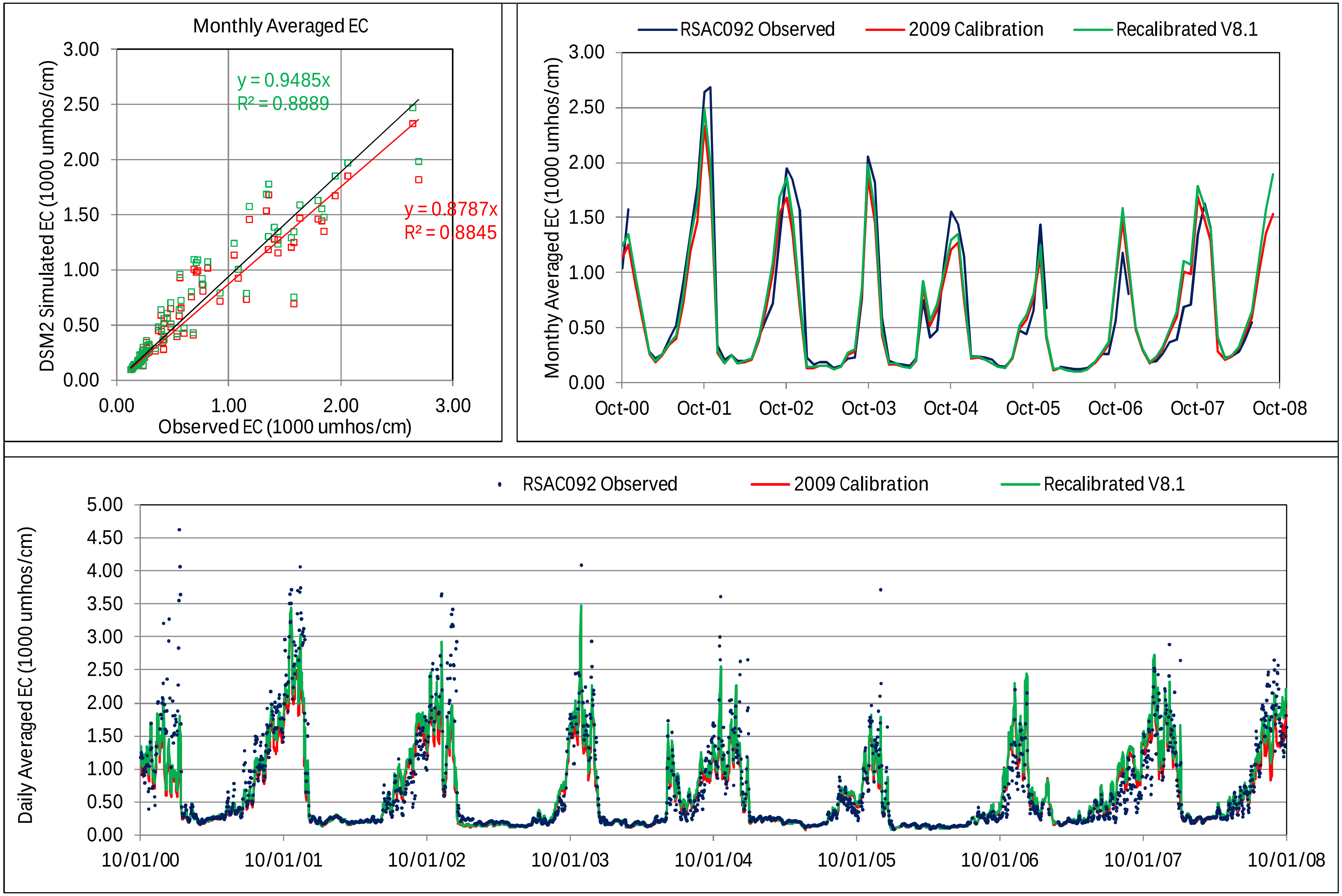

Figure 3-13 Sacramento River at Emmaton (RSAC092)

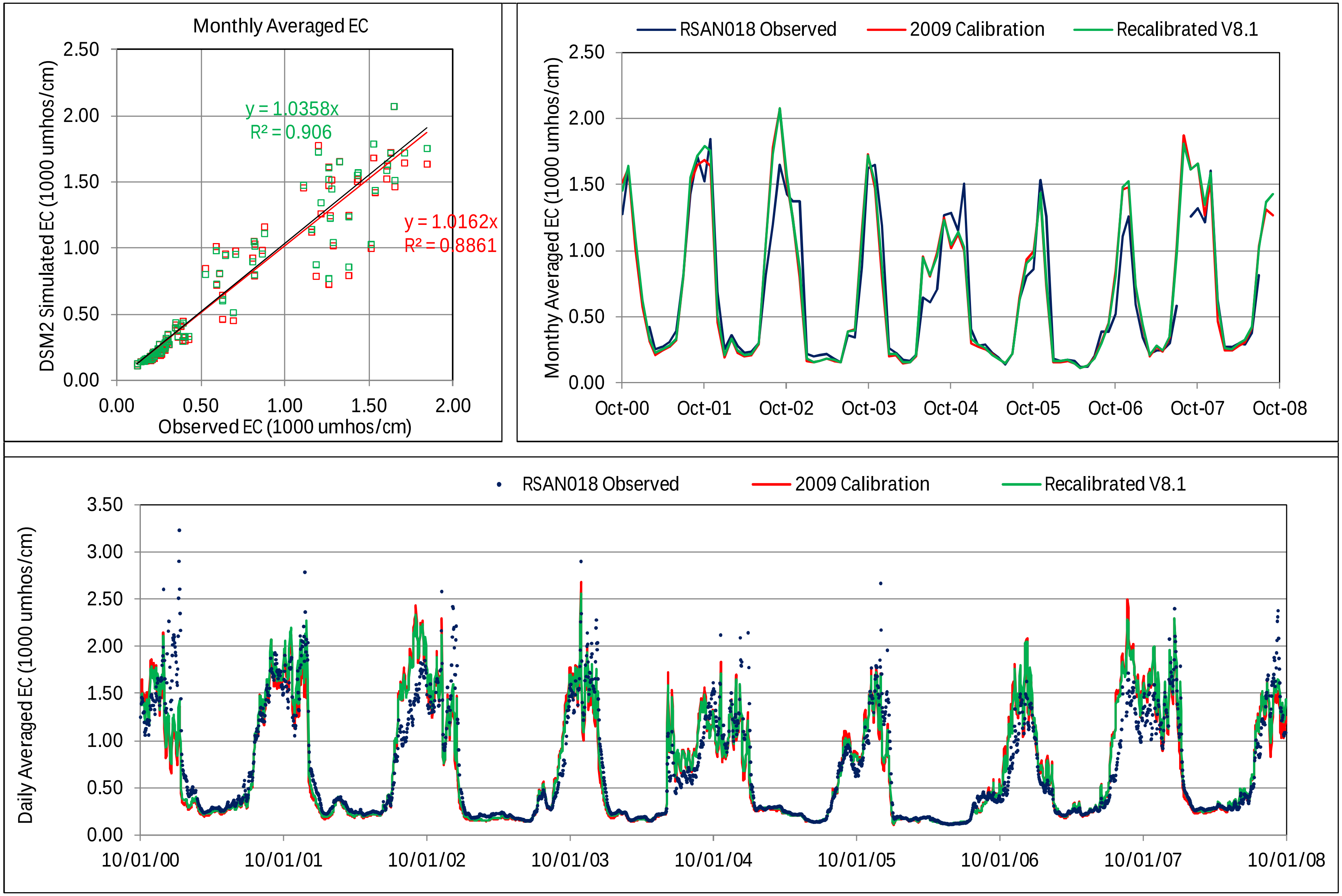

Figure 3-14 San Joaquin River at Jersey Point (RSAN018)

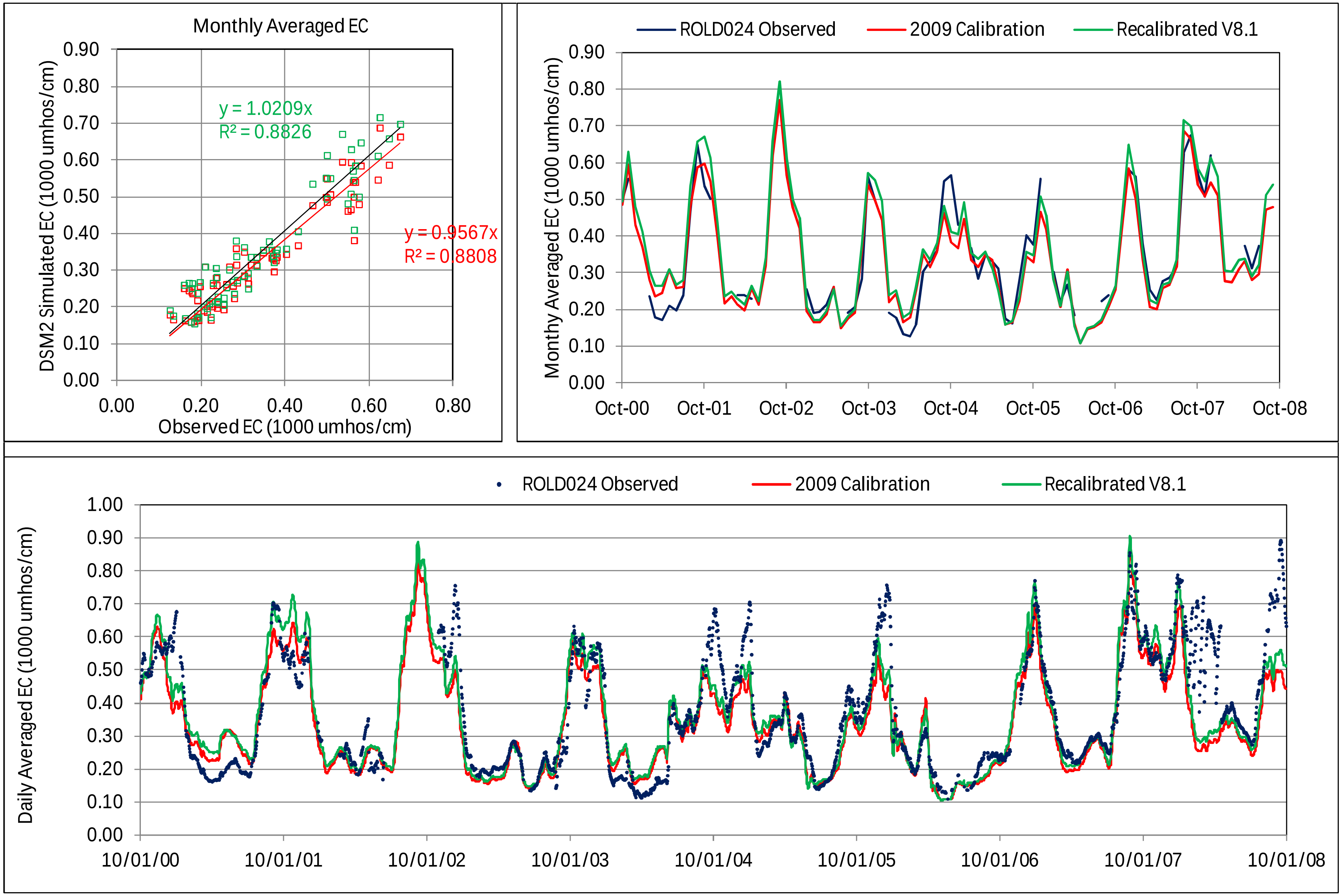

Figure 3-15 Old River at Bacon Island (ROLD024)

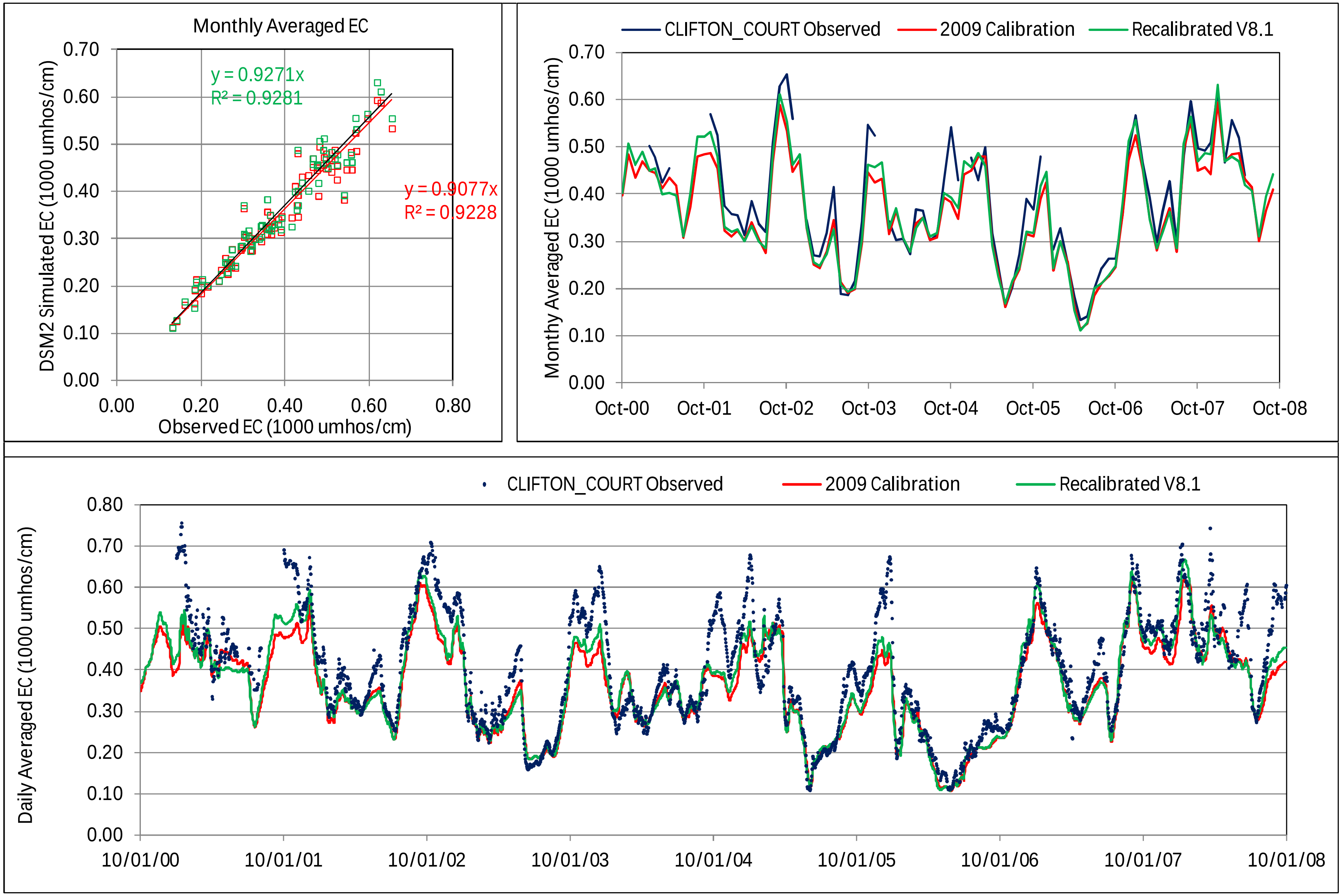

Figure 3-16 Clifton Court Forebay

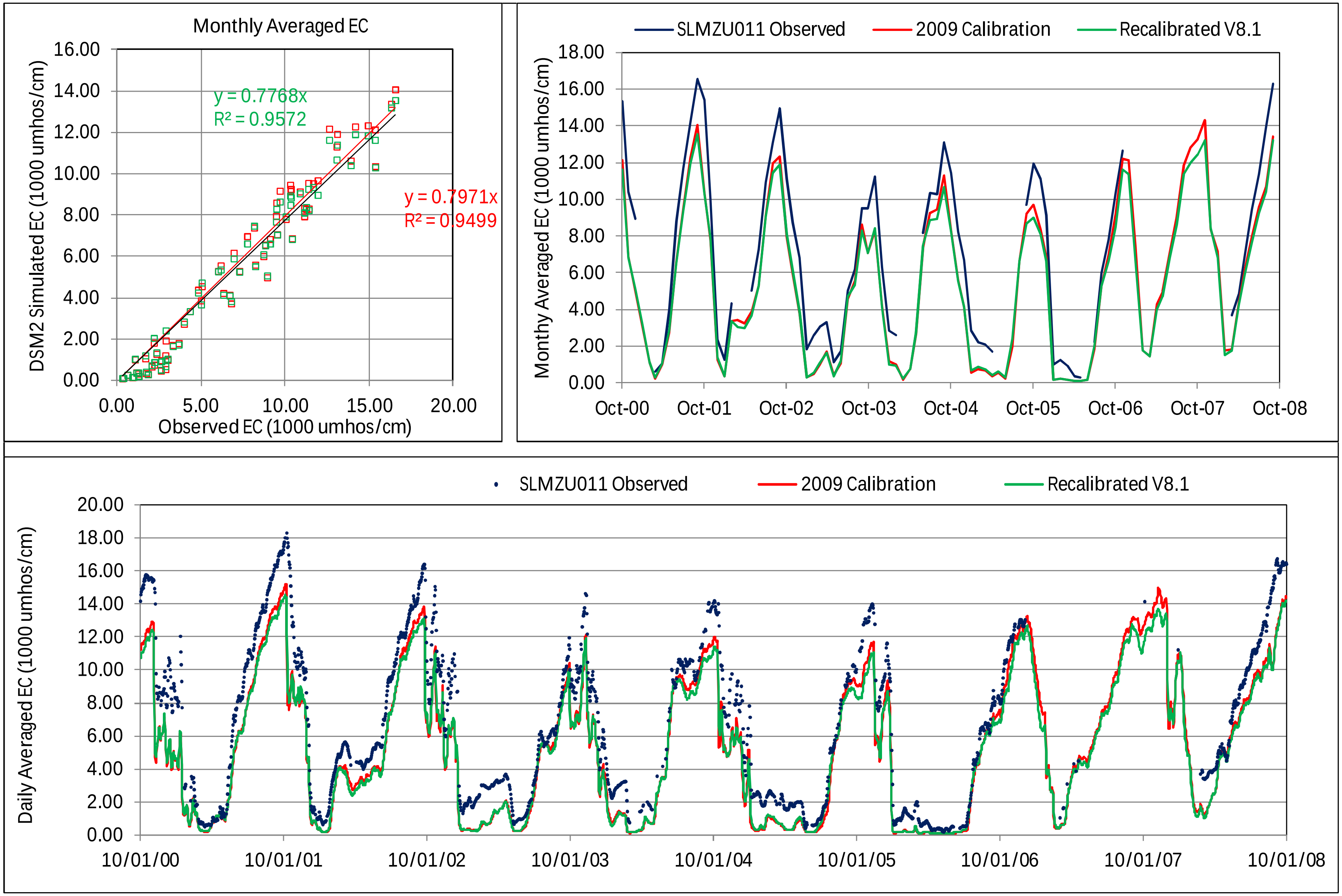

Figure 3-17 Montezuma Sl at Beldons (SLMZU011)

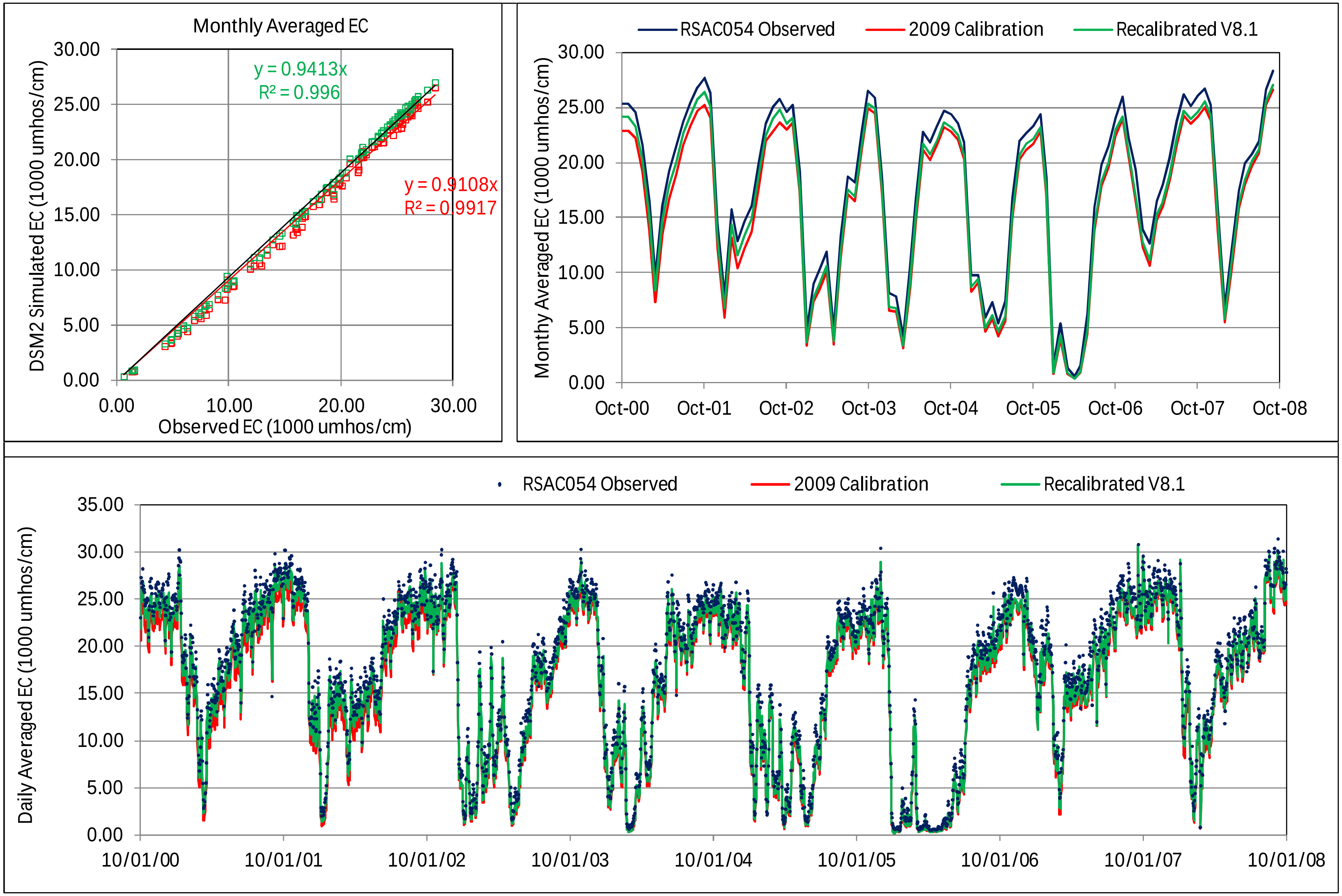

Figure 3-18 Martinez Boundary

3.4 Summary

DSM2 Version 8.1 incorporates the latest improvements to the DSM2 code and a new calibration with NAVD88 datum. The modifications of channel geometry interpolation and dispersion formulation in Version 8.1 improved the model reliability and convergence. Mass conservation was checked for both Hydro and Qual. Sensitivity and convergence tests were done to determine appropriate time steps to use. The conversion to NAVD88 stage datum improved the comparison of predicted and observed stages in the Delta. Errors in Clifton Court Gate operation data, Martinez stage data, and Martinez EC data were corrected.

The model predicted EC at key stations in Central Delta fairly well (Collinsville, Emmaton, Antioch, Jersey Point). The new calibrated model results are generally very close to the 2009 BDCP calibration results, although there are significant changes of Manning's n values and dispersion coefficients. Improvements were seen in a few places in Hydro and Qual, but not as big as we hoped. Flow around Franks Tract area and EC at South Delta are the most desirable to be improved.

This recalibration was done mainly by adjusting Manning's coefficients and dispersion coefficients. Further improvements would involve bigger changes, e.g., improve the channel schematic; regenerate cross sections based on better bathymetry data; improve flow around Franks Track area; improved estimates of diversions, return flows, and return flow water quality; Clifton Court gate modeling improvement; etc.

3.5 Acknowledgement

We would like to acknowledge Ralph Finch (DWR) for providing quality controlled data for the calibration, Lan Liang (DWR) for updating the historical run to 2012 and corrections made to Martinez stage and Clifton Court Gate operation data, Qiang Shu for help with VTools and writing some of the scripts used in the data analysis, and Parviz Nader-Tehrani for valuable suggestions.

3.6 References

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Chapter 4
Adding Salmon Route Selection Behavior to DSM2 Particle Tracking Model

Authors: **Xiaochun Wang,**
Delta Modeling Section,
Bay-Delta Office,
California Department of Water Resources

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4 Adding Salmon Route Selection Behavior to DSM2 Particle Tracking Model

4.1 Introduction

DSM2 Particle Tracking Model (PTM) simulates the transport and fate of individual neutrally buoyant particles through the Sacramento – San Joaquin Delta. This model has evolved since its initial development in 1993. New features, such as attaching fish-like behaviors to particles, have been added to the model. Although the model itself has been calibrated and validated using a field dye study, the adequacy of the model for simulating fish migration has never been quantitatively evaluated due to the lack of field fish monitoring data. Recent developments in the field monitoring, especially in acoustic telemetry fish tag studies, have made it possible for evaluating the adequacy of applying PTM to simulating fish behaviors.

This chapter describes the implementation of fish route selection behavior in PTM and the results of the implementation. The approach for using PTM to simulate fish behaviors and the improvements needed for PTM to better simulate fish behaviors are also discussed.

4.2 Fish Route Selection Behavior Relationship – A Generalized Linear Model

An important fish behavior is route selection when fish reaches a junction. A generalized linear model (GLM) was developed (Bowen, Hanson, & Perry, 2012) to predict the probability of late fall-run juvenile Chinook salmon route selection at a junction. This model is based on the acoustic telemetry tag data collected at the Georgiana Slough (GS) and Sacramento River (Sac. R.) junction in 2011. The fate of individual fish (whether entering GS or remaining in Sac. R.) was modeled as a Bernoulli random variable (coded as 1 for entering a particular channel and 0 for not entering). The analysis assumed the probability of entering GS has a trinomial distribution. A logit link function was used as the linear function of the covariates. The covariates included: 1) operation of the non-physical barrier; 2) time of day; 3) flow entering the river junction; 4) the cross-stream, horizontal position of each individual fish; and 5) the location of the critical streakline in the cross section. Turbidity and water velocity upstream of the non-physical barrier were considered as possible covariates at the beginning of the analysis but were not included in the model because they were found to be highly correlated with the discharge. The critical streakline is the line that divides the river channel into two water parcels entering either GS or Sac. River. Fish in the GS water parcel have a higher probability of entering GS, and those in Sac. River parcel have a lower probability. The streakline was estimated by channel width multiplied by the flow split ratio of the flow entering GS to the total inflow. The values of the covariates were obtained when fish were closest to the junction. The model was selected according to the best fit and Bayesian Information Criterion, a model selection criterion widely used for model identification in linear regression.

4.3 PTM Implementation and Results

The GLM discussed above was implemented in PTM. The implementation only applied for the environmental conditions that the GLM is based on– that is, the GLM was only used for the simulation when a particle reached the GS and Sac. River junction and under the unidirectional flow condition. The purpose of this implementation was to assess whether the implementation of the behavior relationship (behavior vs. environment) in PTM could substantially improve the model's prediction of fish behavior.

The values of the GLM hydrodynamic covariates (flow, depth, width, etc.) in the model were simulated by DSM2 Hydro. A DSM2 Hydro run from 2/1/2011 to 5/20/2011 was performed. DSM2 historical flow and stage boundary conditions for the period were used in the simulation. Figure 4-1 through Figure 4-3 show simulated versus observed flows entering the junction (Figure 4-1), downstream of the junction at Sac River (Figure 4-2), and GS (Figure 4-3), respectively. The simulated flows matched the field data well, except for the period with the maximum flows. During this period, the model underestimated the flows. However, the mismatch could have been caused by the uncertainty in the field data as there were many missing data points in the observed time series. Non-physical barrier operation was obtained for the model input. All simulations assumed daylight conditions because light intensity data are currently not available. The night condition will be simulated in the future when light intensity data become available.

Four PTM runs were performed for high/low flow and barrier on/off conditions. For each run, 1000 particles were inserted at 13,989 feet (DSM2 node 341) upstream of the junction node (DSM2 node 343) on 3/20/2011 and 4/16/2011, respectively. The 1,000 particles were released randomly across the cross-section within a day. The positions of the particles approaching the junction were simulated by the PTM. The simulated cross channel distributions of the particles at the junction are shown in Figure 4-4. From the simulation, the simulated distributions showed two peaks, one near the GS side and the other near the Sac. River side under both the high and low flow conditions. For the high flow condition, the simulation showed that particles were more evenly spread over the channel. These simulated particle distribution patterns were somewhat different from the field observed fish distribution patterns (Figure 4-5) in which fish were more concentrated near the center of the channel on the Sac. River side. The difference could have been caused by the original fish release locations. In the field study, the fish were released at the center of the channel while the particles in the simulation were released randomly across the channel, which is the way PTM is set up. The fish released at the center might not have enough time to spread out over the channel when they approached the junction.

Table 4-1 lists the simulated versus observed percentage of fish/particles entering GS. The simulation with the GLM implementation agreed reasonably well with the field observation, especially under the low flow conditions, which indicates that the PTM is able to predict certain fish behavior as long as an adequate fish behavior relationship is implemented. Under the high flow condition, the PTM with GLM appeared under-predict the probability of fish entering GS. This could have been caused by the initial fish release positions as explained above. Table 4-1 also shows the comparison between the PTM simulations with and without the GLM implemented. By implementing the GLM, the PTM improvement on predicting the behavior was substantial, especially under the low flow conditions.

4.4 Further Improvement

Many other fish behaviors could affect fish migration through the delta. For example, swimming behavior determines fish travel time, residence time, and the timing of reaching important locations such as a crucial junction. Survival behavior determines fish survival through the Delta. To make PTM more scalable/flexible so it can incorporate these important behaviors for different fish species, the PTM recently has been redesigned and is currently going through a major code rewriting. An open source project website is also under development to allow other public agencies and private consultant firms to contribute to the PTM behavior development.

Field fish monitoring and data collection are also crucial to improve the model's fish behavior prediction. More acoustic telemetry tag data will be needed to cover a wider spectrum of environmental conditions throughout the delta so that various behavior relationships can be established and the PTM can be calibrated and validated. Fortunately, more field fish monitoring studies have been planned for important delta junctions and channels. Furthermore, the data that have been collected are being analyzed to establish statistical behavior relationships. When these relationships become available, they will be implemented in PTM.

The PTM flow field simulation can also be improved. A computer interpolation program for a finer resolution flow field in the delta will be available later this year. The program will interpolate DSM2 Hydro outputs for a higher resolution grid using sophisticated interpolation schemes. The improvement to the quasi-three-dimensional velocity profiles is also taken under consideration.

4.5 Conclusion

The Delta is a complex system as river and tidal forces alternately dominate. Manmade structures and their operations add more complexities to the system. When fish migrate through this complex system, they interact with the system and display seemingly uncertain and unpredictable behaviors. Because of the limitations in our understandings of fish behaviors and their relationship to the system, oftentimes it is difficult to mechanistically simulate the behaviors. However, with the accumulation of field monitoring fish tag data, it is possible to statistically describe the relationships between fish behaviors and the system. PTM, as a surrogate tool to evaluate fish behaviors, can utilize those statistical relationships to improve its representation of fish behaviors in the model. The results from the current implementation of the GLM indicate that the model's prediction of certain fish behaviors can be improved substantially when the relationship between the behavior and environmental conditions is statistically described and implemented in the model. It is expected that when more behavior relationships are established for wider ranges of environmental conditions and are implemented in PTM, the model can predict behavior patterns more accurately and help to identify the factors that affect fish behaviors and survival in Delta.

4.6 Reference

Bowen, M., Hanson, D., & Perry, R. (2012). *2011 Georgiana Slough Non-Physical Barrier.* Draft, California Department of Water Resources, Sacramento.

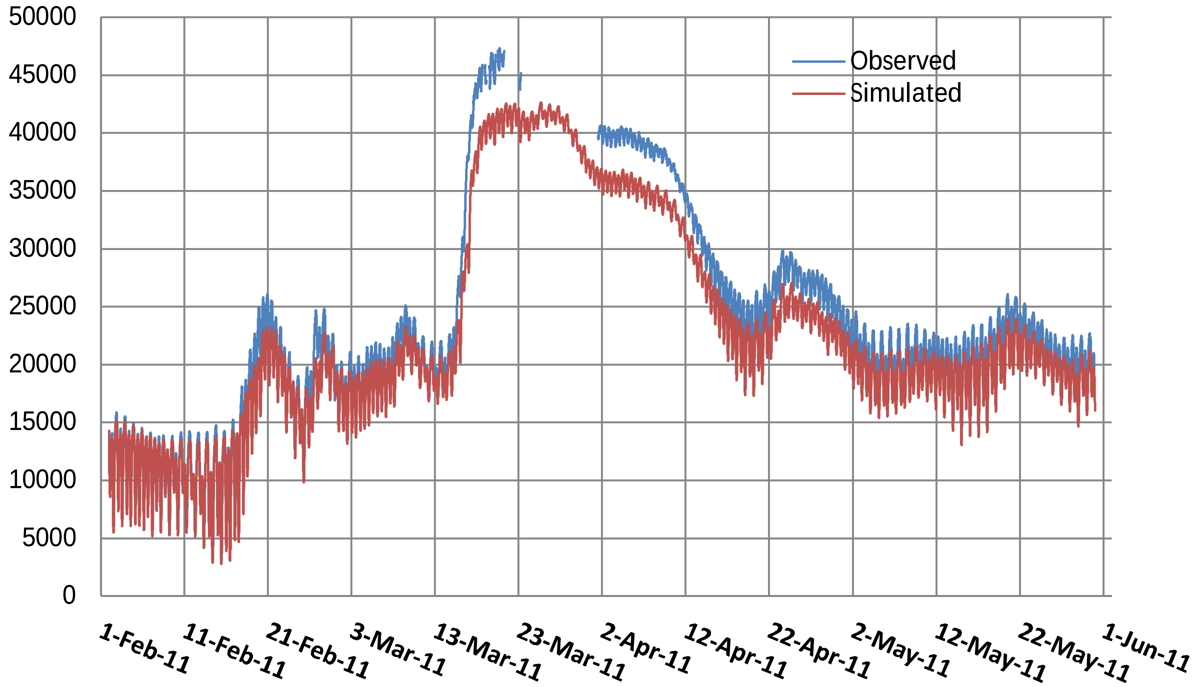

Figure 4-1 Simulated vs. Observed Flows (CFS) at GS and Sac. R. Junction

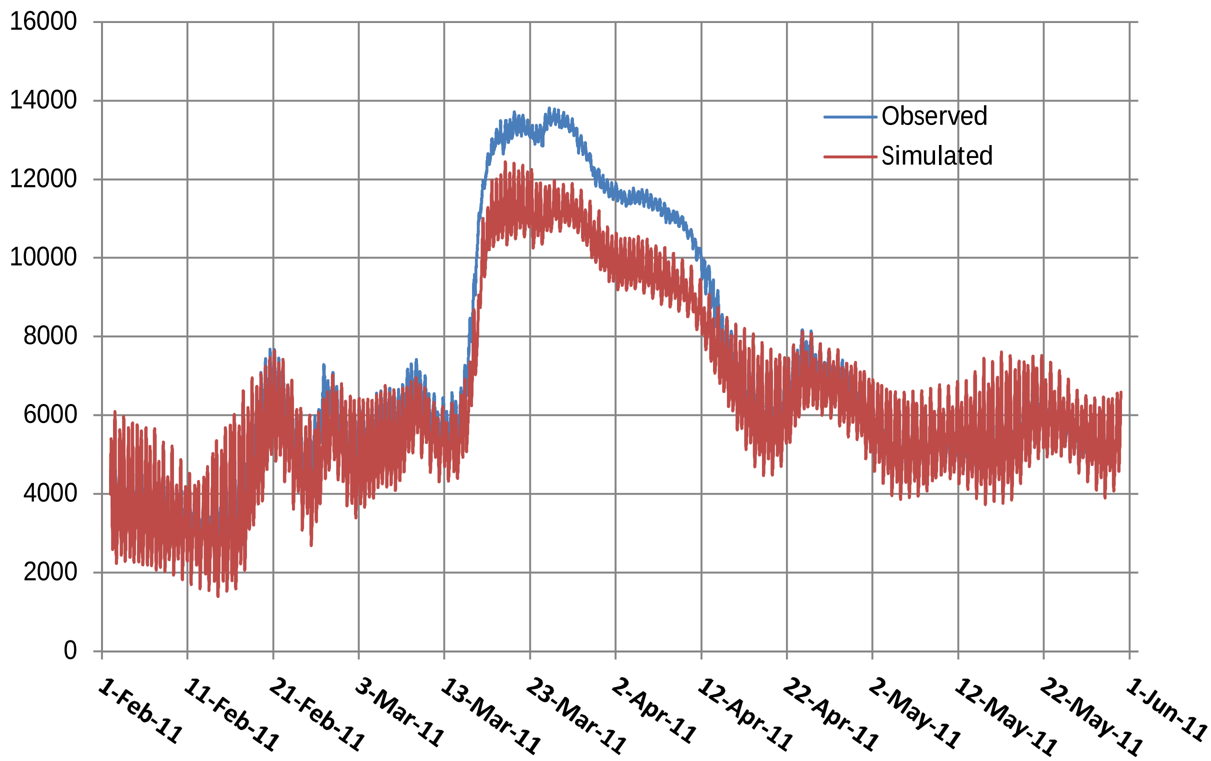

Figure 4-2 Simulated vs. Observed Flows (CFS) Entering Georgiana Slough

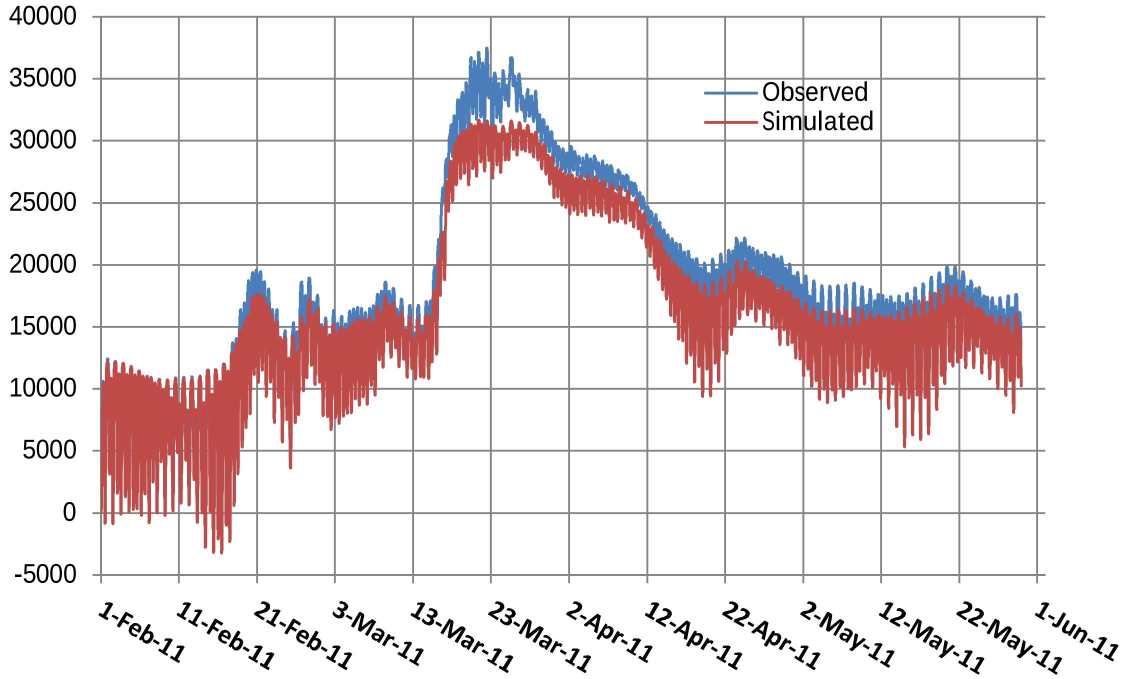

Figure 4-3 Simulated vs. Observed Flows (CFS) Entering Downstream Sac. R.

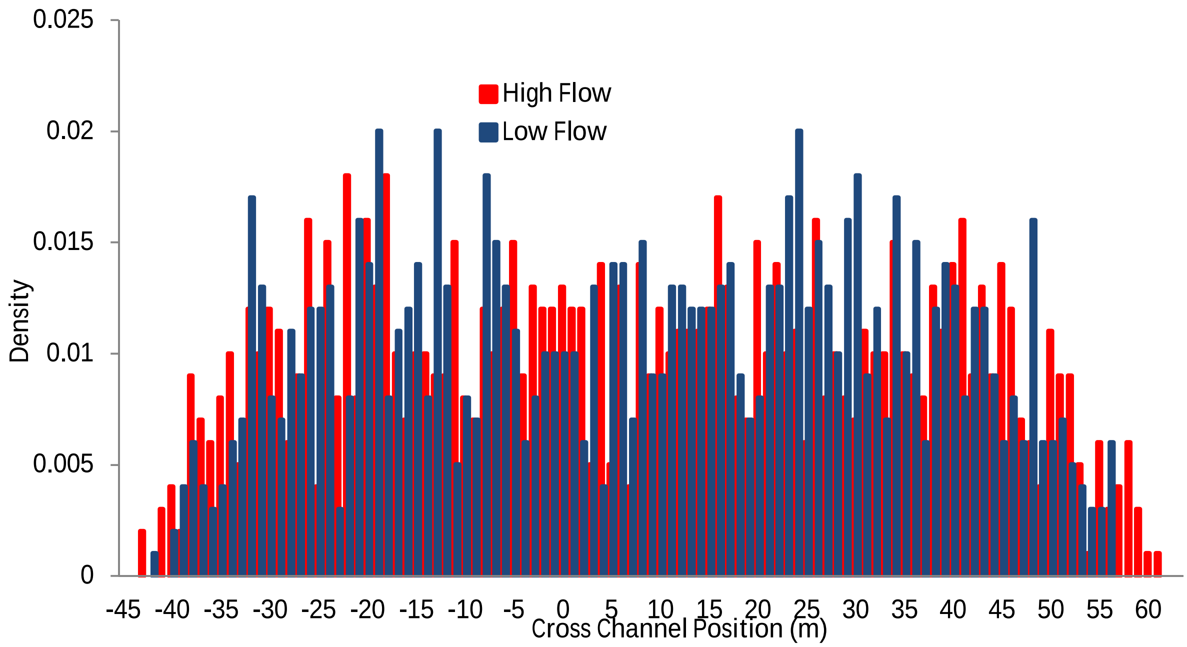

Figure 4-4 Simulated Particle Cross Sectional distribution at the Junction

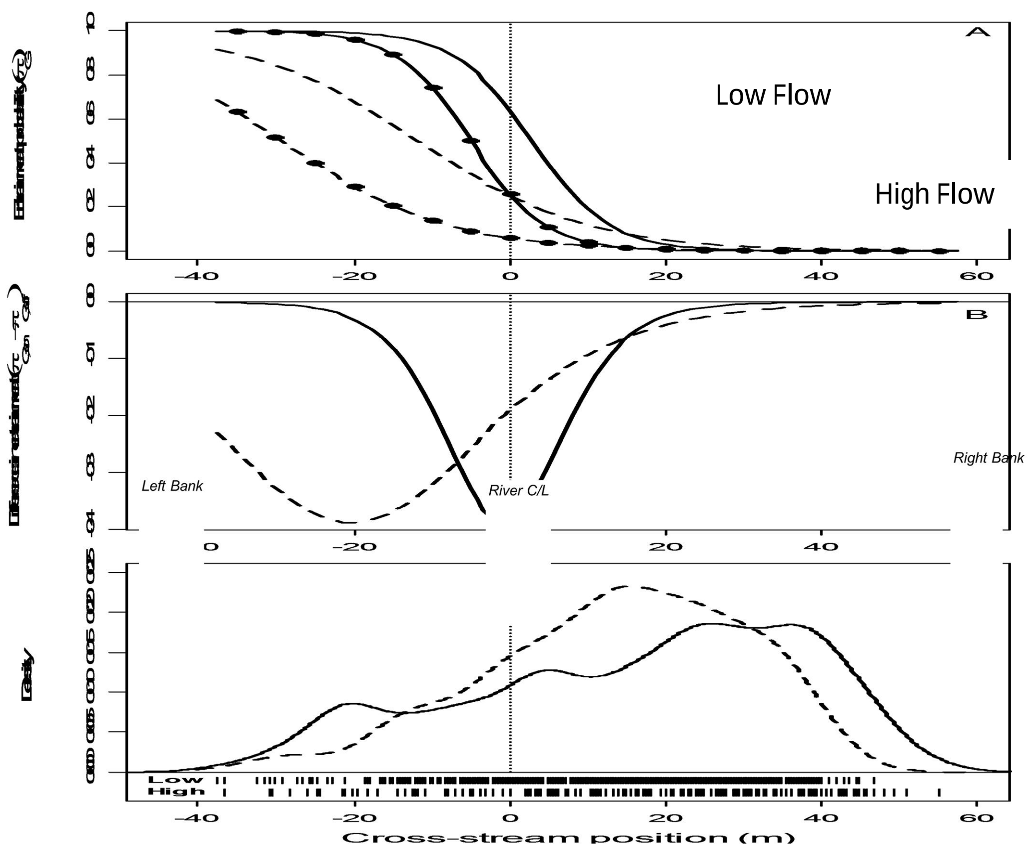

Figure 4-5 Observed Fish Cross Sectional Distribution at the Junction

Table 4-1 Particle Fraction Entering Georgiana Slough (%)[1]

Flow	Barrier	Observed	GLM	PTM W/ GLM	PTM W/O GLM
Low	On	1.7 (SE* 0.007)	4.7 (SE 0.015)	5.2 (SE 0.003)	30.0
	Off	19.3 (SE 0.023)	16.7 (SE 0.012)	15.9 (SE 0.007)	30.0
High	On	21.1 (SE0.048)	14.9 (SE 0.034)	14.6 (SE 0.009)	29.9
	Off	29.5 (SE 0.045)	32.2 (SE 0.039)	25.0 (SE 0.012)	29.9

* SE: standard error.

[1] In the field study, 1500 acoustically tagged late fall-run Chinook salmon were released into the Sacramento River at 29,199 feet upstream of the Georgiana Slough junction from March 15 to May 16, 2011. The fish were released to the center of the channel in a small group about every 3 hours (due to the weather and equipment conditions, the release interval was not strictly 3 hours).

Table 4-2 Flow Category

Inflow Category	Data Type	Barrier Operation	Flow (cfs x 1000)
Low	Observed	On	24.3 (SD* 3.1)
		Off	24.9 (SD 3.2)
	PTM W/GLM	On	24.0 (SD 1.5)
		Off	24.0 (SD 1.5)
High	Observed	On	44.6 (SD 1.2)
		Off	43.0 (SD 4.0)
	PTM W/GLM	On	41.0 (SD 1.0)
		Off	41.0 (SD 1.0)

* SD: standard deviation

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Chapter 5
Particle Filter for DSM2-PTM

Authors: **Yu Zhou and Kijin Nam,**
Delta Modeling Section,
Bay-Delta Office,
California Department of Water Resources

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5 Particle Filter for DSM2-PTM

5.1 Introduction

The intent of this study is to develop a PTM module feature which simulates directing/blocking particles without affecting flows.

One of the major applications of this particle filter is to simulate fish screens and non-physical barriers, which could prevent fish from entering an area. Another application is to provide an option to keep fish from entering agricultural diversions, seepage to groundwater, and water transfer facilities.

5.2 Filter Algorithm

In DSM2-PTM, model grids are configured as waterbodies connected at nodes. The designed filter is only for modifying particle movement at nodes, which represent the waterbody junctions in the real world.

Therefore, this filter must have two major functions:

- Redirect particles exiting nodes from the default flow-split ratio;
- Block particles entering nodes.

The designed filter is the combination of the two functions described above; it has both functions activated from its upstream and downstream sides. Therefore, as particles flow back and forth due to tides, they could meet different functions of the filter when passing through from different flow directions. Programming details are in Appendix B.

5.2.1 Filter after a Node

PTM uses flow ratios to direct particles into different branch waterbodies (channel, reservoir, transfer, and boundary) at nodes (junctions). This filter is programmed as a readjustment factor to modify this function, i.e. the new split ratio is based on $flow * filter\_operation$. Figure 5-1 shows an example of this algorithm.

In the case without the filter particles are split based on the branch flow ratios, e.g.

$$flow_1 : flow_2 = 50:50 = 1:1$$

This case results in half the particles in each branch (Figure 5-1, top graphic).

In the case with a filter, the new split ratio would be recalculated with the filter operation, a fraction between zero and one: zero means totally-block; one means 100% passing; values in between will readjust the split ratio, e.g.

$$\left(flow_1 * filter_{1_{op}}\right) : (flow_2) = (50 * 0.25) : (50) = 1:4$$

This case partially blocks particles entering the filtered branch, and directs 80% of the particles to the unfiltered branch (Figure 5-1, bottom graphic).

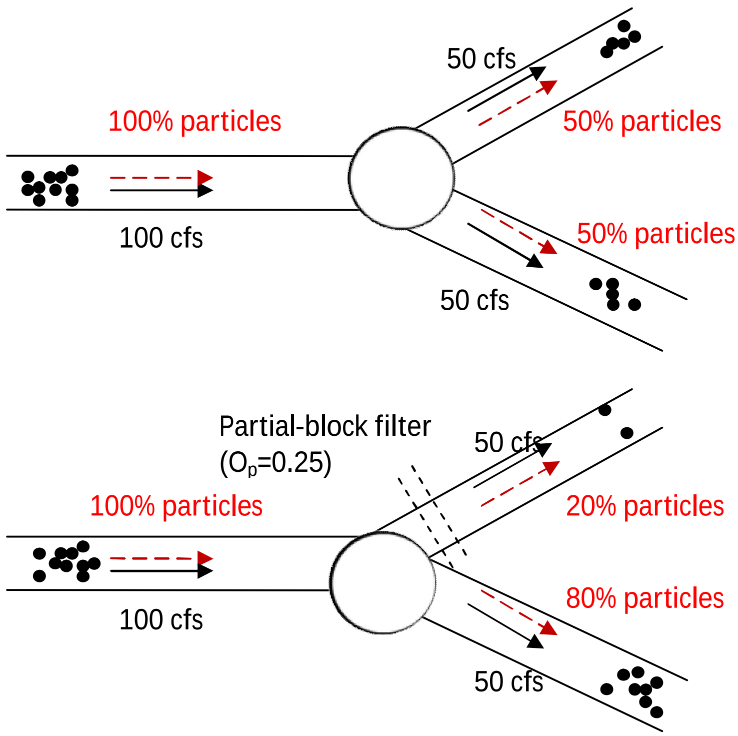

Figure 5-1 Flow and particle fluxes at two equal-branch junctions, with a partially-block filter set on one branch (Solid arrows depict flow; dashed arrows depict particle fluxes). The particle amount in the plot is for illustration only, and is not the actual amount.

When this algorithm is applied to channels without branches, the filter will block particles when its value is zero, and totally pass with all the other values (Figure 5-2).

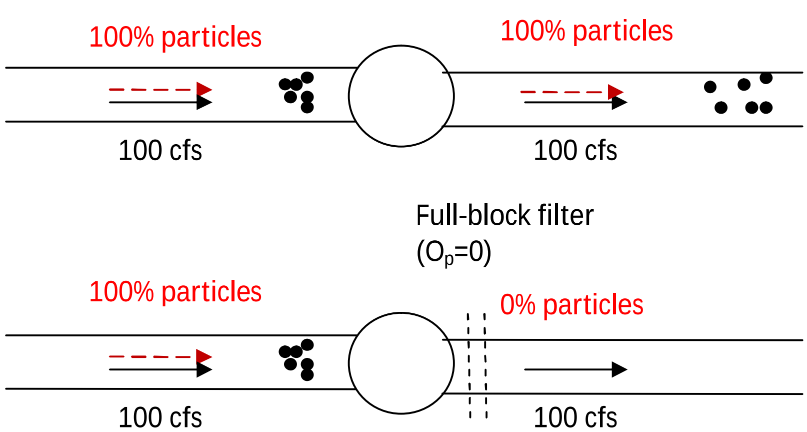

Figure 5-2 Flow and particle fluxes without and with a full-block filter set after the particle-entering node (Solid arrows depict flow; dashed arrows depict particle fluxes).

Reservoir, transfer, and boundary share the same algorithm for filter after a node. Since DSM2-PTM has two steps for particles transferring from reservoirs to channels (or transfers), this filter algorithm only functions at the 2nd step. Figure 5-3 shows an example of this case:

- Particles first determine which node they flow to, based on the ratio of flow*time step/reservoir

$$flow_1 * \text{time step / reservoir volume} \qquad \text{(Miller, 2002)}$$

- Particles then utilize adjusted flow ratios (same as described in the previous paragraphs) to split, if there are multiple channels (or transfers), i.e. filters after one node won't affect particles' ability to move to other nodes of the same reservoir.

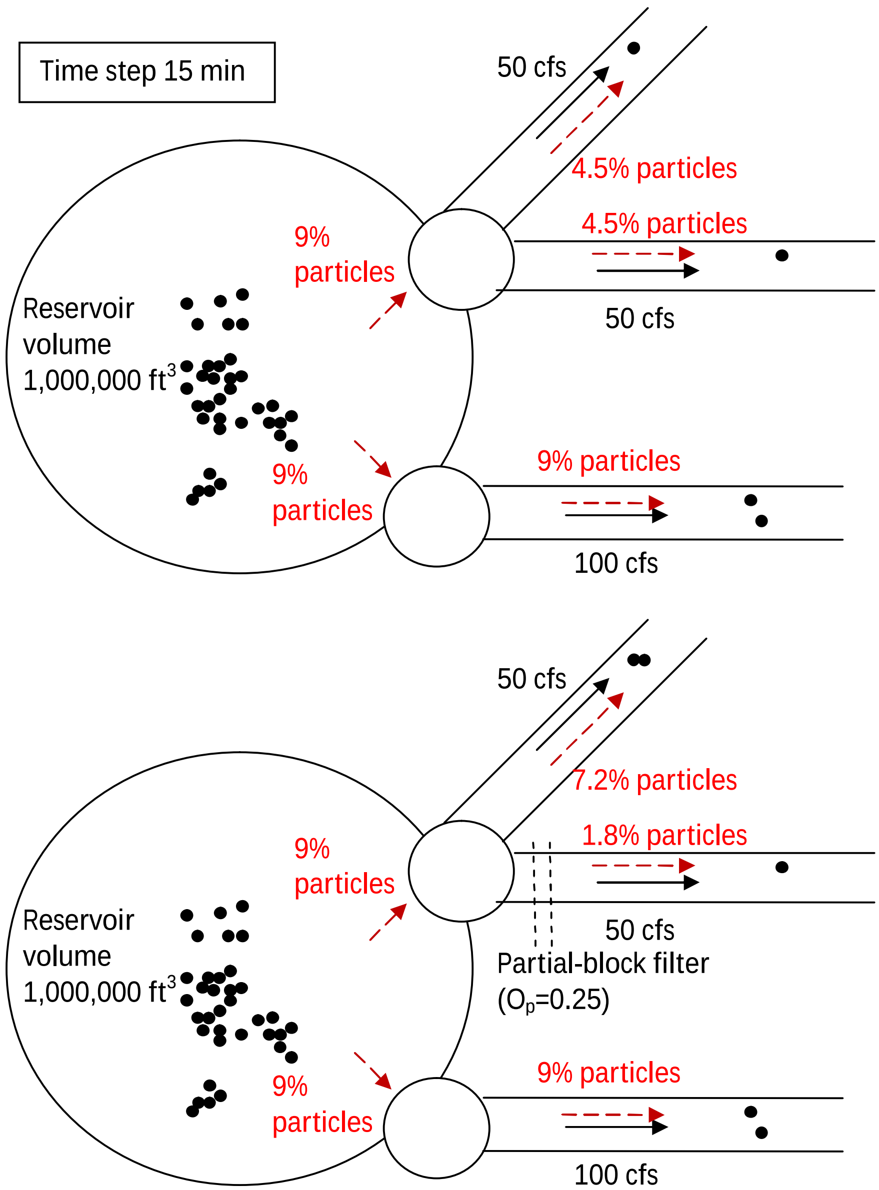

Figure 5-3 Flow and particle fluxes w/o and with a partial-block filter set after the particle-entering node in grid with reservoir (Solid arrows depict flow; dashed arrows depict particle fluxes).

5.2.2 Filter before a Node

A filter with operation 0 would also serve as a block for particles entering a node. A filter with all the other operations (>0 and <=1) would behave as no-filter condition, i.e. totally pass. Figure 5-4 shows an example of this algorithm at channels. Reservoir, transfer, and boundary have the same application with this function.

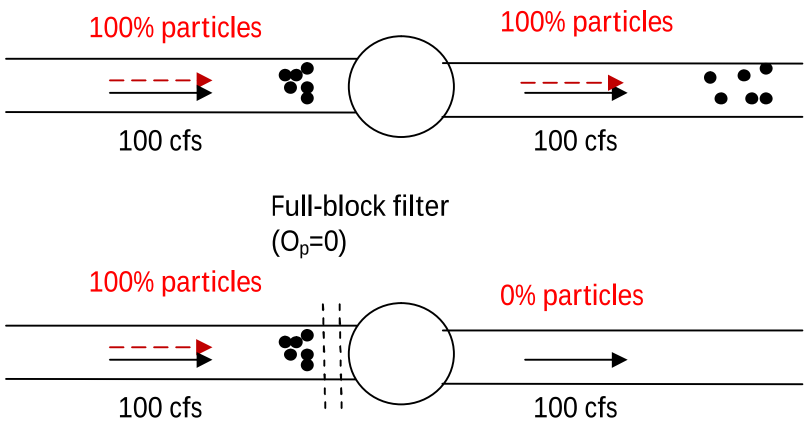

Figure 5-4 Flow and particle fluxes w/o and with a full-block filter set before the particle-entering node (Solid arrows depict flow; dashed arrows depict particle fluxes).

5.3 Filter Input Table

There are two filter input text tables used to control the filters described here.

- "PARTICLE_FILTER" is for normal filters located at DSM2 grid nodes.
- "PARTICLE_RES_FILTER" is for filters operating at special reservoirs (e.g., Clifton Court Forebay in the standard Delta grid) which directly connect to source flows. In this case, implicit nodes are generated during the DSM2-PTM grid initialization process, and are assigned to the filters.

As mentioned in the previous section, a filter is assigned to a DSM2 grid node (or reservoir as the special case), and one neighbor waterbody specified as the control side. The waterbody could be any type of waterbody in the PTM module: channel, reservoir, boundary (source flow, stage boundary), and transfer. These are defined under entries NODE and WATERBODY.

FILE and PATH are entries for filter operation:

- Constant filters are defined with FILE: constant; PATH: a real number between 0 and 1
- Time-varying filters are defined with FILE: location on computer + DSS filename, which allows relative location; PATH: DSS pathname
- Filter value should be a real number between 0 and 1

Following are two samples of these two input tables. Details and explanations are in Appendix A.

```
PARTICLE_FILTER
NAME    NODE WATERBODY  FILLIN FILE           PATH
280_357  280   chan:357      last    ./Filter_OP_NF.dss /HIST/280_357/FILTER_OP//IR-DECADE/DWR/
END

PARTICLE_RES_FILTER
NAME     RES_NAME   WATERBODY  FILLIN FILE       PATH
div_bbid  clifton_court qext:div_bbid last ./filterOp.dss /HIST/CLFC_DIV/FILTER_OP//IR-DECADE/DWR/
END
```

Table 5-1 Table Identifiers and their respective descriptions in filter input text blocks

Identifier	Field Descriptions
NAME	Name assigned to the particle filter
NODE	The ID of the node to which the filter is assigned
WATERBODY	The type and ID of the waterbody to which the filter is attached, separated by a colon (:)
FILLIN	Method for filling in data if the time step of the assigned series is greater than the time step of the model. See FILLIN types (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/definitions/fillin.html).
FILE	DSS or text file in which data are stored. Enter the word constant to assign a constant value to the input (the value will be entered in the next column).
PATH	The path within the text or DSS file of the time series data. If the constant keyword was used in the Input File column, enter the value here. The stored variable is the particle passing efficiency, a floating-point number value between 0 and 1; 0:block; 1:pass.
RES_NAME	The name of the reservoir to which the filter is applied

5.4 Summary

The PTM filter is designed to change the particle flux without affecting flows. This filter feature is configured in the DSM2 text input system:

- Its location can be specified with a combination of nodes and waterbodies in the DSM2 grid.
- Filter operation can be constant or time-varying (DSS format), and can have a partial passing efficiency for junction split decision.

Validation tests were conducted to ensure the programming meets the design purpose. Please see test details in Appendix C and other PTM test chapters in this report (Zhou, 2013) (Zhou & Nam, 2013).

5.5 Acknowledgements

We thank Nicky Sandhu, Tara Smith, Min Yu, and Xiaochun Wang for their help in the study initial discussion and report revision.

5.6 References

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Zhou, Y., & Nam, K. (2013). Chapter 6, DSM2-PTM Improvements. *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 34th Annual Progress Report* .

5.7 Appendices

Note: All appendices are stored in DWR Bay-Delta Office DSM2 User Group website.

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_filter/

Appendix A: Input Table Design for DSM2-PTM Particle Filter

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_filter/AppA_input_table.docx

Appendix B: Programming Details for DSM2-PTM Particle Filter

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_filter /AppB_coding.docx

Appendix C: Validation Test for DSM2-PTM Filter Design

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM_filter /AppC_test.docx

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

34th Annual Progress Report
June 2013

Chapter 6
DSM2-PTM Improvements

Authors: **Yu Zhou and Kijin Nam,**
Delta Modeling Section,
Bay-Delta Office,
California Department of Water Resources

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6 DSM2-PTM Improvements

6.1 Introduction

This chapter describes bug fixes and related tests of DSM2-PTM, with a focus on convergence tests for different PTM time steps. Bugs discovered are:

1. Missing advection: in the loop through the sub-time steps within one PTM time step, the last sub-time cycle is usually missed. This can delay particle motion and the accumulated error can be significant.
2. First time-step error: PTM reads hydrodynamics information from the tide file and the first time-step has an initial calculation error. This leads to erroneous results when particles are released at the beginning of PTM simulation start time.
3. Time interpolation factor (θ) inconsistence: two different weighting average factors between the current and the previous time step are inconsistent for flow, depth, cross-section area, and stage.
4. Missing dispersion: when a particle arrives at the end of a channel, the random motion in the Y and Z axes is missed for the last sub-time step. This leads to erroneous results, especially in a grid system with many connected channels such as the Delta.
5. Error warning for transfer: an error exists in the function that checks flow balance for nodes connecting transfers and reservoirs. This doesn't affect the calculated value but will slow down the module running when the grid has this kind of waterbody combination.

6.2 Background

DSM2-PTM is a quasi-three-dimensional particle tracking model which is used extensively in Sacramento-San Joaquin Delta studies. This model has been verified, calibrated, and documented in several reports (Smith, 1998), (Miller, 2000), (Wilbur, 2000), (Miller, 2002). Recently, the authors conducted several tests of DSM2-PTM, as part of the DSM2 Version 8.1 package.

Various test grids were applied, e.g., chained channels, bifurcated channels, reservoir, transfer, etc., as well as the Sacramento-San Joaquin Delta historical grid. Various hydrodynamic environments were also applied, e.g., steady uniform flow and tidal time-varying flow.

This chapter lists bugs found and corresponding corrections. The attachments include the primary configuration of the tests and important result comparison in plots. Please contact the authors for detailed information about the tests and the results.

6.3 Bugs and Corresponding Fixes

6.3.1 Missing advection

In DSM2-PTM, the user-defined time step is divided into sub-time steps for particle movement calculation. The sub-time step is calculated by dividing the time step by the number of sub-time steps, and then subtracted from the original time step for each sub-time step cycle. Because of the limited numerical precision of the variables, the summation of sub-time step does not add up to the PTM time step exactly. This bug usually results in the last sub time-step being smaller than the normal one. The current design does not perform this last sub time-step, since the loop exits when the time left is less than the sub-time step size.

PSEUDO-CODE OF PREVIOUS SUB-TIME STEP CALCULATION

```
If (time left >= sub-time step)
   Move particles within one sub-time step
   Subtract sub-time step from time left
Else
   Exit loop
```

It is hard to estimate the typical amount of accumulated effect of the error, since the size of the unspent time depends on the sub-time step, which in turn depends on the channel geometry and dispersion coefficient, i.e. either a different input time step or different channel geometry could result in different amount of the error.

It is supposed that this error would result in delay for particle movements. In a uniform flow environment, the amount of this error could build up quickly. As Attachment B-1 shows, the delay in cases with certain time steps could be large compared to others. In a time-varying tidal environment, this delay could be hard to identify, due to the frequently alternating flow direction.

To correct this bug, we introduce a new variable (`tmToAdv`) and add an `IF` conditional control statement. This will ensure all the time is spent.

PSEUDO-CODE OF CORRECTED SUB-TIME STEP CALCULATION

```
If (time left > 0)
      If (time left ≤ sub-time step)
            Replace sub-time step with time left
      Move particles within 1 sub-time step
      Subtract sub-time step from time left
Else
      Exit loop
```

6.3.2 First time step error

Another bug is in the PTM hydrodynamic I/O routine. DSM2-PTM reads the DSM2-HYDRO tide file for flow information (flow rate, cross-section area, etc.), then calculates weighted flow averages over the current and previous time steps. However, this routine assumes the previous time step is already read and stored in memory, which is not the case for the first time step. Uninitialized values are set to zero, thus the weighted averaged values for the first time step are not correct (half values of the current time step in the previous code), much less than what they are supposed to be.

This error only affects the first time step of a simulation, causing particle velocities to be larger than expected (same flow, smaller cross-section area), i.e. earlier arrival. Fortunately, this influence can't be large since it's only one time step. Besides, this error could be avoided by releasing particles with a delay. Therefore, this first time step error would not be serious for most cases.

To correct this error, we introduce an `IF` conditional control statement. This will adjust the flow variable values back to its correct value.

PSEUDO-CODE OF CORRECTED FIRST TIME STEP ERROR

If (current time == start time)

```
      depth = depth / θ
      stage = stage / θ
      area = area / θ
```

6.3.3 Time interpolation factor (θ) inconsistence

PTM uses a weight parameter *theta* (θ) between the current and previous time steps when calculating averages for several variables (flow, depth, cross-section area, and stage). For example, for down_node cross-section area in channels, the following function is applied:

PSEUDO-CODE OF TIME INTERPOLATION EQUATION FOR VARIABLES

area = area_current * θ + area_previous * (1- θ)

θ was defined twice in the program: flow is calculated in DSM2-HYDRO module (`netcntrl_common.f`); stage, depth, cross-section area are using what is defined in DSM2-PTM module (`ptm_local_data.f`). The two modules used different θ values. The effect of this inconsistence depends on hydrodynamic conditions. To correct the error, several changes were made in the PTM Fortran code.

6.3.4 Missing dispersion

When a particle arrives at the end of a channel, the random motion in the Y and Z axes are missed for the corresponding sub time-step.

Less dispersion could make the velocity profile more centralized to their average velocity, which results in particles more centralized to their average arrival time (“steeper” arrival curve), and this dispersion error would accumulate in a grid with more junction nodes. However, the effect of this error is minimal since the amount of dispersion is usually small in PTM (the Delta is an advection-dominant system).

To correct this error, two Y and Z calculation lines of code were added to the calculation method.

6.3.5 Error Warning for Node Flow Balance Check at Transfer

PTM checks input flow for all waterbodies connected to each node, in each time step. It requires the sum of each node’s flows to be close to zero, within a tolerance 2 cfs.

However, for a transfer flow connected to reservoirs, the signing definition for water body “reservoir” omits in the case of flow transfers into reservoir. A warning (Figure 6-1) will be displayed every time-step. This will slow down the simulation when such a condition exists.

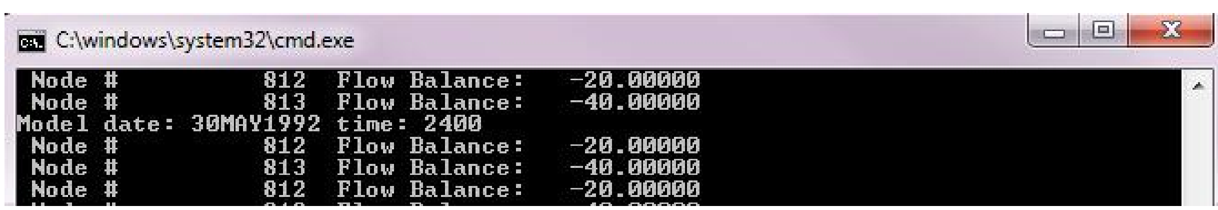


Figure 6-1 Warning message from balance check at transfer bug

To correct this error, a condition control has been added to eliminate the false warning message.

6.4 Debug Tests and Analysis

The designed standard PTM test suite (Zhou, Chapter 5, DSM2-PTM Standard Test Suite Design and Automation, 2013) is used to perform tests for new PTM (as well as DSM2 HYDRO versions) (Table 6-1), with application of all the basic test grids, Delta test grids, and Convergence test grids. Only those with obvious effect are included in the report appendices, to show the improvement. Contact the authors for further information.

- Version v806 is the original scenario. It has both HYDRO and PTM from the standard package of DSM2 v8.0.6. It includes all the bugs described previously.

- Version h811 is the scenario with newly developed "Hydro 8.1.1." It provides the hydrodynamic environment for this PTM debug study, i.e. all the other debug tests utilize the same "hydro.exe," which makes it the baseline scenario for all the investigations (when the updates on grids, boundary, etc. of DSM2 version 8.1.1 are completed, the corresponding tests will also be included). Its changes from v806 could be up to 4% at Delta historical boundary outputs.
- Version pf is the scenario with newly developed "PTM particle filter" feature. It doesn't introduce any change for the normal running results (details in the report of Particle filter development). Thus it's been incorporated in all the versions after v806.
- Versions b1 through b4 are combinations of Hydro v8.1.1 (h811) with individual PTM bug fixes for the errors described above.

Table 6-1 Test version names and their explanation for convergence test

Test Version Name	HYDRO	PTM	Expected Results After Debug
v806	v806	v806	Original
h811	v811, with v806 grids and boundary inputs	v806	Baseline
pf		v806 + filter feature	No change
b1		v806 + bug1 fix	Earlier arrival
b2		v806 + bug2 fix	Slightly delay at beginning
b3		v806 + bug3 fix	Depend on HYDRO
b4		v806 + bug4 fix	Slightly delay
v811		v806 + all bugs fixes	Mixed effect

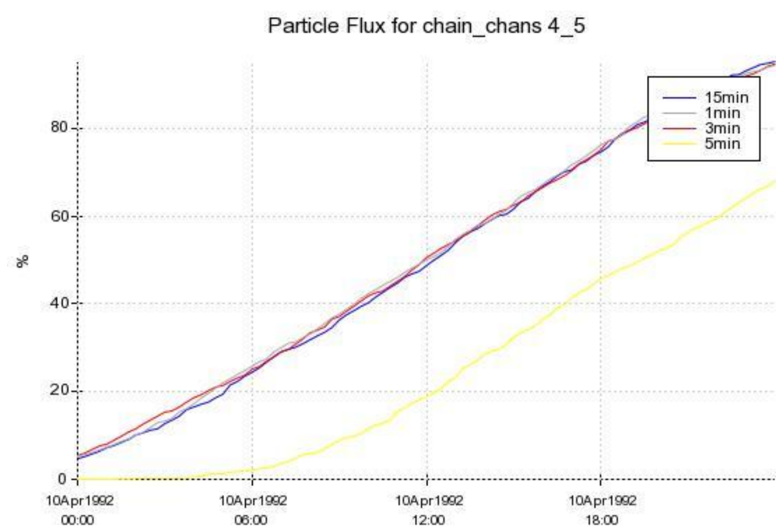
* Tests are not conducted for Bug 5, since it doesn't affect the simulation results.

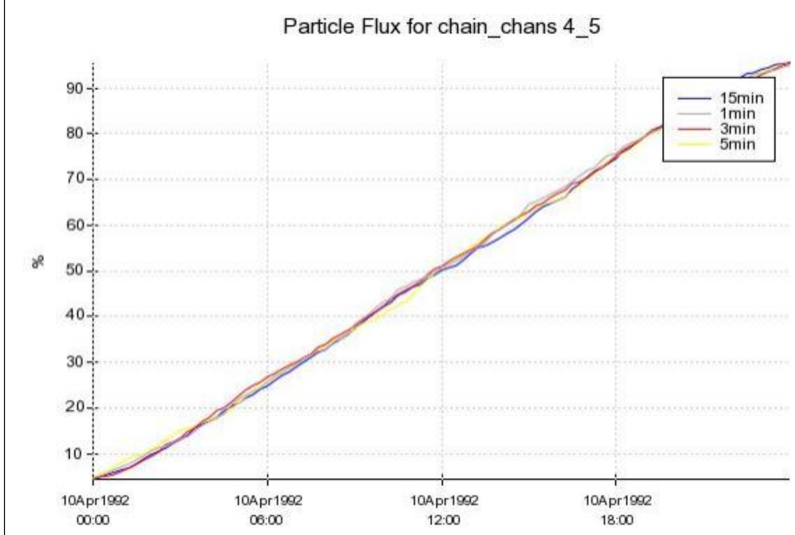
Each debug's test has its fixed version on top of baseline version separately, in order to view its effect clearly. Since Bug 2 and 3 are related, additional tests are conducted for their combined effect.

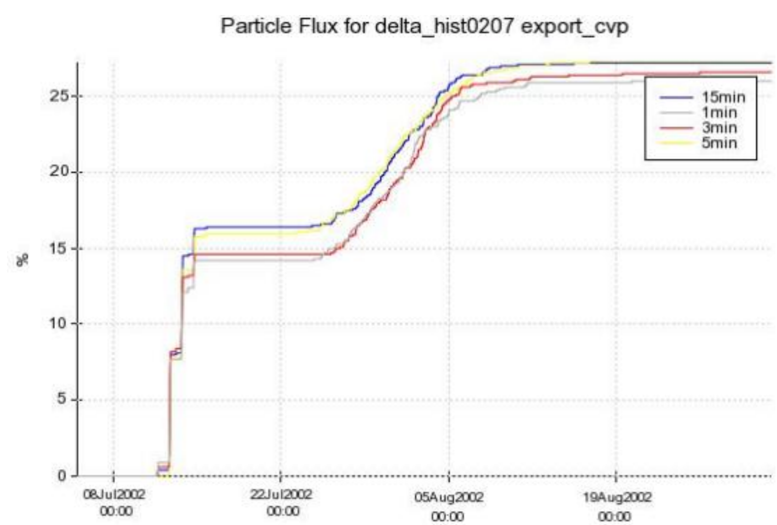
- The fix of bug 1 improves the convergence among different time steps, with the biggest improvement on time step 5 min (For details in convergence test of chain channels, see attachment B_1). Other bug fixes do not show such obvious improvement.
- Tests in Delta historical grid show that the impact of debugging on simulation result is not significant, and consistent in the complex Delta grid system, especially with tidal effect. But differences could be up to 2-3% at boundary output locations.

Figure 6-2 illustrates the test result samples of the bug 1 fix, showing its difference from the version 806. Details are included in Appendices A, B1-3, C-3.

	Version 806	After bug 1 fix
Test on chain channels (Appendix B-1)	see chart 1 below	see chart 2 below
Test on Delta historical (Appendix B-2)	see chart 3 below	see chart 4 below







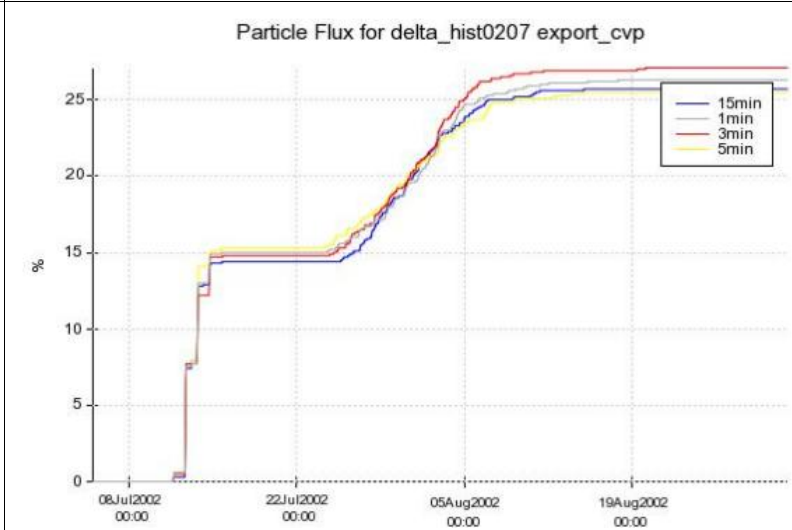


Figure 6-2 Extractions of convergence test result for bug 1 (missing advection) fix

6.5 Conclusions

This chapter lists the major debugging work for DSM2-PTM and corresponding tests and analyses. Improvement of the PTM is validated, with the fixes of missing advection and dispersion calculation, inconsistence of time interpolation, and lack of convergence among different PTM input time steps.

6.6 Acknowledgements

Xiaochun Wang and Tara Smith helped with the test scenarios and reviewing reports.

6.7 References

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HEC-DSSVue. (n.d.). Retrieved May 2013, from US Army Corps of Engineers, Hydrologic Engineering Center: http://www.hec.usace.army.mil/software/hec-dssvue/

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Zhou, Y., & Nam, K. (2013, June). Chapter 7, DSM2-PTM Improvements. (R. Finch, Ed.) *Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh, 34th Annual Progress Report*.

6.8 Appendices

Note: All appendices are stored in DWR Bay-Delta Office DSM2 User Group website:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/

Use the following links to access each individual appendix:

Appendix A: Test Grids for DSM2-PTM v806 Debugging:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/A_testgrid.docx

Appendix B-1: Convergence Tests on Chain channels, steady flow:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/B1_convg_chain.docx

Appendix B-2: Convergence Tests on Delta Dry Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/B2_convg_delta0207.docx

Appendix B-3: Convergence Tests on Delta Wet Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/B3_converg_delta9601.docx

Appendix C-1: Comparison Tests on Chain channels, steady uniform flow:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/C1_cmp_chain.docx

Appendix C-2: Comparison Tests on Delta Dry Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/C2_cmp_delta0207.docx

Appendix C-3: Comparison Tests on Delta Wet Season:

http://baydeltaoffice.water.ca.gov/downloads/DSM2_Users_Group/PTM806_Debug/C3_cmp_delta9601.docx

Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh

34TH ANNUAL PROGRESS REPORT
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Chapter 7
DSM2-PTM Standard Test Suite Design and Automation

AUTHORS: **YU ZHOU,**
DELTA MODELING SECTION,
BAY-DELTA OFFICE,
CALIFORNIA DEPARTMENT OF WATER RESOURCES

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7 DSM2-PTM Standard Test Suite Design and Automation

7.1 Introduction

The DSM2-PTM Module is undergoing development for new features and bug fixes (Zhou & Nam, 2013). It is essential to have module testing standardized and automated for the changes to the code and input data.

This chapter describes the PTM standard test suite design, including several DSM2 test grids, their respective key configuration variables, and design purpose. Scenario runs and plot generation can be batch processed for every version of DSM2-PTM. This batch automation is implemented by Python scripts.

7.2 Standard Test Design Methodology

7.2.1 Scripts Automation

The proposed PTM standard test suite is designed to be placed under the DSM2 folder, e.g., `D:\delta\dsm2_v8\`. It includes python scripts (*.py), DSM2 grid scenarios ("Simple_grid," "Delta_grid," and "Convg_test" folders), output ("plot" and "plot_compare" folders), shown in Table 7-1.

Python scripts are used for automation control (green-boxed files in Figure 7-1), with the help of Vtools.[1] The functions include:

- Running HYDRO and PTM in each scenario
- Making DSS files of result timeseries, which need to be compared (between different output locations, or between different versions)
- Generating plots for particle flux

Table 7-1 Python batch process scripts and their functions

Scripts	Functions
runPTMsuite.py	Control all of the test scenarios running for each DSM2-PTM (or HYDRO) executable version
comparePTMsuite.py	Make output comparisons among multiple DSM2-PTM (or HYDRO) executable versions
batchSimple.py batchDelta.py batchConvg.py	Provide special functions for Simple Grids Test, Delta Historical Test, Convergence Test
batchGeneric.py functions.py envvar.py	Provide generic functions and variables
out_bpart.py (usually under each scenario folder)	Provide plots with the respective output locations and time windows for its resident scenario

[1] Vtools is a Python library authored by the Bay-Delta Office that offers access to data stored in HECDSS format and that simplifies analysis of time series data using the Python numerical package NumPy (NumPy). It is similar in function to Vscript (Sandhu, 1999) and HECDSS-Vue (HEC-DSSVue).

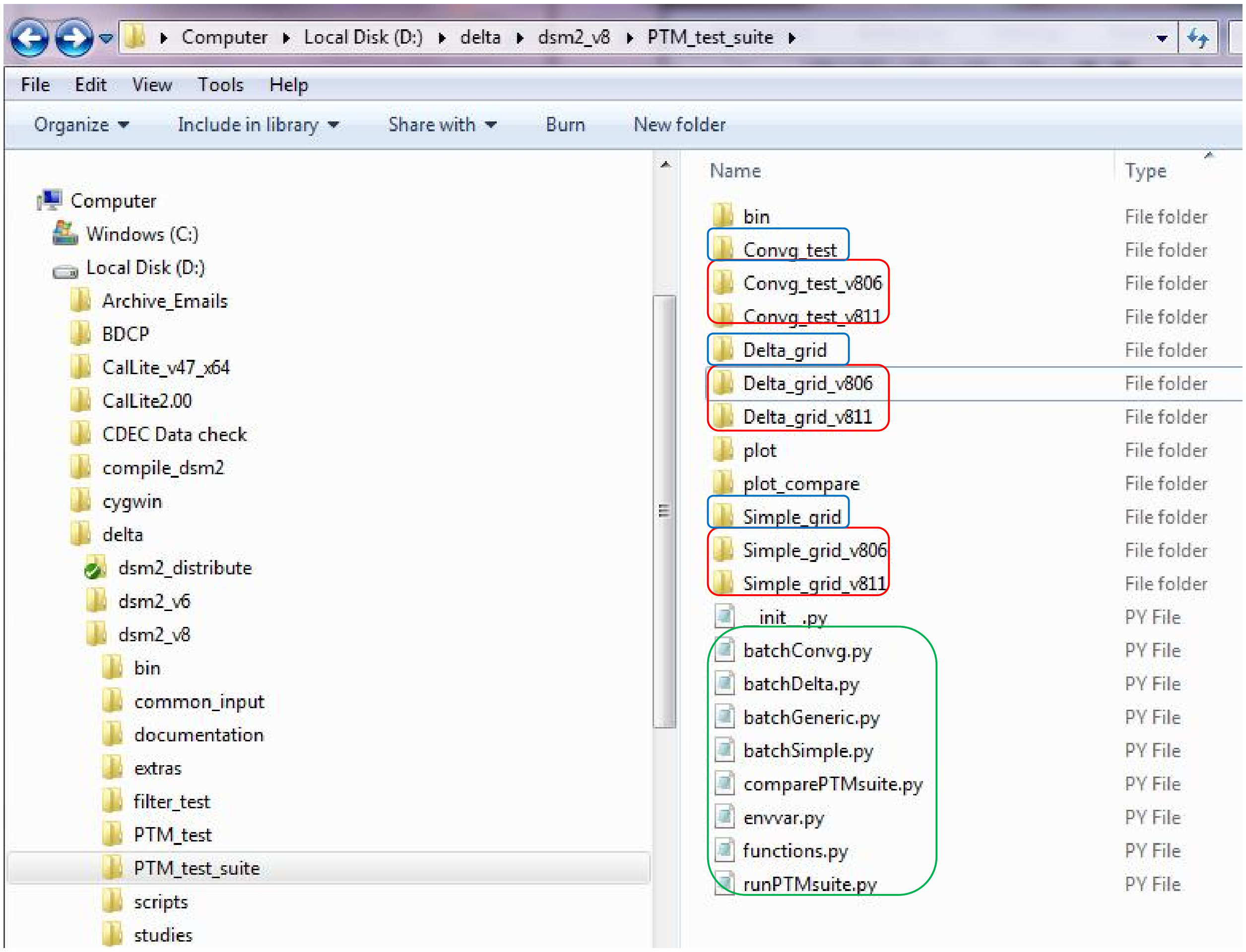

Figure 7-1 Example file organization of PTM standard test suite

7.2.2 Files Organization

Three major categories of test grids are created in this study:

- Simple Grid Test: test particle movement in several simplified grids, which represent different waterbodies or hydro conditions
- Delta Historical Test: test particle movement in the Sacramento-San Joaquin Delta, under historical configuration of various hydrological conditions
- Convergence Test: vary PTM calculation time step to examine the result convergence

Standard scenarios are provided for the above 3 categories (blue-boxed folders in Figure 7-1). They serve as the running base for every new test version change; every test version uses a special version name as its index. This version name (e.g., v806, v811) is determined by the user, when the DSM2 binary, Delta grid, or timeseries is changed. It is input in runPTMsuite.py, and then used to generate the duplicate result output folders (red-boxed folders in Figure 7-1).

Under either of above 3 categories, each scenario folder represents one unique HYDRO condition (different grid or time period) (red-boxed folders in Figure 7-2). Each HYDRO scenario can have multiple PTM particle insertions scenarios. Test results are included in the respective folder “output;” plots are included in the respective "output_plot" folder. The results are then copied to folder "plot" in the upper directory for users' convenience.

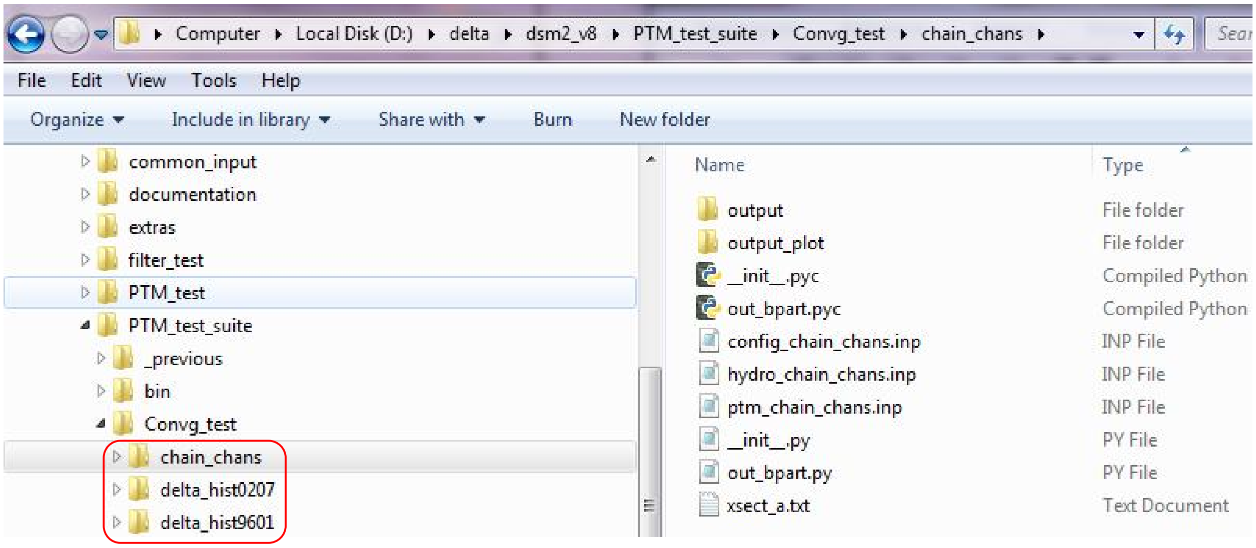

Figure 7-2 DSM2 configuration files sample in one simulation scenario

To compare results from different test versions, users can run comparePTMsuite.py, specifying the version names in the script. The "plot_compare" folder is used to store DSS and plots of comparison results.

7.3 Test Grid Designs

7.3.1 Simple Grids Test

This set of simple grids tests particle movement in several simplified grids (comprised of limited or single type waterbodies), which represent different waterbodies or hydro conditions.

Usually all channel lengths are 15,000 ft. All the channels share the same trapezoidal cross-section (Table 7-2). 200cfs flow release at upstream; 0 ft. stage at downstream. Output locations are depicted by the diamond symbols in Figure 7-3. All grids follow a similar design. Details are in the configuration files.

Table 7-2 Channel cross section for test grid

Distance ft.	Elevation ft.	Area ft.^2	Width ft.	Wet Perimeter ft.
0.5	20	2640	160	160
	0	960	80	80
	-24	0	40	40

CHAIN CHANNELS, STEADY FLOW

Purpose: Test particle movement in channels, with uniform and steady hydraulic conditions.

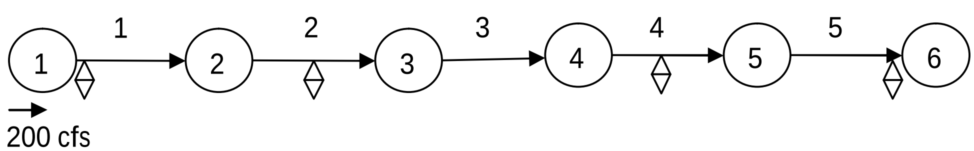

Figure 7-3 DSM2 grid for chain channels, steady flow

CHAIN CHANNELS, TIDAL STAGE AT THEIR DOWNSTREAM END

Purpose: Test particle movement in channels, with uniform spatial environment but time-varying hydraulic conditions.

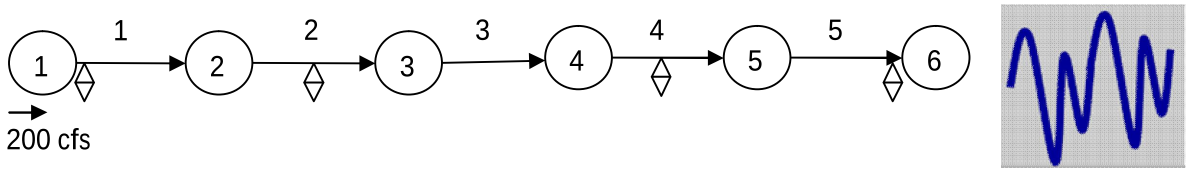

Figure 7-4 DSM2 grid for chain channels, tidal stage at their downstream end

TWO BRANCHED CHANNELS, STEADY FLOW

Purpose: Test particle splitting at junction, with uniform and steady conditions.

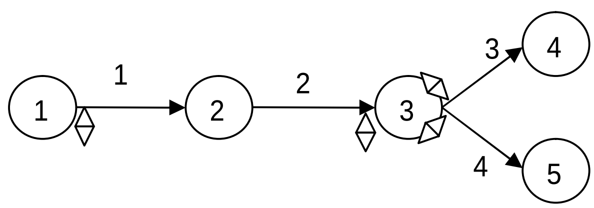

Figure 7-5 DSM2 grid for two branched channels, steady flow

TWO BRANCHED CHANNELS, TIDAL STAGES AT THEIR DOWNSTREAM ENDS (TWO TIDES ARE THE SAME)

Purpose: Test particle splitting at junction, with uniform spatial environment but time-varying conditions.

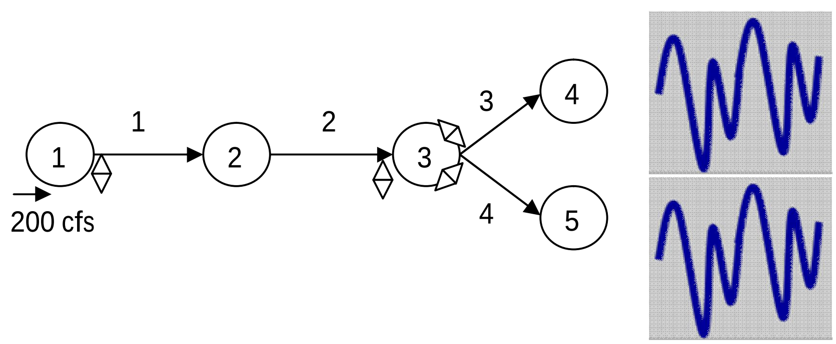

Figure 7-6 DSM2 grid for two branched channels, tidal stages (same frequency) at their downstream ends

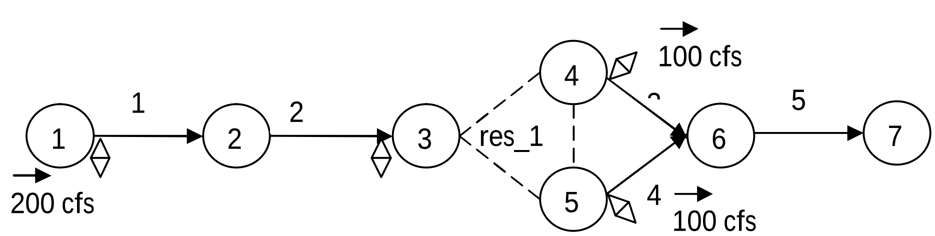

Figure 7-7 DSM2 grid for chain channels with reservoir, steady flow

CHAIN CHANNELS WITH DIVERSIONS, STEADY FLOW

Purpose: Test particle's movement at diversions (diversion at channel node, diversion at reservoir node, diversion directly at reservoir), with uniform and steady conditions.

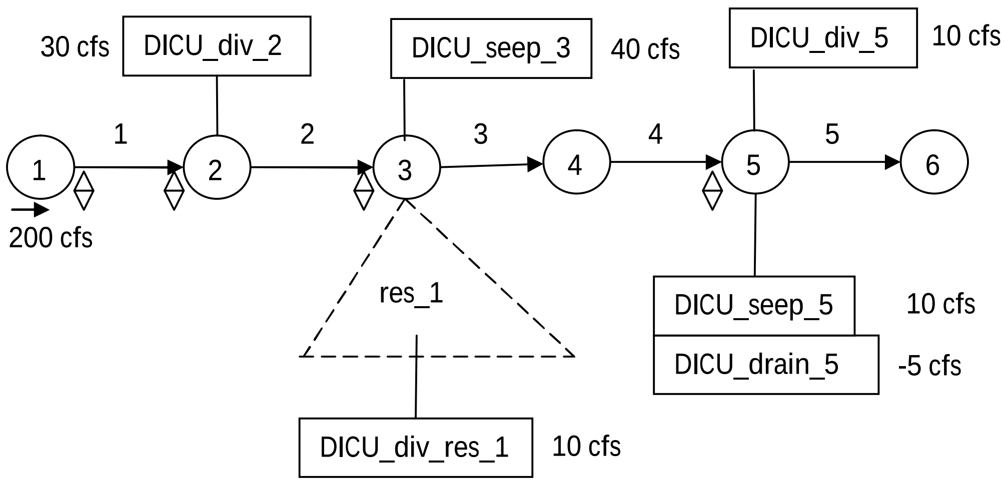

Figure 7-8 DSM2 grid for chain channels with diversions, steady flow

Purpose: Test particle movement at transfer (node->node, reservoir->reservoir, node->reservoir, reservoir->node), with uniform and steady conditions.

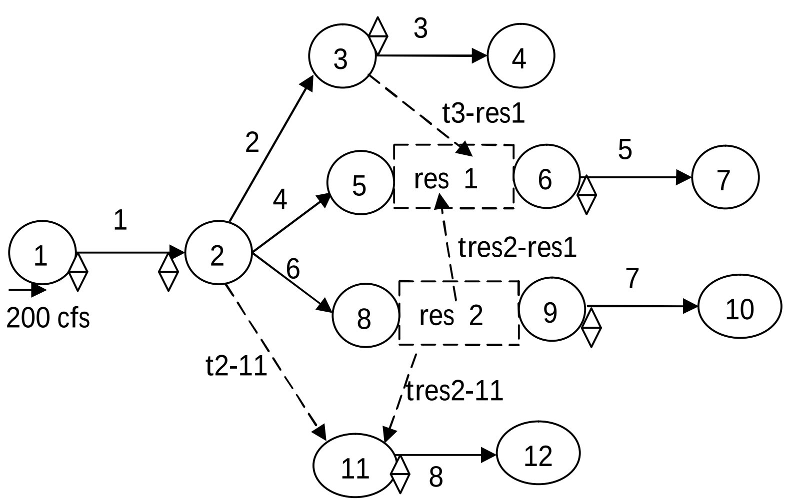

Figure 7-9 DSM2 grid for multiple branched channels with different types of transfers

7.3.2 Delta Grid Test

This tests particle movement in the Sacramento-San Joaquin Delta under historical hydrological conditions.

The Delta is a complex river and bay system under tidal influence and the most important implementation of the DSM2 module. Since its grid system is usually unchanged, emphasis has been put on different hydrological conditions (with specified running periods) and particle release locations.

In order to represent the diversity of hydrological conditions, different Water Years (WY) are selected for the tests, e.g., WY 1996 for Wet Year, and WY 2002 for Dry Year. Then seasons are selected, e.g., Jan-

Feb for flooding season, Jul-Aug for dry season, and Apr-May for fish migration season (usually with complex facility operations) as shown in Table 7-3.

Table 7-3 Simulation periods for the Delta grid test in PTM unit test suite

Year	Water Year Type	Month	DCC	HORB[1]
1996	Wet	Jan-Feb	Closed	Closed
		Apr-May	Closed	Closed-Open-Closed
		Jul-Aug	Open	Closed
2002	Dry	Jan-Feb	Closed	Closed
		Apr-May	Open-Closed-Open	Closed-Open-Closed
		Jul-Aug	Open	Closed

[1]Head of Old River Barrier

Different locations are selected for particle insertion (Table 7-4) and particle flux output (Table 7-5), in order to investigate various areas of interest in the Delta.

Table 7-4 Particle insertion locations for the Delta grid test in PTM unit test suite

Location	DSM2 Node
Sacramento River, Freeport	335
San Joaquin River, Mossdale	6
Calaveras River	21
Mokelumne & Cosumnes Rivers	257
Sacramento River, Rio Vista	351

Table 7-5 Simulation periods for the Delta grid test in PTM unit test suite

Location	Explanation
SWP export	Particles out to State Water Project
CVP export	Particles out to Central Valley Project
Martinez boundary	Particles out to the ocean
DICU diversion	Particles out of agricultural diversions
Whole Delta	Particles which stay in Delta

7.3.3 Convergence test

This set of tests varies the PTM calculation sub-time-step to examine the result convergence. Investigated time-steps: 1 minute, 3 minutes, 5 minutes, 15 minutes, 30 minutes, and 1 hour (HYDRO calculation time-step is 15 minutes; PTM output time step is 15 minutes).

CHAIN CHANNELS, STEADY FLOW (SAME CONFIGURATION IN 7.3.1)

Purpose: Test PTM simulation time-step convergence in a connected channels chain, with uniform and steady environment.

DELTA GRID 1996 JAN-FEB (SAME CONFIGURATION IN 7.3.2)

Purpose: Test PTM simulation time-step convergence in Sacramento - San Joaquin Delta, during flooding season of Wet Water Year.

DELTA GRID 2002 JUL-AUG (SAME CONFIGURATION IN 7.3.2)

Purpose: Test PTM simulation time-step convergence in Sacramento - San Joaquin Delta, during dry season of Dry Water Year.

7.3.4 Other Potential Tests under development

Convergence test with both HYDRO and PTM time steps varied.

Particle insertion duration varied as 0 day (all are inserted immediately), 1 day, 30 day, etc.

7.4 Conclusions

The newly developed test suite provides a comprehensive package covering various simulation conditions for DSM2-PTM. It enables module developers to investigate changes to their programming more efficiently and consistently, by batch-running, automated plot generation, comparison among different module versions, etc. Other test conditions could be incorporated into this suite framework in the future.

7.5 Acknowledgements

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7.6 Bibliography

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