Task 2 Technical Memorandum
Analytical Modeling of the San Joaquin River

A Deliverable
for
California Urban Water Agencies (CUWA)
and the
Central Valley Drinking Water Group

Prepared by

Joel Herr
Systech Water Resources, Inc.
Walnut Creek, CA 94596

October 20, 2008

TABLE OF CONTENTS

List of Figures

List of Tables

ABSTRACT

The Watershed Analysis Risk Management Framework (WARMF) was applied to the San Joaquin River from 2005-2008 to determine the source of oxygen depleting materials which impair the Stockton Deep Water Ship Channel for fish passage. In the process, the model was calibrated for flow, TDS/EC, suspended sediment, nutrients, organic carbon, and phytoplankton. The Central Valley Drinking Water Group has a need for analytical modeling of the San Joaquin River to calculate concentration of total dissolved solids and organic carbon as input to the Delta DSM2 model, which in turn predicts water quality at the Delta drinking water intakes. The calibrated WARMF model simulates total dissolved solids, dissolved organic carbon, and total organic carbon well. There are some discrepancies between simulated and measured organic carbon. The simulated summer peaks of total organic carbon are not matched by observed data in 2000-2002, but this can be explained by the analytical method used when measuring total organic carbon. There were measured winter peaks of organic carbon, at least sometimes associated with rising flow of spring snowmelt season, which were not simulated correctly. There are multiple possible explanations for this discrepancy which targeted monitoring could help identify. WARMF is able to trace TDS and organic carbon back to its sources in the San Joaquin River tributaries, agricultural drains, and groundwater accretion. WARMF can simulate alternate land uses and watershed management plans to determine potential threats to drinking water quality and methods to mitigate those threats.

1 INTRODUCTION

Background

The Watershed Analysis Risk Management Framework (WARMF) was applied to the San Joaquin River watershed from 2005-2008 to investigate the causes of dissolved oxygen impairment in the Stockton Deep Water Ship Channel ("DWSC"). Considerable scientific studies have been conducted to investigate the causes of low DO in the DWSC, including data collections, data analyses, and modeling.

In 2003, CALFED funded the directed action project for monitoring and investigations of the San Joaquin River and tributaries related to dissolved oxygen. A comprehensive field program was established to measure flow and water quality in the Upper San Joaquin River and its tributaries. Meanwhile, USGS and University of California Davis have collaborated to measure sources and transport of nutrients and algae during summer and fall of 2000 and 2001 (Kratzer at al. 2004). Jones & Stokes (2005) created a data atlas by compiling all these data into a CD to support data analysis and modeling. Task 6 of the upstream study was for the development, calibration, and application of the San Joaquin River Model.

The monitoring program performed for the upstream dissolved oxygen studies included extensive collection of flow, nutrients, sediment, phytoplankton, organic carbon, individual ions, and electrical conductivity. The monitoring data provided a strong basis with which to calibrate WARMF on the San Joaquin River under a variety of hydrologic conditions. The calibration of WARMF to the San Joaquin River is described in detail in the San Joaquin River Dissolved Oxygen TMDL Upstream Studies Task 6 Final Report (Herr, Chen, and van Werkhoven 2008).

The Central Valley Drinking Water Work Group is concerned about the concentrations of salt and organic carbon at its members' drinking water intakes in the Sacramento / San Joaquin River Delta. To determine the sources of pollutants both in the present and in the future, the Work Group called for development of analytical models of the Sacramento and San Joaquin River watersheds. The analytical models would then be linked to the DSM2 model of the Delta to determine how pollutants from the upstream watersheds would impact water quality at the drinking water intakes.

Because the WARMF model had already been set up and calibrated for the San Joaquin River for multiple water quality parameters, the Work Group chose to use that model and then focus on the parameters of concern. The model was re-evaluated to determine if the calibration of TDS/EC and organic carbon could be improved upon.

Modeling Objective

The objective was to evaluate and improve the San Joaquin River WARMF model simulations of TDS/EC and organic carbon to suit the needs of the Drinking Water Group. Following are the objectives of this modeling task:

1. Refine the calibration of TDS and EC to improve its simulation under a variety of hydrologic conditions

2. Refine the calibration of dissolved and total organic carbon. The original calibration of WARMF did not include organic carbon as part of its focus, although it was calibrated. The simulated organic carbon under the original calibration of WARMF did not match measured winter peak concentrations at Vernalis. Simulated total organic carbon showed peaks from phytoplankton blooms in summer which were not measured in water quality data.

3. Characterize the sources of TDS/EC and organic carbon as they vary throughout the year and between wet and dry years.

San Joaquin River WARMF Application

The San Joaquin River WARMF application simulates point and nonpoint source pollutant loads to the San Joaquin River. Within the river, WARMF also simulates and the growth, decay, and transport processes which would ultimately impact the pollutant load to the Delta at Vernalis. The model domain was initially set with its upstream boundary at the Lander Avenue bridge on the San Joaquin River. The model domain was extended upstream to Friant Dam in 2008 (Herr and Chen 2008) although Lander Avenue is still used as an upstream boundary condition when simulating the lower portion of the river.

The lower San Joaquin River has three eastside tributaries (Stanislaus River, Tuolumne River, and Merced River) that drain the Sierra-Nevada western slope westward to San Joaquin River. On the west side, there are six tributaries (Hospital/Ingram Creek, Del Puerto Creek, Orestimba Creek, Los Banos Creek, Mud Slough, and Salt Slough) that drain the Diablo Coastal Range eastward to the San Joaquin River. Upstream boundary conditions for the model were established at monitoring locations on each of these tributaries. The land areas draining to the San Joaquin River and its tributaries between these boundaries and the Old River were included within the WARMF model domain. The shallow groundwater flow and nonpoint source pollution from the land areas was simulated in WARMF is automatically added to the adjacent river segments during simulations. The map of the watershed downstream of Lander Avenue is shown in Figure 1.1 with the model domain highlighted. The model domain includes 93 river segments and 30 catchments.

WARMF is a GIS based watershed model for TMDL analysis. It is a public domain model, available from US EPA website (Google EPA WARMF). The model is a mature model that is

compatible with other watershed models contained in the EPA BASINS. The model has complete technical documentation (Chen, Herr, and Weintraub 2001) and has been peer reviewed (Keller, 2000, 2001, Driscoll, Jr. et al. 2004). The User's Manual is available (Herr et al. 2001).

WARMF simulates the watershed processes to calculate hydrology and nonpoint source loads of pollutants from various land uses (urban, native vegetation types, and agricultural areas). The input data includes the locations of agricultural diversions, daily diversions, and amount of irrigation water applied to the agriculture lands. The model simulates percolation of irrigation water through soil, evapotranspiration of water through crops, change of groundwater table, agricultural return flow, and groundwater accretion to the river reaches. The model also simulates the nonpoint loads of pollutants due to fertilizer applications, leaching of cations and anions from the soil, and erosion of soils from land.

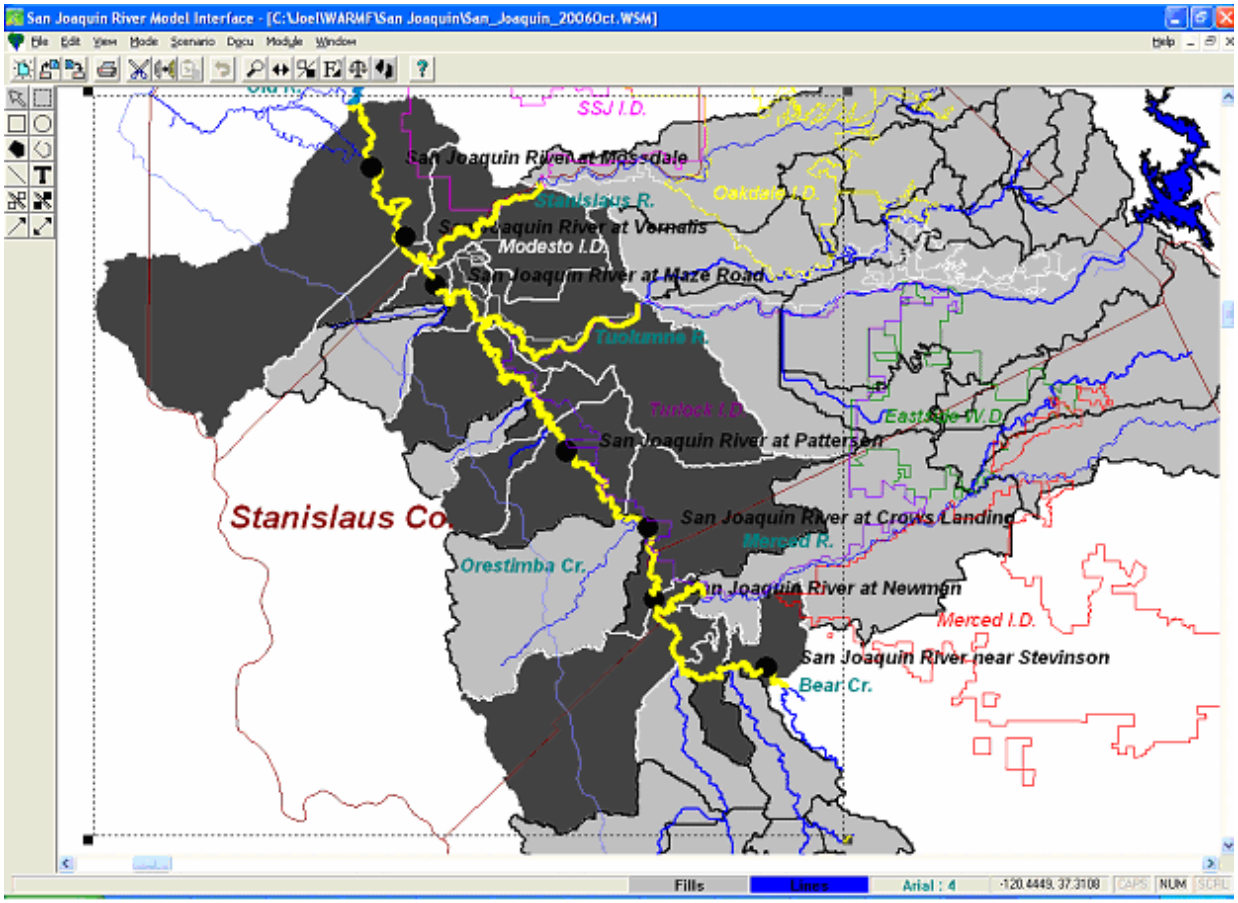

Figure 1.1 The San Joaquin River WARMF Application and Model Domain

Hydrologic Simulation

WARMF simulates hydrology based on water balance and physics of flow. It begins with precipitation on the land surface. Precipitation and irrigation water can percolate into the soil. Within the soil, water first goes to increase the moisture in each soil layer up to field capacity. Above field capacity, water percolates down to the water table, where it flows laterally out of the land catchment according to Darcy's Law. Water on the soil or within the soil is subject to evapotranspiration, which is calculated based on temperature, humidity, and season. The amount of water entering and leaving each soil layer is tracked. If more water enters the soil than leaves it, the water table rises. If the water table reaches the surface, the soil is saturated and overland flow occurs. The overland flow is calculated by Manning's equation.

Rivers accept the subsurface and overland flow from catchments linked to them. They also receive point source discharges and flow from upstream river segments. Diversion flows are removed from river segments. The remaining water in the river is routed downstream using the kinematic wave algorithm. The channel geometry, Manning's roughness coefficient, and bed slope are used to calculate depth, velocity, and flow. The velocity is a measure of the travel time down the river, which in turn affects the water quality simulation. A thorough description of the processes simulated by WARMF is in the WARMF Technical Documentation (Chen, Herr, and Weintraub 2001).

Water Quality Simulation

The fundamental principle which guides WARMF simulation of water quality is heat and mass balance. Heat enters the soil in water from precipitation and irrigation. Heat is exchanged between catchments and the atmosphere based on the thermal conductivity of the soil. Heat in water leaving the catchments enters river segments, which combine the heat from multiple sources. As in catchments, there is thermal exchange with the atmosphere based on the difference in temperature between the water and the air. Temperature is then calculated by heat balance throughout the model.

Chemical constituents enter the model domain from atmospheric deposition and from point source discharges. They can also enter the land surface in irrigation water and fertilizer application. Chemical species move with water by percolation between soil layers, groundwater lateral flow to rivers, and surface runoff overland. Each soil layer is considered to be a mixed reactor, as is the land surface within each land use. Within the soil, cations are adsorbed to soil particles through the competitive exchange process. Anions are adsorbed to the soil using an adsorption isotherm. A dynamic equilibrium is maintained between dissolved and adsorbed phases of each ion. Reactions transform the dissolved chemical constituents within the soil. The dissolved oxygen concentration is tracked, and as D.O. goes to zero, anoxic reactions take place. When overland flow takes place, sediment is eroded from the catchment surface according to the modified universal soil loss equation. The sediment carries adsorbed ions (e.g. phosphate) with it to the river.

Rivers accept the water quality which comes with each source of flow. Each river segment is considered a completely mixed reactor. Ions form an equilibrium between dissolved and adsorbed to suspended sediment. Sediment can settle to the river bed and is scoured from the river bed when velocity is high enough. Chemical reactions are based on first order kinetics with their rate adjusted with a temperature correction. Algae are represented by three types: greens, blue-greens, and diatoms. Each has their own optimum growth rate, nutrient half-saturation concentrations, light saturation, optimum temperature, and temperature range for growth. At each time step, algal growth is a function of nutrient limitation, light limitation, and temperature limitation. Light penetration is a function of the algae, detritus, and total suspended sediment concentrations. Light intensity is integrated over the depth of the river segment.

Simulated Parameters

WARMF simulates a complete set of hydrologic, chemical and physical parameters as shown in Table 1.1.

Table 1.1 Parameters Simulated by WARMF

Hydrology	Flow, velocity, depth, temperature
Nutrients etc.	Ammonia, nitrate, phosphate, organic carbon (including organic nitrogen), total phosphorus, total kjeldahl nitrogen, total nitrogen, total organic carbon, dissolved oxygen
Ions	Calcium, magnesium, potassium, sodium, sulfate, chloride, total dissolved solids, electrical conductivity, alkalinity, pH
Biological	Fecal coliform, diatoms, green algae, blue-green algae, total phytoplankton
Sediment	Clay, silt, sand, total suspended sediment, total sediment

WARMF modeled electrical conductivity (EC) in two forms. One form is an independent constituent. In this case, ECs of inflows, precipitation and irrigation water were specified in the input. The model simply tracked the EC concentration as a conservative substance. The other form was a non-conservative EC, in which WARMF modeled individual cations and anions of water. The individual ions underwent adsorption, desorption, cation exchange with soil, and reactions. The resulting concentrations of individual ions were summed for TDS. The TDS was then converted to EC by multiplying 1.667, which is a factor found to be applicable to the water in San Joaquin River.

Model Inputs

WARMF is a dynamic watershed model. It requires six categories of input data: 1) geometric dimensions of land catchments and river segments and their elevations, 2) soil characteristics of the watersheds 3) model coefficients, 4) land uses of land catchments, 5) meteorological condition, and 6) operating conditions.

The first 4 categories of data are time invariant variables, which do not change values during the model simulation. Soil characteristics include thickness, field capacity, porosity, and hydraulic conductivity of soil layers. The model coefficients include reaction rates and their temperature correction factors. Land use is imported from an ArcView shapefile. The land use types in the shapefile are overlayed with the WARMF catchment boundaries to determine the percentage of each land use in each catchment.

The last two categories of data are time varying. These are sometimes referred to as the driving variables. The meteorology affects the annual and seasonal variations of hydrology (i.e. dry years and wet years) and water quality (i.e. hot summers and cold winters). The operating condition includes such man-made activities as reservoir releases, diversions, irrigation and waste discharges, which can be modified by management alternatives to improve water quality.

The daily values of driving variables are compiled and imported into the Data module of WARMF. During the simulation, the Data module automatically feeds these daily values to the model. The details of all these model inputs are included in the San Joaquin River DO TMDL Task 6 Final Report (Herr, Chen, and van Werkhoven 2008).

2 MODEL CALIBRATION

Procedure

Given meteorological and operational data, the San Joaquin River Model made predictions for stream flow and water quality at various river segments. At locations where monitoring data was collected, the model predictions should match the measured stream flow and water quality. Initially, some model coefficients, such as physical properties of the watershed, are known. Other coefficients are left at default or typical literature values. The initial predictions made did not necessarily match the observed values very well. Model calibration was performed by adjusting model coefficients within reasonable ranges to improve the match between model predictions and observed data.

The model predictions and observed data were compared graphically. In the graph, the time series of model predictions were plotted in a curve on top of measured data. If the observed values fell on top of the curve, the match could be determined as good or poor by visual inspection.

The model predictions and observed data were also compared statistically. The differences between the predicted and observed values are errors. The magnitudes of the errors were calculated in the statistical terms of relative error, absolute error, root mean square error, and correlation coefficient.

Both graphical and statistical comparisons were made with WARMF. WARMF has a scenario manager, where each scenario is a set of model input coefficients and corresponding simulation results. Scenario 1 may be used to represent a set of numerical values of model coefficients used in the simulation. Scenario 2 may be used to represent a second set of modified model coefficients used in the simulation. After the simulation, WARMF can plot the observed data as well as the model predictions for both scenarios on the same graph. By visual inspection, it is relatively easy to see whether the changes to model coefficients improve the match.

Likewise, WARMF calculates the values of various error terms for the model predictions. The comparison of the numerical values of errors for two scenarios can lead the user to adjust the model coefficients in the right way to reduce the errors.

Model calibration followed a logical sequence. Hydrological calibration was performed first, because an accurate flow simulation is a pre-requisite for accurate water quality simulation. The calibrations for temperature and conservative substances were performed before the calibration of nutrients (phosphate, ammonia, and nitrate), algae and dissolved oxygen concentrations.

Only a few model coefficients were adjusted for each calibration. For hydrological calibration, the boundary river inflows were checked for accuracy. Evapotranspiration coefficients, field capacity, saturated moisture, and hydraulic conductivity are then adjusted so that the simulated agricultural return flow and groundwater accretion could account for flow changes between the monitoring stations. For water quality calibration, the growth rate and half saturation constants of algae have been measured in the field program. The measured values were used to replace the default values contained in WARMF.

After submission of the Calibration Report (Herr and Chen 2006a), riparian diversions were added to WARMF in response to feedback from the Modesto and Turlock Irrigation Districts. A review of the model performed by Flow Science (List and Paulsen 2008) recommended several improvements to the calibration. The calibration was modified in response to this feedback. Adjustments were also made to the calibration for the Drinking Water Group's focus on total dissolved solids and organic carbon.

Calibration

The many parameters simulated by WARMF are interdependent. Flow affects the relative percentages of various sources which are mixed together. The travel time is the limiting factor for phytoplankton growth. Temperature is affected by river depth and light penetration but in turn affects reaction rates. Suspended sediment adsorbs some constituents (including organic carbon and some components of TDS) which can then be sequestered or released as the sediment settles to the river bed or is scoured during high flow. Nutrients, temperature, and light all affect phytoplankton growth, which converts inorganic carbon into organic carbon.

The San Joaquin River DO TMDL Upstream Studies Task 6 Report (Herr, Chen, and van Werkhoven 2008) includes a detailed discussion of the calibration of all the water quality parameters which in turn affect TDS and organic carbon, the constituents of primary concern to the Drinking Water Work Group. This discussion focuses on the calibration of the various forms of TDS and organic carbon. TDS and organic carbon differ greatly in how they interact with other parameters simulated by WARMF. Organic carbon comes from a combination of decayed plant matter, phytoplankton, and point sources.

The calibration is shown for five water quality stations along the San Joaquin River: Lander Avenue (Stevinson), Crows Landing, Patterson, Maze Road, and Vernalis. Crows Landing and Patterson are between the confluences of the Merced and Tuolumne Rivers. Maze Road is between the Tuolumne and Stanislaus Rivers. Vernalis is downstream of all the major east side tributaries.

The following sections describe the calibration results for TDS (using two EC measures) and organic carbon (dissolved and total). For each water quality parameter, the simulated results (blue lines) and observed data (black circles) are compared from the most upstream station to the most downstream station.

Total Dissolved Solids / Electrical Conductivity

Since TDS is largely conservative, calibration is a matter of accounting for the correct amount of salt at upstream boundary conditions and in the nonpoint source load of shallow groundwater. Because it is easily measured, there is generally ample data to characterize the upstream boundary conditions. The load from shallow groundwater is largely a function of mass balance. Irrigation water from various sources is applied to the land using the water quality of the water source. Thus, water diverted from the San Joaquin River introduces more salt to the shallow groundwater than water from the Delta-Mendota Canal or the Tuolumne River. WARMF simulates the evapotranspiration of water from the soil and the resulting concentration of dissolved ions within the remaining groundwater. The model simulates the subsurface flow including the dissolved ions and exfiltration to the San Joaquin River and its tributaries within the model domain.

There are two parameters used in calibration to adjust the amount of evapotranspiration: magnitude adjustment and skewness (seasonal) adjustment. These parameters are described in the WARMF Technical Documentation (Chen, Herr, and Weintraub 2001). Although these parameters have an important effect on concentration of TDS in shallow groundwater, they were only adjusted to calibrate the simulation of flow. The initial soil pore water concentrations of the various ions (NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl, PO_4, inorganic carbon) can impact simulation results because the soil represents stores a large quantity of ions. Rather than calibrate these initial concentrations, it was assumed that there would be minimal long-term trend in ionic concentrations in the soil. Thus, the initial concentrations were set approximately equal to the concentration at the end of the simulation in each soil layer of each catchment.

Total dissolved solids / electrical conductivity calibration is presented in two ways. The first is "Conservative EC", which is an independent parameter. "Conservative EC" is added to all model inputs and processed through the model without any reactions, adsorption, or other transformations. "Calculated EC" is calculated within WARMF as the sum of the individual ions of which it is composed.

Conservative EC

Figure 2.1 through Figure 2.5 compare the predicted and observed time series of "Conservative EC" at various stations along the San Joaquin River for the 2000 through 2007 water years. Although the simulations follow the pattern of observed data closely, the simulation results are generally lower than the observed data.

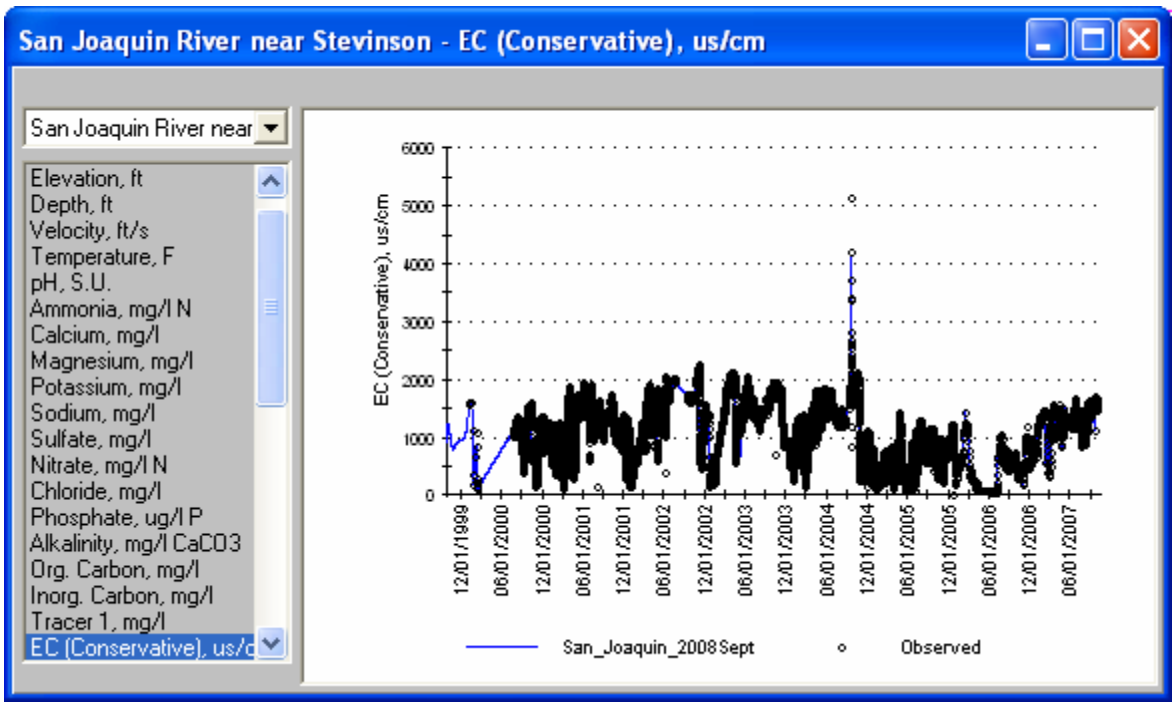

Figure 2.1 Simulated vs Observed "Conservative EC" at Lander Avenue

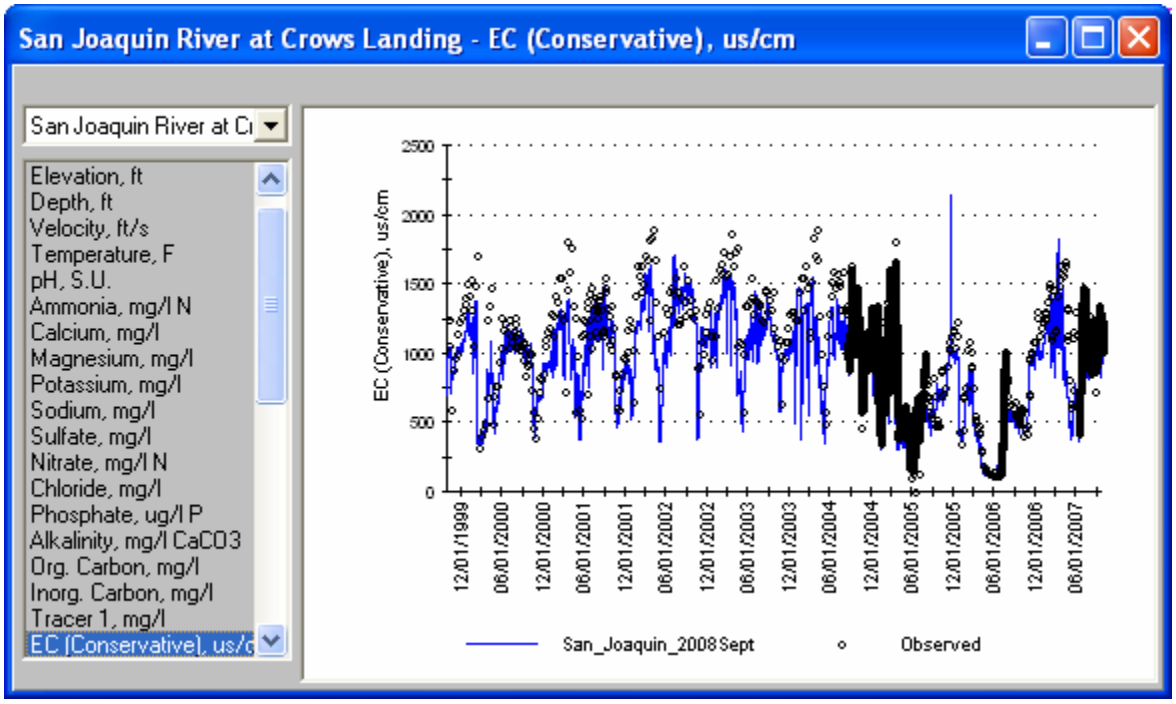

Figure 2.2 Simulated vs Observed "Conservative EC" at Crows Landing

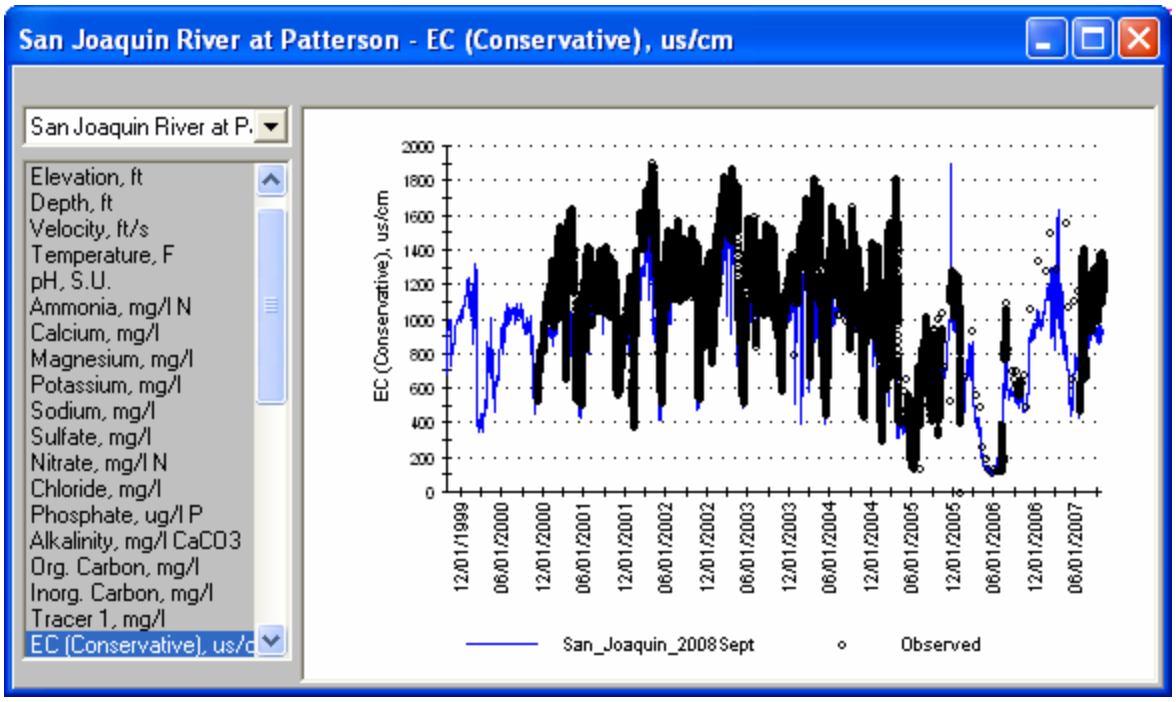

Figure 2.3 Simulated vs Observed "Conservative EC" at Patterson

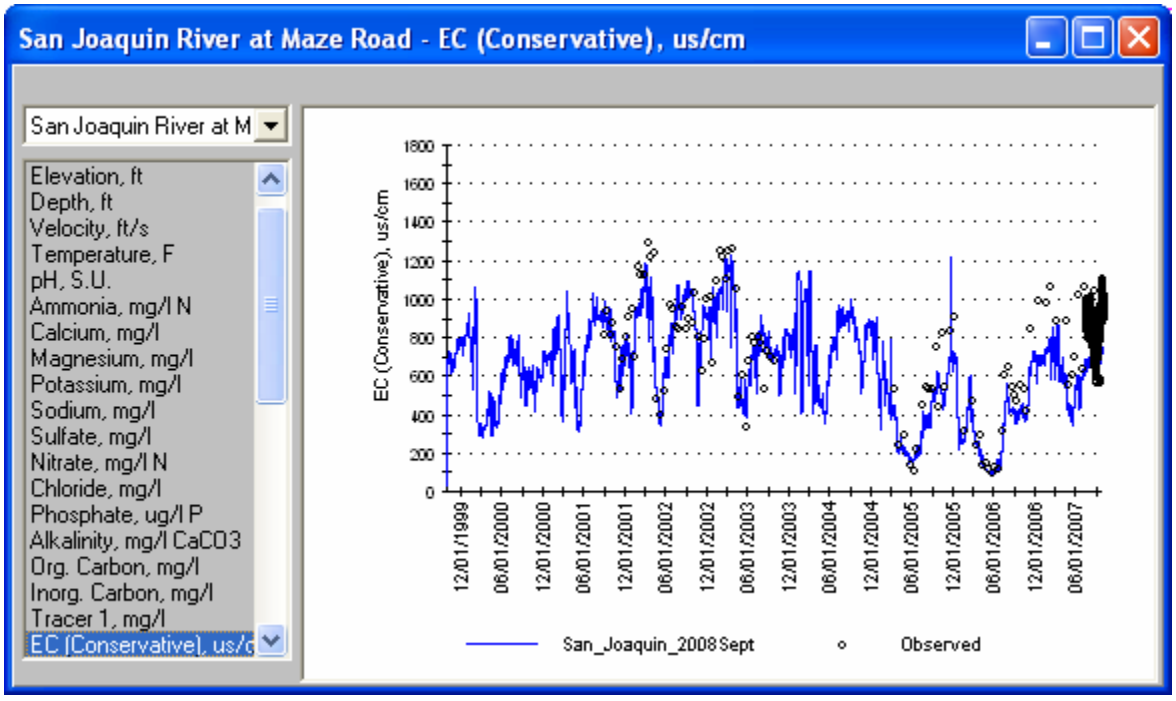

Figure 2.4 Simulated vs Observed "Conservative EC" at Maze Road

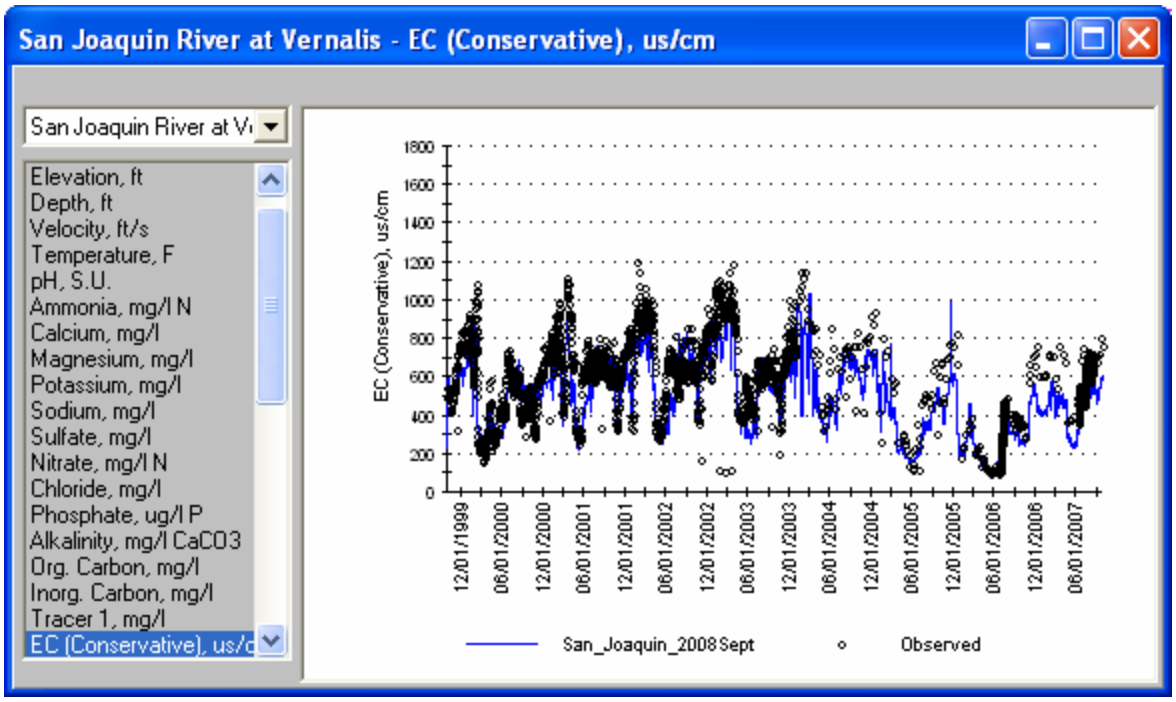

Figure 2.5 Simulated vs Observed "Conservative EC" at Vernalis

Table 2.1 shows the model errors for "Conservative EC" at the various monitoring stations on the San Joaquin River. There is a systematic error of 10-20% in the simulation results at all stations.

Table 2.1
Model Errors for "Conservative EC" in the San Joaquin River

Monitoring Station	Relative Error	Absolute Error
Stevinson	-1%	5%
Crows Landing	-17%	19%
Patterson	-16%	18%
Maze Road	-19%	22%
Vernalis	-11%	18%

Non Conservative EC

Figure 2.6 through Figure 2.10 compare the predicted and observed time series of "non conservative EC" at various stations along the San Joaquin River. Unlike "conservative EC", "non-conservative EC" reflects processes which can affect ions as they are transported throughout the watershed, including adsorption, settling, and equilibration of inorganic carbon with the atmosphere. The predicted "non conservative EC" tracked the seasonal patterns of observed EC closely and without the bias shown in simulations of "Conservative EC".

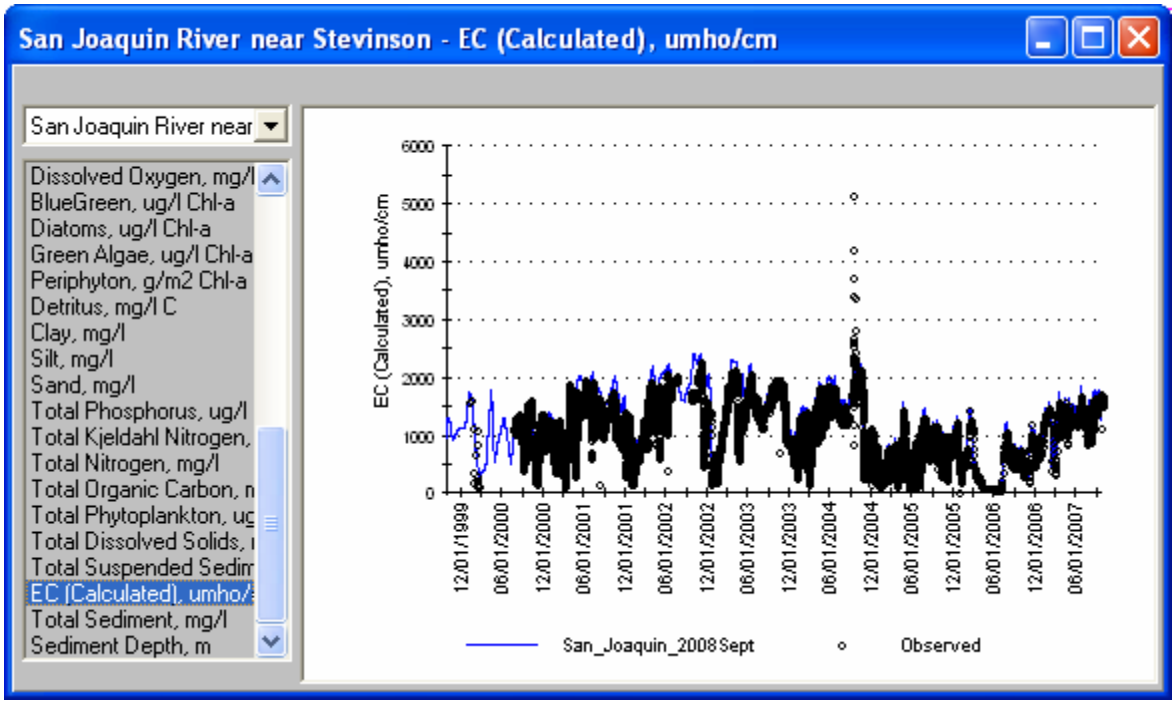

Figure 2.6 Simulated vs Observed "Non conservative EC" at Stevinson (Lander Ave.)

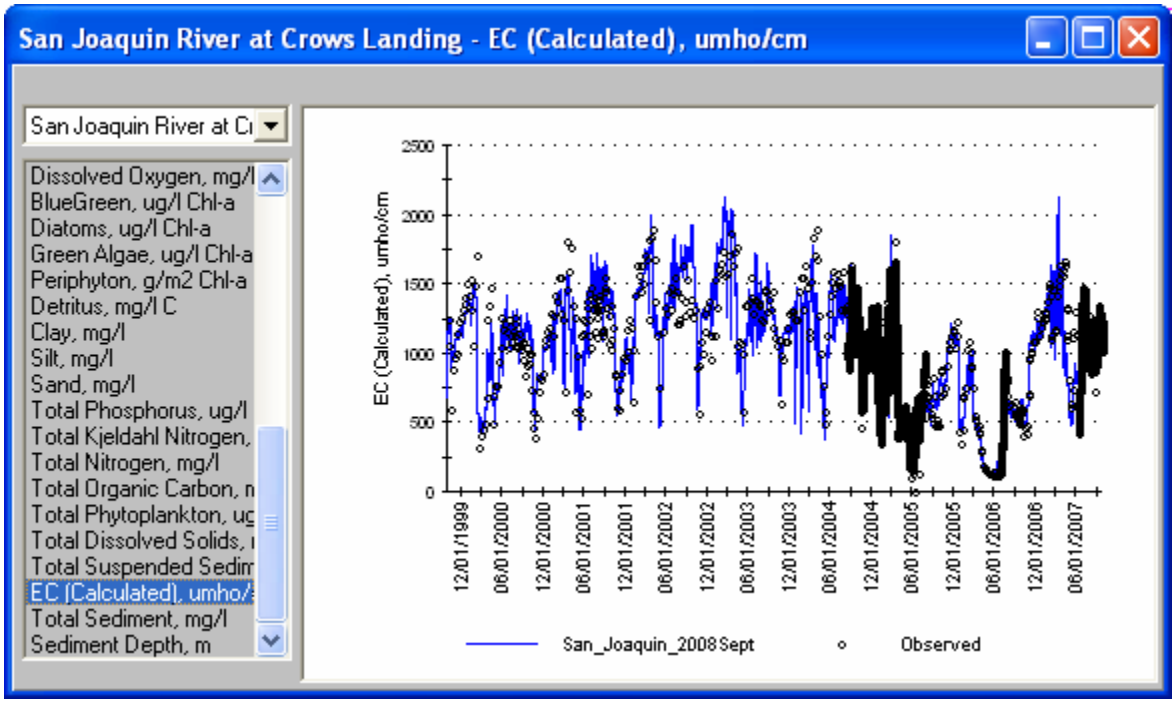

Figure 2.7 Simulated vs Observed "Non conservative EC" at Crows Landing

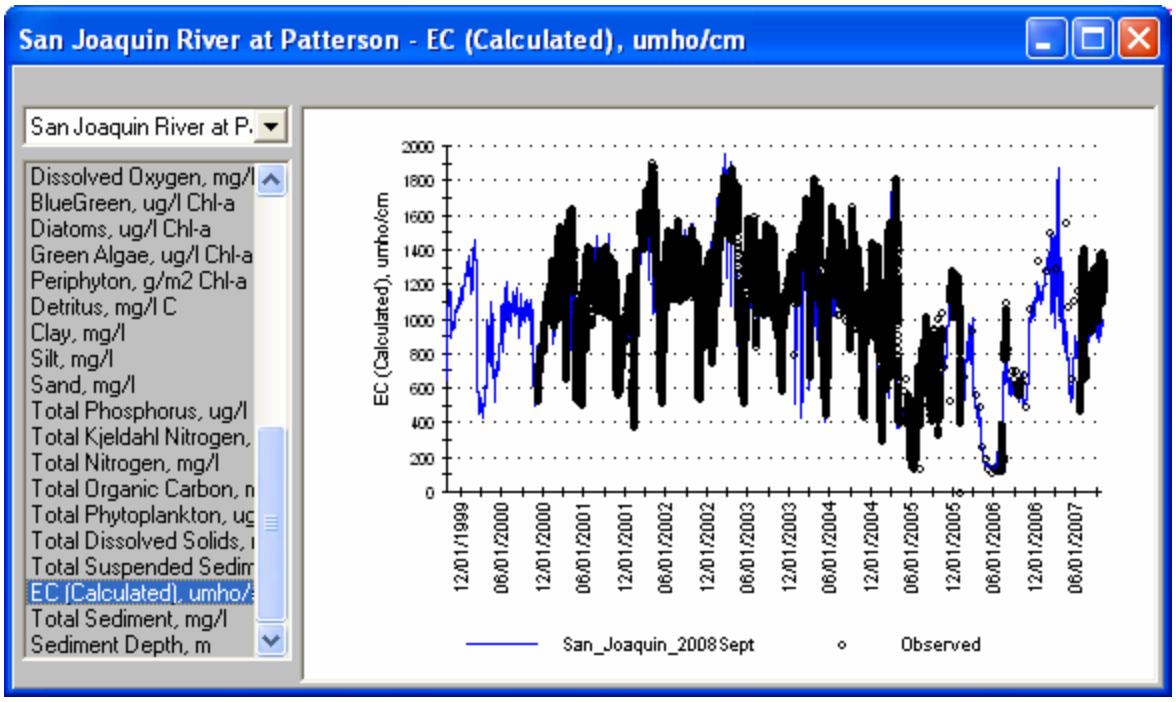

Figure 2.8 Simulated vs Observed "Non conservative EC" at Patterson

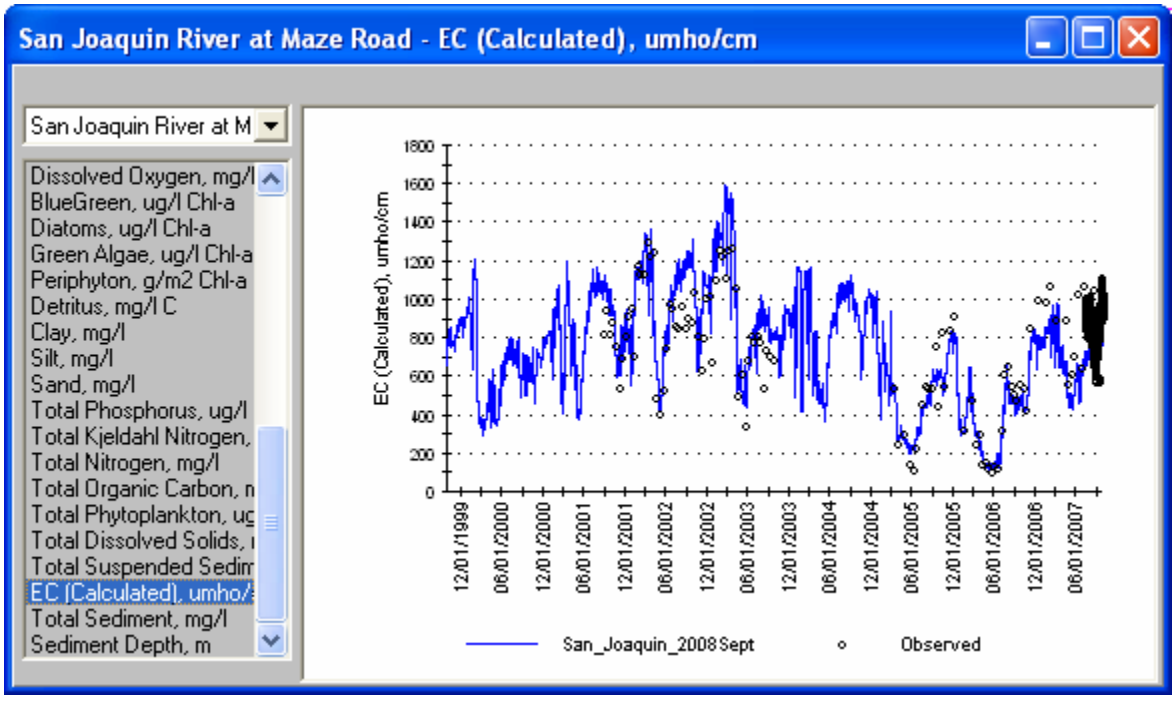

Figure 2.9 Simulated vs Observed "Non conservative EC" at Maze Road

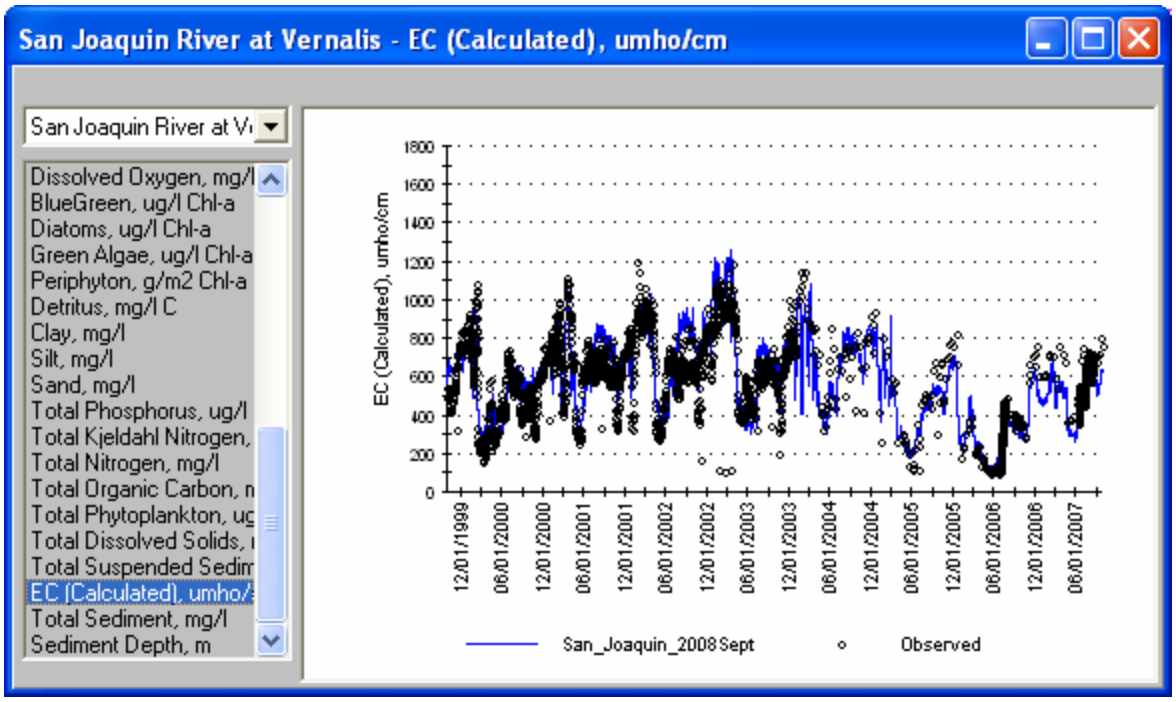

Figure 2.10 Simulated vs Observed "Non conservative EC" at Vernalis

Table 2.2 shows the model errors for "non conservative EC" at various monitoring stations on the San Joaquin River. Although there is error at the Lander Avenue upstream boundary condition, the relative error elsewhere is under 10% indicating little model bias. Absolute errors were under 20% at all stations.

Table 2.2
Model Errors for "Non conservative EC" in the San Joaquin River

Monitoring Station	Relative Error	Absolute Error
Stevinson	17%	20%
Crows Landing	-4%	14%
Patterson	-6%	14%
Maze Road	-8%	19%
Vernalis	4%	17%

Organic Carbon

In WARMF, organic carbon includes a combination of compounds from a variety of sources. It includes the humic and fulvic acids resulting from the decay of leaf litter on land and also living and dead phytoplankton. It can also come from point source discharges, urban runoff, and animals. Like total dissolved solids, organic carbon is also recycled from the San Joaquin River through agricultural fields and back to the river as nonpoint source load.

Dissolved Organic Carbon

Figure 2.11 through Figure 2.15 compare the time series of simulated and observed dissolved organic carbon at various stations along the San Joaquin River. The match for predicted and observed dissolved organic carbon concentration was generally good for all stations, but the model did not predict some measured peak concentrations.

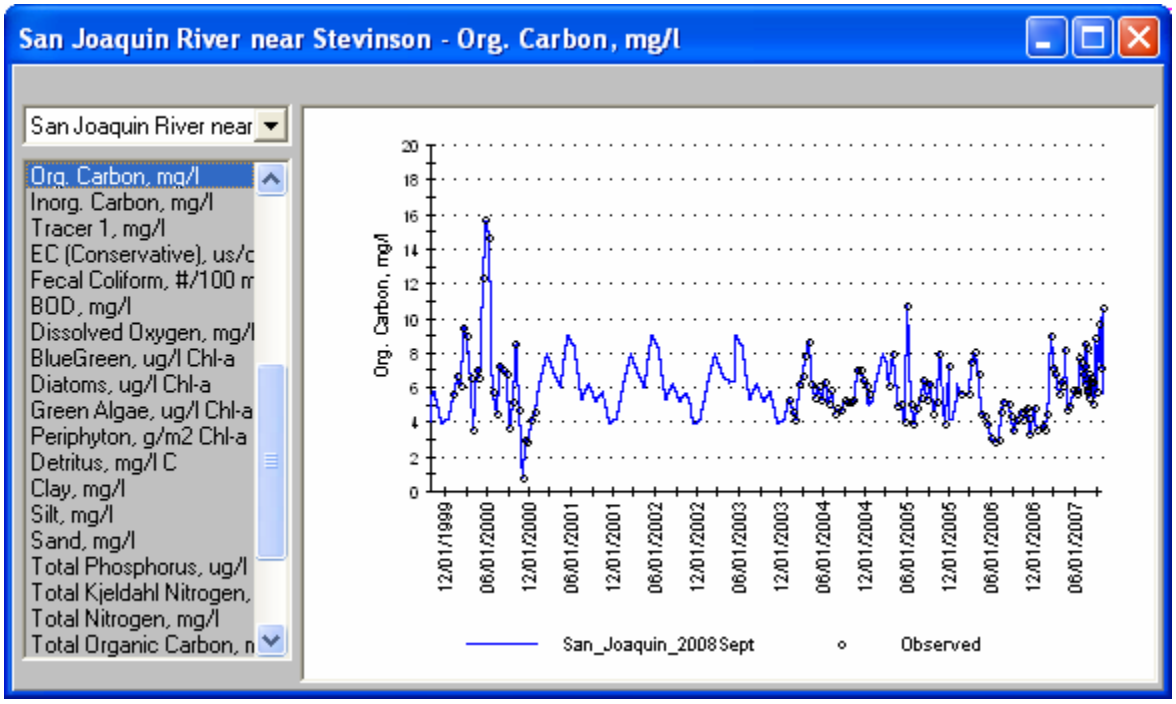

Figure 2.11 Simulated vs Observed Dissolved Organic Carbon at Lander Avenue

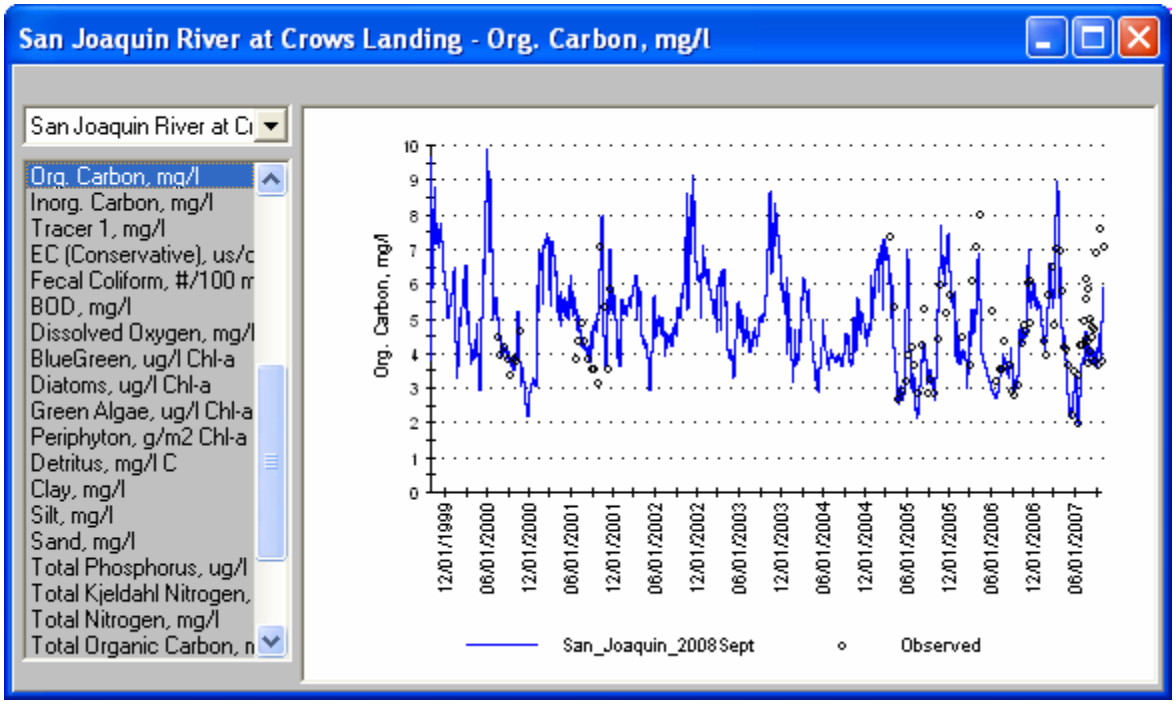

Figure 2.12 Simulated vs Observed Dissolved Organic Carbon at Crows Landing

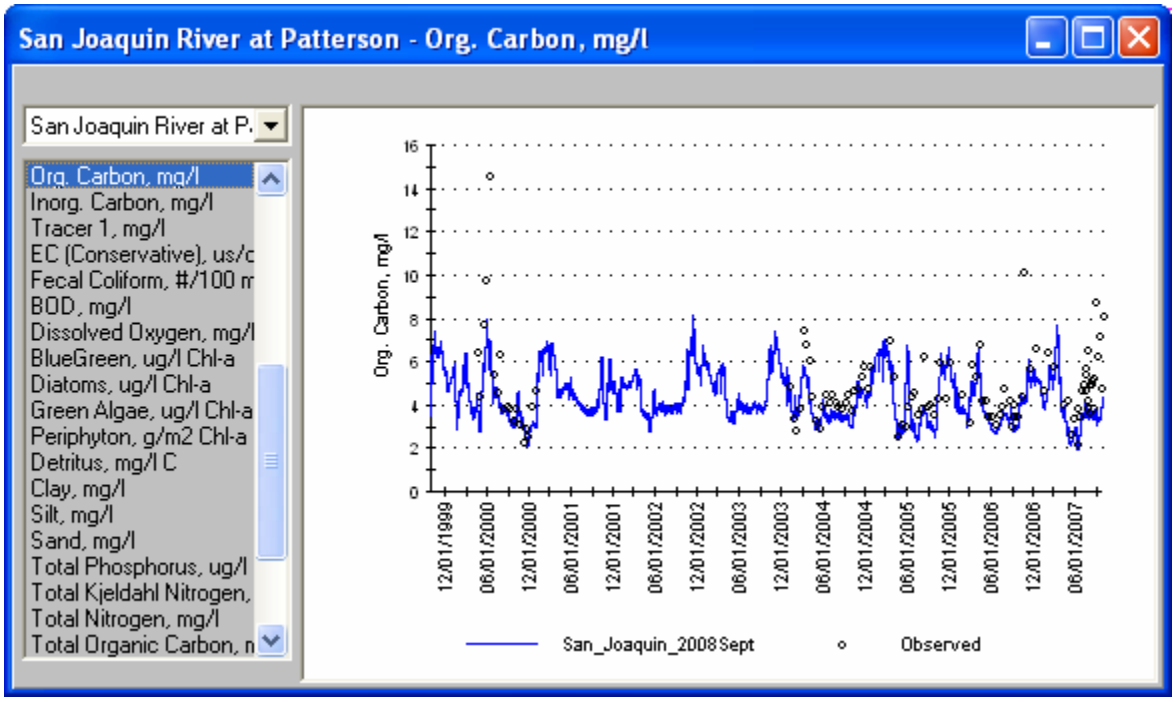

Figure 2.13 Simulated vs Observed Dissolved Organic Carbon at Patterson

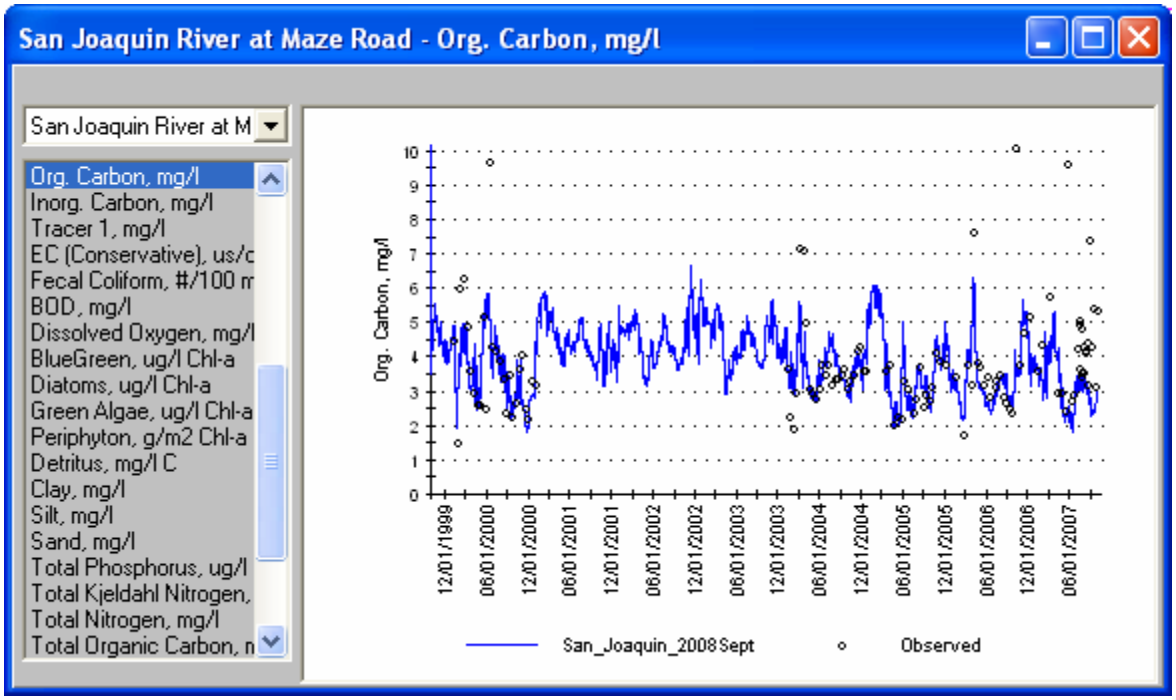

Figure 2.14 Simulated vs Observed Dissolved Organic Carbon at Maze Road

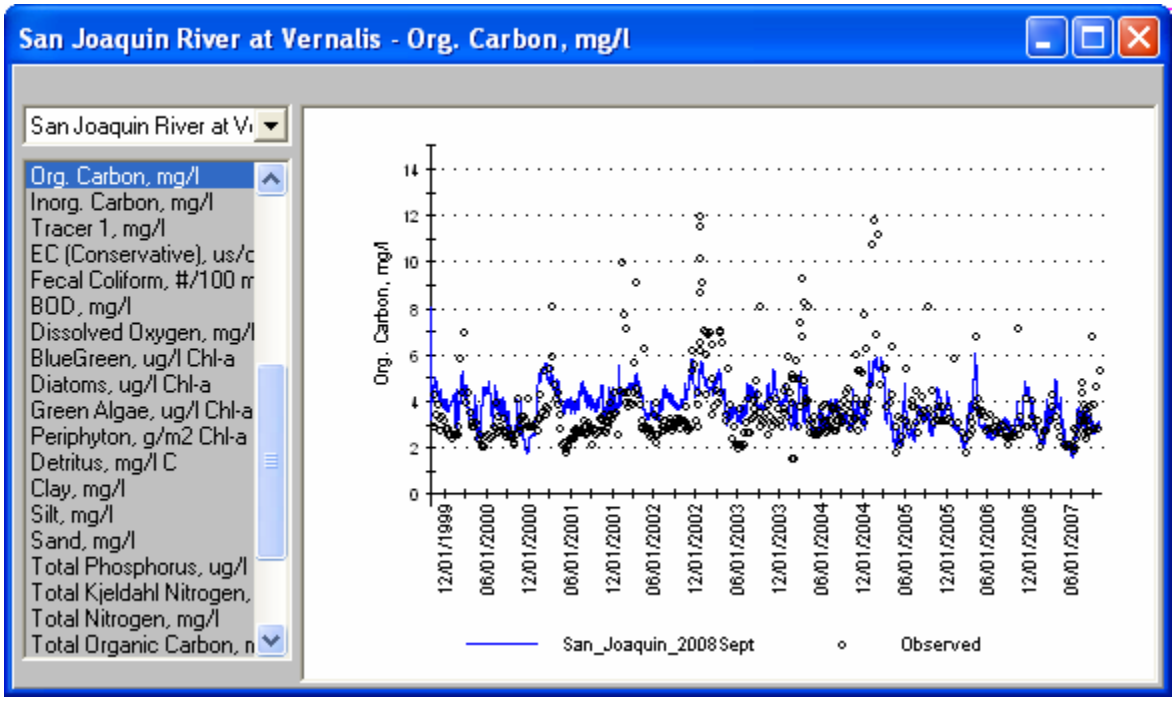

Figure 2.15 Simulated vs Observed Dissolved Organic Carbon at Vernalis

Table 2.3 shows the model errors of dissolved organic carbon at various monitoring stations on the San Joaquin River. Monitoring for organic carbon was done most frequently at Vernalis. Although the relative error is very low there, Figure 2.15 shows the underprediction of winter

peak concentrations in 2000-2005. The possible causes of this error are discussed later in this section. In other seasons, the simulations track the measured data well.

Table 2.3
Model Errors of Dissolved Organic Carbon Concentration in the San Joaquin River

Monitoring Station	Relative Error	Absolute Error
Stevinson	0%	2%
Crows Landing	-6%	17%
Patterson	-21%	24%
Maze Road	-14%	24%
Vernalis	1%	26%

Total Organic Carbon

Figure 2.16 through Figure 2.20 compare the time series of predicted and observed total organic carbon concentration at various stations along the San Joaquin River. Total organic carbon includes dissolved organic carbon, organic carbon adsorbed to suspended sediment, and biological organic carbon in phytoplankton and detritus.

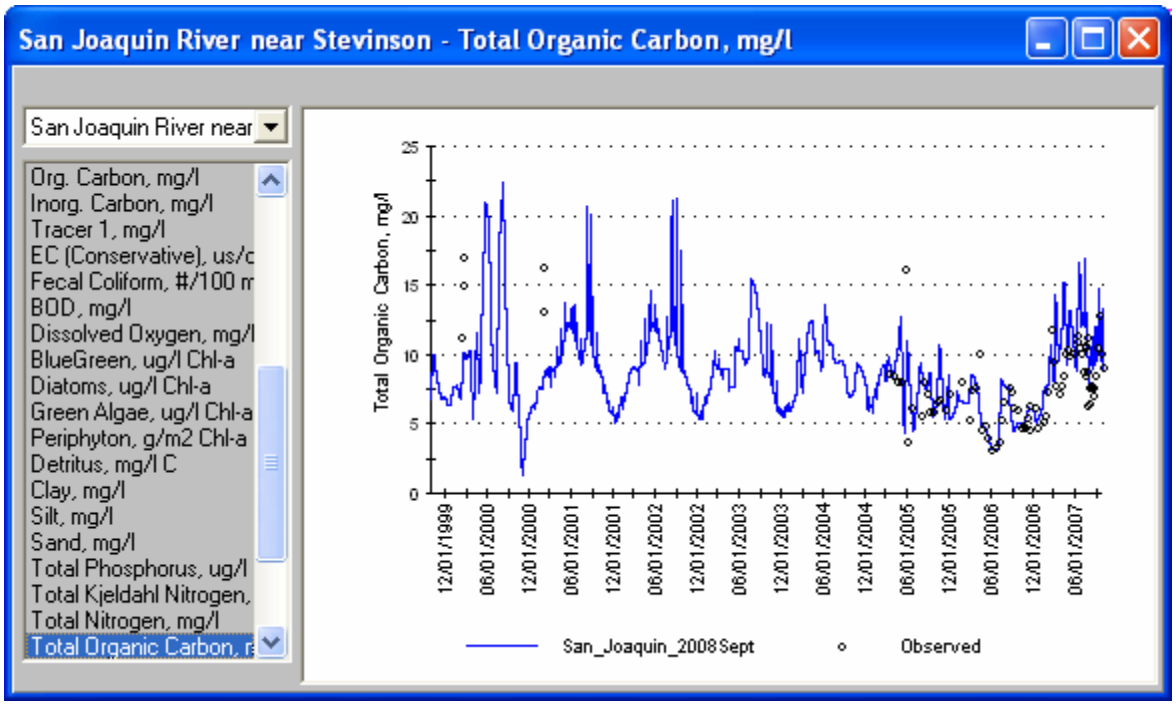

Figure 2.16 Simulated vs Observed Total Organic Carbon at Lander Avenue

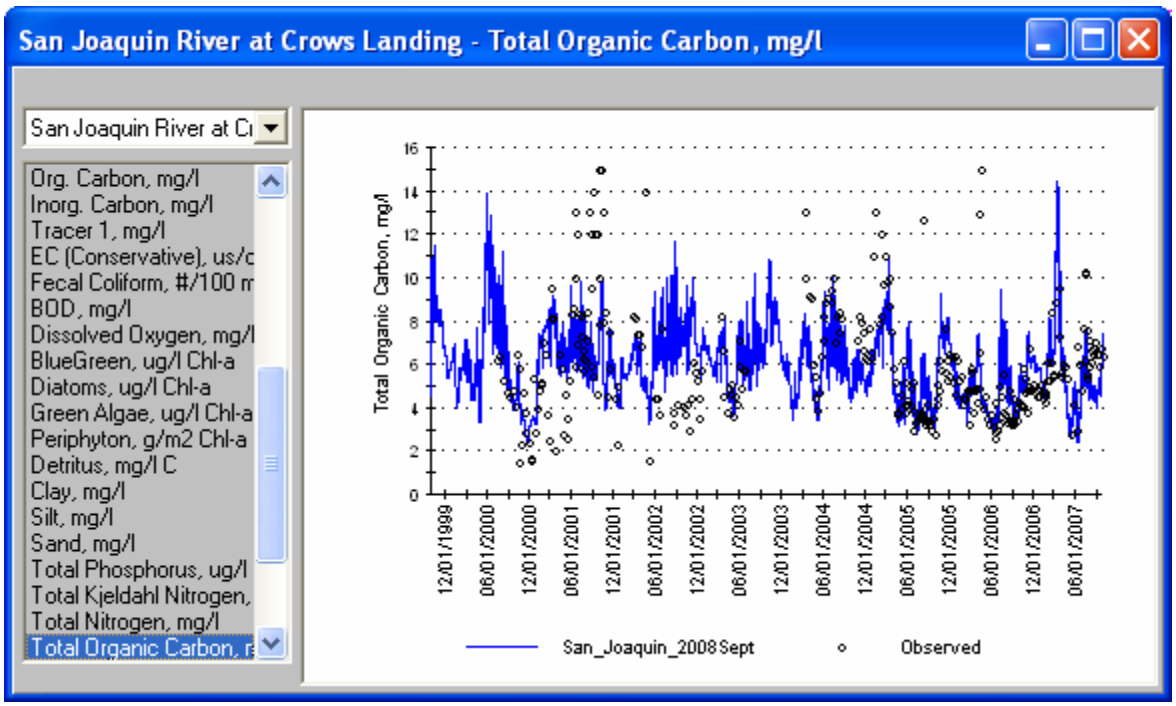

Figure 2.17 Simulated vs Observed Total Organic Carbon at Crows Landing

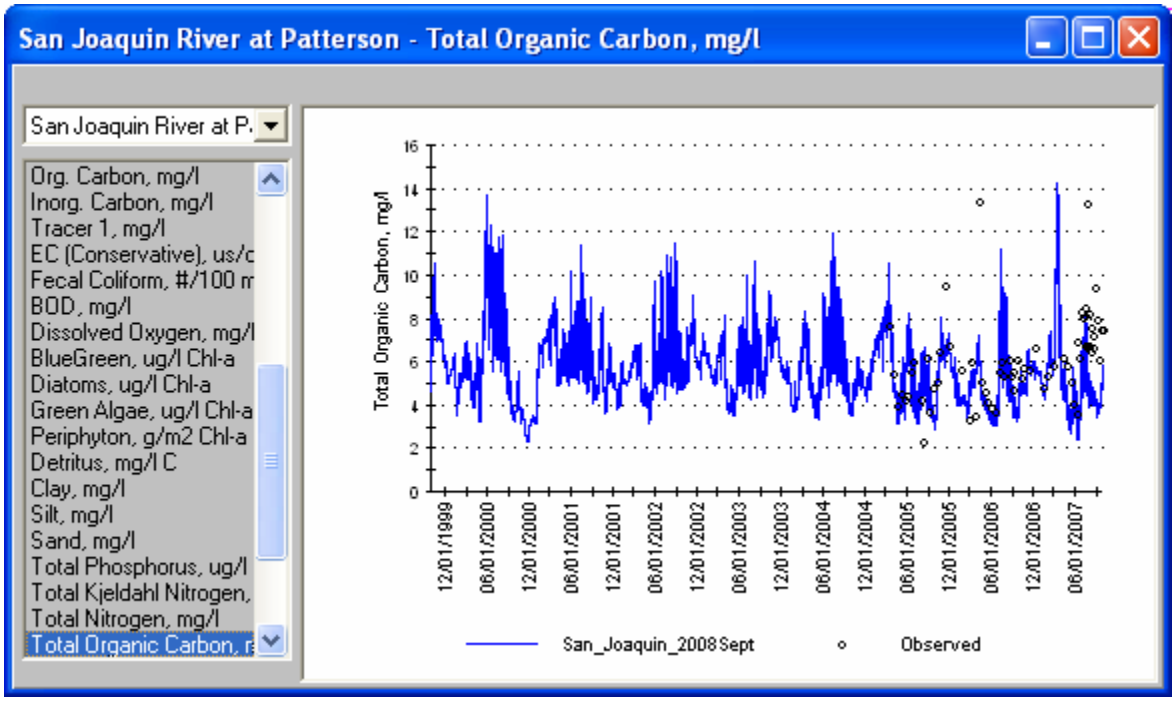

Figure 2.18 Simulated vs Observed Total Organic Carbon at Patterson

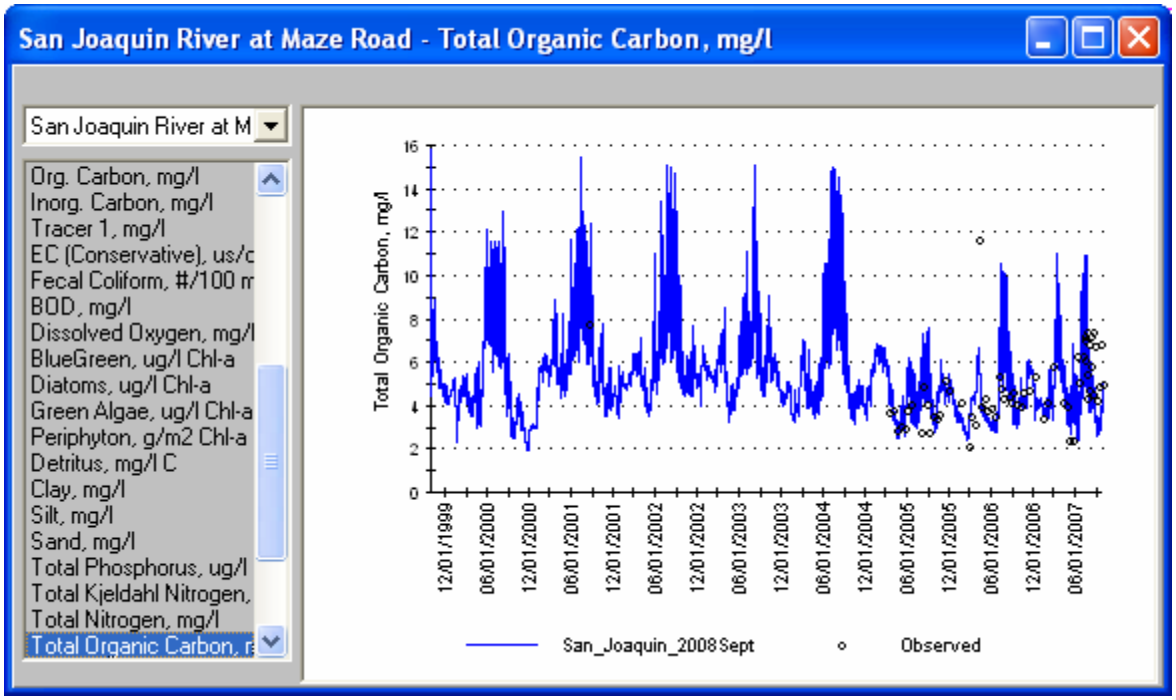

Figure 2.19 Simulated vs Observed Total Organic Carbon at Maze Road

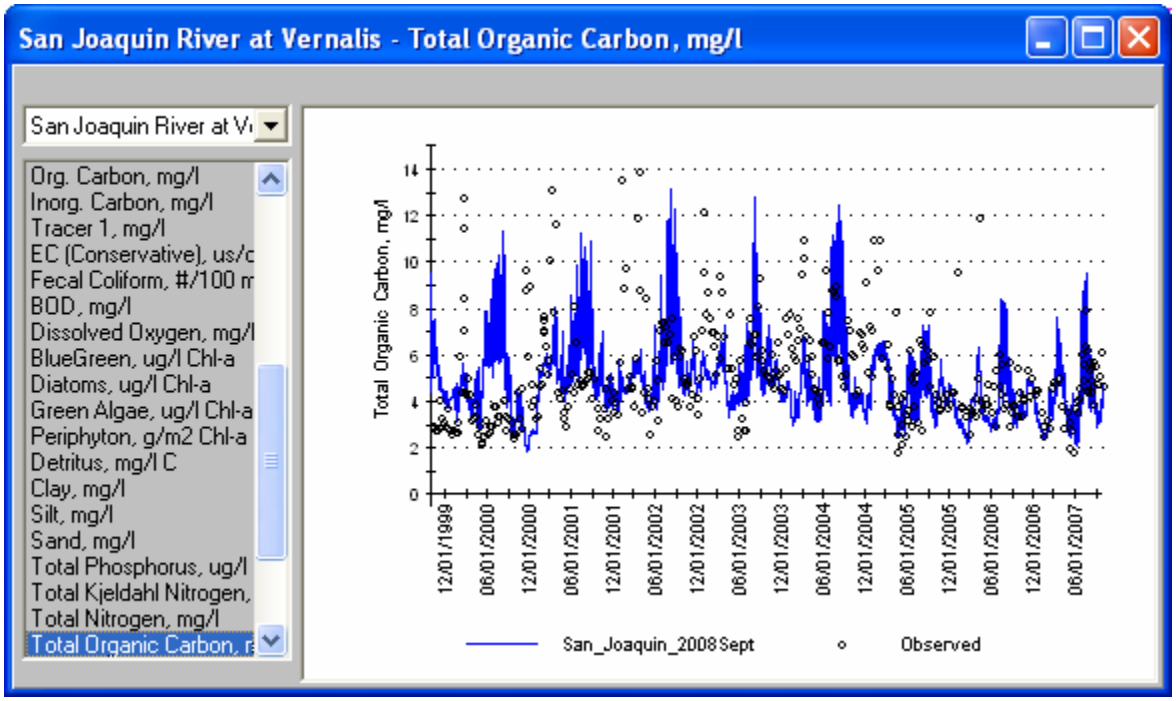

Figure 2.20 Simulated vs Observed Total Organic Carbon at Vernalis

Table 2.4 shows the model errors for total organic carbon at various monitoring stations on the San Joaquin River. As with dissolved organic carbon, most of the total organic carbon monitoring data was collected at Vernalis. There are two reasons why the absolute error is greater than 20%, which is the goal of calibration. As with dissolved organic carbon, the

simulation does not capture peak winter concentration of organic carbon. Unlike dissolved organic carbon, simulated total organic carbon was significantly higher than measured in the summers of 2000-2002. The possible causes of these errors are described in the following section of this report.

Table 2.4
Model Errors for Total Organic Carbon in the San Joaquin River

Monitoring Station	Relative Error	Absolute Error
Stevinson	10%	27%
Crows Landing	-2%	26%
Patterson	-22%	28%
Maze Road	-5%	23%
Vernalis	-11%	32%

Errors in Organic Carbon Simulation

In revisiting the calibration of WARMF for the San Joaquin River, the causes of the summer and winter errors in simulations of organic carbon need to be determined. Each could be a case of model error, data error, a combination of the two.

Winter Organic Carbon Concentration Peaks

For the failure of the model to predict the winter peak concentrations of both dissolved and total organic carbon, there are multiple possibilities:

- Storm runoff from urban areas is causing the measured concentration peaks but are not being simulated correctly
- Storm runoff from confined feeding operations is causing the measured concentration peak but are not being simulated correctly
- Winter organic carbon concentration is not represented correctly in tributary inflows

To determine the correlation between local precipitation and total organic carbon concentration at Vernalis, we can plot them together. Figure 2.21 and Figure 2.22 show measured total organic carbon at Vernalis and precipitation measured at Modesto for February-March of 2000 and 2001, respectively. In 2000, the total organic concentration peak comes 1-3 days after a 3 cm precipitation event. This implies a source of organic carbon related to storm flow.

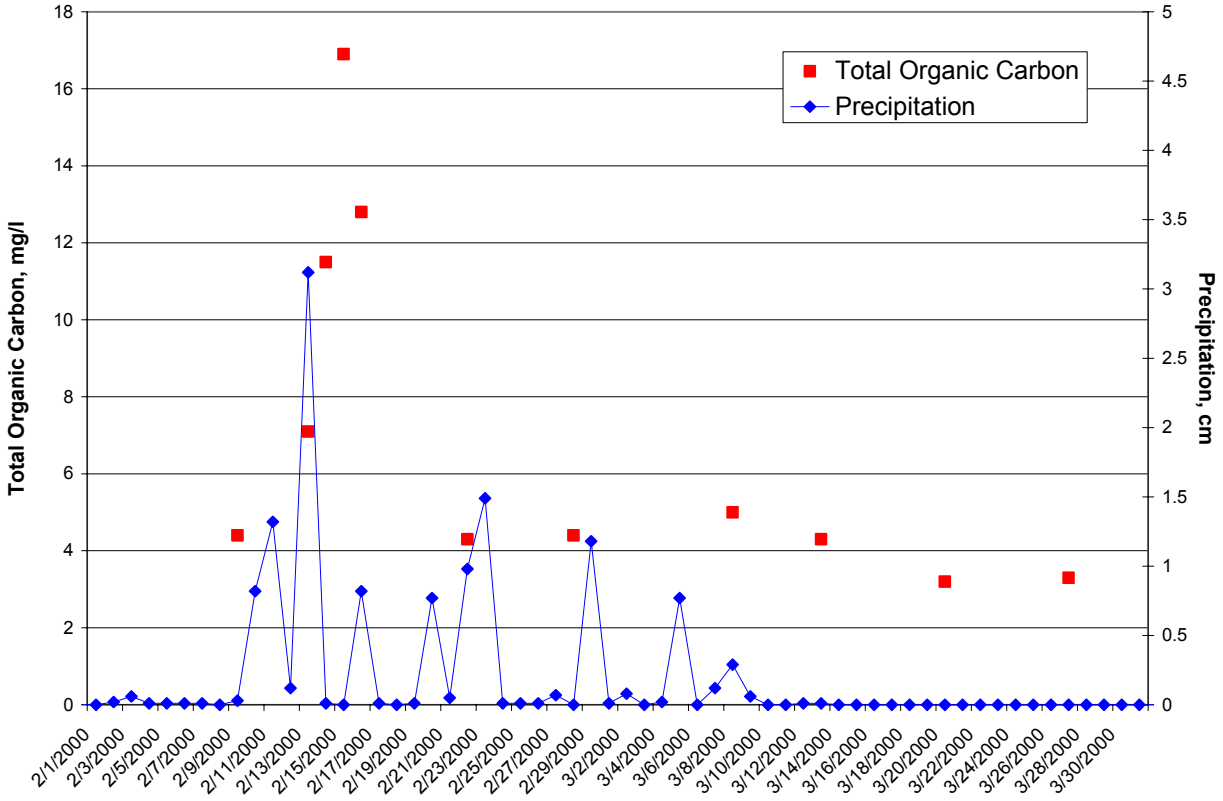

Figure 2.21 Measured Total Organic Carbon and Precipitation, February-March 2000

In Figure 2.22 showing February-March 2001, the total organic carbon concentration is elevated before, immediately after, and also weeks after a 2.6 cm rainfall event. Unlike the year 2000, storm runoff does not appear to be a good explanation for the measured peak organic carbon concentration in February and March.

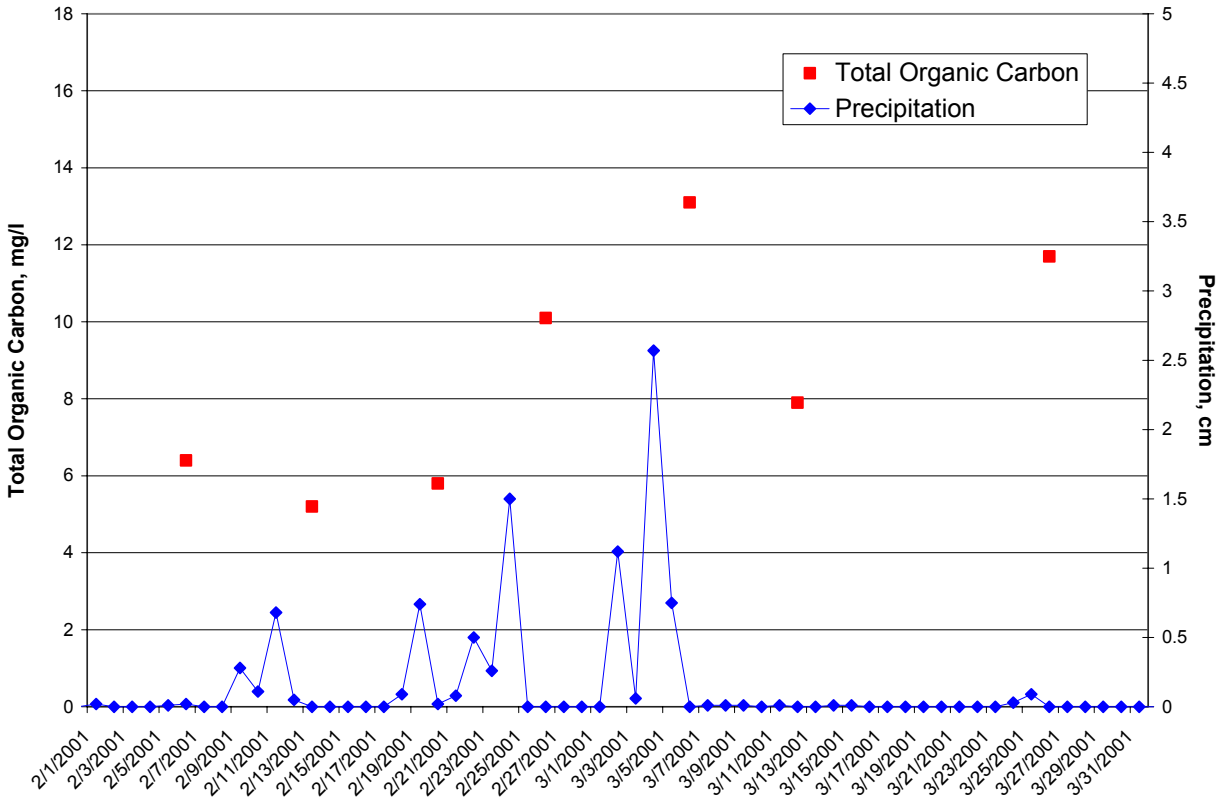

Figure 2.22 Measured Total Organic Carbon and Precipitation, February-March 2001

To test the local storm runoff hypothesis, a WARMF simulation was run with a very large land application rates to determine if winter storms could be causing significant runoff of organic carbon. The model's original application rates of organic carbon were multiplied by 100 for residential and commercial land uses. The new loading rates were set to 50 and 100 kg/ha/month respectively in each land use for the test simulation. With unrealistically high application rates, a response in the model should be apparent. Figure 2.23 shows the result of the test in green with the base case simulation in blue. Although the test case shows concentration spikes of up to 2 mg/l from the unrealistically high urban land application rates, the observed concentration spikes are closer to 10 mg/l. Urban runoff from land within the WARMF model domain is thus not an explanation for the discrepancy between simulated and measured organic carbon.

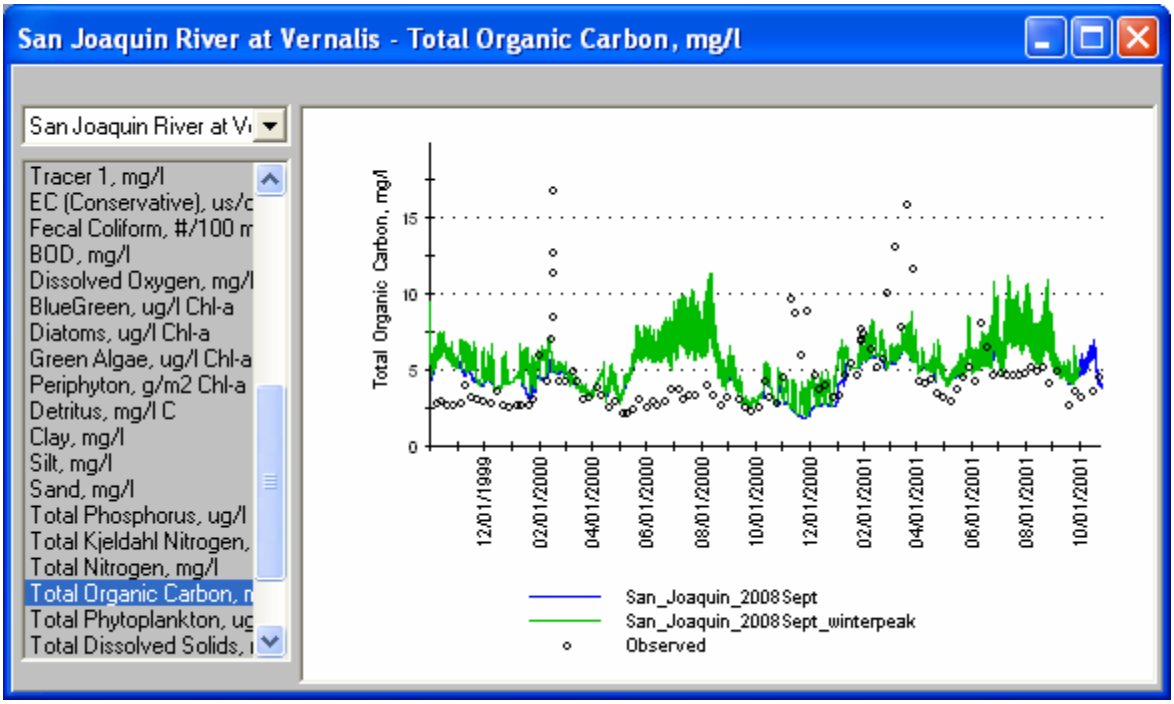

Figure 2.23 Test of 100X Organic Carbon Loading from Urbanized Land Uses

The organic carbon concentration peak of February 13-16 of 2000 coincides with rapidly increasing flow of the San Joaquin River at Vernalis as shown in Figure 2.24. The origin of that flow increase was the Merced and Tuolumne Rivers. Although the source of the organic carbon could have been within reservoir releases, the increasing flow could also have flushed organic matter from the riparian zone of the rivers which had previously been above the water level. The similar time period from 2001, shown in Figure 2.25, does not show such a clear relationship between rising flow and high organic carbon concentration. The organic carbon concentration persists at over 10 mg/l after the flow peak has risen and receded.

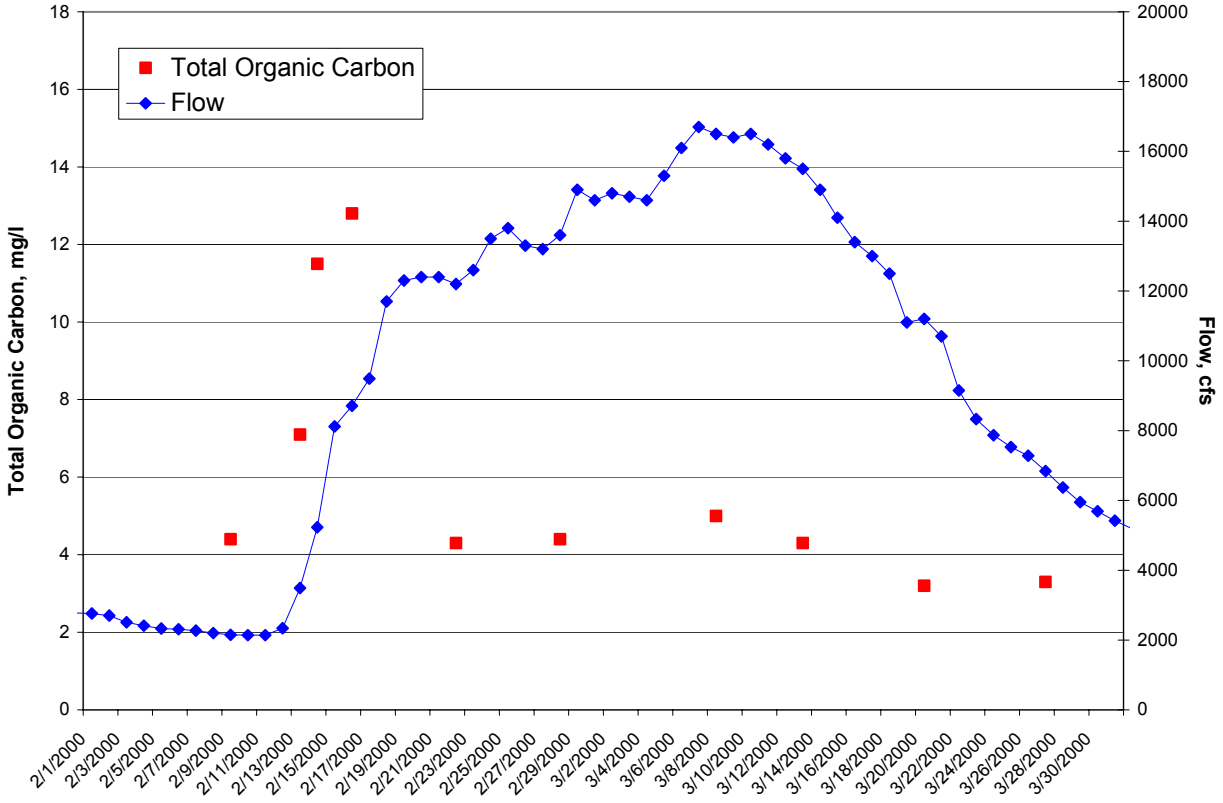

Figure 2.24 Measured Total Organic Carbon and Flow at Vernalis, February-March 2000

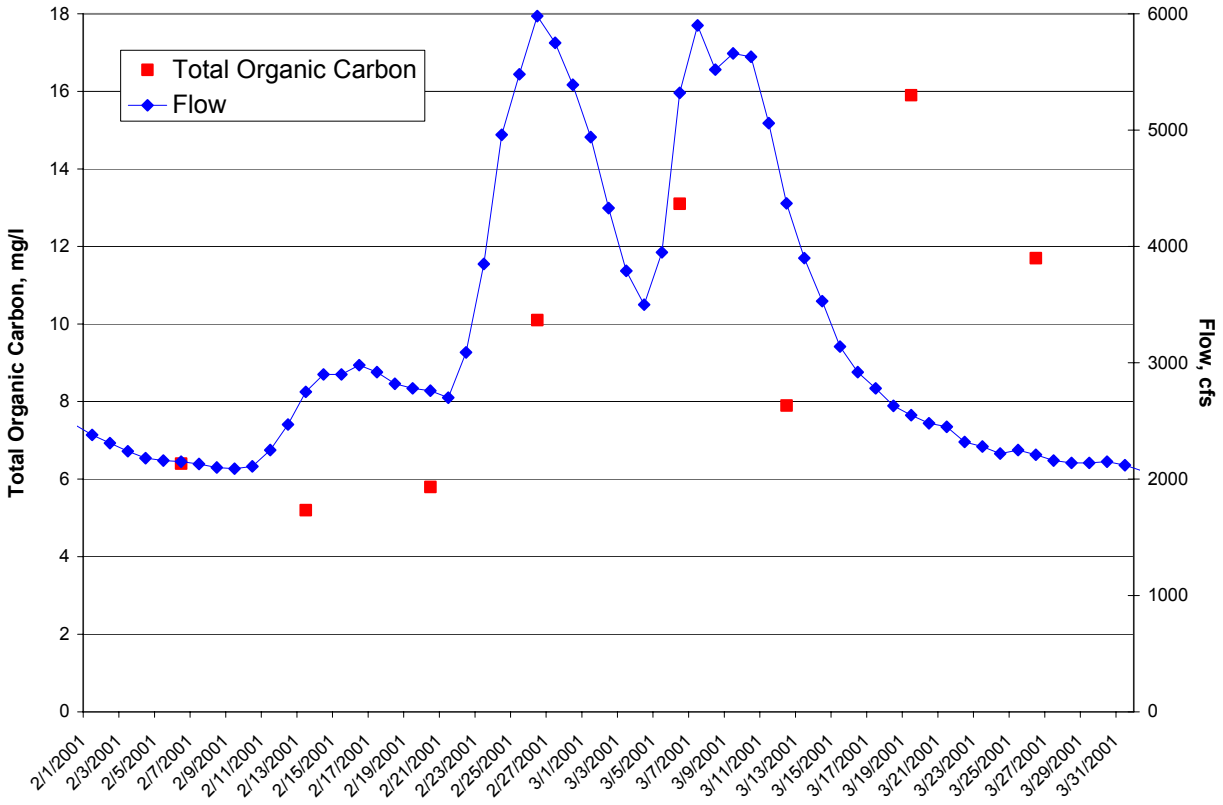

Figure 2.25 Measured Total Organic Carbon and Flow at Vernalis, February-March 2001

Another potential source of error between model predictions and measured data is insufficient data at the upstream boundary conditions. The peak concentration events could be occurring outside the model domain in one or more tributaries to the San Joaquin River. There was no organic carbon data for the tributaries in 2001, so the inflows were assumed to have average concentrations for that time of year based on other years for which there was data. Although organic carbon data was collected for the tributaries in 2000, no data happened to be collected in the tributaries from February 13-16 when the concentration peak was observed at Vernalis. The inflow concentrations were interpolated between days when data was collected on either side of the peak time period.

Simulated Summer Organic Carbon Concentration Peaks

The simulated summer peaks of total organic carbon are caused by the carbon in phytoplankton and detritus. Since the model is well-calibrated for phytoplankton, it is expected that the simulation of carbon associated with that phytoplankton would also be reasonably accurate. One possibility for the discrepancy between simulated results and observed data could be that the measurements and simulations are not comparable to each other.

Will Stringfellow of the Lawrence Berkeley Laboratory and University of the Pacific collected a large number of water quality samples as part of the dissolved oxygen TMDL upstream studies

project. He indicated that the collection and analytical methods would tend to under-represent to an unknown extent the phytoplankton and detritus (personal communication 2008). To determine if the analytical measurement method for total organic carbon could explain the discrepancy, a test simulation was created. While the original simulation includes all of the carbon in phytoplankton and detritus as part of total organic carbon, the test simulation includes only 10% of each. Figure 2.26 shows the results of this test with the original simulation in blue and the test simulation in green.

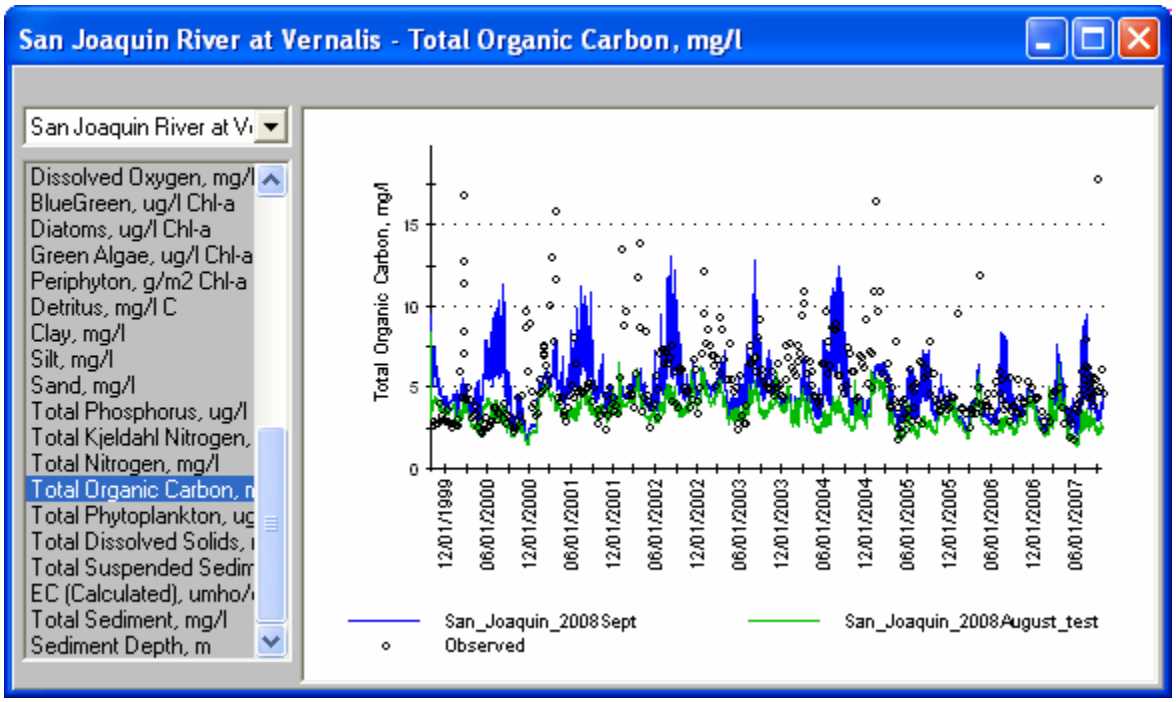

Figure 2.26 Test of Phytoplankton/Detritus Content in Total Organic Carbon at Vernalis

In the figure, the difference between the blue and green lines is exclusion of 90% of the phytoplankton and detritus from the total organic carbon tabulation. The test simulation matches the measured data from the summers of 2000 and 2001, indicating that the analytical method used for those measurements could explain the difference between the base case WARMF simulation and the measured data. The summer monitoring data from 2000 through 2004 was collected exclusively by the Department of Water Resources (DWR). In 2005 through 2007, total organic carbon data was collected by DWR and by the dissolved oxygen TMDL upstream studies.

Summary

This report focuses on the calibration of TDS/EC and organic carbon in the San Joaquin River WARMF application. Although WARMF simulates EC in two ways, the better performing method was the non-conservative EC which the model calculates by adding up the concentrations of each ion. The simulations did a good job predicting the magnitude and seasonal pattern of EC with error less than the target for calibration.

Two apparent errors in simulation results of organic carbon were noted. The first was a failure of the model to predict winter peak concentrations of both dissolved and total organic carbon observed in the water quality data. The error does not appear to be caused by the model underestimating storm water runoff from urbanized areas. There could be a flushing effect from increasing flows collecting organic matter from the riparian zone or the source of the organic carbon could be outside the WARMF model domain. There is insufficient data to explain the error.

The second discrepancy in organic carbon simulation was the model's prediction of summer peaks of total organic carbon in 2000-2002 which were not observed in water quality monitoring data. This discrepancy between the simulated and observed can be explained by the analytical technique used to measure total organic carbon under-accounting for phytoplankton and detritus.

3 SOURCE CONTRIBUTION

Introduction

The water quality calibration in Chapter 1 is useful for checking simulations against observed data. The model also provides information about source contribution of pollutants useful to the understanding of watershed system behaviors and important to the formulation of management alternatives. WARMF keeps track of not only pollutant mass, but also its source. The sources include upstream inflows at the boundary of the model domain, point sources, and nonpoint sources identified by land use.

Sources of Total Dissolved Solids

The concentration of total dissolved solids (TDS) at Vernalis is a marker indicative of salty agricultural surface and subsurface drainage entering the San Joaquin River. TDS is highly correlated to electrical conductivity, which is easily measured and used to estimate the sources of TDS.

Table 3.1 summarizes the fluxes of TDS load to the San Joaquin River over the 2000 through 2007 water years. Mud Slough, Salt Slough, agricultural drains and groundwater accretion from the land are the largest sources of TDS. Together, they account for 74% of the total source loads.

Diversions removed about 12% of the TDS load. Since two of the diversions are upstream of the Tuolumne River confluence and a third diversion is upstream of the Stanislaus River, the diverted water has high TDS. The salts removed from the river eventually return as irrigation water applied to the land which drains back to the San Joaquin River through agricultural facilities or groundwater accretion.

Table 3.1
Sources of Total Dissolved Solids to the San Joaquin River

Sources	Total Dissolved Solids (tons/day)
Stanislaus River	125
Tuolumne River	232
Merced River	111
San Joaquin River	192
Salt Slough	466
Mud Slough	606
Los Banos Creek	90
Orestimba Creek	26
Del Puerto Creek	6
Hospital & Ingram Creeks	26
Agricultural Spills / Drains + Modesto WQCF	251
Groundwater Accretion and Surface Runoff	943
Resuspension from River Bed	0
Sinks	
Settling to River Bed	0
Net Uptake/Adsorption/Deaeration	147
Diversions	375
Net Load in San Joaquin at Old River	2,552

Figure 3.1 shows the relationship between TDS load and TDS concentration at Vernalis. High TDS loads led to high TDS concentration in the receiving water. From midsummer through midwinter, the TDS concentration increased with higher TDS loads from agricultural drainage, Mud Slough, and Salt Slough. The concentration generally increased as flow from the east side tributaries decreased. In the spring, the TDS load to the San Joaquin River was relatively low while flow was high, producing the lowest seasonal TDS concentrations.

The relationship between TDS loads and TDS concentration was unusual in the wet years of 2005 and 2006. Both TDS load and TDS concentration were dominated by the boundary river inflows in late winter and early spring. Although the load was high, the TDS concentration was lower than in a normal year.

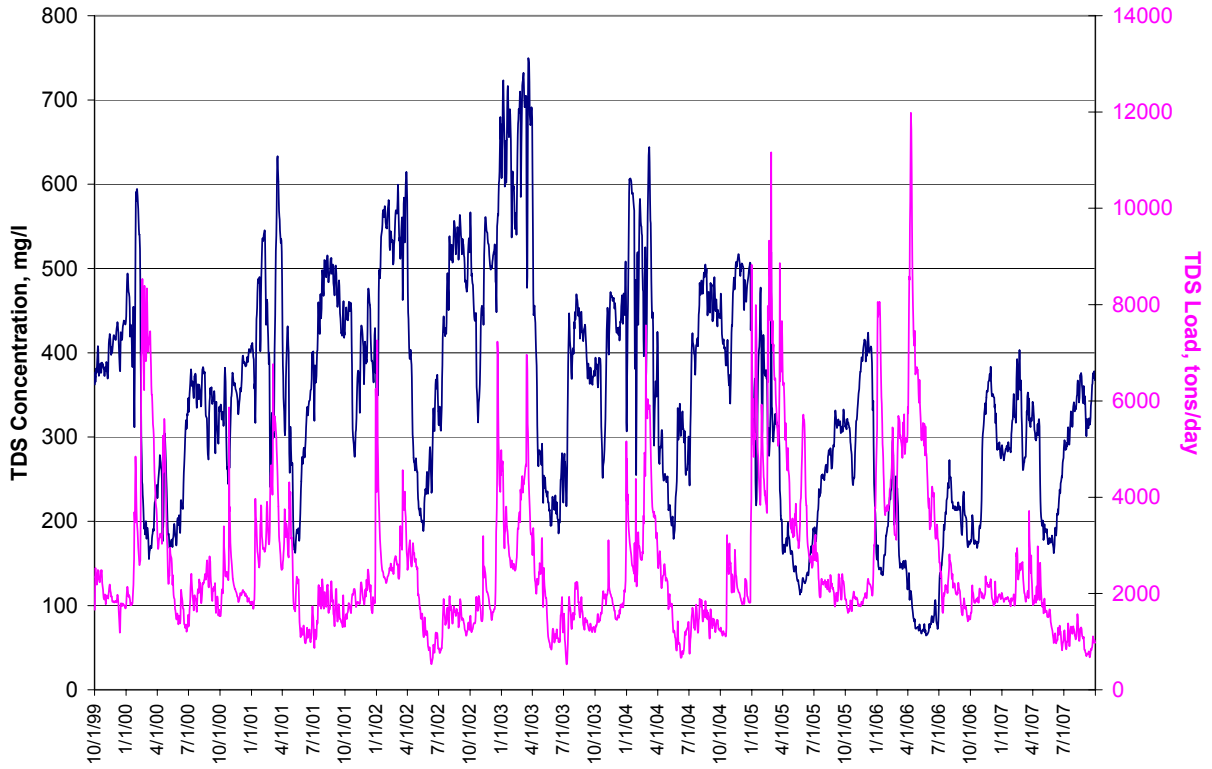

Figure 3.1 TDS Load (Pink Line) vs. TDS Concentration (Black Line) at Vernalis

Sources of Total Organic Carbon

Table 5.3 summarizes the sources of total organic carbon load to the San Joaquin River. The boundary river inflows contributed 69% of the total organic carbon loaded to the San Joaquin River. 5% was contributed by agricultural drains and spills. Nonpoint source load from the land contributed 18% of the load. Net growth of phytoplankton in the river was responsible for 8% of the total organic carbon. Diversions removed 13% of the organic carbon from the river.

Figure 3.2 shows the relationship between total organic carbon load and concentration at Vernalis. Spring runoff after wet winters produced the highest loading of organic carbon. Although total organic concentrations were typically elevated in summer, the load was not elevated since this is the low flow season.

Table 3.2
Sources of Total Organic Carbon to the San Joaquin River

Sources	Total Organic Carbon (tons/day)
Stanislaus River	5.7
Tuolumne River	7.7
Merced River	5.0
San Joaquin River	7.6
Salt Slough	4.1
Mud Slough	4.1
Los Banos Creek	1.1
Orestimba Creek	0.4
Del Puerto Creek	0.1
Hospital & Ingram Creeks	0.2
Agricultural Spills / Drains + Modesto WQCF	2.5
Groundwater Accretion and Surface Runoff	9.3
Net Production	4.0
Resuspension from River Bed	0.1
Sinks	
Settling to River Bed	0.5
Diversions	6.6
TOTAL	44.8

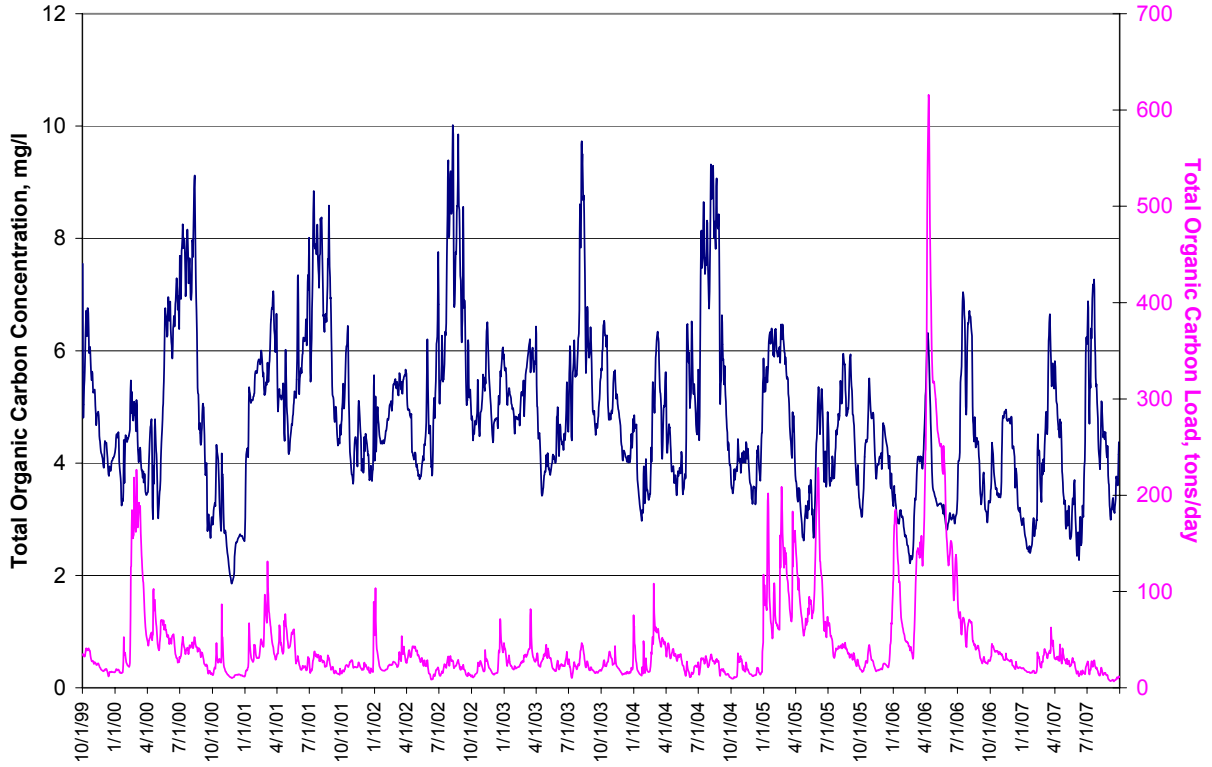

Figure 3.2 Total Organic Carbon Load (Pink Line) vs. Concentration at Vernalis

4 CONCLUSION AND RECOMMENDATIONS

The calibration of the WARMF model showed reasonable results for total dissolved solids / electrical conductivity, dissolved organic carbon, and total organic carbon. Calibration of electrical conductivity met the targets of less than 10% relative error and less than 20% absolute error. Total organic carbon simulations showed two types of systematic errors in the early part of the simulation period: a failure to simulate the winter peaks which were measured at Vernalis and simulation of summer peaks which were not measured in 2000-2002. The latter problem can be explained by analytical technique when measuring total organic carbon, but there are multiple possible explanations for the observed winter peaks.

Since the winter peaks of organic carbon can coincide with the rising limb of the spring runoff hydrograph, targeted monitoring can evaluate whether the source of the high organic carbon concentration is the reservoirs, the east side tributaries, or the San Joaquin River proper. Measuring the dissolved and total organic carbon in the tributaries and at multiple locations in the San Joaquin River during the start of spring runoff is recommended to identify the source of the organic carbon loading.

The sources of total dissolved solids were identified. About ¾ of the TDS loading comes from the concentrated sources of groundwater accretion, Mud Slough, Salt Slough, and agricultural drains. Since TDS from groundwater and west side tributaries contribute substantial loading to the San Joaquin River, the concentration of TDS is in large part a function of the amount of fresh water from the east side tributaries is available for dilution. Control of TDS at Vernalis can be done by changing agricultural practices which cause the TDS loading or changing the management of the east side reservoirs which dilute it.

Total organic carbon loading is not dominated by a few concentrated sources, but rather comes from a combination of groundwater accretion, tributary inflows, and in-stream generation by phytoplankton. Peak concentrations in summer caused by phytoplankton blooms occur when flow is relatively low, while winter peak concentrations occur when flow is high. Control of the seed phytoplankton entering the San Joaquin River from its tributaries can reduce the summer peak concentrations, but more needs to be learned about the cause of winter organic carbon peak concentrations before control strategies can be devised.

The San Joaquin River WARMF application is ready to simulate present and future water quality conditions as input to the Delta DSM2 model. Future conditions which can be simulated include land use changes, best management practices, new reservoir release regimes, and changed irrigation practices. Under all simulated scenarios, the key pollutant sources can be identified and tracked through WARMF and DSM2 to determine the ultimate impact at the Delta drinking water intakes. Results from DSM2 can be used to prioritize the upstream management practices to improve drinking water quality when it is most critical.

5 REFERENCES

Driscoll, Jr. C. T., R.A. Bodaly, O.R. Bullock, Jr., D.P. Krabbenhoft, R.P. Mason, C.D. Pollman, and T. A. Wool. 2004. "Report of The Peer Review Panel on the Development of the Watershed Analysis Rish Management Framework (WARMF) Model to Assess Mercury in the Western Lake Superior Basin, Minnesota", University of Minnesota Sea Grant Program, Duluth, Minnesota, Publication No. CT 15.

Herr, J., Weintraub, L.H.Z., and Chen, C.W. 2001. "User's Guide to WARMF: Documentation of Graphical User Interface," EPRI, Palo Alto, CA. Topical Report.

Herr, J., and C. W. Chen 2006 (a). "Calibration Report": a deliverable report for the CALFED Project ERP-02D-P63, Monitoring and Investigation of the San Joaquin River and Tributataries Related to Dissolved Oxygen, Task 6 Model Calibration and Forecasting. Systech Engineering, Inc. San Ramon, California.

Herr, J., C. W. Chen 2008. "Extension of WARMF Model of the San Joaquin River from Lander Avenue to Friant Dam (Phase I) ": a deliverable report for the Bureau of Reclamation WARMF Extension Contract. Systech Water Resources, Inc. Walnut Creek, California.

Herr, J., C. W. Chen, and K. van Werkhoven 2008. "Final Report for the Task 6 Modeling of the San Joaquin River": a deliverable report for the CALFED Project ERP-02D-P63, Monitoring and Investigation of the San Joaquin River and Tributaries Related to Dissolved Oxygen, Task 6 Model Calibration and Forecasting. Systech Water Resources, Inc. Walnut Creek, California.

Jones & Stokes. 2005. "San Joaquin River Deep Water Ship Channel Demonstration Dissolved Oxygen Aeration Facility Initial Study/Mitigated Negative Declaration". Prepared for California Department of Water Resources.

Keller A., 2000 "Peer review of the watershed analysis risk management framework (WARMF): an evaluation of WARMF for TMDL applications by independent experts using USEPA guidelines", Electric Power Research Institute, Palo Alto, CA. Technical Report 1000252.

Keller A. 2001. "Peer Review of the Acid Mine Drainage Module of the Watershed Analysis Risk Management Framework (WARMF) – An evaluation of WARMF/AMD using EPA Guidelines", Electric Power Research Institute, Palo Alto, CA. Technical Report 1005182.

Kratzer, C.R., P.D. Dileanis, C. Zamora, S. R. Silva, C. Kendall, B.A. Bergamaschi, and R. A Dahlgren. 2004. "Sources and Transport of Nutrients, Organic Carbon, and Chlorophyll-a in the

San Joaquin River Upstream of Vernalis, California, during Summer and Fall, 2000 and 2001", Water Resources Investigations Report 03-4127, US Geological Survey, Sacramento, CA.

List, E.J. and S.C. Paulsen, 2008. "Peer Review of San Joaquin River Watershed Modeling" Final Draft, Flow Science Incorporated, Pasadena, CA.