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San Joaquin Valley Drainage Authority

San Joaquin River
Up-Stream DO TMDL Project
ERP - 02D - P63

Task 6: Modeling Study

Forecasting Results Report

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INTRODUCTION

This is a deliverable report of Task 6 Model Calibration and Forecasting. The task is a part of the CALFED Project (ERP-02D-P63): Monitoring and Investigation of the San Joaquin River and Tributaries Related to Dissolved Oxygen. The Forecasting Procedure Report of December 2006 (Herr and Chen 2006b) outlined the procedure for forecasting dissolved oxygen in the Stockton Deep Water Ship Channel (DWSC). This report describes the results of forecasting which took place in summer 2007.

The usefulness of a model can be judged by its capability to make predictions. Given the input data of meteorology (daily precipitation, daily maximum and minimum ambient temperatures, wind speed, solar radiation, etc.) and operating conditions (flow releases from reservoirs, irrigation diversions, irrigation applications, waste discharges, aerator operation, etc.), the model should accurately predict the stream flows and water quality at various stations along the river system.

The predictive capability of the model can be tested in different stages of model development and application. For model calibration, the actual meteorological and operating data for the field sampling period are used to drive the model. The model predicts the stream flows and water quality which are compared to the observed values for confirmation. If they do not match, the model coefficients are adjusted to reduce the initial uncertainties of model coefficients to yield improved simulations.

For application to real time water quality management in the future, the anticipated meteorological and operating data are used to drive the model. The model forecasts the stream flows and water quality, which are compared to the water quality objectives. If the predicted water quality does not satisfy the objectives, the model can be used to design an operational plan to meet water quality objectives by exploring various operational changes or remedial measures to improve the water quality.

Forecasting was performed in July 2007 based on an anticipated action to shut off flow from the San Luis Drain. This report describes the procedure used, predictions made, and how the projected model inputs and model predictions compare to measured data.

Real Time Water Quality Management of Dissolved Oxygen

The methods used for model forecasting are demonstrated in an existing system. California Department of Water Resources (DWR) in cooperation with US Bureau of Reclamation (Reclamation) has previously developed a real time water quality management system of total dissolved solids (TDS) for the Upper San Joaquin River. The general concepts for the water quality management system have been described by Quinn et al. (1997). The purpose is to create a framework for various water resource managers to coordinate their flow releases to meet the EC objectives for the San Joaquin River at Vernalis.

The real time water quality management of dissolved oxygen will follow the same concepts and procedures for the real time water quality management of TDS. However, it will be more complex, because it requires two models to make the forecasts instead of one, and there are several more water quality parameters requiring model inputs.

The dissolved oxygen criterion is sometimes violated at the DWSC, which is located in the Lower San Joaquin River near Stockton. It was caused in part by the large river loads (i.e., high concentrations) of algae from upstream (Chen and Tsai 2000). The forecasting model must include the DWSC and the upstream San Joaquin River segments.

The San Joaquin River downstream of Vernalis is influenced by tides, which requires an estuary model. The non-tidal San Joaquin River, on the other hand, is strongly influenced by agricultural practices, which requires a watershed model.

An estuary model has already been developed for the tidal portion of the San Joaquin River, extending from Mossdale to the Stockton DWSC at Venice Island (Schanz and Chen 1993, and Chen and Tsai 2002). The WARMF watershed model has been developed and calibrated for the San Joaquin River Basin upstream of Mossdale, which is the interface point for the two models.

To link the two models together, a graphical user interface has been developed as shown in Figure 1. The interface automatically transfers the output from the Upper San Joaquin River Basin model to the input of the estuary model of the Lower San Joaquin River. One can, therefore, run both models through the interface.

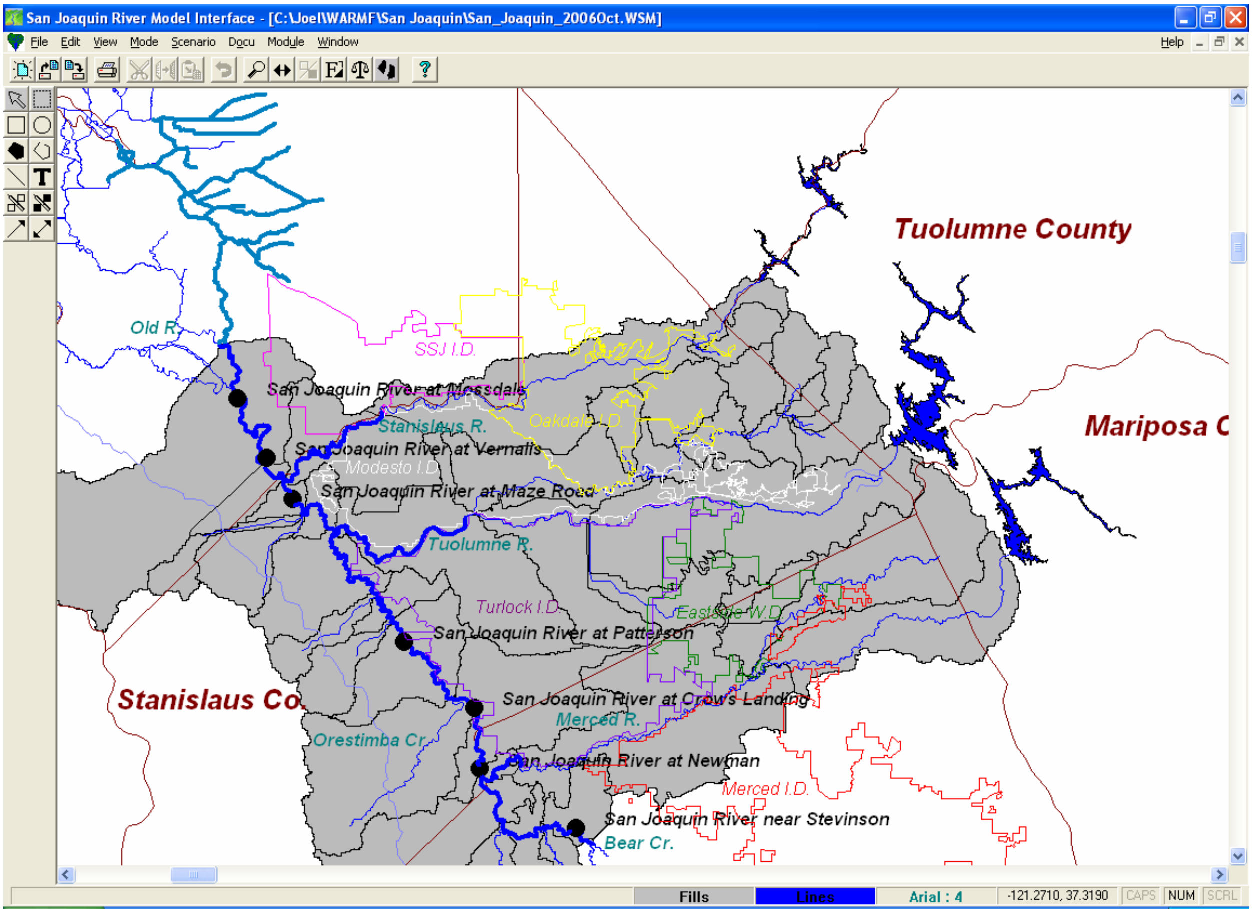

Figure 1 Graphical User Interface for the Upper San Joaquin River Basin Model and the Estuary Model of the Lower San Joaquin River and DWSC

The WARMF San Joaquin River Basin Model has been calibrated (Herr and Chen 2006a). For the calibration, the meteorology and river flow data was compiled for the period of water years 2000 to 2005, when bi-weekly river water quality data were collected. With this data, the model predicts stream flow and water quality at various locations where the data has been monitored. The calibrated model can then predict the future conditions given projected model inputs and determine the effectiveness of measures designed to reduce the organic loading to the DWSC.

Testing Organic Load Reduction Strategies

Multiple strategies have been proposed to reduce the organic loading to the DWSC and increase the dissolved oxygen concentration. The strategies involve alterations of the flow regime, a reduction in phytoplankton loading to the San Joaquin River, and direct injection of oxygen into the DWSC. Two proposed methods were tested in WARMF: recirculation of Delta-Mendota Canal water to the San Joaquin River via the Newman Wasteway and temporary shutoff of the San Luis Drain. The first strategy has two potential positive effects: dilution of phytoplankton and decrease in travel time down the river to reduce phytoplankton growth. The benefit of shutting off San Luis Drain is to remove a large source of phytoplankton seed to the upper part of the river so that exponential growth of the reduced phytoplankton seed will result in less phytoplankton entering the DWSC.

To test these strategies, the historical simulation period of water years 2000-2005 was used. Each strategy was put into operation in WARMF one week before dissolved oxygen concentrations in the DWSC dropped below 5 mg/l and remained in operation until the dissolved oxygen concentration recovered. Figure 2 shows the time series results at Vernalis for summer of 2002. Blue represents the base case simulation with no action taken; green is recirculation of 250 cfs of Delta-Mendota Canal water; red is shutting off the San Luis Drain.

The figure shows that the changes don't always result in a reduction of phytoplankton loading at Vernalis. The Delta-Mendota Canal recirculation strategy results in higher predicted phytoplankton loading in early July. Over the entire period from May 15 – October 15, 2002, however, the simulated Delta-Mendota Canal recirculation strategy had 3% less phytoplankton loading at Vernalis than the do nothing case. The shutoff of the San Luis Drain reduced phytoplankton loading by 6% on average.

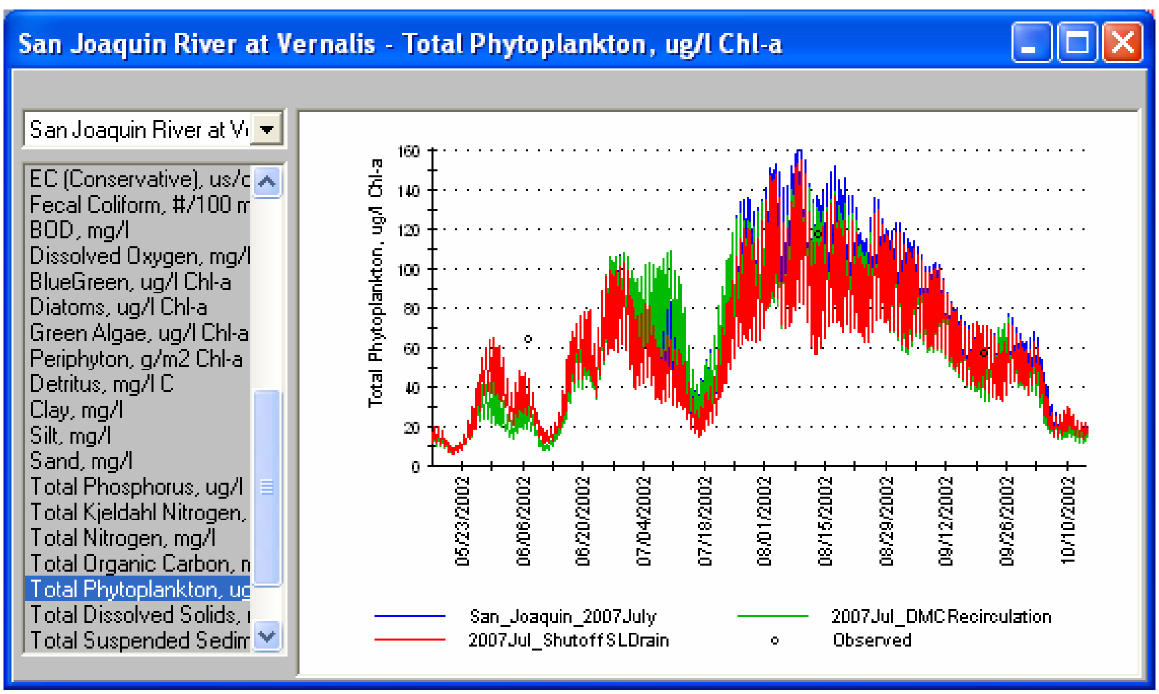

Figure 2: Predicted phytoplankton concentrations at Vernalis for organic load reduction strategies

The predicted change to phytoplankton concentration at Vernalis, however, had almost no effect on predicted dissolved oxygen in the DWSC as shown in Figure 3. A more thorough examination of the Link-Node model would be required to determine why the changes to organic loading appeared to have little effect on dissolved oxygen concentration in the DWSC.

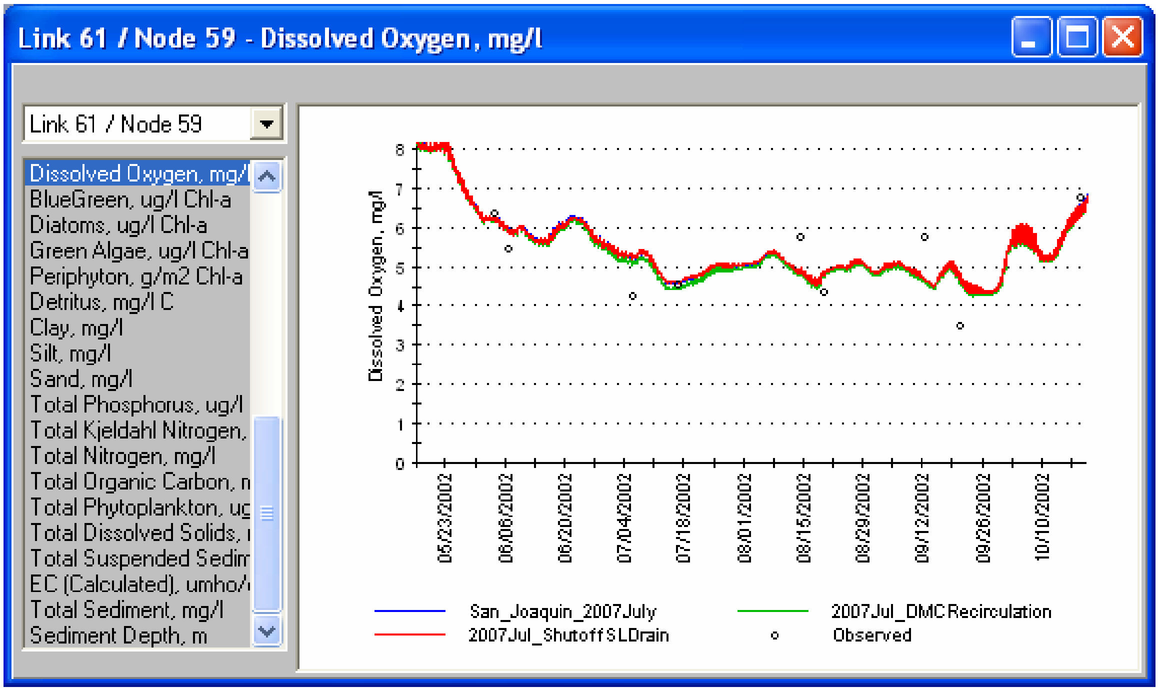

Figure 3: Predicted dissolved oxygen concentrations at Buckley Cove (DWSC) for organic load reduction strategies

Real-time Forecasting Simulation

A field test to confirm the effectiveness of the strategy to shut off the San Luis Drain was scheduled for July 23, 2007 to last for up to one week. This provided the opportunity to test the application of WARMF as a forecasting tool.

There are many time series inputs required to run WARMF including tributary inflows, agricultural drains, and diversions. For diversions, only flow data is required. Tributary inflows and agricultural drains require flow, temperature, EC, and all other water quality constituents. Of particular importance are those water quality constituents impacting phytoplankton growth: nutrients, sediment, and phytoplankton concentration itself.

Real-time data sources provide some of these model inputs, but most require estimation. To get estimates, an analogous time period is used. Since 2007 is a dry year, a similar year is needed within the 2000-2005 water years for which model time series data is complete. To find an analogous year, the river flow was analyzed for the first two weeks in July for each year as shown in Table 1.

Table 1: Average Flows, July 1-14

Year	Mud Slough	Salt Slough	SJR at Lander	Merced River	Tuolumne River	Stanislaus River	SJR at Vernalis
2000	73	221	97	194	509	423	1884
2001	74	167	41	147	204	555	1396
2002	73	143	30	96	228	528	1275
2003	56	136	11	115	352	612	1630
2004	91	150	14	101	246	601	1199
2005	91	225	174	1267	2934	323	5446
2007	**24**	**147**	**31**	**173**	**257**	**451**	**1076**

Either 2002 or 2004, both drier than average years with low flow at Vernalis, could be used as an analog for 2007. The combined tributary flows in 2002 are 15 cfs greater than those observed in 2007 and the flow at Vernalis is 199 cfs greater. 2004 tributary flows combined are 120 cfs more than in 2007 but the flow at Vernalis was just 124 cfs greater than in 2007. 2002 was chosen as the analog year because of the closer match of its tributary flows, although a match of tributary flows is not necessarily more important than a match of Vernalis flow in finding a suitable analog year.

Table 2 shows the sources of data used for the forecasting simulation. Real-time flow data was available up until the time the simulation was run on July 19th for the major tributaries. Temperature and EC data was available for most of the tributary inflows, but there was no real-time data available for phytoplankton or other water quality parameters. All 14 simulated agricultural drains and all 18 simulated diversions used 2002 data because no real-time data was available.

Table 2: Sources of tributary inflow data for 2007 forecasting simulation

Tributary Inflow	Flow	Temperature	EC	Phytoplankton	Other WQ
Stanislaus River	Real-time	2002 data	2002 data	2002 data	2002 data
Tuolumne River	Real-time	Real-time	Real-time	2002 data	2002 data
Merced River	Real-time	Real-time	Real-time	2002 data	2002 data
San Joaquin River	Real-time	Real-time	Real-time	2002 data	2002 data
Salt Slough	Real-time	Real-time	Real-time	2002 data	2002 data
Mud Slough	Real-time	Real-time	Real-time	2002 data	2002 data
Los Banos Creek	2002 data	2002 data	2002 data	2002 data	2002 data
Orestimba Creek	Real-time	Real-time	Real-time	2002 data	2002 data
Del Puerto Creek	2002 data	Real-time	Real-time	2002 data	2002 data
Hospital Creek	2002 data	Real-time	Real-time	2002 data	2002 data
Ingram Creek	2002 data	Real-time	Real-time	2002 data	2002 data
Delta-Mendota Canal	2002 data	Real-time	Real-time	2002 data	2002 data
Modesto Canal	Real-time	2002 data	2002 data	2002 data	2002 data
Turlock Canal	2002 data	2002 data	2002 data	2002 data	2002 data

Real-time flow data was projected into the future by first comparing the data at each tributary inflow between July 1-14, 2007 and July 1-14, 2002. A ratio of the flows between 2007 and 2002 was calculated for each tributary based on the average flows shown in Table 1 and then 2002 flows from July 15-August 6 2002 were modified based on those ratios to represent July 15-August 6, 2007.

A similar method was used to calculate projected EC from 2002 and 2007 data for the Merced and Tuolumne Rivers. The Stanislaus River has no real-time EC monitoring, so 2002 data was used unaltered. Mud Slough and the San Joaquin River at Lander Avenue showed strong decreasing trends in measured EC leading up to the date the simulation was run, so for those locations a constant EC was used representing the end of the trend in the data. Salt Slough showed a relatively constant EC (916-2020 μs/cm) for the weeks leading up to the simulation, so an average value was used for the forecasted EC.

The model was run from July 1 through August 6 using the hybrid data from 2007 and 2002. A base case simulation was run assuming no action was taken. Then the tributary inflow file for Mud Slough was modified to simulate the elimination of the contribution from San Luis Drain from July 23 through July 30. Historical data was examined to determine the proportion of Mud Slough flow, EC, phytoplankton, and other water quality constituents contributed by the San Luis Drain under summer conditions. The data indicated that San Luis Drain would represent essentially all the flow in Mud Slough, so the assumption was made that the shutoff would reduce the Mud Slough flow and loading to zero.

Forecasting Inputs

The tributary flow and phytoplankton concentrations are the model inputs to which the forecasts of phytoplankton concentration at Vernalis are most sensitive. Flow inputs affect travel time down the San Joaquin River, which in turn controls how much phytoplankton is able to grow. Phytoplankton inputs are the amount of seed phytoplankton available in the upper part of the San Joaquin River for exponential growth as it flows downstream.

Flow Inputs

Real-time flow data through July 18, 2007 was included in the forecasting simulation, but flow had to be forecasted for July 19 through August 6. Real-time monitoring data was subsequently collected after the conclusion of the forecast period. Figure 4 shows the forecast and measured flow for Mud Slough, Salt Slough, and the San Joaquin River at Lander Avenue. Solid colors represent the forecasted flows and the discrete shapes are measured data. Mud Slough never went below 9 cfs, indicating the assumption that all Mud Slough flow came from the San Luis Drain is not valid. Measured flow in the San Joaquin River at Lander Avenue was less than the forecast. Forecasted flow for Salt Slough was accurate one week into the future, but was greatly overestimated for the second and third weeks.

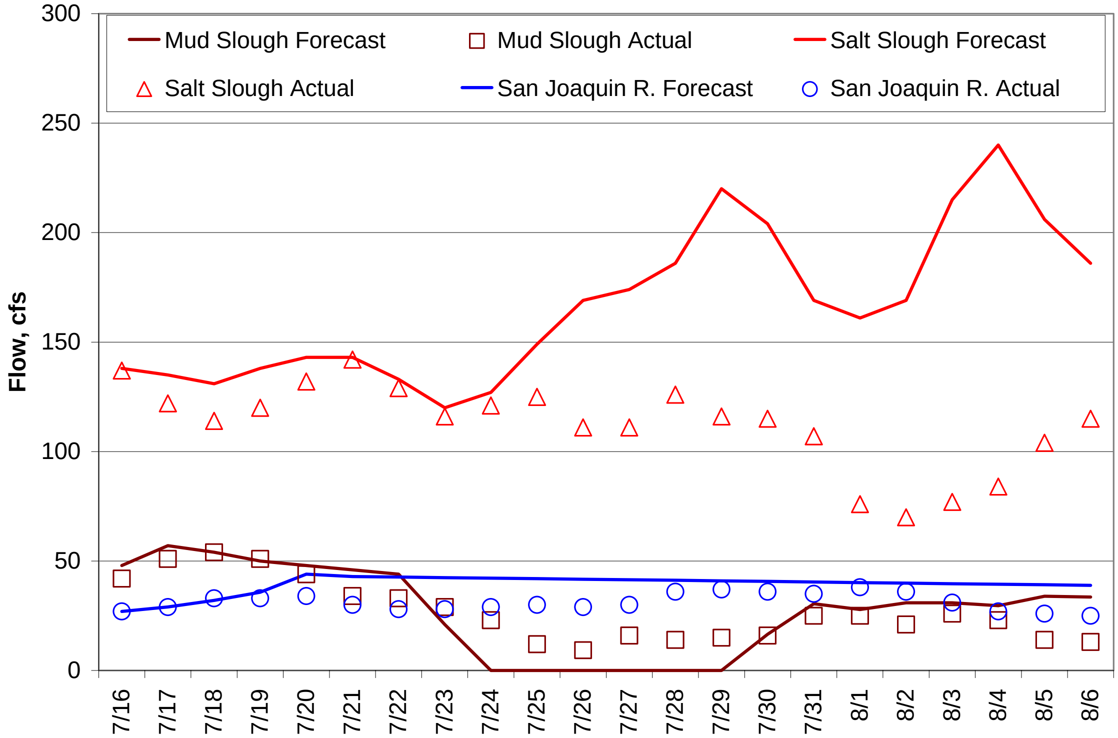

Figure 4: Forecast and actual flow inputs for Mud Slough, Salt Slough, and San Joaquin River at Lander Avenue

Figure 5 shows the forecasted flows (in solid lines) for the three major east side tributaries compared against the subsequently measured flows (discrete shapes). Forecasted flow for the Merced River and Stanislaus Rivers was too low. The measured Tuolumne River flow was close to the forecasted flow for two weeks, but the forecasted flow was too high in the final week of the simulation.

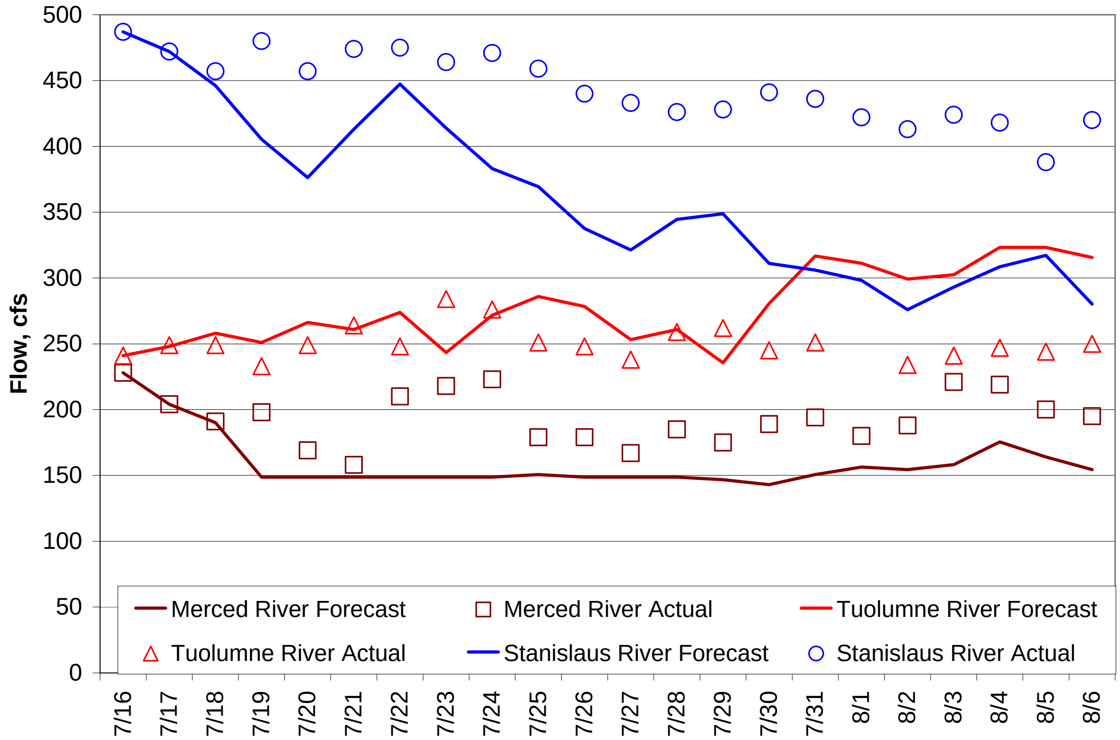

Figure 5: Forecast and actual flow inputs for Merced River, Tuolumne River, and Stanislaus River

The relative error of forecasted flows shown in Table 3 is the average forecasted flow minus the average observed flow, divided by observed flow. It is a measure of bias in the forecast. Since there was significant error in most of the flow forecasts, alternate methods of forecasting future flows should be explored to find methods with greater accuracy.

Table 3: Relative error of forecasted flows, July 19 – August 6, 2007

	Mud Slough	Salt Slough	San Joaquin River	Merced River	Tuolumne River	Stanislaus River
Forecast	0%	+55%	+30%	-21%	+12%	-22%

Phytoplankton Inputs

No real-time data is available for phytoplankton concentrations, so the concentrations from 2002 were used for all model inputs when running the forecasting simulations. Collection of phytoplankton data during the forecasting period allows us to check the assumptions made in the model inputs to determine the error in the forecasts used to drive the model. Figure 6 shows the forecasted phytoplankton concentrations in solid lines and the measured data in discrete shapes. The 2002 phytoplankton concentrations used for 2007 forecasts were much higher than actual 2007 data for Mud Slough. Forecasted phytoplankton concentrations for the San Joaquin River at Lander Avenue were lower than measured data in the first week of the forecast and then higher than actual concentrations for the remaining two weeks of the simulation. The 2002 phytoplankton data used to forecast Salt Slough concentrations in 2007 were relatively accurate.

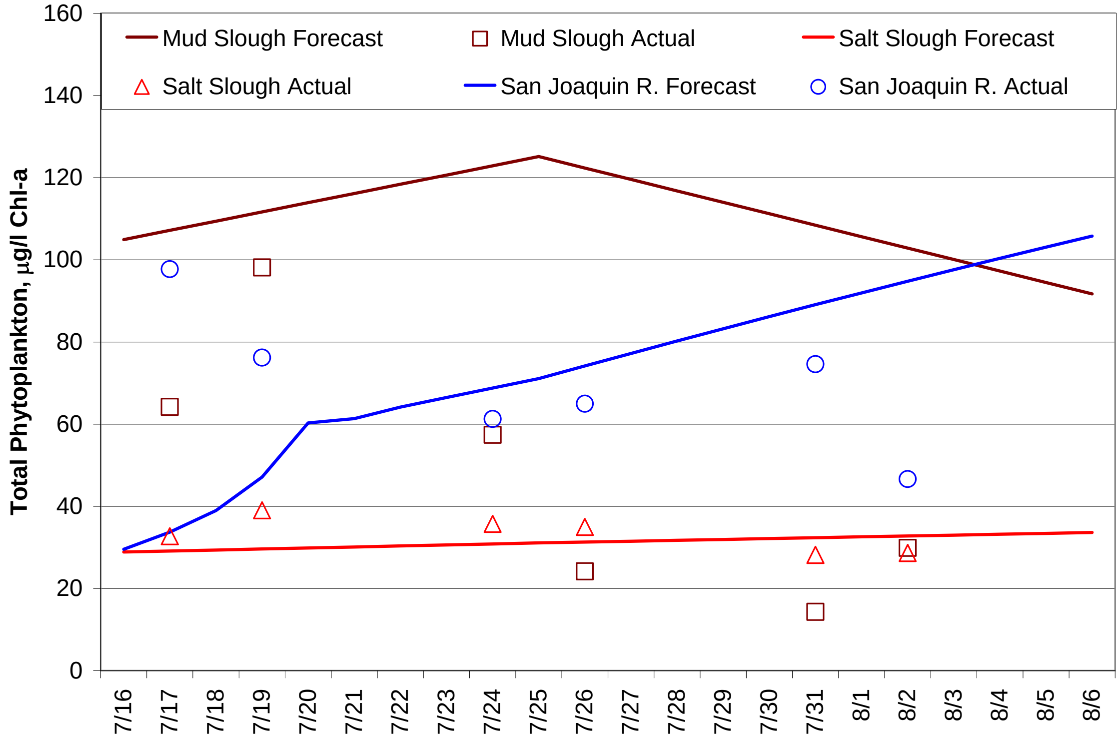

Figure 6: Forecast and actual phytoplankton concentration inputs for Mud Slough, Salt Slough, and San Joaquin River at Lander Avenue

The model inputs and measured phytoplankton concentrations for the major east side tributaries are shown in Figure 7. Although the phytoplankton concentrations of both model inputs and measured data are very low, the model input concentrations are much higher than the observed for all three rivers.

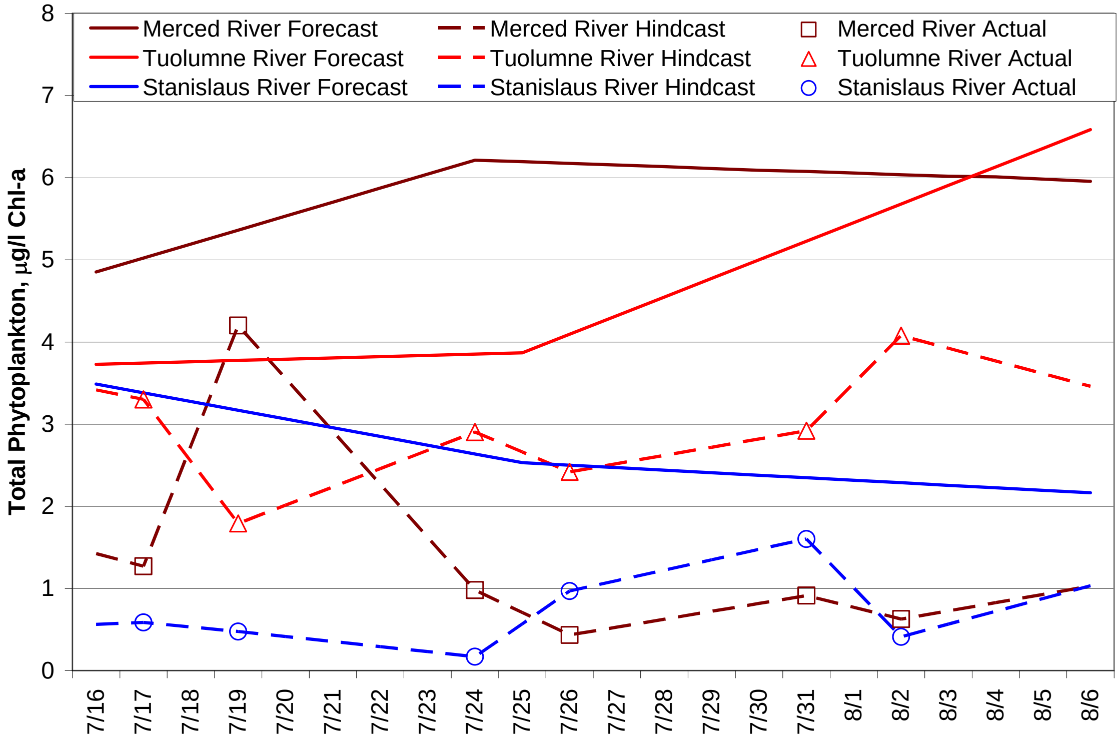

Figure 7: Forecast and actual phytoplankton concentration inputs for Merced River, Tuolumne River, and Stanislaus River

The relative error of forecasted phytoplankton shown in Table 4 is the average forecasted phytoplankton minus the average observed values, divided by observed. The use of 2002 phytoplankton data for the model forecast caused large errors in the model inputs for Mud Slough, Merced River, Tuolumne River, and Stanislaus River.

Table 4: Relative error of forecasted phytoplankton, July 16 – August 6, 2007

	Mud Slough	Salt Slough	San Joaquin River	Merced River	Tuolumne River	Stanislaus River
Forecast	+250%	-5%	+8%	+601%	+57%	+525%

Electrical Conductivity Inputs

Although EC has no direct bearing on the phytoplankton concentration of the San Joaquin River where it enters the DWSC, it is a measure determining whether the proportion of fresh and saline flow sources used by the model is accurate. Real-time EC data through July 18, 2007 was included in the forecasting simulation, but EC had to be forecasted for July 19 through August 6. Real-time monitoring data was subsequently collected after the conclusion of the forecast period. Figure 8 shows the forecast and measured EC for Mud Slough, Salt Slough, and the San Joaquin River at Lander Avenue. Solid colors represent the forecasted EC and the discrete shapes are measured data. The

Mud Slough, Salt Slough, and San Joaquin River at Lander Avenue EC forecast all assumed a constant concentration. Mud Slough and San Joaquin River both recorded rapidly decreasing EC leading up to the simulation, so the forecasted values assumed a value at the end of the trend. Measured EC at Salt Slough was very constant (913-1020 µs/cm) in the two weeks leading up to the simulation, so the average over that time period was used in the forecast. Forecasted EC was usually less than subsequently observed for all three locations as shown in Figure 8. Solid lines are the forecasted EC and discrete shapes are the observed for each location.

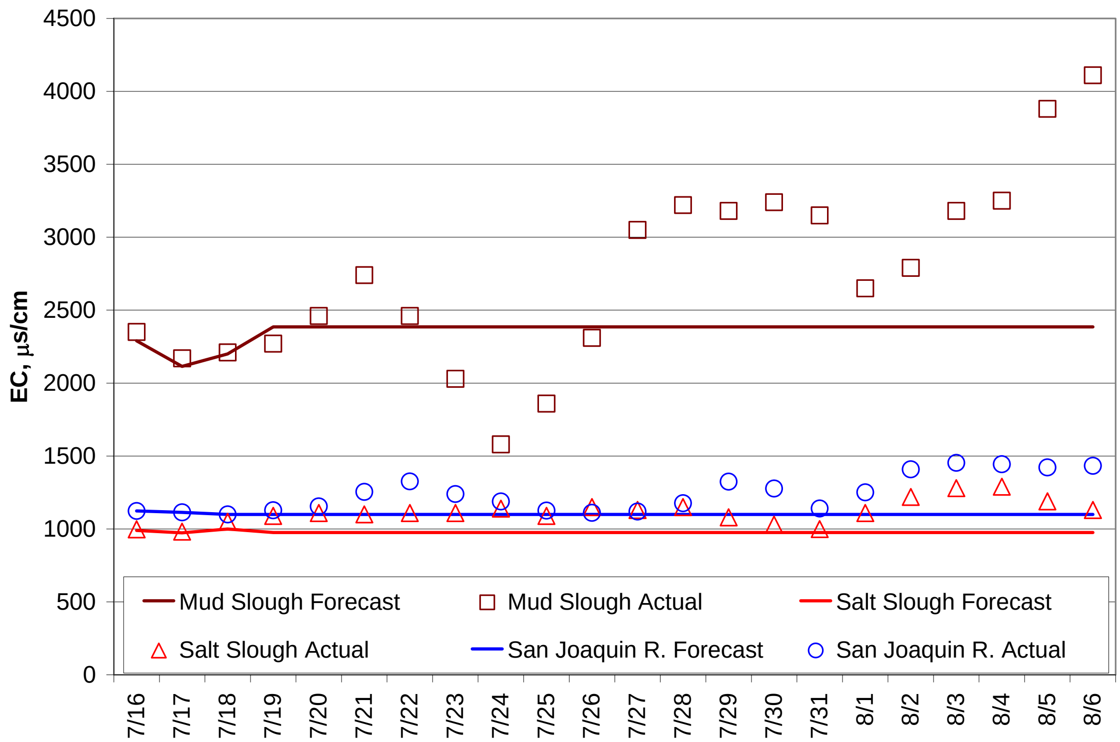

Figure 8: Forecast and actual EC inputs for Mud Slough, Salt Slough, and San Joaquin River at Lander Avenue

Figure 9 shows the forecasted EC (in solid lines) for the three major east side tributaries compared against the subsequently measured EC (discrete shapes). The forecasted EC for the Merced River was reasonably good, but for Tuolumne River it was higher than measured. Grab samples measuring EC for the Stanislaus River recorded slightly higher values than those used as model inputs.

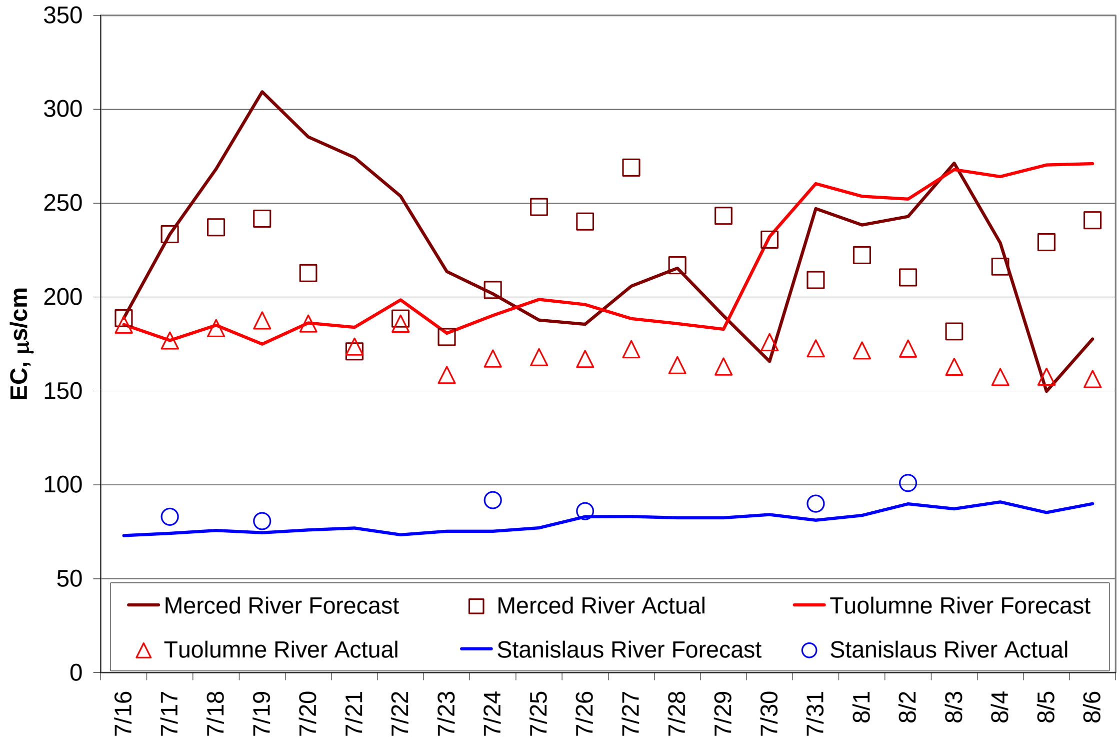

Figure 9: Forecast and actual EC inputs for Merced River, Tuolumne River, and Stanislaus River

The relative error of EC shown in Table 5 is the average forecasted EC minus the average observed EC, divided by observed EC. Having real-time data for EC provided a good basis for forecasting and produced much better accuracy than the forecasted phytoplankton.

Table 5: Relative error of forecasted EC, July 19 – August 6, 2007

	Mud Slough	Salt Slough	San Joaquin River	Merced River	Tuolumne River	Stanislaus River
Forecast	-15%	-14%	-13%	+2%	+29%	-10%

Forecasting Outputs

The simulated flow, EC, and phytoplankton of a forecasting simulation can be compared against subsequently measured data. The comparison tells us if the combination of forecasting technique, data available for forecasting, and calibrated model can predict water quality accurately.

Simulated and observed flow at Vernalis is shown in Figure 10. The simulated flow is initially 35% greater than the observed data, but overall averages 20% more than measured values. The chosen analog year of 2002 used for diversions, agricultural drains, and smaller tributary inflows had higher flow at Vernalis than was observed in 2007. The effects of that discrepancy are embedded in the forecasted flow.

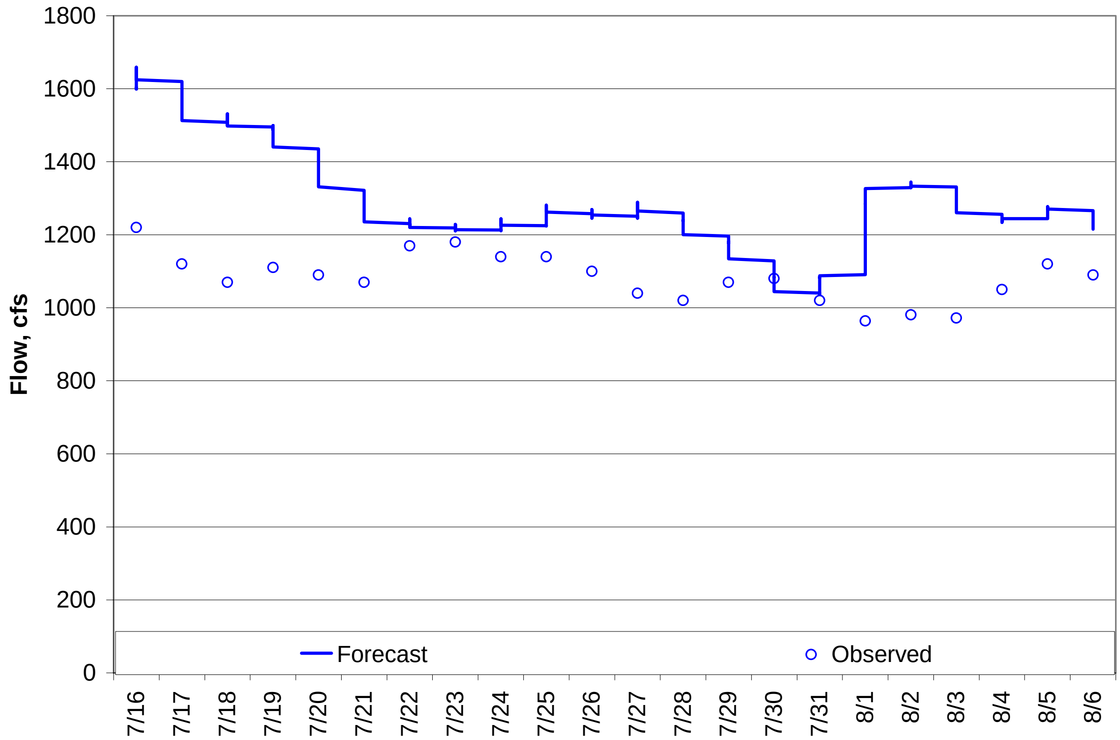

Figure 10: Forecasted vs measured flow, San Joaquin River at Vernalis

Figure 11 shows the model prediction and subsequent measurements of the phytoplankton concentration at Vernalis under the forecasted base (do nothing) scenario and with implementation of the San Luis Drain shutoff strategy. The base case is in blue; the simulated effect of the San Luis Drain shutoff is shown in green, subsequently measured data is in black circles, and the model predicted percent reduction is in red using the scale on the right. There is a predicted time lag in the effectiveness of the shutoff, with no effect noticed until two days after the shutoff and peak reduction of phytoplankton concentration reached after about 6 days. After the San Luis Drain resumed discharging, there was a similar time lag and little residual benefit left after one week. The peak forecasted reduction of phytoplankton was 19%. The three measured data points from before and one day after the shutoff average 68 μg/l Chl-a, while the measured phytoplankton starting 3 days after the shutoff average 54 μg/l Chl-a, 20% less. Data from Mud Slough indicates that the phytoplankton concentration in its discharge remained much lower than before the San Luis Drain was shut off even after flow resumed in the drain. Although it is not clear why the phytoplankton concentration in Mud Slough did not increase after flow resumed in the San Luis Drain, the data implies that reduction of loading from Mud Slough does have a significant impact upon the loading in the San Joaquin River at Vernalis.

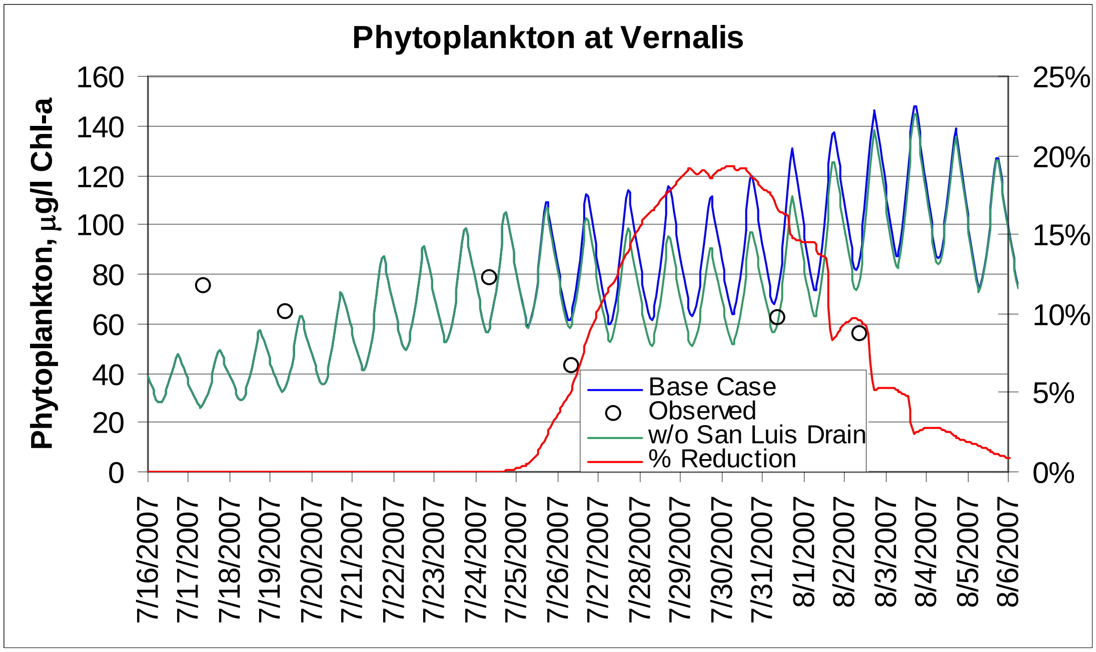

Figure 11: Forecasted reduction of phytoplankton concentration at Vernalis, San Luis Drain load eliminated

The San Luis Drain and Mud Slough is a major source of EC to the San Joaquin River. The forecasted Mud Slough EC for this simulation period was over 2000 µs/cm. Since EC does not grow exponentially like phytoplankton, however, reducing EC from Mud Slough does not have a similar impact to reducing phytoplankton loading. Figure 12 shows the reduction of EC at Vernalis resulting from shutting down the San Luis Drain. The peak reduction was less than 4%. The pattern of the reduction is similar to that for phytoplankton, taking a week to see the full effects of the drain being shut off and then opened again. The EC monitoring data is similar to the forecast. The small reduction in EC predicted in the forecast can not be discerned in the measured data.

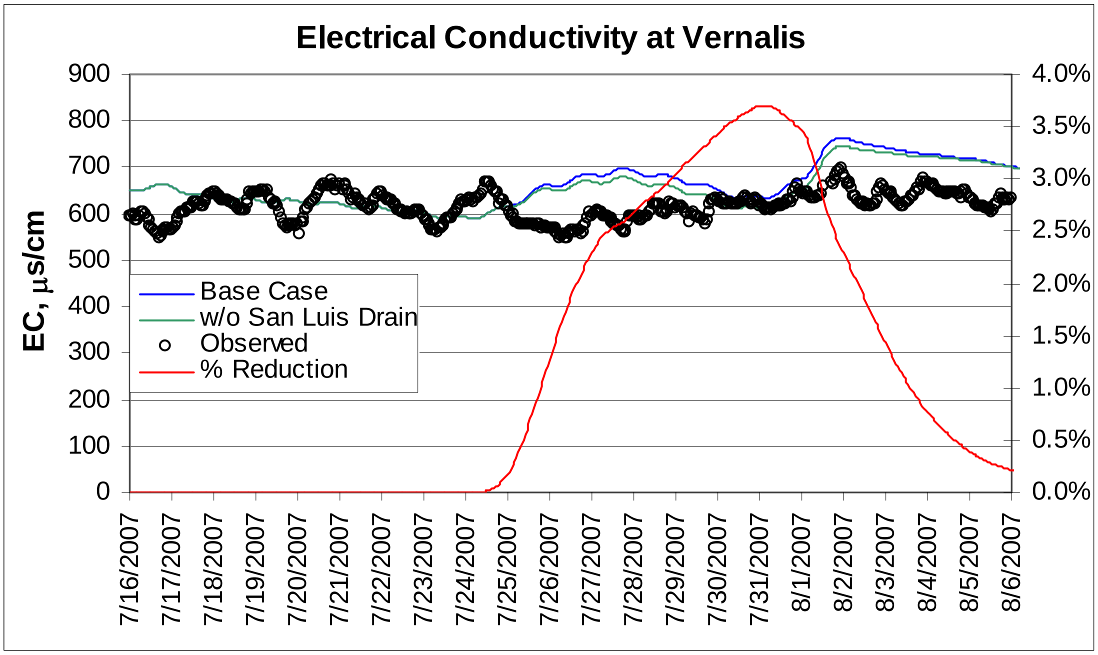

Figure 12: Forecasted reduction of EC at Vernalis, San Luis Drain load eliminated

It was not known at the time of the simulation whether the shutoff of the San Luis Drain would result in a net reduction of loading to the San Joaquin River or just a shift of loading to the time periods immediately before and/or after the shutoff. To estimate the effect of a shift in loading, an additional simulation was run. The loading which would have been discharged from the San Luis Drain under a do-nothing scenario was added to the week prior to the scheduled shutoff. The simulation results are shown in Figure 13. In this case, the base case shown in blue represents even flow and loading throughout the simulation. The simulation of the San Luis Drain shutoff case in green includes an increase in flow and loading in the week of July 16 through 23 and a corresponding decrease from July 23 through 30. As before, the phytoplankton load shows a delayed response. With the shift in load, however, the phytoplankton load increases at Vernalis by a similar amount to the subsequent decrease. The change is shown in red.

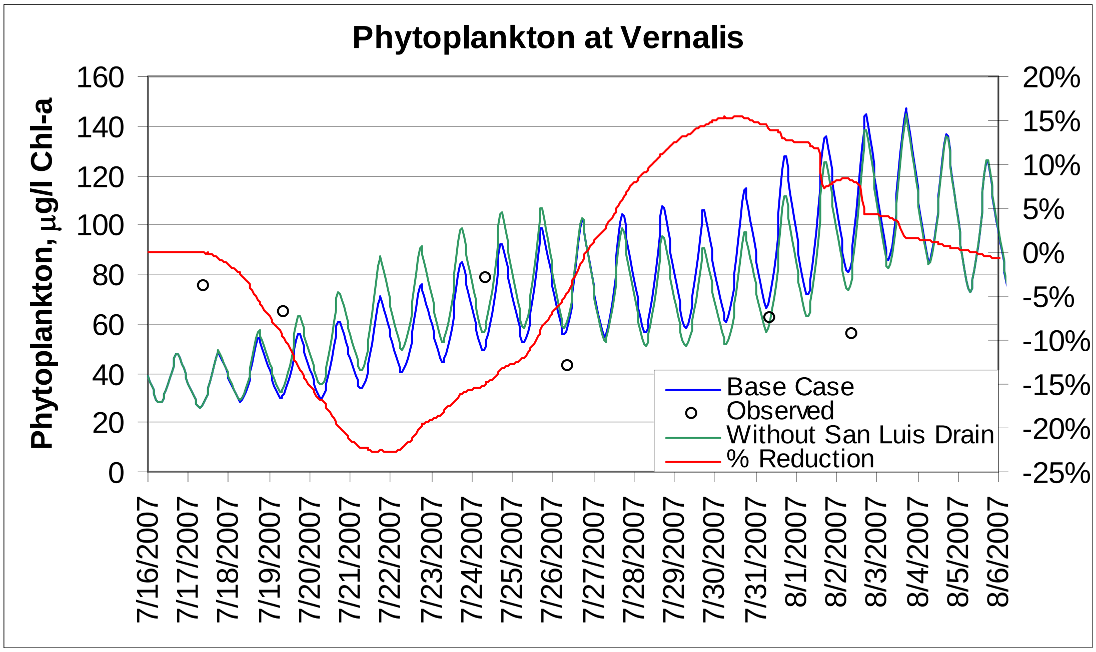

Figure 13: Forecasted reduction of phytoplankton concentration at Vernalis, San Luis Drain load shifted

Figure 14 shows the changes in simulated EC at Vernalis resulting from shifting the load of the San Luis Drain. Like phytoplankton, there is an increase in EC during the week with extra loading and a decrease when the San Luis Drain is shut off.

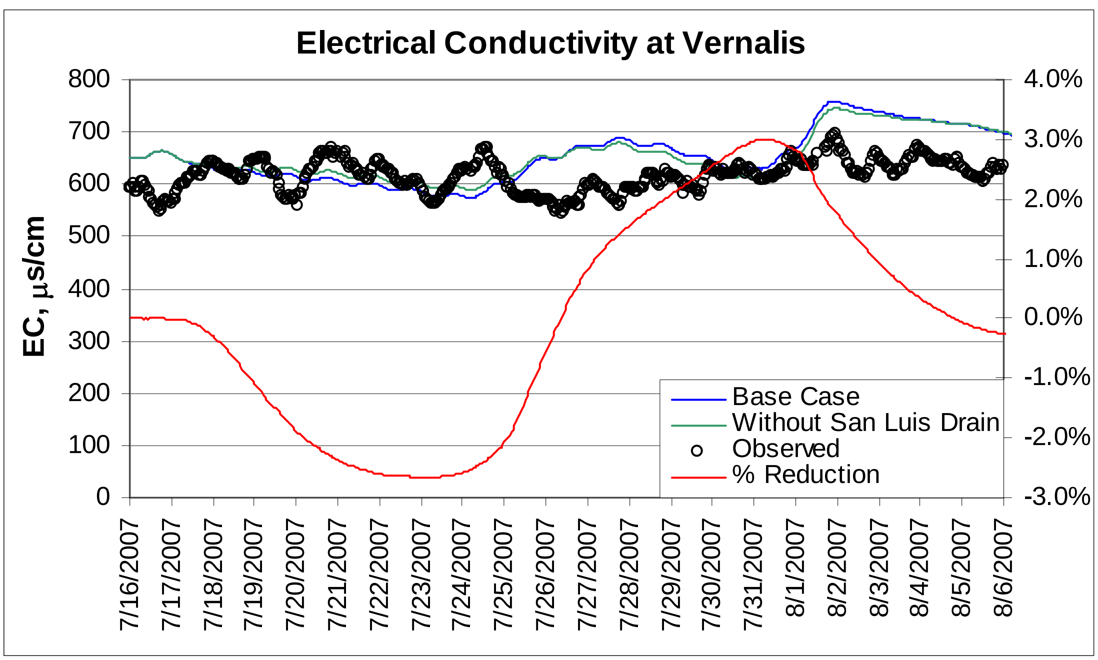

Figure 14: Forecasted reduction of EC at Vernalis, San Luis Drain load shifted

The ultimate goal of the forecasting model runs is to predict dissolved oxygen concentration in the DWSC. WARMF has been linked to the Link-Node model, which simulates the estuarine part of the San Joaquin River downstream of the Old River junction. The Link-Node input file for the boundary condition at the Old River includes the WARMF model output for water quality constituents such as phytoplankton, dissolved oxygen, and nutrients. The cause of the Link-Node model's insensitivity to changes in organic loading during test simulations should be examined in order to have higher confidence in its forecasted predictions.

The WARMF simulations in forecasting mode were posted on Systech Engineering's FTP site prior to the actual shutoff of the San Luis Drain for analysis by other interested parties. The forecast could then be evaluated after the event to determine the accuracy of the forecast and how the assumptions of the simulation could be improved for future forecasting.

SUMMARY

The calibrated WARMF model of Upper San Joaquin River Watershed was applied to perform forecasting 3 weeks into the future. By comparing a "do nothing" scenario with a planned temporary shut off of the San Luis Drain, a phytoplankton concentration reduction of 19% at Vernalis was predicted. The predicted reduction in EC was only 3%. Monitoring data from before, during, and after the San Luis Drain shutoff showed a similar decrease in phytoplankton concentration after the load from San Luis Drain was stopped, but the concentration in Mud Slough at at Vernalis did not increase back to its original level when the drainage flow resumed.

The forecasted flow and water quality of tributary inflows to the model were calculated using a combination of 2002 data and real-time data from the two weeks immediately prior to the forecast simulation. The error between forecast and measured flows ranged from -21% to +55% and the simulated flow at Vernalis was 20% greater than observed. Alternate techniques should be tested using historical data to determine a better method of estimating future flows. The error of forecasted EC was -15% to 29% with only a 6% average error in simulated EC. This suggests that the model and forecasting methodology can produce reasonable predictions of EC. With no real-time data collected for phytoplankton, all model inputs relied upon data from a similar time period in 2002. In practice, the measured concentrations in 2002 differed markedly from those later measured in 2007. This introduces a major source of error in the model forecasts. If reliable real-time data becomes available for phytoplankton, that could provide important guidance in predicting phytoplankton load to the San Joaquin River.

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