Characterizing Water Quality Linkage Between the Delta-Mendota Canal and the San Joaquin River Using WARMF

A Deliverable
For
Metropolitan Water District of Southern California

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TABLE OF CONTENTS

TABLE OF CONTENTS I

1 INTRODUCTION 1-1

SALINITY IN THE SAN JOAQUIN RIVER 1-1
WARMF MODELING OF THE SAN JOAQUIN RIVER WATERSHED 1-1

2 DELTA-MENDOTA CANAL SALINITY SCENARIOS 2-1

SCENARIO TEST CONDITIONS 2-2

3 SCENARIO SIMULATION RESULTS 3-1

CALIBRATION SCENARIO 3-1
TRANSIENT SIMULATION 3-3
DYNAMIC EQUILIBRIUM SIMULATION 3-7

4 CONCLUSION 4-1

5 REFERENCES 5-1

List of Figures

FIGURE 1.1: SAN JOAQUIN RIVER WARMF APPLICATION 1-2
FIGURE 2.1 ELECTRICAL CONDUCTIVITY OF THE DELTA-MENDOTA CANAL, BASELINE AND ALTERNATIVES 2-2
FIGURE 2.2 FREQUENCY DISTRIBUTION OF WATER YEARS: HISTORICAL VS SIMULATION PERIOD. 2-3
FIGURE 2.3 SALINITY OF DELTA-MENDOTA CANAL FOR FOUR SALINITY SCENARIOS 2-5
FIGURE 3.1 CALIBRATION OF FLOW, SAN JOAQUIN RIVER AT VERNALIS 3-2
FIGURE 3.2 CALIBRATION OF ELECTRICAL CONDUCTIVITY, SAN JOAQUIN RIVER AT VERNALIS .. 3-3
FIGURE 3.3 TRANSIENT SIMULATION OF ELECTRICAL CONDUCTIVITY, SAN JOAQUIN RIVER AT VERNALIS 3-4
FIGURE 3.4 ALTERNATIVE TRANSIENT EC RELATIVE TO HISTORICAL, SAN JOAQUIN RIVER AT VERNALIS 3-5
FIGURE 3.5 TRANSIENT SIMULATION ANNUAL AVERAGE EC, SAN JOAQUIN RIVER AT VERNALIS 3-6
FIGURE 3.6 TRANSIENT RATIO OF ALTERNATE TO HISTORICAL EC, SAN JOAQUIN RIVER AT VERNALIS 3-7
FIGURE 3.7 EQUILIBRIUM SIMULATION ELECTRICAL CONDUCTIVITY, SAN JOAQUIN RIVER AT VERNALIS 3-8
FIGURE 3.8 ALTERANATIVE EQUILIBRIUM EC RELATIVE TO HISTORICAL, SAN JOAQUIN R. AT VERNALIS 3-9
FIGURE 3.9 EQUILIBRIUM SIMULATION ANNUAL AVERAGE EC, SAN JOAQUIN RIVER AT VERNALIS 3-10
FIGURE 3.10 EQUILIBRIUM RATIO OF ALTERNATE TO HISTORICAL EC, SAN JOAQUIN RIVER AT VERNALIS 3-11

List of Tables

TABLE 2.1 DEPARTMENT OF WATER RESOURCES WATER YEAR TYPES FOR SIMULATION PERIOD. 2-4

1 INTRODUCTION

Salinity in the San Joaquin River

The water supply pumps in the southern Sacramento-San Joaquin River Delta are a major source of water for agricultural and urban use. The water quality is degraded by salinity from seawater intrusion into the Delta and from the San Joaquin River. The origin of the San Joaquin River's salinity is primarily irrigation water (Larry Walker & Associates et. al. 2010). There are many irrigation water sources in the San Joaquin Valley which vary greatly in their salinity. East of the San Joaquin River, the largest irrigation water source is the Tuolumne River, which has low salinity characteristic of Sierra Nevada runoff. The west side of the San Joaquin River uses a variety of irrigation water sources including groundwater, the Delta-Mendota Canal, and the San Joaquin River itself. Groundwater salinity is quite variable and uncertain but is generally much higher than irrigation water sources east of the San Joaquin River. According to data collected from 1984-2007 by the California Department of Water Resources and California Data Exchange Center, the electrical conductivity of the Delta-Mendota Canal averages about 440 µs/cm. Electrical conductivity data collected by various agencies from the San Joaquin River at Crows Landing averages 920 µs/cm. The average electrical conductivity of the Tuolumne River at Modesto is 150 µs/cm.

Because of the irrigation water sources used on the west side of the San Joaquin River, there is a positive feedback when the salinity of irrigation water is reduced. Some of the water in the Delta-Mendota Canal comes from the San Joaquin River via the Old River. Irrigation water pumped from the San Joaquin River is also used within its watershed. As less salt is applied to the watershed in irrigation, less salt runs off to the San Joaquin River in agricultural drainage. Improvement in the quality of the San Joaquin River then leads to further reductions in loading from irrigation. There are thus two important mechanisms in effect: reduction in loading to the San Joaquin River resulting from less salt in irrigation water supplied by the Delta-Mendota Canal and the additional feedback resulting from improved San Joaquin River water quality.

WARMF Modeling of the San Joaquin River Watershed

The San Joaquin River application of the Watershed Analysis Risk Management Framework (WARMF) (Figure 1.1) is used to dynamically simulate flow and water quality within the watershed on a daily or hourly time step. The San Joaquin River watershed is set up to simulate the watershed from Friant Dam to the Old River, but the model is not fully parameterized for the portion of the watershed between Friant Dam and the Lander Avenue gage on the San Joaquin River. Because of this, the watershed model is disconnected upstream of Lander Avenue, where the San Joaquin River is usually dry, so that simulations of the upper part of the watershed do not affect the lower watershed. Measured flow and water quality at Lander Avenue is used as a boundary inflow to the lower San Joaquin River. Unlike earlier versions of the San Joaquin River WARMF model, the entire west side of the watershed is part of the model domain. This allows the model to simulate the full effect of Delta-Mendota Canal water quality on the water quality of the San Joaquin River. The San Joaquin River WARMF application has been calibrated for flow, salinity, turbidity, and other water quality parameters (Systech 2011). WARMF includes technical documentation (Chen et. al. 2001) and a user's guide (Herr et. al. 2001).

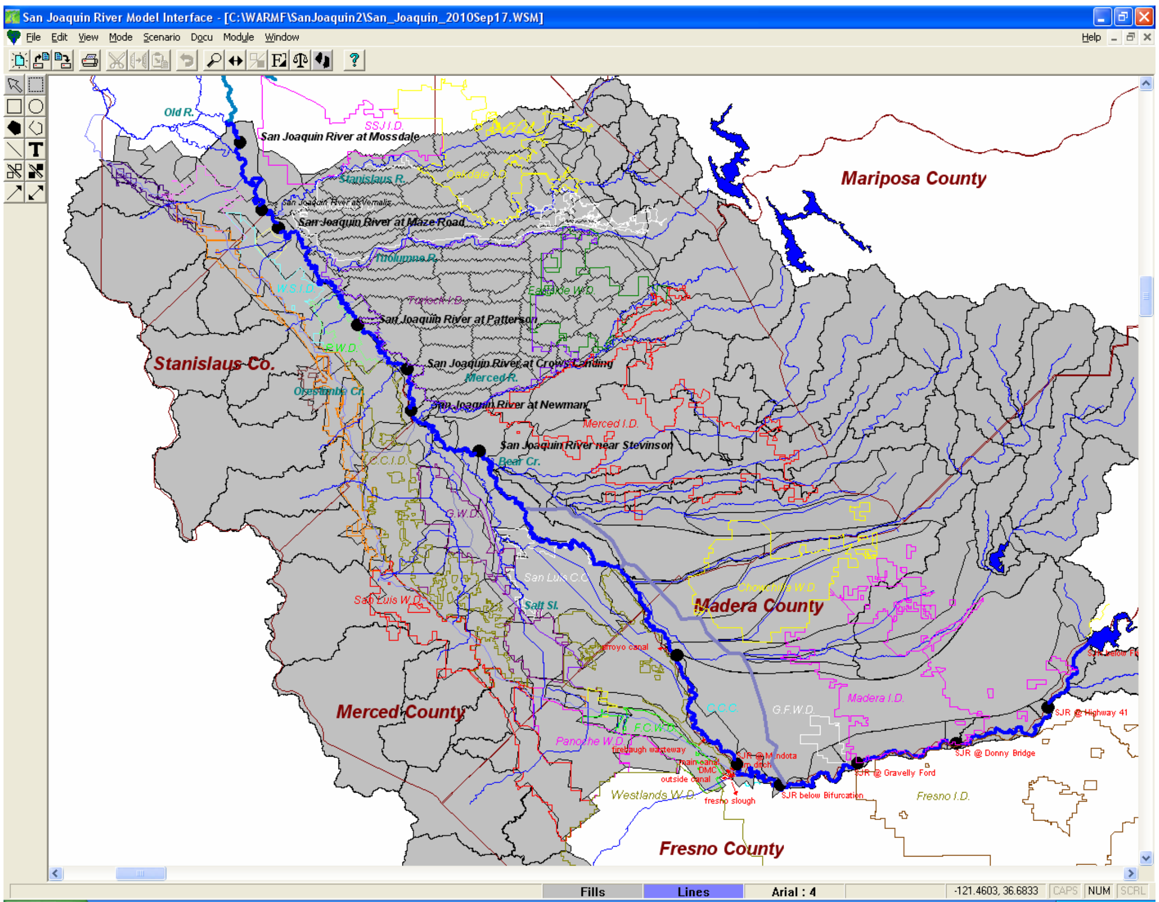

Figure 1.1: San Joaquin River WARMF Application

In the process of simulating the watershed, the WARMF model determines the sources and fates of pollutants. Many chemical and physical parameters are simulated including temperature, nitrogen species, phosphorus, major ions, organic carbon, dissolved oxygen, suspended sediment, turbidity, phytoplankton, total dissolved solids, and electrical conductivity. The model has been used for a variety of purposes including phytoplankton study and management, organic carbon and salinity source identification, and tracking nitrate and salinity.

WARMF tracks salinity from its various irrigation water sources through the land to the San Joaquin River. Irrigation water from the Delta-Mendota Canal is applied at the salinity of the Canal. The salt then passes through or over the soil in agricultural runoff, eventually draining to the San Joaquin River. Changing the salinity of the Delta-Mendota Canal in the model would thus produce the predicted response in the San Joaquin River in model output. The lowered salinity in the San Joaquin River would also be used for irrigation whose source is the River, so the model would simulate that additional feedback mechanism. A third feedback mechanism affects the salinity in the Delta-Mendota Canal. Since a portion of the flow in the canal originates in the San Joaquin River, a decrease in San Joaquin River salinity would reduce the salinity in the Delta-Mendota Canal. Since the WARMF model does not include the Delta within its model domain, this last feedback mechanism is not included in this analysis. The reductions predicted by WARMF in the San Joaquin River at Vernalis could be used to determine the magnitude of the feedback mechanism through the Delta.

2 DELTA-MENDOTA CANAL SALINITY SCENARIOS

Various alternatives have been proposed to reduce the salinity of the Delta-Mendota Canal and California Aqueduct at their headworks in the south Delta by routing more Sacramento River water across the Delta. These alternatives include a peripheral canal, tunnel, or gates across Delta sloughs to reduce sea water intrusion and segregate Sacramento River water from San Joaquin River water. This proposed infrastructure would be combined with limitations on flow imposed by the infrastructure or by environmental requirements. The Bay Delta Conservation Plan (BDCP) has prepared monthly projections of salinity at the Delta-Mendota Canal headworks for various infrastructure / flow management alternatives using the CALSIM model. Three of these projections, referred to as "Alt1", "Alt2", and "Alt3", were analyzed to determine their effect on the water quality of the San Joaquin River. These projections (referred to as "Alt1", "Alt2", and "Alt3") have been applied to the water year 1922-2003 time period for comparison against a baseline CALSIM historical scenario. All three alternatives assume that a tunnel or canal would be built across the Delta with a 15,000 cfs capacity. The alternatives differ in how much the cross-Delta water would mix with water within the south Delta. Alt1 has the most mixing, Alt2 includes additional restrictions on mixing in the south Delta, and Alt3 is for a conveyance whose water would be isolated from south Delta water. Figure 2.1 shows the monthly average electrical conductivity of the Delta-Mendota Canal over the 1922-2003 time period for each alternative.

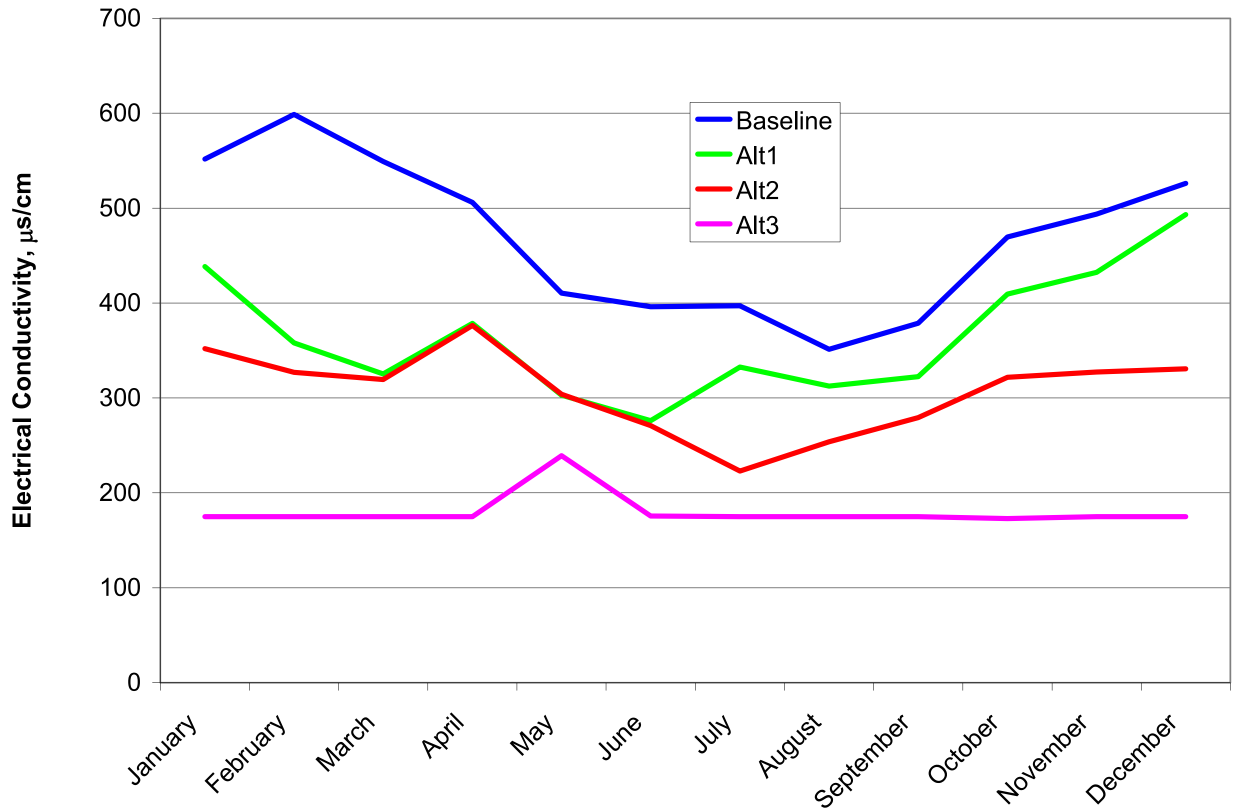

Figure 2.1 Electrical Conductivity of the Delta-Mendota Canal, Baseline and Alternatives

The average salinity of the Delta-Mendota Canal is 22% less than the Baseline condition under the Alt1 scenario. The salinity of the Alt2 scenario would average 35% less and the salinity of the Alt3 scenario would be 62% less. Under both baseline and alternative scenarios, the monthly salinity varies by water year. In wet years, the salinity is lower than in dry years.

Scenario Test Conditions

WARMF uses many time series inputs based on historical data. This data is most complete for the 1998 through 2010 water years. The three alternatives prepared by BDCP and the baseline condition are all output from CALSIM simulations. Simulating the entire CALSIM time period from 1922-2003 using CALSIM model output as WARMF input is possible but has significant disadvantages. Running an 82 year WARMF simulation has a long simulation time and increases the risk of errors during simulation. CALSIM has much lower spatial resolution than WARMF, so there are many WARMF inputs such as flow deliveries to individual irrigation districts which do not have a corresponding CALSIM output. The WARMF historical data can be extrapolated backward in time to accommodate the CALSIM simulation period, but there is a risk of mismatch between WARMF inputs and CALSIM.

To test the results of the three BDCP alternates, the electrical conductivity (EC) at the head of the Delta-Mendota Canal predicted by the alternate scenarios was compared with the BDCP baseline. The ratio of EC under each alternate relative to the baseline was calculated for every month of the CALSIM simulation period. The ratios for each month of the year were then aggregated by year type. The California Department of Water Resources labels each year as wet, above normal, below normal, dry, or critically dry for the Sacramento and San Joaquin River watersheds. Since the Sacramento River is the largest source of water to the Delta, the hydrologic condition of the Sacramento River was used to classify the results of the BDCP alternate scenarios.

To determine the effect of the BDCP alternatives using WARMF, a time period representative of the long-term hydrologic record but with complete model inputs had to be used. From 1922 through 2010, there were 27 wet years, 13 above normal years, 16 below normal years, 19 dry years, and 13 critically dry years in the Sacramento River watershed (DWR 2009). A WARMF simulation time period of 10/1/1997 through 9/30/2010 includes 13 water years with a very similar proportion of water year types as in the entire historical record (Figure 2.2). The water year type for each year of the simulation period is shown in Table 2.1.

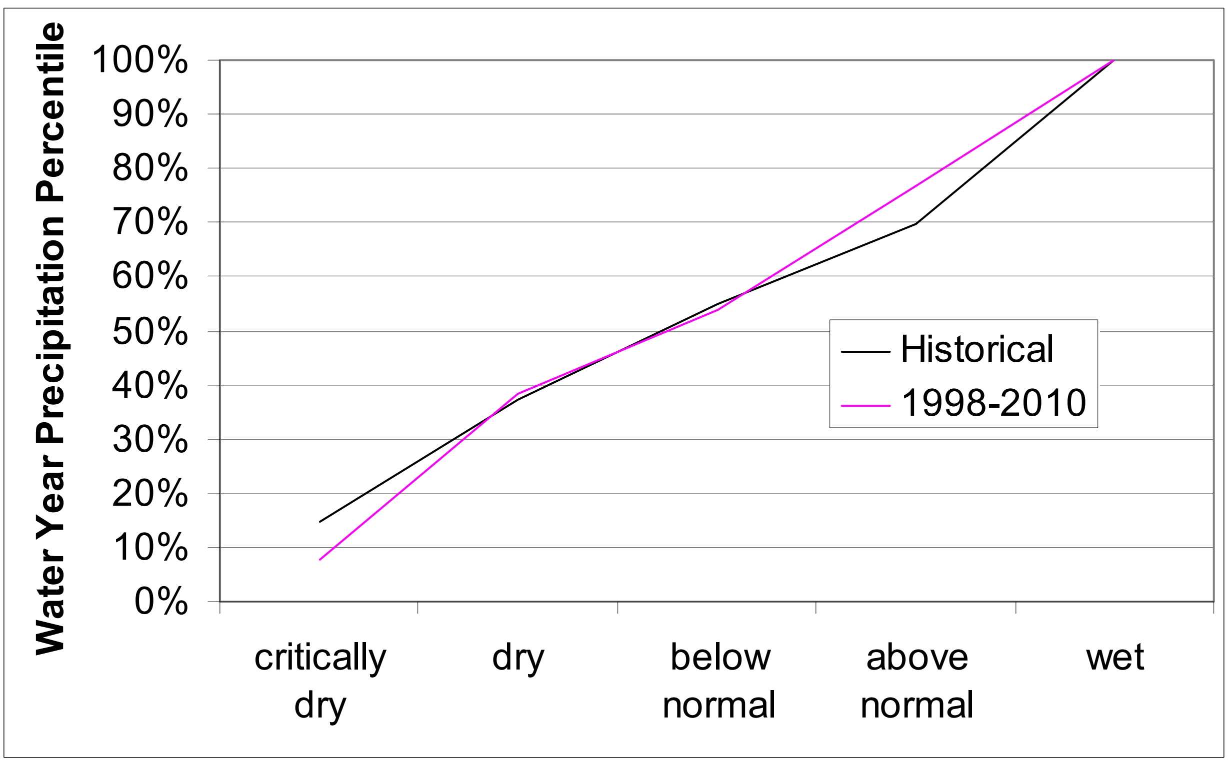

Figure 2.2 Frequency Distribution of Water Years: Historical vs Simulation Period

Table 2.1 Department of Water Resources Water Year Types for Simulation Period

Year	Sacramento River Water Year Type
1998	wet
1999	wet
2000	above normal
2001	dry
2002	dry
2003	above normal
2004	below normal
2005	above normal
2006	wet
2007	dry
2008	critically dry
2009	dry
2010	below normal

Four scenarios were created in WARMF for the historical case and each of the three alternatives. They differed only in the salinity of the Delta-Mendota Canal shown in Figure 2.3. The loading of total dissolved solids in the Delta-Mendota Canal at its headworks averaged 22% less than the historical condition for Alt1. Alt2 and Alt3 had loading reductions of 35% and 62% respectively relative to the historical. The WARMF historical scenario used daily measured data of EC as a model input for the Delta-Mendota Canal. To create BDCP alternate scenarios in WARMF, the monthly EC percentage reductions for each water year type calculated from the BDCP alternate scenario output were applied to the historical EC over the WARMF simulation time period.

Two simulations were performed for each scenario. The first run of the 13 year time period represented the transient state during which the watershed was adjusting from its current dynamic steady state conditions to the new conditions driven by the change in the Delta-Mendota Canal. Because there is a large volume of ions adsorbed to soil particles in the watershed, it takes several years for the watershed to reach its new equilibrium between inputs from irrigation and outputs to groundwater and surface water. A second run of the simulation period was run using the end of the first for initial conditions. This reflects the new dynamic steady-state of the watershed after the transient effects have washed out.

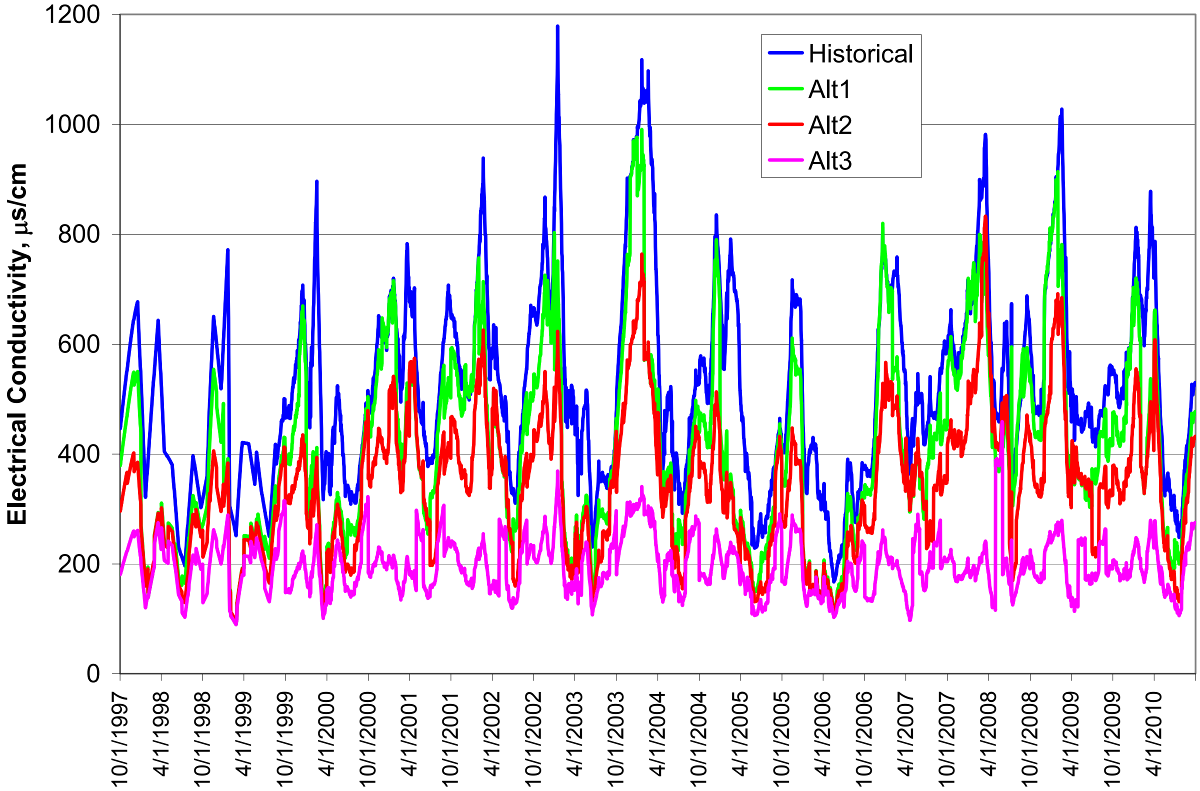

Figure 2.3 Salinity of Delta-Mendota Canal for Four Salinity Scenarios

3 SCENARIO SIMULATION RESULTS

Calibration Scenario

Simulations of the San Joaquin River watershed were performed with WARMF version 6.5. The historical simulation uses measured data as model inputs, so it can be compared against measured surface water data to determine how well the model is calibrated. Simulations of flow (Figure 3.1) and EC (Figure 3.2) show simulations generally tracking the measured data very closely in the San Joaquin River at Vernalis. The degree to which simulations match observed data is measured quantitatively using relative error and absolute error. Relative error is the average of the differences between simulated and observed values and is a measure of model accuracy or bias. Absolute error is the average of the absolute values of the differences between simulated and observed, so it measured model precision. The simulated flow has an average relative error of 0.6% less than measured flow. The average absolute error of flow over all simulation days is 13%. Simulated EC has a relative error of 3.9% less than measured. The average absolute error of EC is 20%.

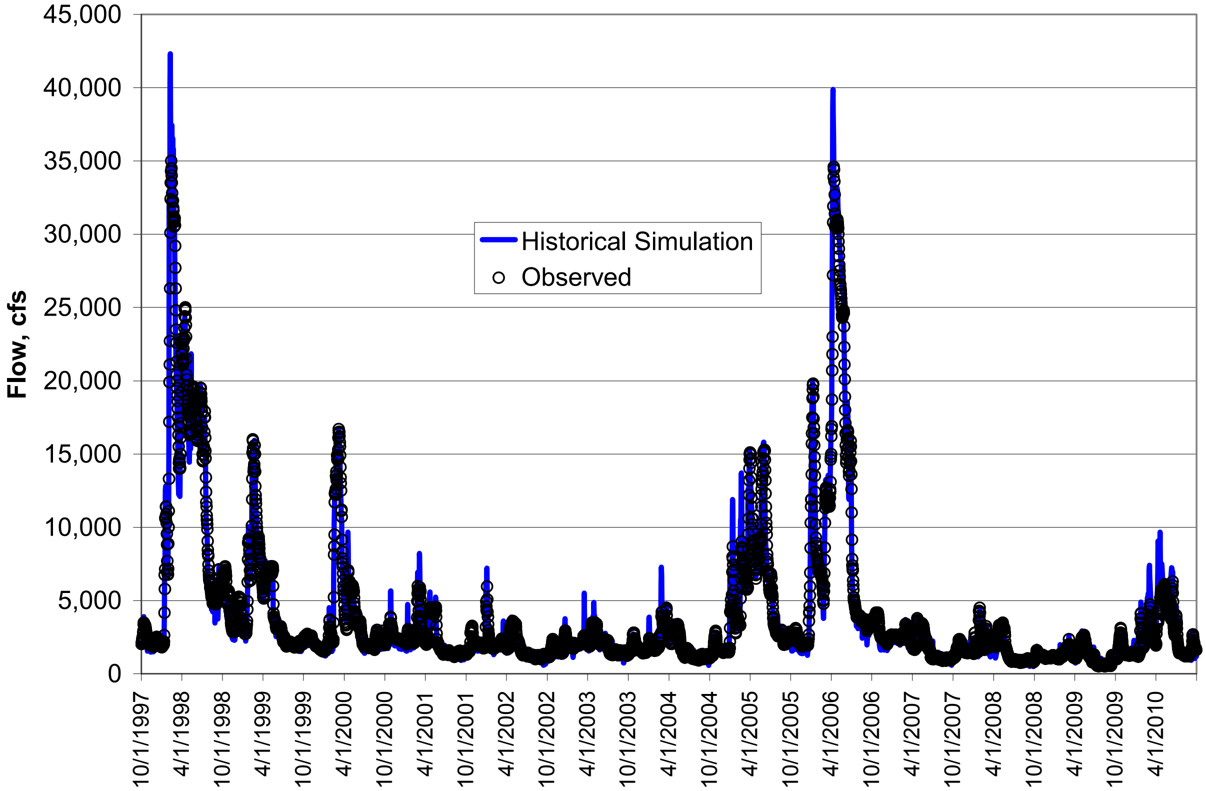

Figure 3.1 Calibration of Flow, San Joaquin River at Vernalis

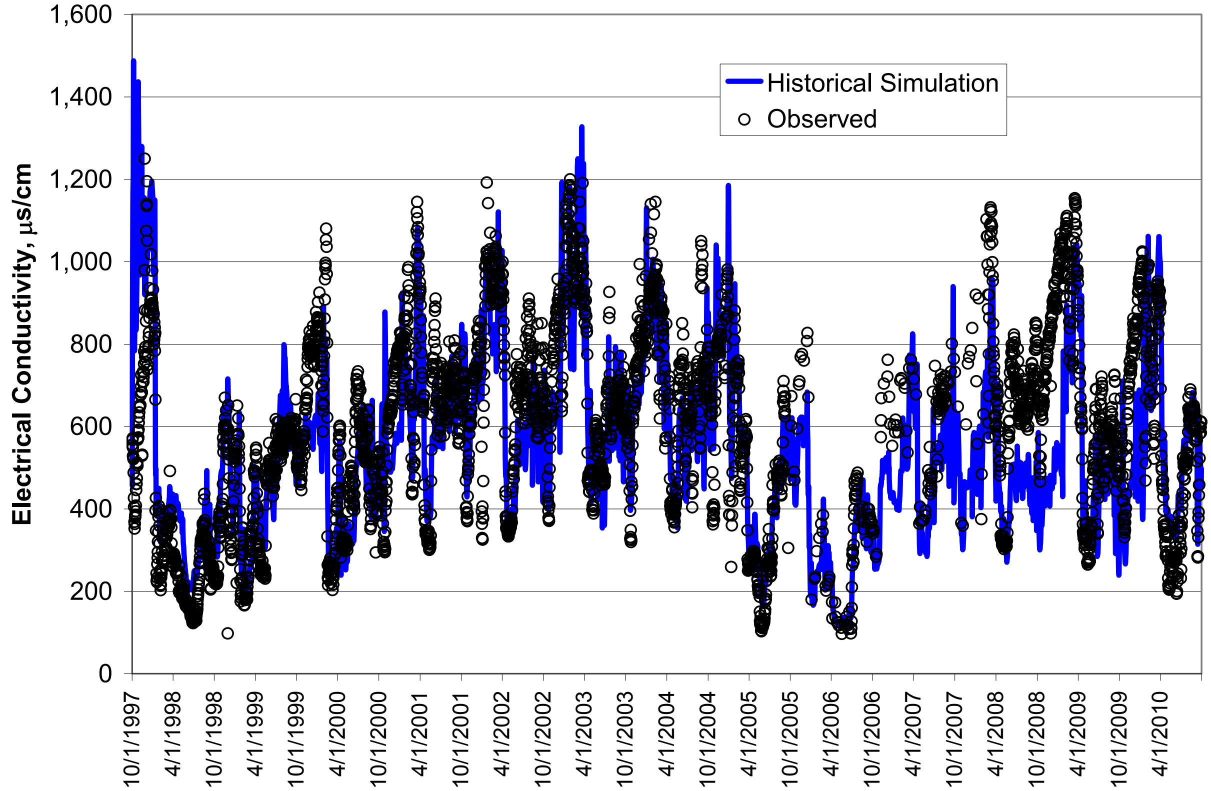

Figure 3.2 Calibration of Electrical Conductivity, San Joaquin River at Vernalis

Transient Simulation

There is a large amount of salt stored in the soil pore water and adsorbed to soil particles. The concentration of salt varies with wet years and dry years but is in a long-term dynamic equilibrium driven by average climatic conditions, water usage, and water quality of irrigation sources. When in dynamic equilibrium, the inputs of salt to the land equal the outputs from the land over a representative time period. Decreasing the salinity of the Delta-Mendota Canal, a major irrigation water source, will decrease the input of salt to the land so outputs will exceed the input until a new dynamic equilibrium is achieved.

The objective of the transient simulation is to determine how long it will take the watershed to respond to implementation of measured to reduce salinity in the Delta-Mendota Canal. It is important to understand the time required to respond so that stakeholders will have an accurate assessment of the benefit after the salinity reduction begins. The transient simulation begins with initial conditions in the watershed appropriate for current conditions. The model then simulates 13 years of watershed response assuming that there is a sudden decrease in salinity of the Delta-Mendota Canal at the beginning of the simulation.

The four scenario runs have the same hydrologic inputs, so the simulated flow of the San Joaquin River at Vernalis is the same for all. Figure 3.3 shows the daily time series of EC for the historical simulation and each of the three alternates for the San Joaquin River at Vernalis. The salinity in the San Joaquin River responds to the degree of salinity reduction represented by the alternate scenarios. Figure 3.4 shows the same time series expressed as a ratio of each scenario to the historical simulation.

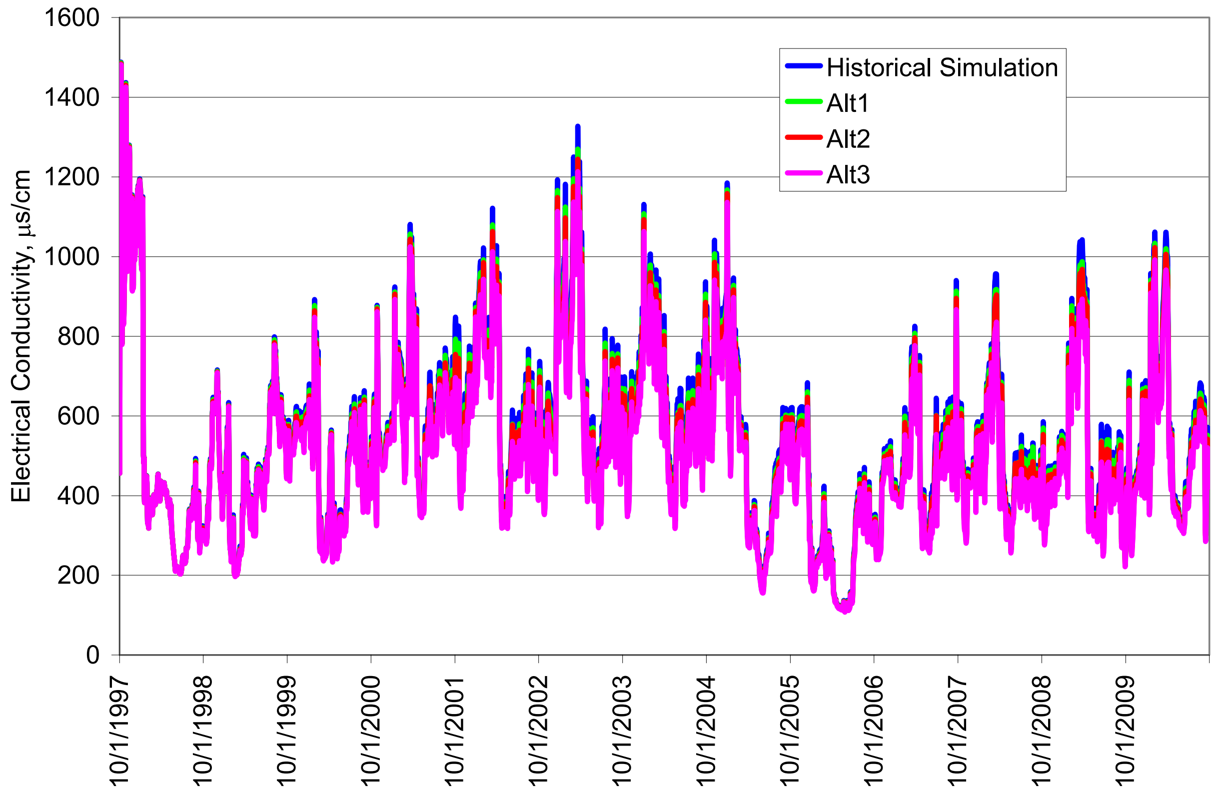

Figure 3.3 Transient Simulation of Electrical Conductivity, San Joaquin River at Vernalis

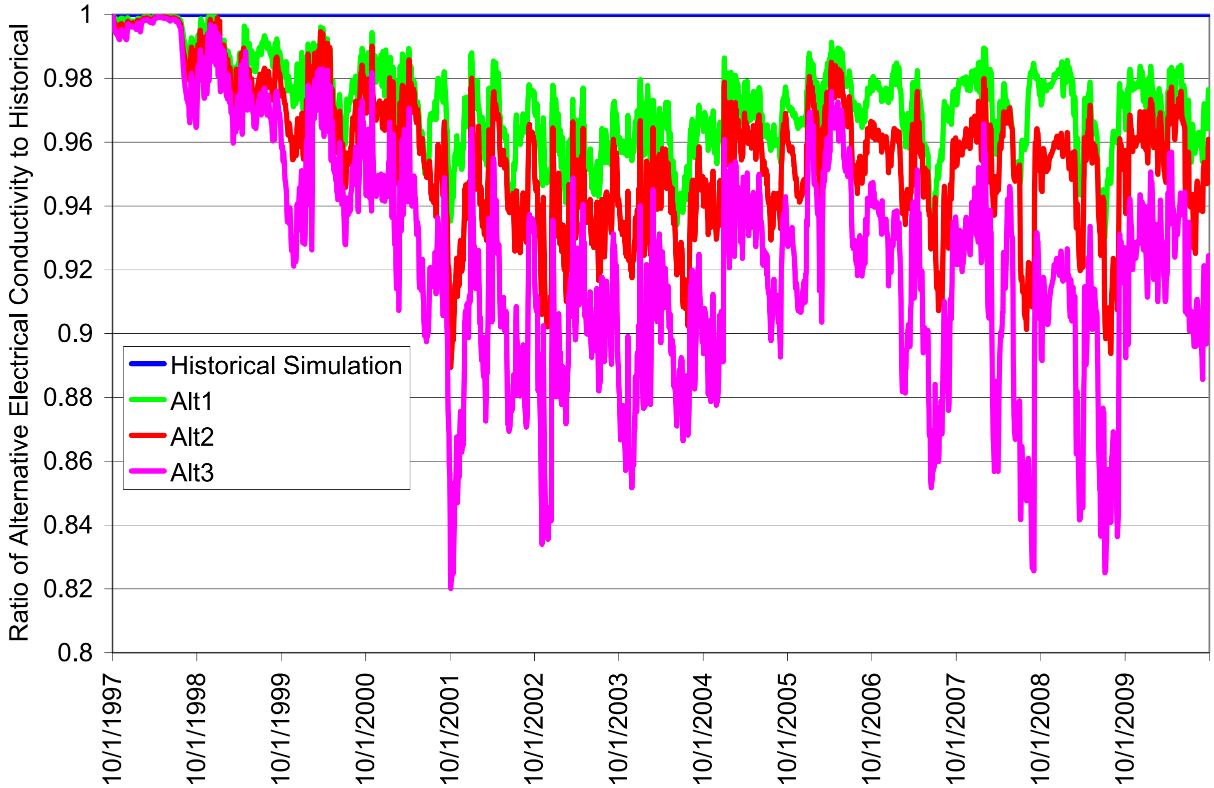

Figure 3.4 Alternative Transient EC Relative to Historical, San Joaquin River at Vernalis

The Vernalis salinity time series is presented as an annual average in Figure 3.5 with the ratio of annualized salinity relative to the historical simulation shown in Figure 3.6. Looking at the annual trend of the alternate scenarios with respect to the historical simulation gives an indication of the duration of the transient phase. Although the effect of the DMC alternates varies depending on how wet or dry each water year is, there is a trend from 1998-2003 showing decreasing ratios of alternate concentration to historical concentration for each of the DMC alternates. After 2003, it appears that the salinity reduction is in a new dynamic equilibrium. This implies that it will take approximately five years to receive maximum benefit of improvement in DMC salinity in the San Joaquin River at Vernalis.

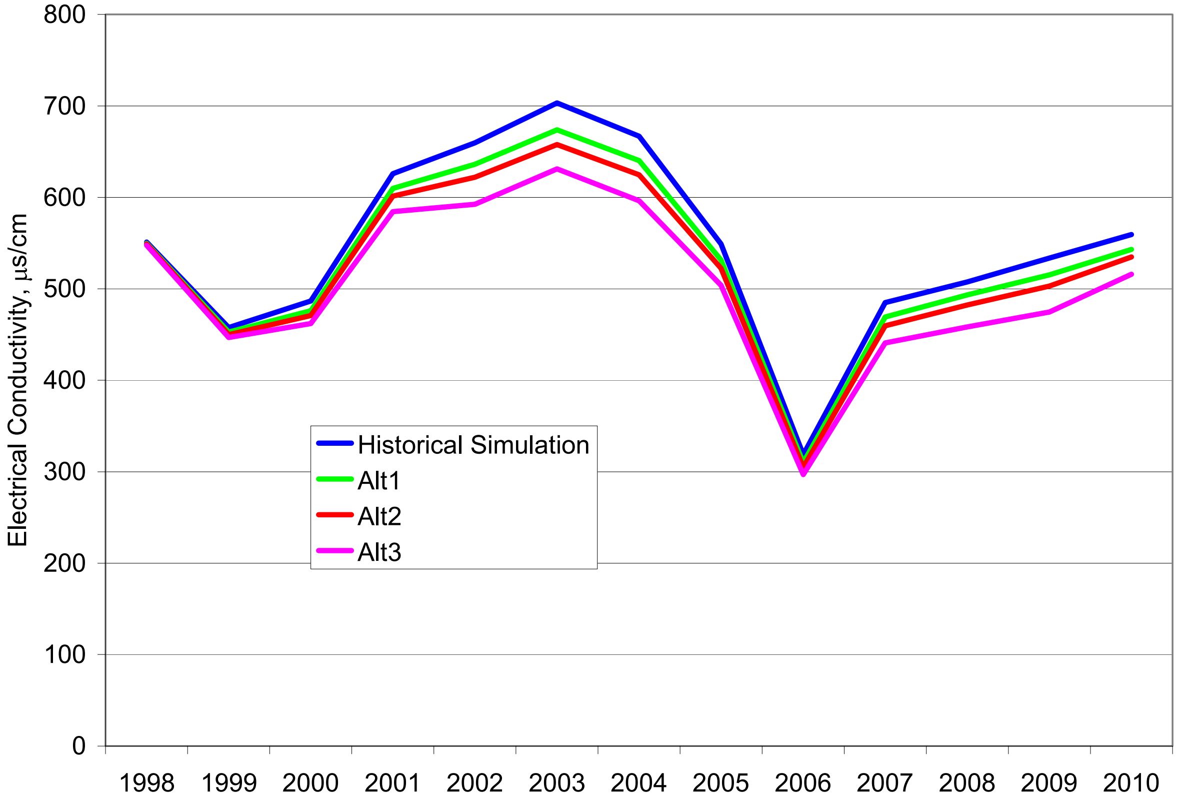

Figure 3.5 Transient Simulation Annual Average EC, San Joaquin River at Vernalis

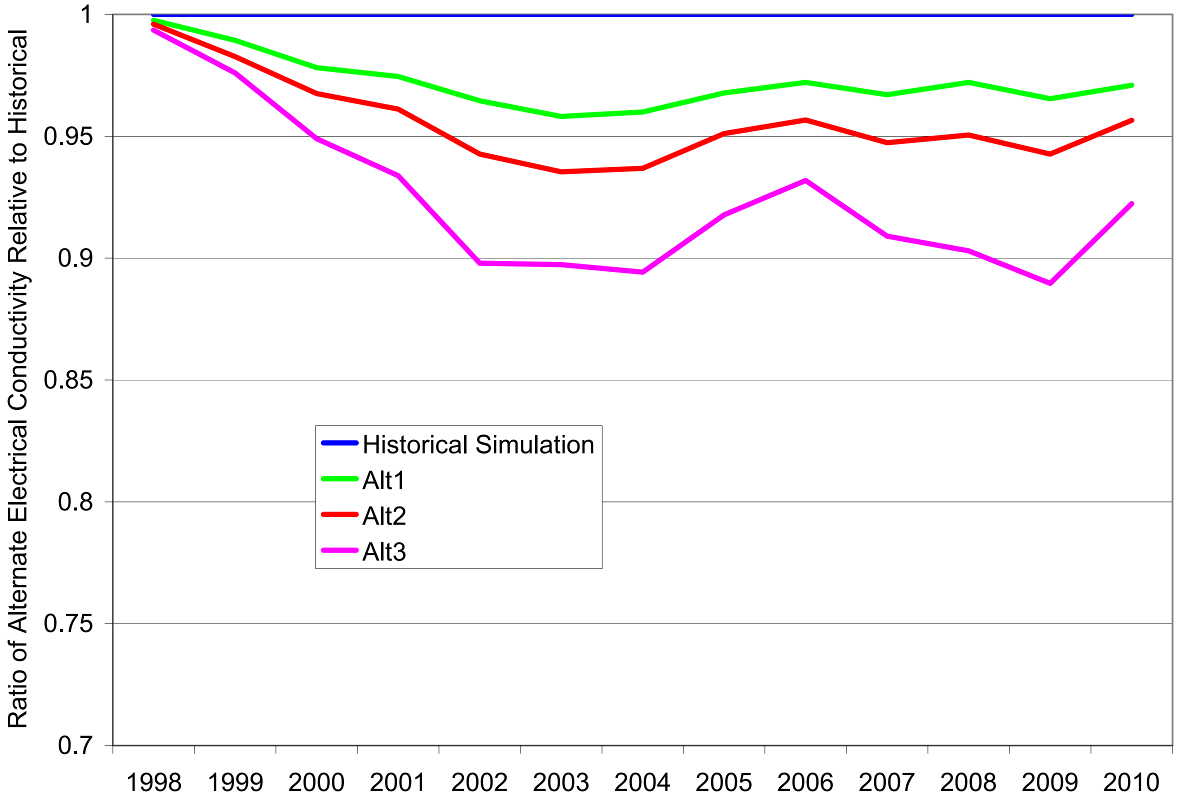

Figure 3.6 Transient Ratio of Alternate to Historical EC, San Joaquin River at Vernalis

Dynamic Equilibrium Simulation

Dynamic equilibrium represents the state of the watershed after the full effect of the Delta-Mendota Canal salinity reduction has been achieved. For the dynamic equilibrium simulation, it was assumed that the watershed would reach its equilibrium within the 13 year time frame of the transient simulation. The results of the transient simulation indicate that a new dynamic equilibrium is actually achieved in approximately five years. The initial conditions of the dynamic equilibrium simulation use the conditions in the watershed at the end of the transient simulation. The simulation is otherwise the same as the transient simulation.

Simulation of flow is the same for all scenarios. Figure 3.7 shows the daily time series of EC in the San Joaquin River at Vernalis for the dynamic equilibrium simulation. The difference between the historical and alternate scenarios is apparent especially during high salinity periods. Figure 3.8 shows the same time series expressed as a daily ratio of each scenario to the historical simulation.

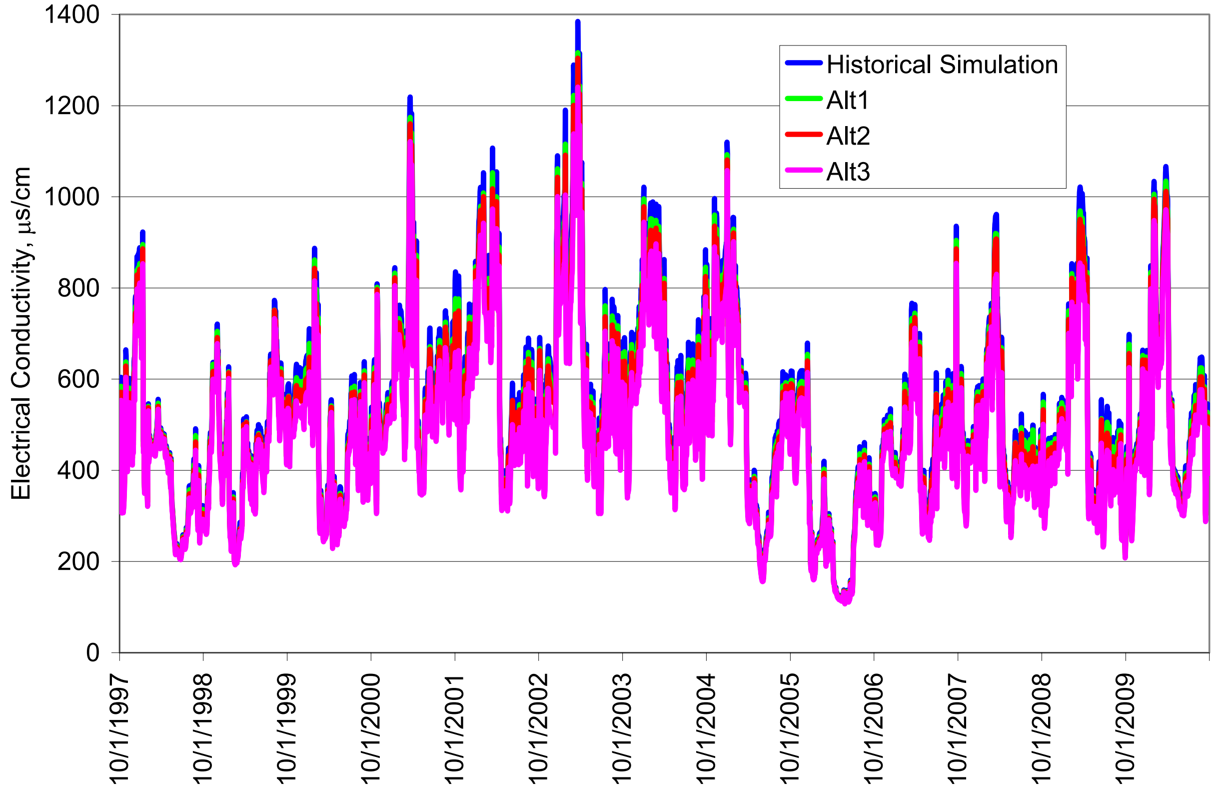

Figure 3.7 Equilibrium Simulation Electrical Conductivity, San Joaquin River at Vernalis

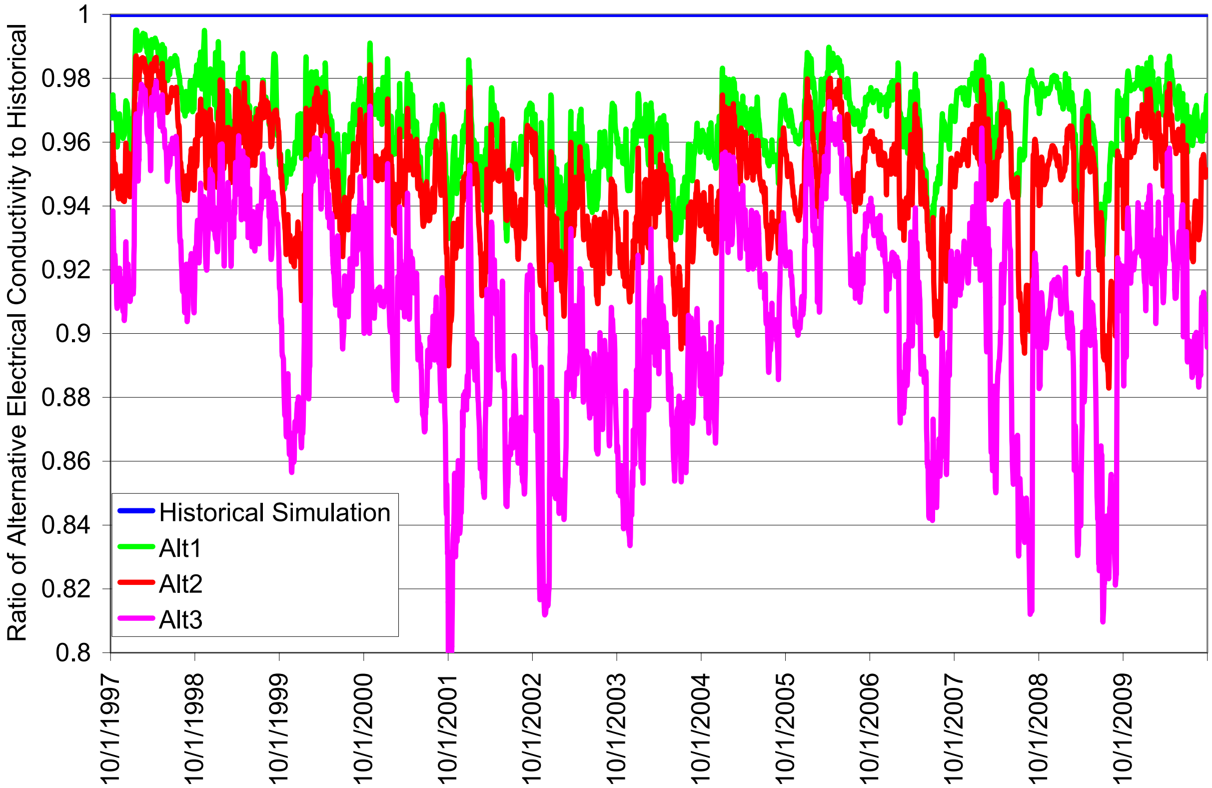

Figure 3.8 Alteranative Equilibrium EC Relative to Historical, San Joaquin R. at Vernalis

The daily time series of Figure 3.7 is presented as annual average EC in Figure 3.9. The annual average shows the effect of drier years such as 2003, with higher salinity in the San Joaquin River and greater impact of the DMC salinity reduction scenarios. The relative impact of the scenarios in different years is shown in Figure 3.10. The strictest control of salinity in the Delta-Mendota Canal would reduce the average salinity in the San Joaquin River at Vernalis by 6-12% with the greatest reduction during dry years such as 2001-2004 and 2007-2008. Comparing Figure 3.10 showing dynamic equilibrium impact of the salinity reduction with Figure 3.6 showing the same for the transient simulation shows that 80% of the equilibrium salinity reduction in the San Joaquin River has been realized after five years.

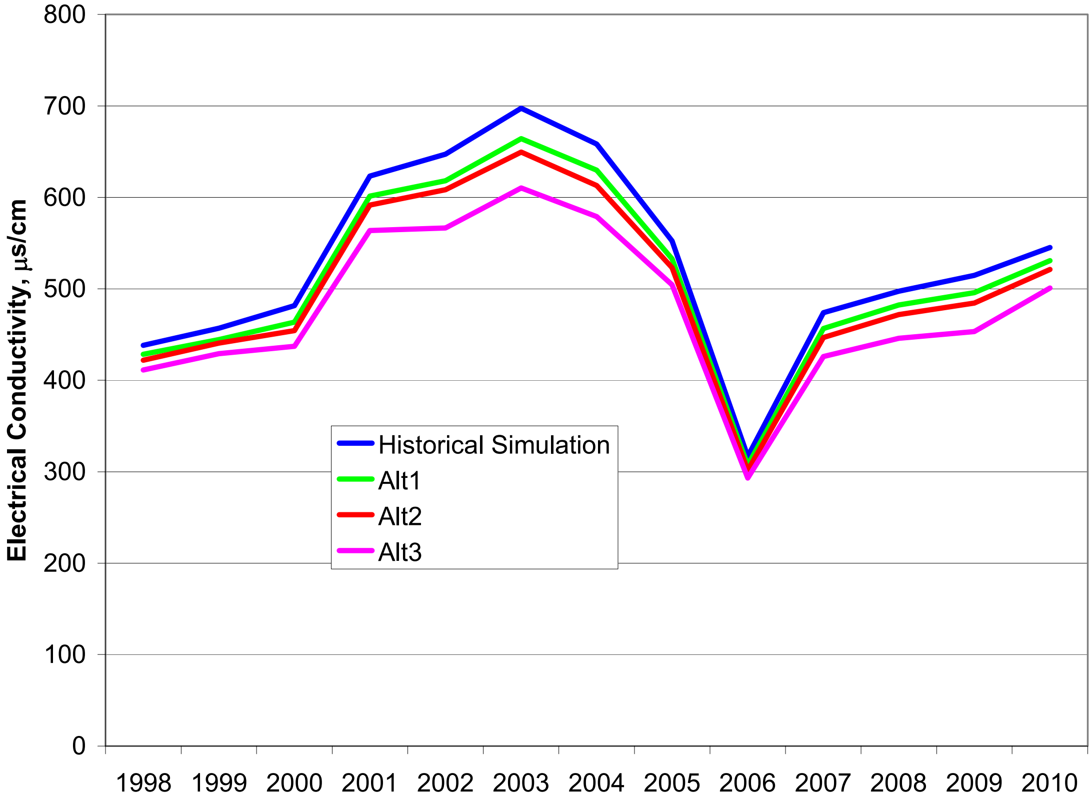

Figure 3.9 Equilibrium Simulation Annual Average EC, San Joaquin River at Vernalis

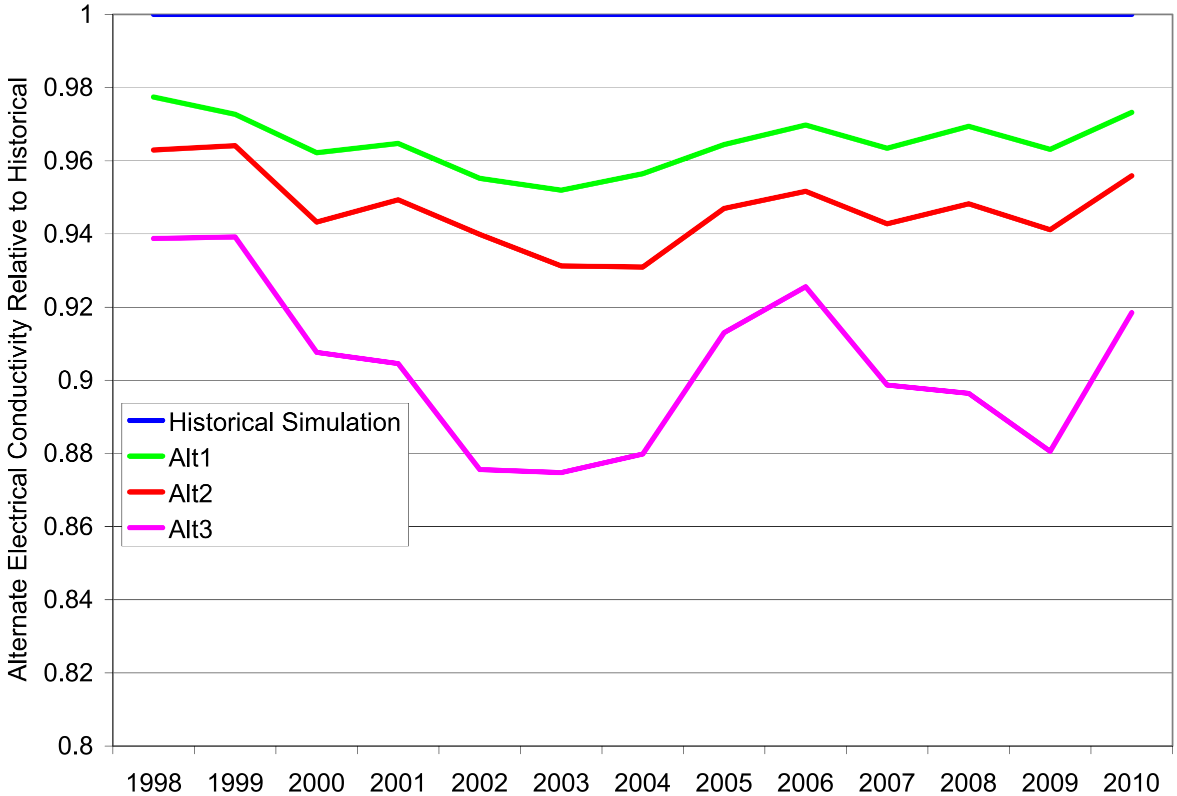

Figure 3.10 Equilibrium Ratio of Alternate to Historical EC, San Joaquin River at Vernalis

4 CONCLUSION

Simulations of the San Joaquin River watershed were performed using WARMF to determine the effect upon the San Joaquin River of proposed salinity reductions in the Delta-Mendota Canal. Three alternatives run using the CALSIM model by the Bay Delta Conservation Plan ("Alt1", "Alt2", and "Alt3") were compared against the CALSIM baseline simulation to determine the predicted monthly percent reductions in Delta-Mendota Canal salinity in each of the five DWR water year types. Those reductions were applied to daily historical DMC salinity data in WARMF inputs to determine the water quality linkage between the Delta-Mendota Canal and the San Joaquin River where it enters the Delta near Vernalis. A 13 year simulation period of 10/1/1997 through 9/30/2010 was used because complete WARMF inputs were available and the hydrologic conditions were representative of the 1922-2010 historical record. Simulations were run for the transient case, during which time the watershed would adjust to its new salinity input, and for the dynamic equilibrium case. The transient simulation determined how fast the watershed would respond to changes in Delta-Mendota Canal salinity and the dynamic equilibrium simulation determined the long-term benefit in the San Joaquin River.

The simulations showed that Alt1 would reduce salinity in the San Joaquin River at Vernalis by an average of 3.5% compared to the baseline case. Alt2 and Alt3 would reduce San Joaquin River salinity by 5.2% and 9.4% respectively. All scenarios had a greater percentage reduction during dry years when San Joaquin River salinity was highest. The Alt3 scenario produced up to 12% reduction in annual salinity loading in the San Joaquin River at Vernalis. Comparison between the transient simulation and dynamic equilibrium simulation found that approximately 80% of the benefit of reduced salinity in the San Joaquin River would be realized in five years after the improvement in Delta-Mendota Canal salinity.

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