SYSTECH WATER RESOURCES, INC.
ENVIRONMENTAL ENGINEERING AND WATER RESOURCES SYSTEMS ANALYSIS

Focused Agricultural Drainage Study:

Calibration of the Orestimba Creek Watershed in the San Joaquin River WARMF Model

Report 5.2.3

CALIFORNIA DEPARTMENT OF FISH AND GAME
GRANT AGREEMENT E0883006

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Introduction

Systech Water Resources, Inc. has applied the Watershed Analysis Risk Management Framework (WARMF) to the San Joaquin River watershed and the Link-Node estuary model to the Stockton Deep Water Ship Channel (DWSC). These previous modeling efforts are being updated and upgraded to facilitate their use in managing dissolved oxygen concentration in the DWSC suitable to support fish passage. One subtask of work was a focused agricultural study in the Orestimba Creek watershed on the west side of the San Joaquin Valley. The purpose of this subtask was to improve the WARMF hydrology and water quality simulation in Orestimba Creek watershed and identify how agricultural practices such as groundwater usage and fertilization affect loading from agricultural lands.

The Westside of the San Joaquin River Valley is a highly managed agricultural region. The land is heavily irrigated using water from the Delta Mendota Canal, California Aqueduct, San Joaquin River, and pumped groundwater. The water quality in streams and canals draining the region is high in salinity and nutrients due to a combination of poor quality irrigation water, the application of fertilizer, and high evaporation rates. The WARMF model had been previously set up for the Westside San Joaquin River Valley region as part of previous efforts to understand and characterize sources of salt, nutrients and other constituents. However uncertainty regarding water and land management has made it difficult to accurately estimate model inputs and thus accurately simulate the hydrology and water quality of the Westside region.

This focused agricultural study allowed for a reduction in the level of complexity involved and thus facilitated a better understanding of management practices and data sources. By focusing on a small but well-monitored area such as Orestimba Creek, Systech was able to identify important sources of uncertainty and errors in model inputs, test the impact of key assumptions on model results, and ultimately improve model inputs and simulations.

This report summarizes the work completed for this subtask, outlines the improved state of the Orestimba Creek simulations, and provides suggestions for the direction of additional work to further improve simulations and apply the knowledge gained through this focused study to other Westside catchments of the WARMF San Joaquin River Model.

Catchment Re-delineation

WARMF subcatchments in the Westside region were previously subdivided to coincide with boundaries of water and irrigation districts. This delineation was chosen for lack of better information regarding drainage patterns in the valley, as well as to facilitate data transfer with the WESTSIM model (Figure 1). However, as part of this focused study, drainage district boundaries were acquired and a more detailed analysis of aerial photos was performed to more accurately determine of the land area draining to Orestimba Creek (Figure 2). Results of this task highlighted a previous incorrect assumption that drainage boundaries largely coincide with irrigation district boundaries.

The Orestimba Watershed (as delineated in Figure 2) comprises land area within four different water or irrigation districts. These include Oak Flat Water District, Del Puerto Water District, Eastin Water District and Central California Irrigation District (CCID) (Figure 3). Eastin Water District was added to the model as a subcatchment during this study as it was previously not known to exist. One drainage district, the Orestimba Drainage District, is located within the Orestimba Watershed. This district's boundary was the only information provided that indicated which land area within the agricultural valley actually drains to Orestimba Creek. All remaining portions of the watershed were estimated by analysis of aerial photographs.

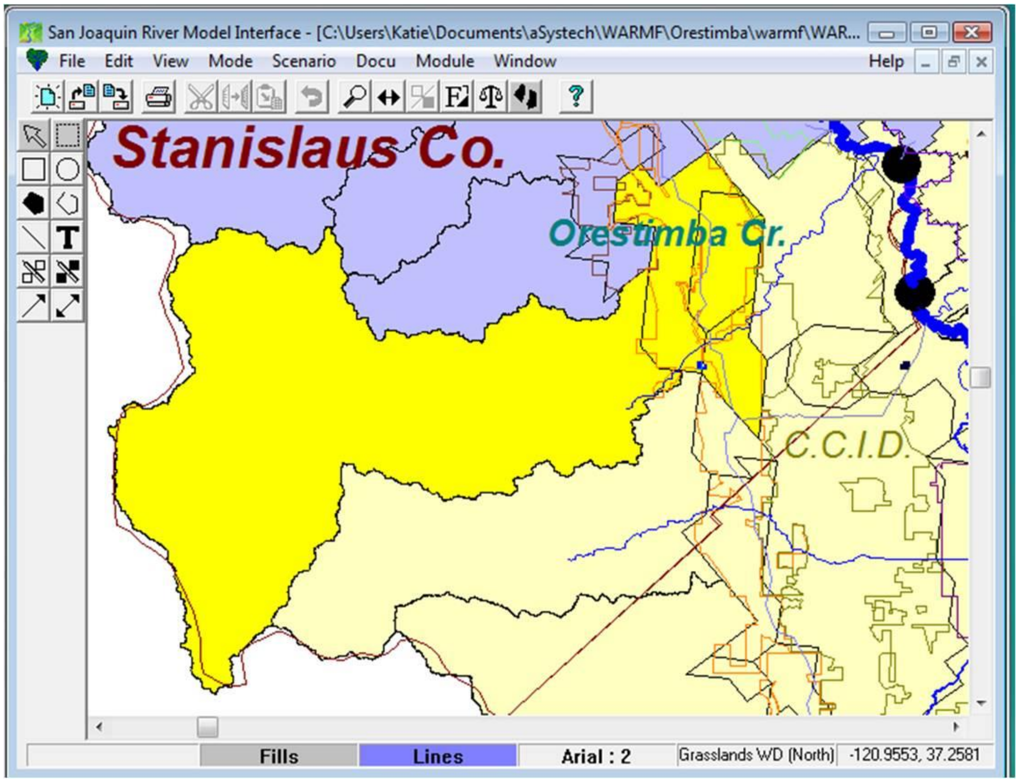


Figure 1 - Previous delineation of Orestimba Creek Subcatchments (bright yellow).

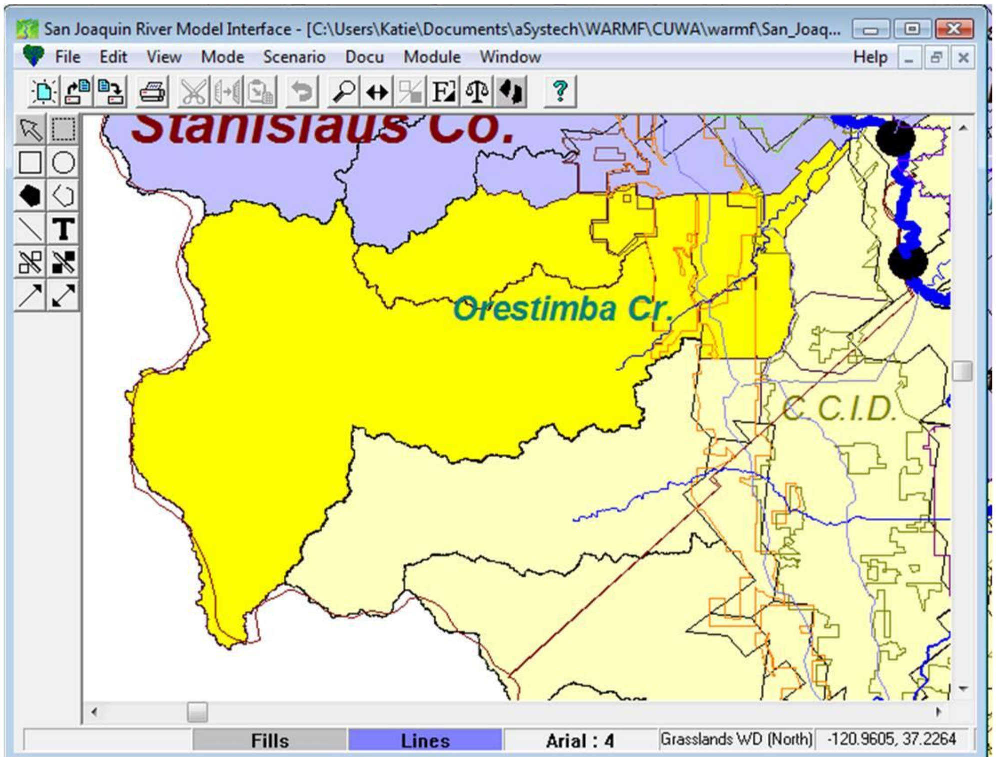


Figure 2 – Updated delineation of Orestimba Creek subcatchments (bright yellow).

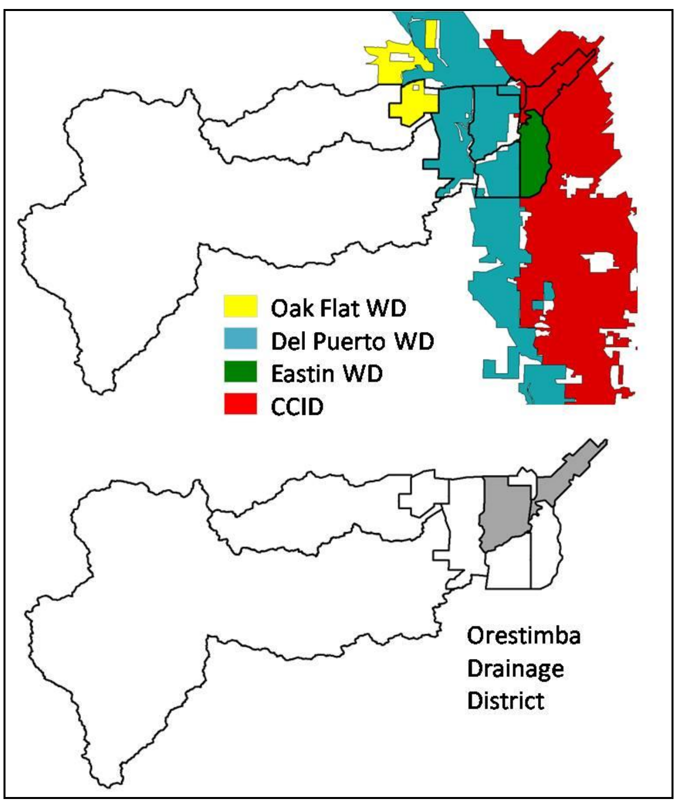


Figure 3 – Irrigation, water, and drainage districts within Orestimba Watershed

Improved Water Management Characterization

An essential component for modeling a highly-managed agricultural watershed, like the San Joaquin Valley, is the accurate characterization of human-induced alterations to the natural movement of water through the region such as irrigation, drainage, groundwater pumping and tailwater reuse. All of these processes were estimated previously for the WARMF San Joaquin River Model. Irrigation sources for the Orestimba Watershed include the Delta-Mendota Canal, California Aqueduct, Mendota Pool and pumped groundwater. In the previous version of the model, irrigation water was assumed to be applied to the land directly from those individual sources, with no mixing between sources. However, it is known that land within the CCID is irrigated by water from the CCID main canal, in which water from the DMC, Mendota Pool and pumped groundwater are mixed before being applied to the land (USBR, 2004). Therefore, in an attempt to better represent CCID water management operations and better simulate the water quality being applied to that district's land, the CCID main canal was added as a river segment to the WARMF model domain as part of this study (Figure 4).

Irrigation water sources for the four irrigation and water districts in Orestimba Watershed are listed in Table 1. The amount of irrigation water applied to a given landuse type in each WARMF catchment was previously estimated based on crop demand for the WARMF San Joaquin River Model. However since catchment boundaries changed during this study, irrigation quantities were recalculated. Since exact values of crop demand by landuse are difficult to estimate, different values have been provided (calculated by different methods or sources) for various different past projects. Thus the demand (and resulting quantity of irrigation water applied) for this study was initially estimated and then treated as an adjustable calibration variable rather than as a known constant. To improve the hydrology and water quality calibration, the total amount of water applied to Del Puerto Water District land areas was reduced during this study. Crop demand reported in the Del Puerto Water District Water Management Plan supports this change (Del Puerto Water District, 2011).

Table 1 – Irrigation water sources in Orestimba Watershed

District Name	**Irrigation Water Source(s)**
Oak Flat Water District	California Aqueduct, pumped groundwater
Del Puerto Water District	Delta-Mendota Canal, pumped groundwater
Eastin Water District	Pumped groundwater
CCID	Delta-Mendota Canal, Mendota Pool, pumped groundwater – all sources via CCID Main Canal.

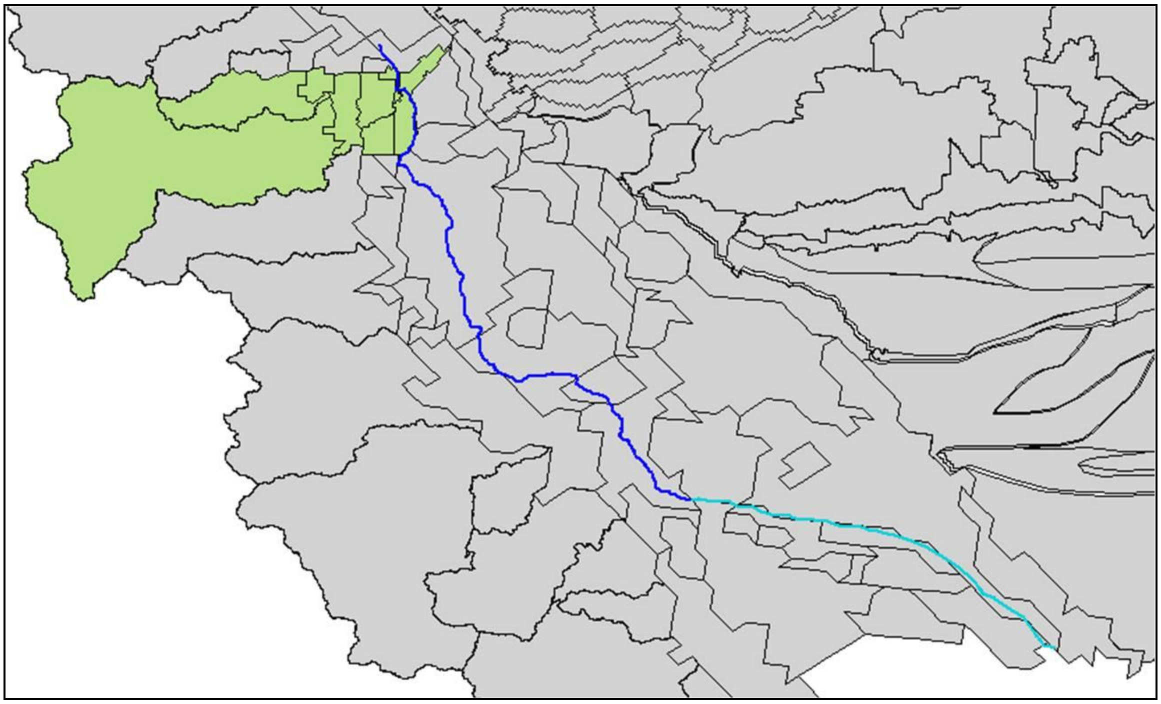


Figure 4 – Upper (light blue) and lower (dark blue) portions of the CCID Main Canal WARMF river segment.

In most Orestimba subcatchments, a portion of irrigation water comes from surface water sources (i.e., the DMC or CA Aqueduct) and a portion comes from pumped groundwater. The one exception is Eastin Water District, which does not receive any surface water delivery and therefore irrigates using entirely groundwater. Since Eastin WD was previously not included in WARMF, this solely groundwater irrigated area was added as part of this study and has a significant impact on Orestimba Creek water quality simulations. In Oak Flat and Del Puerto Water Districts, the proportion of surface versus groundwater (on an annual basis) varies year by year depending on the amount of surface water delivered (Del Puerto Water District, 2011). Since no pumping data is available (to our knowledge), the amount of groundwater applied in these districts is assumed to be the amount necessary to meet the crop demand after all surface water supplies are used. In CCID subcatchments, estimates by year of total pumped groundwater and total surface water deliveries were available. The total of both were assumed to be added to the CCID main canal and subsequently diverted to individual subcatchments based on their crop demand. The water added and removed from the Main Canal's upper and lower segments (see Figure 4) in the WARMF model is defined in Table 2.

Table 2 – CCID Main Canal supplies and diversions simulated in WARMF

Canal Segment	Groundwater Added	Surface Water Added	Surface Water Portion
Upper (above O'Banion Bypass)	CCID Regions D,E,F,G	CCID Mendota Pool CVO Delivery	57% of canal content above O'Banion
Lower (below O'Banion Bypass)	CCID Regions A,B,C	2 CCID DMC Deliveries	97% of remaining canal water below O'Banion

Improved Hydrology Simulation

Once the above changes were made to improve model inputs and the representation of the real system in WARMF, calibration was performed for the hydrology and water quality simulations of Orestimba Creek. Two hydrology gaging stations are located on Orestimba Creek enabling calibration of the upper foothills part of the watershed separately from the lower agricultural part of the watershed. Figure 5 shows the previous (red) and updated (blue) calibration for the upper watershed, corresponding to the gaging station for Orestimba Creek at Newman. The updated calibration reflects changes made for this study, including precipitation data corrections and soil parameter adjustments to improve the speed of hydrograph recession. The calibration statistics for the two simulations listed in

Table 3 indicate the overall improvement in the fit between simulated and observed. Relative error is the average difference between simulated and observed, so it is a measure of model accuracy. Absolute error is the average of the absolute value of the difference between simulated and observed, a measure of precision.

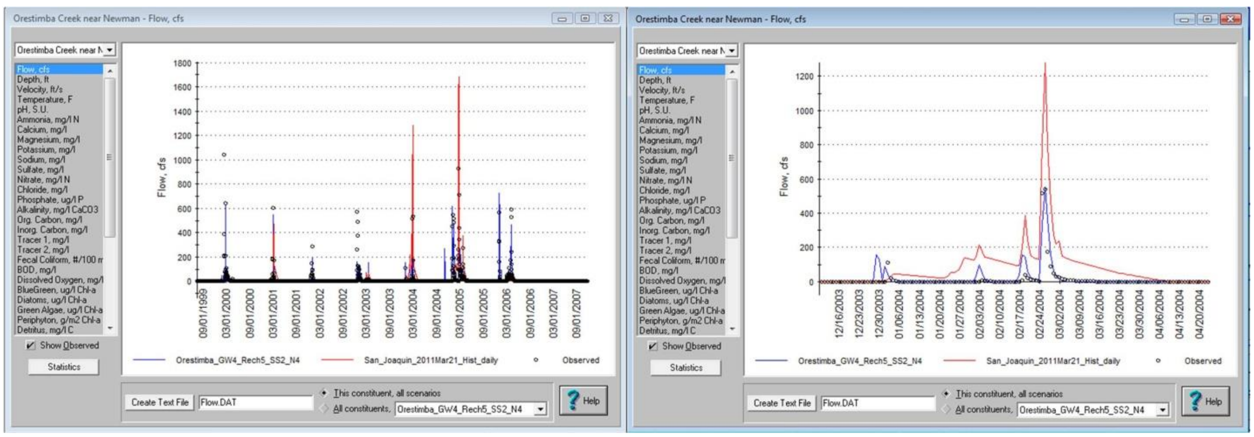


Figure 5 – Previous (red) and updated (blue) hydrology calibration for Orestimba Creek at Newman . The right plot shows the full calibration period of 2000-2007, the left plot zooms into 1 year (2004).

Table 3 – Hydrology calibration statistics for the previous and updated calibration of Orestimba Creek at Newman.

	Relative Error, cfs	Absolute Error, cfs	R squared
Previous Calibration	-4.12	14.46	0.251
Updated Calibration	3.005	12.39	0.50

Improvements made to the upper portion of the watershed also improved the calibration at the lower gaging station, Orestimba Creek at Crows Landing. Figure 6 shows the previous and updated simulated hydrographs at Crows Landing after improving the upstream calibration.

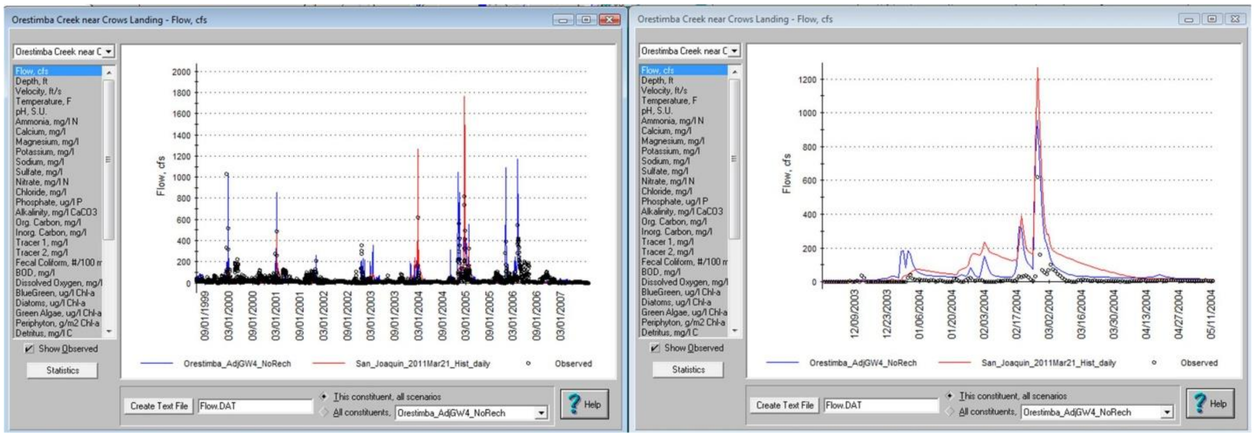


Figure 6 - Previous (red) and updated (blue) hydrology calibration for Orestimba Creek at Crows Landing. The right plot shows the full calibration period of 2000-2007, the left plot zooms into 1 year (2004).

As a first step in the recalibration of the lower watershed simulations, a water balance analysis was completed to compare total watershed inflows versus outflows on an annual basis. This analysis indicated that inflows (precipitation + irrigation) exceeded outflows (evapotranspiration + stream outflow) by zero to 34%, varying by year, with the maximum 34% occurring during the wettest year (2005). The remaining unaccounted loss is assumed to be deep groundwater recharge. Initial estimates of recharge were calculated on a yearly basis as the difference between simulated flow with no recharge and observed flow at the gage. Actual recharge simulated in WARMF is a function of available water in the lower soil layer. Figure 7 shows the simulated versus observed flow at Crows Landing with and without estimated recharge. Adding recharge (shown in green) improves the simulation of both peaks and low flows. The calibration period was extended to 2011 to include more recent years.

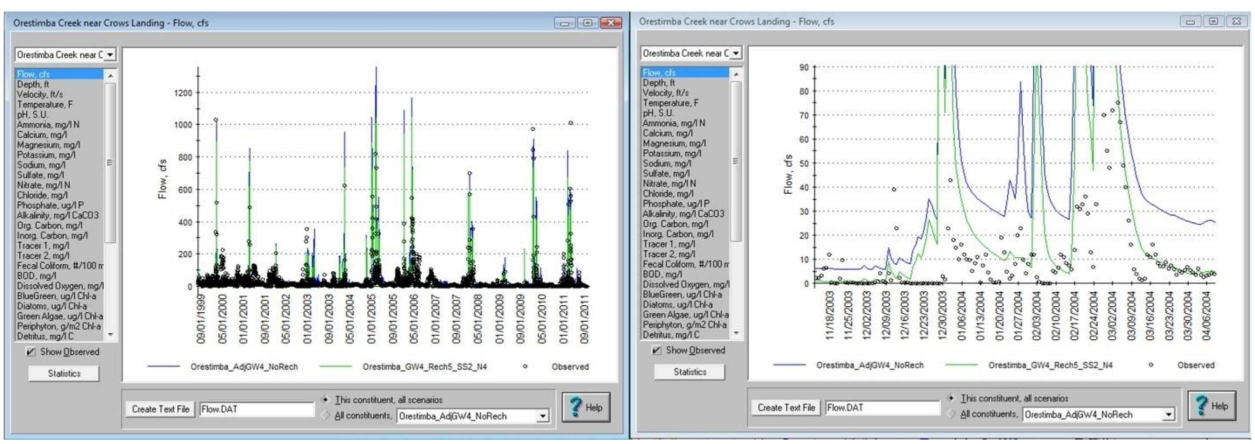


Figure 7 – Simulated versus observed streamflow of Orestimba Creek at Crows Landing showing simulations without recharge estimates (blue) and with recharge estimates (green). The right plot shows the full calibration period of 2000-2011, left plot zooms into low flows for 1 year (2004).

Calibration statistics are listed in Table 4 for Orestimba Creek at Crows Landing for the previous simulation, the updated without recharge simulation and the updated with recharge simulation. The statistics indicate significant improvement in the fit between simulated and observed flow from the previous to the updated scenarios. The reduction in relative error achieved by adding recharge to the updated simulation represents improvement in the simulated annual water balance of the watershed.

Table 4 – Hydrology calibration statistics for Orestimba Creek at Crows Landing for the previous, updated without recharge, and updated with recharge simulations.

	Relative Error, cfs	Absolute Error, cfs	R squared
Previous Calibration	-12.97	30.8	0.193
Updated without recharge	13.3	36.62	0.538
Updated with recharge	2.792	27.88	0.587

During the calibration process, the observed streamflow data was analyzed in detail to better understand why simulations were not matching the observed flows well during certain periods. This analysis revealed some repeated patterns in the observed streamflow data that were not possible to simulate because they featured increased flow during periods of no rainfall or irrigation. Specifically, during the months of October/November nearly every year the gaging data show an increase in streamflow without precipitation and with little irrigation. Figure 8 shows an example of this for years 2005-2006. Similar unexplainable flows also show up at various, more random times throughout the record. Some documentation was found that states that spills occur from CCID Main Canal into Orestimba Creek periodically (CARWQCB, 2009), however discussions with CCID personnel rendered conflicting information. If we assume that the fall flows are in fact the result of canal spills (for lack of any other identified source of the water), the canal inflows in the current model setup (as defined in Table 2) do not provide enough water remaining in the canal after irrigation diversions to simulate the spills. Thus further investigation is necessary to identify the source of more water in the canal in order to simulate these spills fully in WARMF.

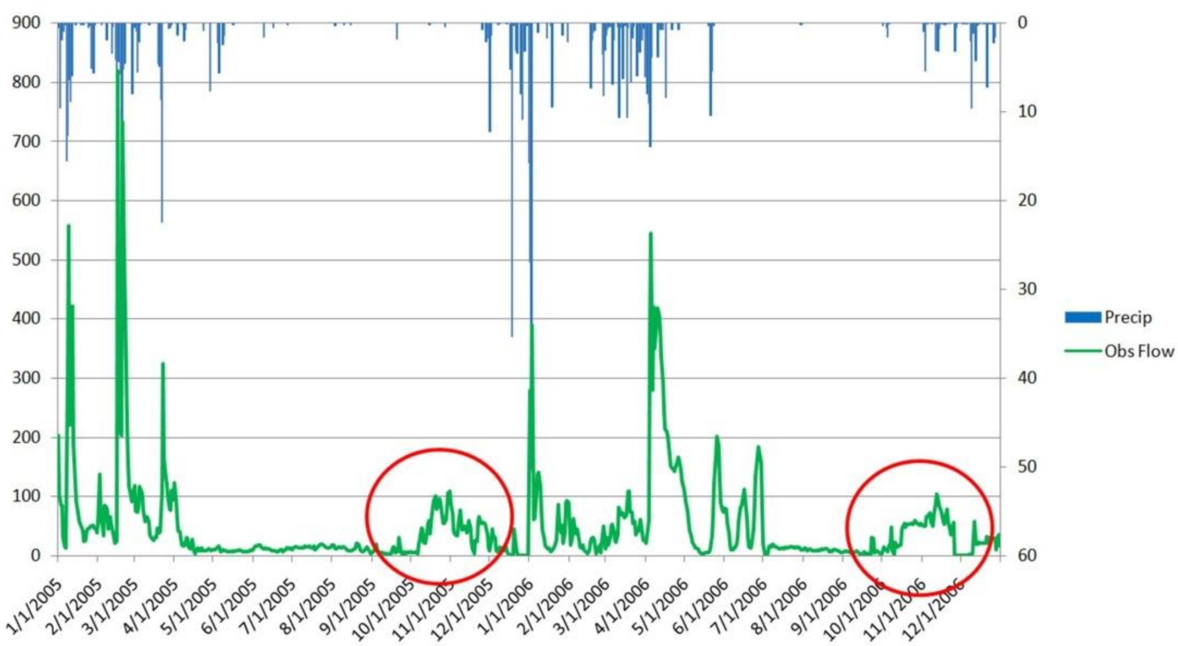


Figure 8 – Examples of streamflow patterns (within red circles) of Orestimba Creek at Crows Landing that occur during periods of little or no rain or irrigation.

Improved Water Quality Simulation

The water quality simulation for Orestimba Creek at Crows Landing in the previous version of the WARMF San Joaquin River Model was poor. Electrical conductivity (EC), individual ions, and nitrate, in particular, were substantially higher than observed. A major objective of this focused study in Orestimba Watershed was to improve the water quality simulation by identifying and adjusting model inputs and coefficients that have a significant impact on simulations of EC and nutrients.

A number of tactics were tested to improve the EC simulation, including adjusting initial ion concentrations in the soil, mineral composition, land application, reaction rates, water quality of applied groundwater, total quantity of irrigation water (to increase dilution), relative proportions of groundwater versus surface water applied, and assuming canal spills occur during summer months. The adjustments that significantly improved simulations were initial ion concentrations, water quality of applied groundwater, and quantity of canal water added during summer months.

The initial ion concentrations in the soil were previously set too high and were reduced to better represent concentrations that likely were present at the start of the simulation. The difference in irrigation sources between catchments (and thus irrigation water quality) resulted in varying soil salt content making it important to set the initial conditions differently for each catchment. In each catchment, initial soil ion concentrations were set under the assumption that there has been little long-term accumulation or depletion of ions in the near-surface soil layers.

Very little data was available to estimate concentrations of water quality constituents in pumped groundwater throughout the Westside region. Furthermore, the data that was obtained demonstrated very highly variable concentrations, both spatially and temporally. For simulation of irrigation in WARMF, daily time series of groundwater quality had to be estimated for each catchment receiving locally pumped groundwater for irrigation, as well as for the 7 CCID regions from which groundwater is pumped into the CCID Main Canal. To do so, mean annual concentrations from the closest well or wells were used for each catchment or CCID region. However such high variability in the data ensured that these estimates were rough at best and adjustment during the calibration process was warranted. The quality of groundwater applied to Eastin Water District, which irrigates entirely by groundwater, had a particularly large impact on overall EC simulations in Orestimba Creek. Figure 9 demonstrates the overall improvement in EC simulations achieved by adjusting initial conditions and groundwater quality as compared to simulations from the previous version of the SJR Model shown in red. The line shown in blue represents the effect of all these changes. Figure 9 also shows that some of the improvement in EC (from the red line to the green) can also be attributed to the improved hydrology simulation described in the previous sections.

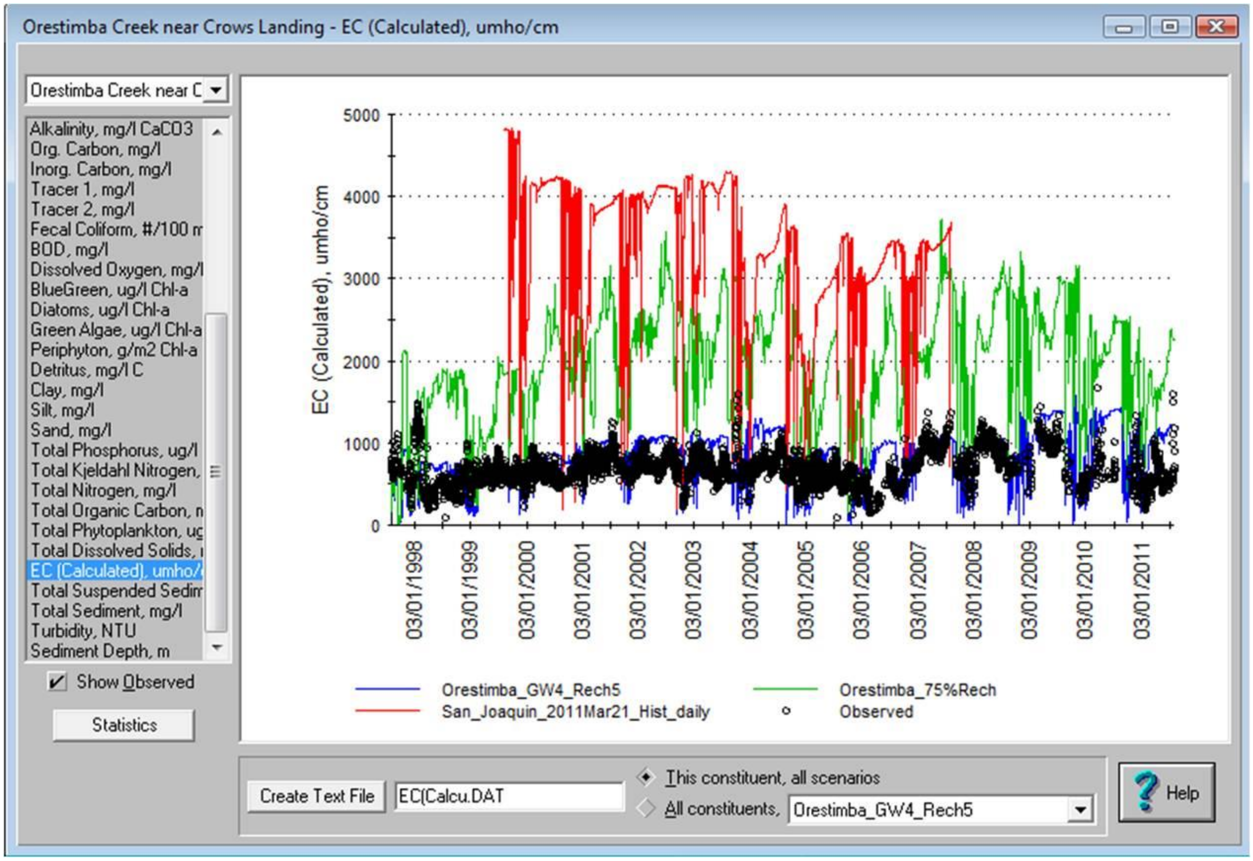


Figure 9 – Electrical conductivity simulations for Orestimba Creek at Crows Landing, showing the previous version (red), the version after updated hydrology simulations (green) and the version after adjustments to initial conditions and groundwater quality (blue).

Though the overall EC simulation was greatly improved by adjusting initial conditions and groundwater quality, specific periods were still too high, primarily during the low flow summer months. Each summer, roughly 10-20 cfs of streamflow was observed in the creek. Initially it was assumed that this flow was entirely from irrigation tailwater. However if the flow was composed mainly of tailwater, the EC would increase, rather than decrease (as seen in the data) through the summer. Moreover the summer concentrations seen in the data could not be simulated given the concentrations in the irrigation source water (mainly DMC) and high evapotranspiration rates. Thus it was concluded that another source of lower EC water must be entering the creek during the summer in addition to tailwater. As discussed previously, some sources indicate that Orestimba Creek contains water spilled from CCID Main Canal. With inflows and diversions as currently defined in WARMF (Table 2), roughly 30 cfs excess flow remains in CCID Main Canal during the irrigation season. Thus it was possible to add small spills to the simulated summer flow, which improved both the water quantity and quality during the irrigation season. Further research to better characterize the composition and sources of water in the creek during the irrigation season could aid in further improving the EC simulations in Orestimba Creek. Figure 10 shows the EC simulation in Orestimba Creek before (in blue) and after (in red) adding summer spills from CCID Main Canal. The right side plot zooms into years 2002-2004 to better demonstrate the improvement in simulated EC.

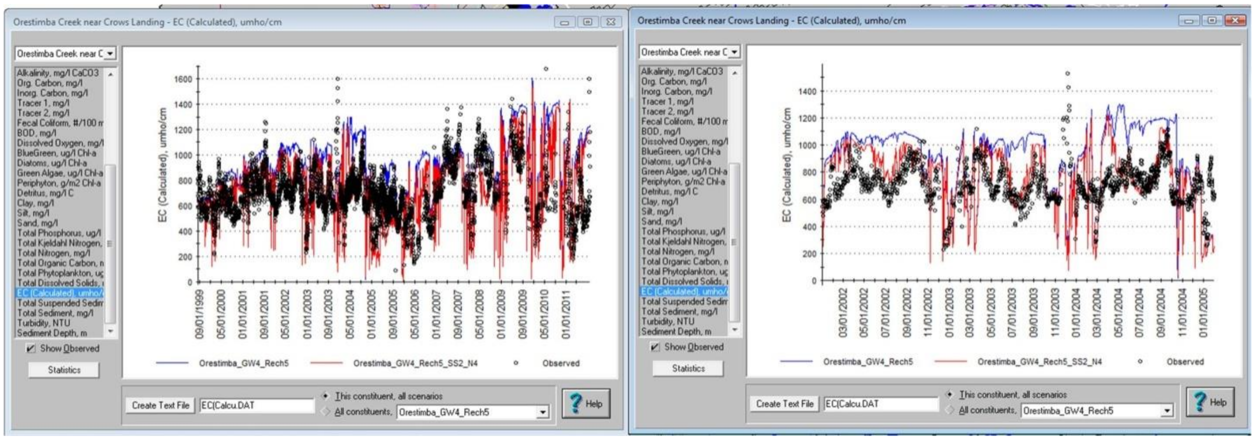


Figure 10 – Electrical Conductivity simulations before (blue) and after (red) adding spills from CCID Main Canal into Orestimba Creek during the irrigation season. Left plot shows the full calibration period from 2000-2011 and the right plot zooms into 3 years from 2002-2004.

In addition to total salt, nitrate is a constituent of concern throughout the Westside region. The nitrate simulation in the previous version of the SRJ Model, though not as poor as the EC simulation, still needed some improvement. The changes made to improve streamflow and EC for this study had some impact on the nitrate simulation, since nitrate concentrations in applied groundwater were adjusted. Changing the nitrate content of applied fertilizer was tested but had little impact on simulations since irrigation water is a much greater source of nitrate in the Orestimba Watershed than land application. However adjusting reactions rates, especially increasing the organic carbon decay rate in the soil, led to further improvement in the NO_3 simulation by causing anoxic conditions which lead to denitrification.. The final updated NO_3 simulation is shown in Figure 11.

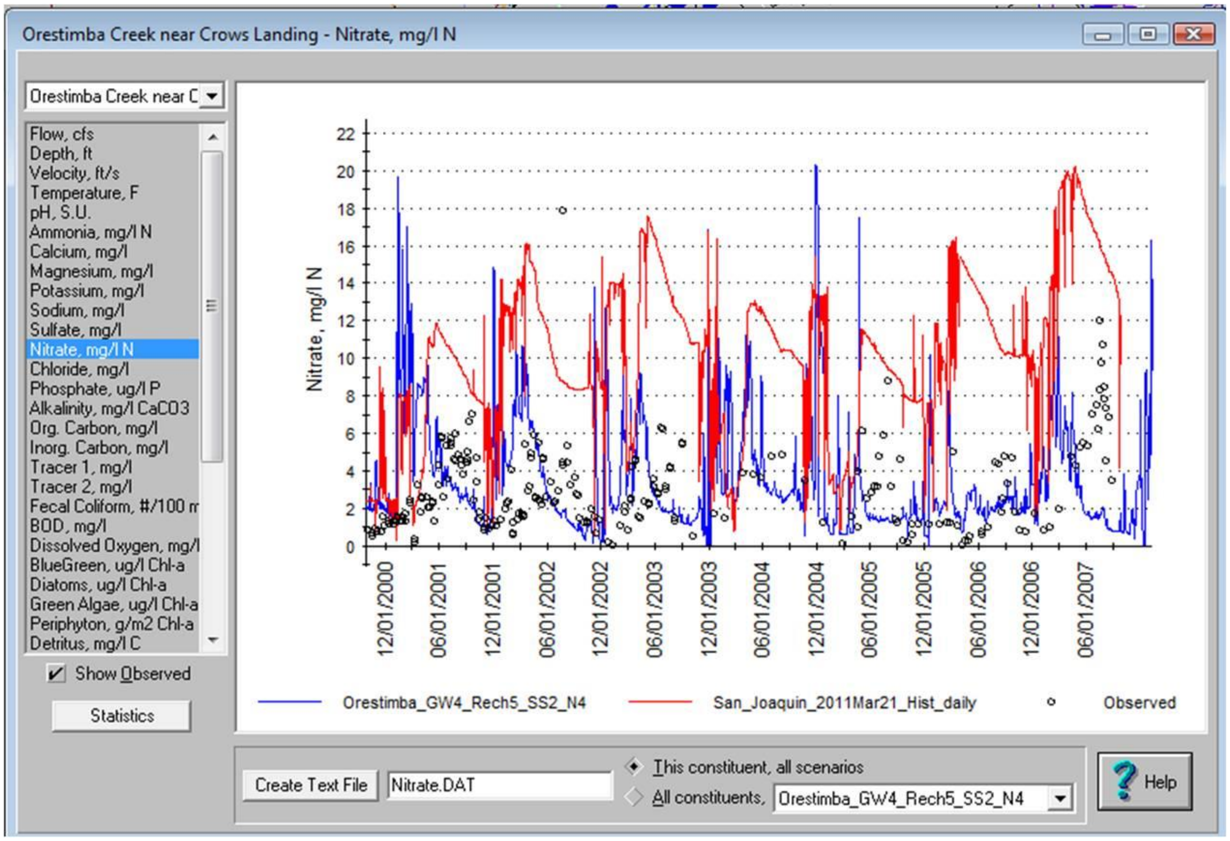
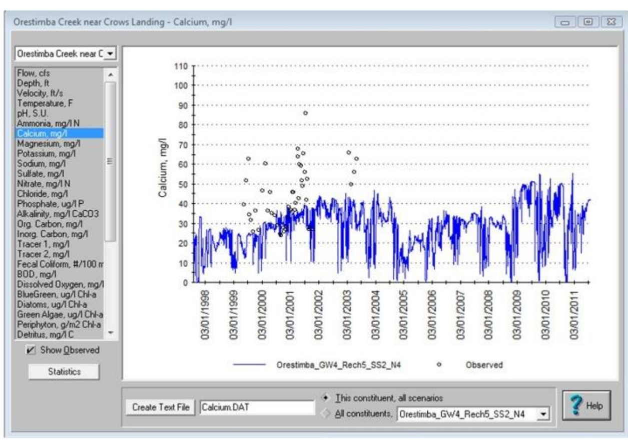


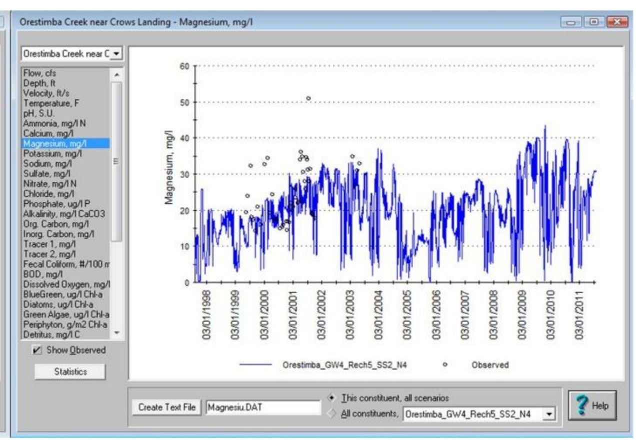
Figure 11 – Previous (red) and updated (blue) nitrate simulations for Orestimba Creek at Crows Landing.

Current State of the Model

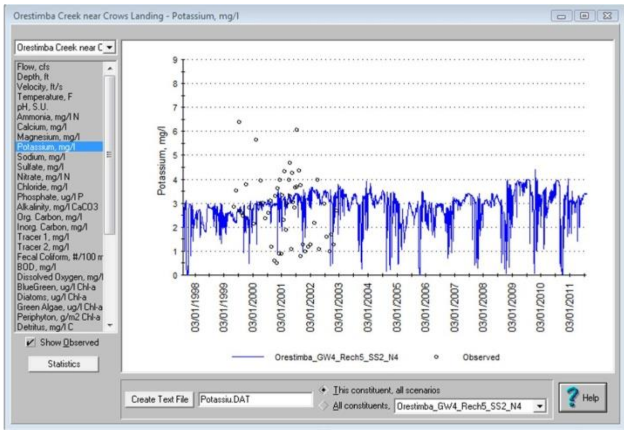
Overall the current hydrology and water quality simulations in WARMF for Orestimba Creek are much improved from the previous version. The effort spent identifying the specific issues unique to the Orestimba Creek watershed give us greater confidence in model simulation results here than for other subwatersheds on the west side of the San Joaquin River. The following figures show the simulations of individual ions and other constituents not presented in the previous sections.



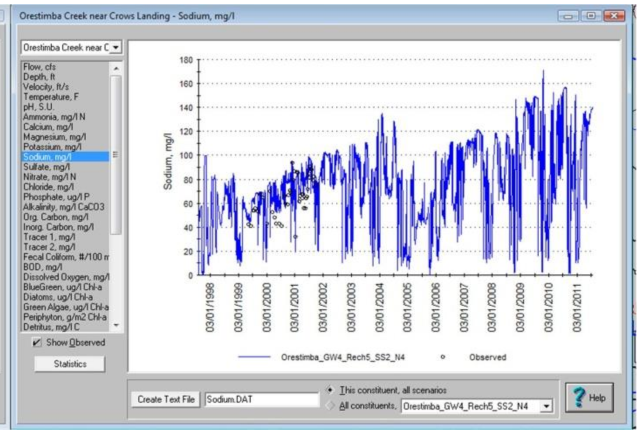
Calcium



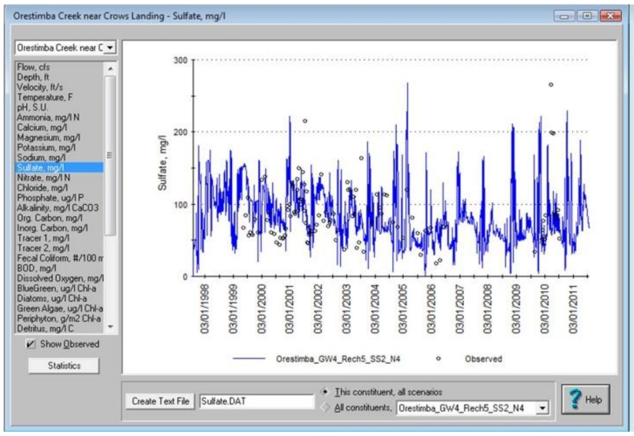
Magnesium



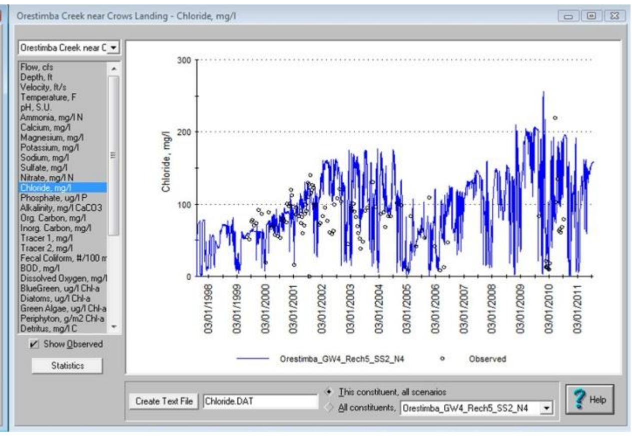
Potassium



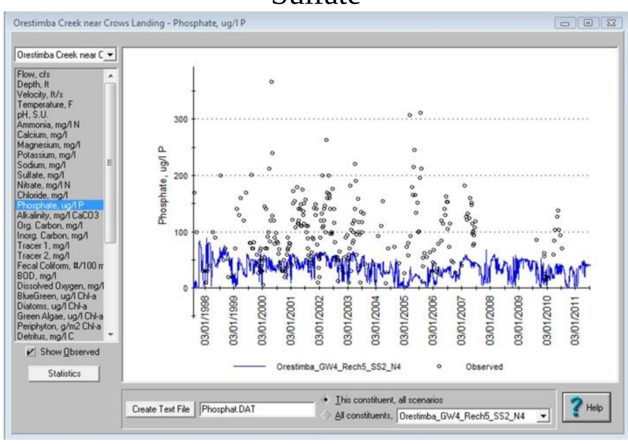
Sodium



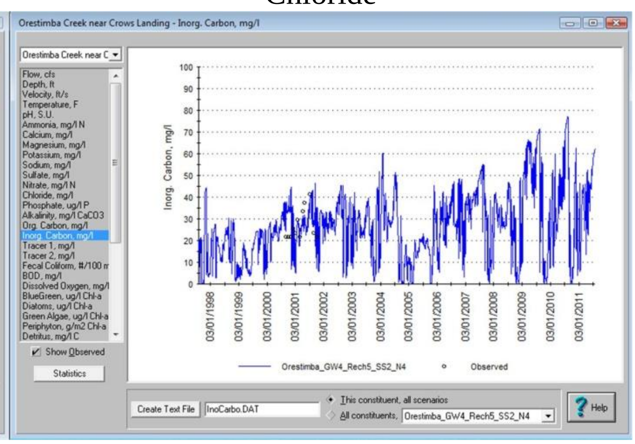
Sulfate



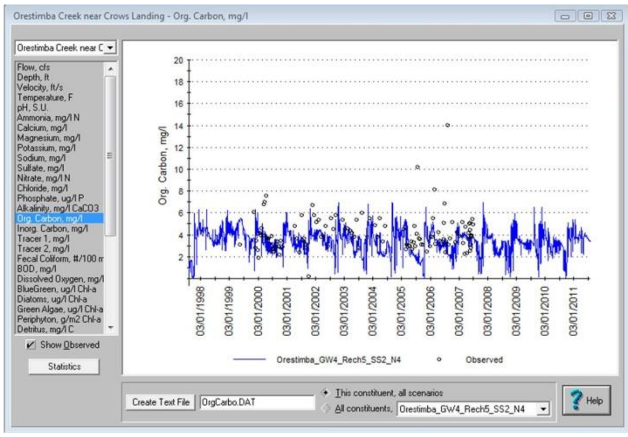
Chloride



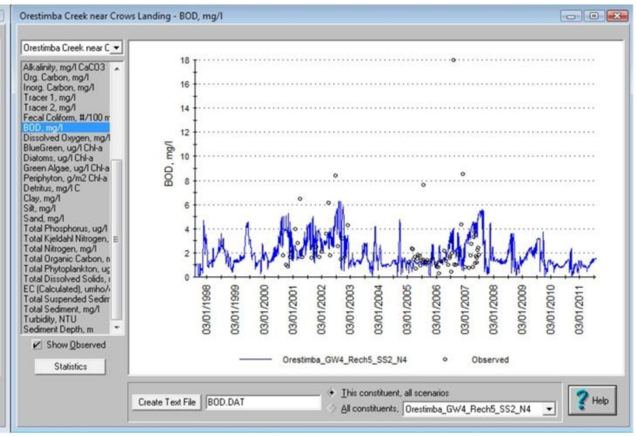
Phosphate



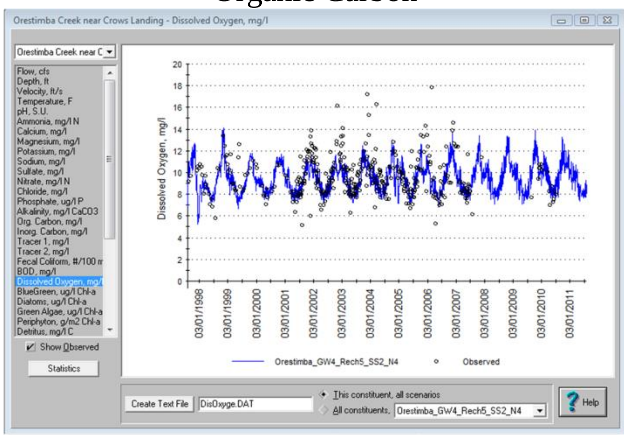
Inorganic Carbon



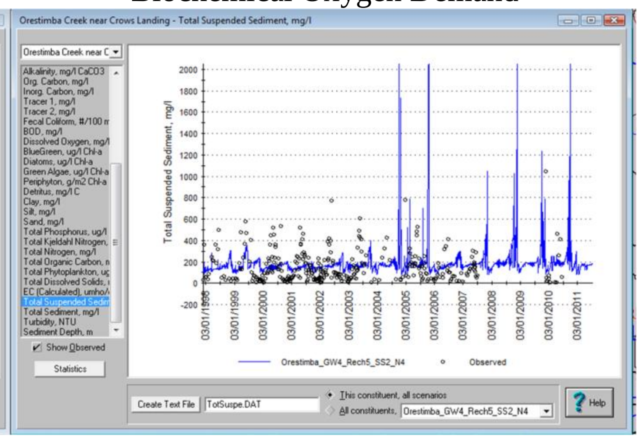
Organic Carbon



Biochemical Oxygen Demand



Dissolved Oxygen



Total Suspended Sediment

Summary

Overall this focused modeling study of the Orestimba Creek Watershed resulted in improved simulations of streamflow, salinity, and nitrate. It also revealed several factors that were important to achieve these improved simulations that are applicable to other portions of the San Joaquin River WARMF model domain. These factors include:

- Delineation of subcatchments corresponding to known drainage boundaries
- More accurate representation of irrigation sources, such as mixing between sources prior to application of the water to the land
- Foothills catchments soil coefficients
- Annually varying recharge estimates
- Catchment-varying initial soil concentrations
- Adjustment of groundwater quality as a calibration parameter
- Consideration of additional, external sources of water

Recommendations

It is recommended that the methods listed above be applied throughout the remainder of the WARMF domain for the Westside region to improve the model's assessment of sources of loading to the San Joaquin River. In addition, though WARMF simulations of Orestimba Creek are in a relatively good state, some limitations still exist. The nutrient simulations need more calibration to improve the timing of nitrate peaks and the range of simulated phosphate concentrations and thus provide a better understanding of nutrient sources. As it stands, it would be difficult to have complete confidence in model scenarios aimed at testing impacts on nutrient loads in Orestimba Creek. In addition, further research into the composition and sources of the creek's flow during the irrigation season is recommended to verify the assumptions made during this study regarding spills from CCID Main Canal and proportions of groundwater versus surface water applied as irrigation. This would provide confidence that the representation in WARMF is accurate and enable creation of model scenarios that test changes to those facets of water management in Orestimba Creek Watershed.

Acknowledgements

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References

California Regional Water Quality Control Board. 2009. Technical Report. "San Joaquin River Basin: Main Stem and Drainage Basin Sites, October 2000-September 2005".

Del Puerto Water District. 2001. Del Puerto Water District Water Management Plan 2008 Criteria.

U.S Department of Interior, Bureau of Reclamation (USBR). 2004. Water Transfer Program for the San Joaquin River Exchange Contractors Water Authority 2005-2014. Final EIS/EIR SCH#2003101106.