Using the WARMF 2008 Model to Quantitate the Effect of Nutrient Control and Tributary Inputs on Water Quality in the San Joaquin River

Report 4.8.1

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List of Acronyms

BOD	carbonaceous biochemical oxygen demand
CALFED	collaboration among state and federal agencies to improve California’s
chl	chlorophyll-a
DO	dissolved oxygen
DWSC	deep water ship channel
ID	identification
kg	kilograms
L	liters
mg	milligrams
PTS	point source file
SJR	San Joaquin River
TDS	total dissolved solids
TMDL	total maximum daily load
WARMF	Watershed Analysis Risk Management Framework

Introduction

The *Watershed Analysis Risk Management Framework* (WARMF) model is a public domain watershed model specifically developed for application to TMDL development (Keller 2000; Chen, Herr et al. 2001; Herr, Weintraub et al. 2001; Chen, Herr et al. 2004). As part of the Upstream DO TMDL Project (2005-2007), CALFED Project ERP-02D-P63, the model was specifically adapted for use in the upstream San Joaquin River (SJR) region (Herr et al. 2008). In 2008, the SJR-WARMF model was published. A user-friendly interface was developed which allows users who are not modeling experts to access the model, examine model input and output, view and update the supporting database, and change model parameters to test total maximum daily loads (TMDL) management scenarios (Herr et al. 2008). The model was calibrated using grab sample data and continuous data collected in the Upstream DO TMDL Project and the model was then tested for use in forecasting (Herr et al. 2008; Herr and Chen 2007; Paulsen and Mead 2008). The calibration for the SJR-WARMF 2008 Model is addressed in Final Report for the Task 6 Modeling of the San Joaquin River (Herr et al. 2008). The model mechanics are described in Watershed Analysis Risk Management Framework (WARMF): Update One (Chen et al. 2001), and further details are provided in the Final Report for the Task 6 Modeling (Herr et al. 2008).

The purpose of this study was to determine the practicality of the SJR-WARMF 2008 Model and to assess if a user familiar with the San Joaquin River Basin, but without a modeling background, can execute model simulation to extract desired information. This study also investigates the use of the SJR-WARMF 2008 Model to test remediation activities, using hypothetical situations.

Previous studies have shown that loads from the SJR contribute to dissolve oxygen (DO) impairment in the San Joaquin/Sacramento Delta (Gowdy and Grober 2003; Lehman et al 2004; Ohte et al. 2007). DO concentration is a fundamental water quality parameter that is a significant indicator of ecosystem health. Aesthetic qualities of water require sufficient DO present to avoid the onset of septic conditions with its attendant malodorous emissions. Sufficient dissolved oxygen concentrations are required for the maintenance of fish and other aquatic life (U.S. EPA, 1976).

Studies have shown that a cause of DO impairment may be associated with nutrient loading and oxygen demanding substances, particularly phytoplankton (Gowdy and Grober 2003; Lehman et al 2004; Ohte et al. 2007). As a result, the nutrient sources and oxygen-consuming material, including phytoplankton concentrations, organic carbon and biological oxygen demand (BOD), were examined in the upper reaches of the SJR by conducting simulation in the SJR-WARMF 2008 Model.

The study area consisted of the upstream portion of the SJR watershed, extending from the SJR at Lander Avenue to the SJR at Vernalis (Figure 1). The model was used to investigate nutrient loading and the effect of agricultural drainage on water quality in the SJR. The study period included a seven year period between October 1, 1999 and September 30, 2007. The constituents analyzed in these simulations included: total ammonia and ammonium nitrogen, nitrate, phosphate, dissolved organic carbon, carbonaceous biochemical oxygen demand, total nitrogen, total phosphorous, total phytoplankton, and total dissolved solids (TDS). In the SJR-

WARMF 2008 Model total ammonia and ammonium nitrogen is reported as ammonia, dissolved organic carbon is reported as organic carbon and carbonaceous biochemical oxygen demand is reported as BOD.

Methods

SJR-WARMF 2008 Model

The SJR-WARMF 2008 Model is a watershed modeling and analysis tool used for short and long term predictions, watershed management, and calculating TMDL (Figure 2). The SJR-WARMF Model consists of catchments, stream segments, and reservoirs that have coefficients and initial conditions for land use, soil layers, sediment transport parameters, flow sources and diversions, meteorology, stage-flow relationships, and reaction rates. The model uses this information to simulate constituent loading and flow relationships along the SJR (Weissmann et al. 2013). The model includes the San Joaquin River watershed and point sources from 30 different sources along the SJR (Table 1), extending from Lander Avenue to the Stanislaus River. In this study, the SJR-WARMF 2008 Model was used to analyze the flow of nutrients, salts, minerals, phytoplankton, and other constituents in the SJR.

The SJR-WARMF 2008 Model operates using a “Scenario Manager”. A scenario is a set of model inputs that represents the conditions of a simulation. A pre-loaded scenario provided by Systech Engineering, San_Joaquin_2008May3, is available spanning between October 1, 1999 and September 30, 2007. A copy of the pre-loaded scenario serves as a baseline and is used to create new scenarios. The copied scenario is renamed and modified to meet the conditions of the desired simulation.

Model Inputs

The SJR-WARMF 2008 Model has individual data files containing historical flow and water quality data for each river segment and tributary. For scenarios examining loading from individual tributaries, data files were modified or edited to adjust load constituents at the inflow water source. In each case, a copy of the data file were created and modified according to the desired simulation. The modifications were made using Microsoft Excel and modified files were imported into the data module spreadsheet for each inflow.

Individual river segments were modified in the engineering module by replacing the tributary inflow file with the desired modified copy. A list of the tributary inflow and river segment IDs along with the point source file are shown in Table 2.

Data inputs can be also changed globally by modifying point and non-point sources. Point sources consist of all true point sources as well as all tributary inflows. Nonpoint sources affect loading from the land to surface waters and include: overland flow, runoff from impervious surfaces, and subsurface flow. Modifications to the point and non-point sources can be made under the “Consensus Menu” through management alternatives. All point and nonpoint sources have a multiplier which can be applied to any chemical constituent. The multipliers are a ratio that can range between 0 and 1, where 1 represents the maximum load.

Simulations

Simulations were run to determine the effects of nutrient loading and agricultural drainage inputs on the SJR. The simulation period spanned from October 1, 1999 to September 30, 2007, using a six hour time step. A baseline scenario was created from a copy of the file San_Joaquin_2008May3 scenario. All simulations for this analysis were produced from a copy of the baseline scenario with modifications to the inflow files or point and nonpoint sources. The scenarios were executed by running the model preloaded subwatersheds Hensley Lake, SJR at Bear Creek, and SJR at Old River. The output results were collected at each of the nodes in the model: SJR at Vernalis, SJR at Maze Road, SJR at Patterson, SJR at Crows Landing, SJR at Newman, and SJR near Stevinson.

Effect of nutrient loading

The effect of nutrient loading was studied using model scenarios. Global changes to the model settings were made to test the effect that nutrients had on the growth of phytoplankton. The multipliers for both point and non-point sources were adjusted under the management alternatives in the consensus menu. The initial conditions for the point and non-point sources were set at 1 and simulated to determine the "baseline loads". To determine the effect of nutrient loading, the point and nonpoint sources for nitrate, ammonia, and phosphate were systematically altered to zero, in other words using the Consensus Menu function to remove nutrient inputs in the system. Seven different scenarios were simulated in order to determine the individual and combined contributions of each constituent on phytoplankton growth.

Effect of agricultural drainage

The effect of agricultural drainage on water quality in the SJR was studied using model scenarios. Loads of various constituents originating from agricultural drains and from rivers upstream of the SJR at Vernalis were removed by changing the constituent concentrations in the PTS source file (Table 2). The following agricultural drains and rivers were evaluated: Salt Slough, Mud Slough, Lander Avenue, Harding Drain, Los Banos Creek, Orestimba Creek, Westport Drain, Del Puerto Creek, Ingram Creek, Hospital Creek, Merced River, Tuolumne River, and Stanislaus River (Figure 1). The load at one tributary/river was removed per simulation by modifying the historical data in the inflow data file. The modified load constituents included ammonia, calcium, magnesium, potassium, sodium, sulfate, nitrate, chloride, phosphate, organic carbon, inorganic carbon, electrical conductance, BOD, dissolved oxygen, diatoms, and clay (clay represents particle size 0.002mm). These constituents were adjusted to zero in order to eliminate the contributing load, while maintaining the same flow, from the individual sources. By removing each load and maintaining the flow, it was possible to determine the effect of loads from individual sources on the SJR at Venalis.

Data Analysis

The data output in the SJR-WARMF 2008 Model for the constituents are in units of concentration (i.e. mg L^{-1}). In order to determine the total load contribution of each parameter the concentration was converted to a load (kg) by multiplying the simulated concentration with the associated simulated flow. Total load was calculated by the summation of the individual load measurements over the simulation period of the analysis. Load contributions were expressed two ways: total load (kg) and the percent of load removed compared to the baseline (%) (Equation 1). A negative percentage indicates the percent of the constituent has increased compared to the baseline. Total phytoplankton was expressed in units of kilograms of chlorophyll-a (CHL). The data was analyzed with Microsoft Excel and JMP 10 and plotted using Grapher 9.

$$Percent\ Removed = \left[1 - \frac{constituent\ load}{baseline\ load}\right] * 100 \qquad (1)$$

Results and Discussion

Upstream of Vernalis, the SJR contains a mixture of pure water sources from the Sierra Nevada Mountains and lower quality waters from local agricultural drainage sources. Monitoring data has been collected for flow and water quality for the tributaries discharging into the SJR and for the SJR location at Vernalis for many years. In the SJR-WARMF 2008 Model, differences between river inputs and outputs are used to calculate subsurface inputs and transformations that occur within the river. The effects of low quality water from the local agricultural drainages along with the contributions from the Sierra Nevada Mountains were examined. The analysis focused on nutrient and phytoplankton loads on the SJR at Vernalis, as it was the furthest downstream location in the SJR-WARMF 2008 Model.

Effect of nutrient loading

Vernalis is the approximate downstream limit of the riverine portion of the SJR and the legal limit of the San Joaquin/Sacramento Delta. The SJR at Vernalis has also been used as a compliance point in previous TMDL studies including the Lower San Joaquin River Salt and Boron TMDL (CA RWQCB Central Valley Region, 2004). The SJR-WARMF 2008 Model simulations were conducted to determine the effect of nutrient loading on the growth of phytoplankton at the SJR at Vernalis. Both point and non-point sources were modified to determine how nutrient loading affected phytoplankton growth. Sources of nitrogen and phosphate were systematically removed in these simulations. The following scenarios were analyzed: Scenario 1 – removal of ammonia, Scenario 2 – removal of nitrate, Scenario 3 – removal of phosphate, Scenario 4 – removal of nitrate and ammonia, Scenario 5 – removal of nitrate and phosphate, Scenario 6 – removal of ammonia and phosphate, and Scenario 7 – removal of ammonia, nitrate, and phosphate.

The results of the nutrient loading simulations on the SJR at Vernalis are presented in Table 3 and Table 4. When phosphate was globally removed from the system, the amount of phosphate along with total phosphorous was reduced by approximately 85% in all scenarios. When ammonia was globally removed from the system, there was a reduction in ammonia by 86% and 17% for total nitrogen. When nitrate was globally removed from the system, there was a 97% reduction in nitrate and a 62% reduction in total nitrogen.

Ammonia, nitrate, and phosphate had various impacts on total phytoplankton when a single nutrient was removed. Ammonia had the greatest impact on reducing the total phytoplankton load, causing a reduction of 32%. The removal of phosphate or nitrate alone caused a reduction of 25% and 13%, respectively. When ammonia or nitrate were removed with phosphate, the reduction in total phytoplankton was between 31% and 36%. The highest reduction in phytoplankton occurred when all inorganic inputs of nitrogen were removed simultaneously from the system. When nitrate and ammonia were removed together the total phytoplankton decreased by 62%. The additional removal of phosphate, with nitrate and ammonia, did not cause a further reduction in phytoplankton load, suggesting phosphate discharges are less critical to eutrophication in the river, possible due to the significant storage of phosphorous in the river. Ammonia displayed the greatest effect on the growth of phytoplankton, according to the model. Phytoplankton can uptake nitrate as a nitrogen source; however, the highest reductions occurred when ammonia was removed from the simulations. This is consistent with the findings of Dortch (1990) that phytoplankton can have a similar growth rate when consuming nitrate as a nitrogen source; however, ammonia is the preferred nitrogen source.

The removal of ammonia and nitrate were further examined. The point and non-point sources for ammonia and nitrate were reduced by 0, 25, 35, 50, 65, 75, and 100 percent and the effect on loads at Vernalis was examined (Table 5, Figures 3 - 6). The results show that the model predicts a linear decrease in ammonia, nitrate and total nitrogen as a function of decreases in discharges (Figure 3-5). Total phytoplankton decreases proportionally as nitrogen inputs are reduced, but then decreases rapidly when loads are reduced over 75% (Figure 6). All other load constituents did not show a significant change with decreases in nitrogen species (Table 5).

Effect of agricultural drainage and rivers upstream of SJR at Vernalis

The effect of agricultural drains and rivers upstream of the SJR at Vernalis were examined by reducing the discharge of all chemical constituents, but maintaining flows from each tributary, as described in the methods. The purpose of this analysis was to use the SJR-WARMF 2008 Model to measure the impact of individual sources to the river on loads in the river at Vernalis. The individual sources (agricultural drains and rivers) investigated were Salt Slough, Mud Slough, Lander Avenue, Harding Drain, Los Banos Creek, Orestimba Creek, Westport Drain, Del Puerto Creek, Ingram Creek, Hospital Creek, Merced River, Tuolumne River, and Stanislaus River (Figure 1). The load at Lander Avenue is an initial input to the SJR-WARMF 2008 Model and cannot be completely eliminated or the model will not run, therefor the constituent loads from Lander Ave were removed by 90% instead of 100%, due to the requirements of the model.

The results of the agricultural drain and river simulations on the SJR at Vernalis are presented in Tables 6-9. The removal of Harding Drain resulted in a decrease in nutrient loads for nitrate, phosphate, and total phosphorous by 8%, 10% and 9%, respectively. The removal of Salt Slough, Mud Slough, or Lander Avenue caused a reduction in dissolved organic carbon, BOD, and total dissolved solids loads at Vernalis of between 6% and 21%. The largest decrease of phytoplankton occurred with the removal of Salt Slough, Mud Slough and Lander Avenue. The effect of each of these tributaries was approximately equal, with removal of any one of these tributaries yielding an approximately 25% reduction in phytoplankton loads at Vernalis (Table

9). The effect of removing inputs from Salt Slough, Mud Slough, and Lander Avenue on total phytoplankton at Vernalis by year for the seven year study period is shown in Figure 7, Figure 8 and Figure 9, respectively. According to the model results, reducing loads from these tributaries would have a beneficial effect on reducing phytoplankton loads from the San Joaquin River to the estuary, but that significant loads of phytoplankton would still be found in the river.

The Stanislaus, Tuolumne, and Merced rivers caused a reduction to the nutrient load on the SJR at Vernalis when removed (Table 6-9). The nitrate and total nitrogen levels decreased between 5% and 15% for all three rivers. There was also a decrease between 9% and 22% for dissolved organic carbon and BOD. The three rivers had a minimal impact on phytoplankton and TDS loads as each river contributed less than 10% of the total load at the SJR at Vernalis (Table 9).

The main contributing agricultural drains and rivers are shown in Table 10 for each load constituent. Either Salt Slough, Mud Slough, or Lander Avenue were consistently in the top four for each load constituent except for ammonia. An analysis was performed to determine the effect on the SJR if the load from all three of these water sources were removed. The results are shown in Table 6-9. When these three systems were removed there was an increase of ammonia of 10% and a reduction of 20% for nitrate and total nitrogen. Dissolved organic carbon, BOD, total phytoplankton and TDS were reduced by 29%, 29%, 76% and 43%, respectively.

Conclusions

The practicality of the SJR-WARMF 2008 Model was assessed to determine if a user familiar with the San Joaquin River Basin, but without a modeling background, can execute model simulation to extract desired information. It was found that the model could be used by non-expert modelers and yield meaningful results; however the model requires extensive formal or self-training to be used in a meaningful manner. The user investigated the water quality and flow of the tributaries and rivers flowing into the SJR using the model. The study area included the SJR watershed extending between SJR at Lander Avenue to SJR at Vernalis. Two analyses were conducted: (1) examining the global effect of nutrients on total phytoplankton and (2) determining the sources of nutrients and phytoplankton in the SJR from agricultural drainage and rivers.

The concentrations of ammonia, nitrate, and phosphate were studied to determine their effect on total phytoplankton. When a single nutrient was removed the reduction of total phytoplankton ranged between 13% and 32% with the removal of ammonia (Scenario 1) generating the greatest reduction 32%. When one nitrogen source was removed, Scenario 5 and Scenario 6, the total phytoplankton reductions were 31% and 36%, respectively. The total phytoplankton load reduction was greatest when all sources of nitrogen were removed at 62% (Scenario 4 and Scenario 7).

The sources of nutrients and phytoplankton were studied at the SJR at Vernalis. The following constituents were analyzed: ammonia, nitrate, phosphate, total phosphorous, total nitrogen, dissolved organic carbon, BOD, total phytoplankton, and total dissolved solids. Scenarios were run with the following tributaries and rivers: Salt Slough, Mud Slough, Lander Avenue, Los Banos Creek, Orestimba Creek, Harding Drain, Westport Drain, Del Puerto Creek, Ingram

Creek, Hospital Creek, Merced River, Tuolumne River, and Stanislaus River. The nutrients analyzed included ammonia, nitrate, phosphate, total phosphorous, and total nitrogen.

According to the results of the model scenarios, the agricultural drains that were the largest contribution of nutrient loading to the SJR were Salt Slough, Mud Slough, Lander Avenue and Harding Drain. Removal of Harding Drain showed the largest decrease in phosphate and total phosphorous at 10% and 9%, respectively. The removal from Mud Slough caused the largest decrease of nitrate and total nitrogen in the SJR at Vernalis at 12% and 9%, respectively. The rivers that had the largest contribution to nutrient loading on the SJR at Vernalis were the Tuolumne River and the Merced River. The Tuolumne River had the greatest impact on nitrate, total nitrogen, phosphate, and total phosphorous causing a reduction of 15%, 14%, 3%, and 7% respectively, when loading from this river were removed.

Dissolved organic carbon and BOD were used as measurements for oxygen consuming material. The two tributaries contributing the most dissolved organic carbon and BOD were Lander Avenue and Mud Slough. The removal of Lander Avenue reduced the baseline load of dissolved organic carbon and BOD in the SJR at Vernalis by 15% and 13%, respectively; while, Mud Slough reduced the baseline load by 8% and 9%, respectively. The reduction of dissolved organic carbon and BOD by the rivers ranged between 9% and 22%. The Tuolumne River was the highest contributing river source of dissolved organic carbon and BOD in the SJR at Vernalis at 19% and 22%, respectively.

The total phytoplankton in the SJR-WARMF 2008 Model was a measurement of algae concentrations and is in units of kilograms of CHL. The removal of Salt Slough had the greatest reduction of total phytoplankton on the baseline scenario followed by Lander Avenue and Mud Slough, causing reductions of 32%, 27% and 26%, respectively. All other tributaries and rivers caused a reduction of less than 10% in the baseline for total phytoplankton when removed.
An analysis was conducted with Salt Slough, Mud Slough, and Lander Avenue removed. The nitrate and total nitrogen each decreased by 20% and the ammonia load increased by 10%. The phosphate and total phosphorous were reduced by 6% and 13%, respectively. The total phytoplankton at the SJR at Vernalis was reduced by 76%.
The main tributaries contributing nutrients into the SJR were Harding Drain, Salt Slough, Mud Slough, and Lander Avenue. The leading sources of phytoplankton were in the upstream reach of the SJR and included Salt Slough, Mud Slough and Lander Avenue.

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Table 1. Point sources in the SJR-WARMF 2008 Model.

Point Source File	PTS File Name
Del Puerto Creek Inflow	Del Puerto Inflow.PTS
Delta-Mendota Canal	Delta-Mendota.PTS
Inflow to SJR from Friant Dam	Friant Inflow.PTS
Hospital Creek Inflow	Hospital Inflow.PTS
Ingram Creek Inflow	Ingram Inflow.PTS
Los Banos Creek Inflow to SJR	Los Banos Inflow.PTS
Marshall Road Drain	Marshall Road.PTS
Merced River Inflow to SJR	Merced Inflow.PTS
Modesto Irrigation District Lateral #4 Spill	MID4.PTS
Modesto Irrigation District Lateral #5 Spill	MID5.PTS
Modesto Irrigation District Lateral #6 Spill	MID6.PTS
Modesto Irrigation District Main Spill	MIDMain.PTS
Modesto Water Quality Control Facility	Modesto.PTS
Diversion to the MID Main Canal	ModestoCanal.PTS
Moran Drain	Moran.PTS
Mud Slough Inflow to SJR	Mud Inflow.PTS
Orestimba Creek Inflow	Orestimba Inflow.PTS
Salt Slough Inflow to SJR	Salt Inflow.PTS
Inflow from the SJR Upstream	San Joaquin Inflow.PTS
Spanish Land Grant Drain	Spanish Grant.PTS
Stanislaus River Inflow to SJR	Stanislaus Inflow.PTS
Turlock Irrigation District Lower Lateral #2 Spill	TID2.PTS
Turlock Irrigation District Lateral #3 Drain (Westport Drain)	TID3.PTS
Turlock Irrigation District Lateral #5 Drain (Carpenter Drain)	TID5.PTS
Turlock Irrigation District Lower Lateral #6 and #7 Spills	TID6-7.PTS
Turlock Irrigation District Harding Drain	TIDHarding.PTS
Turlock Irrigation District Lower Stevinson Spill	TIDLSTV.PTS
Tuolumne River Inflow to SJR	Tuolumne Inflow.PTS
Diversion to the MID Mail Canal	TurlockCanal.PTS
Westley Wasteway	Westley.PTS

Table 2. Agricultural drains and rivers studied in this analysis and with the identification number of the river segments and tributary inflows for the locations analyzed in the SJR-WARMF 2008 Model.

Agricultural Drains and Rivers	River Segment ID Number[1]	PTS File Name
Salt Slough	450	Salt Inflow.PTS
Mud Slough	452	Mud Inflow.PTS
Lander Avenue	383	San Joaquin Inflow.PTS
Los Banos Creek	487	Los Banos Inflow.PTS
Orestimba Creek	164	Orestimba Inflow.PTS
Harding Drain	202	TIDHarding.PTS
Westport Drain	204	TID3.PTS
Del Puerto Creek	174	Del Puerto Inflow.PTS
Ingram Creek	176	Ingram Inflow.PTS
Hospital Creek	175	Hospital Inflow.PTS
Merced River	631	Merced Inflow.PTS
Tuolumne River	624	Tuolumne Inflow.PTS
Stanislaus River	620	Stanislaus Inflow.PTS

[1]Identification number used in the SJR-WARMF 2008 model.

Table 3. Primary output data for the study period of October 1, 1999 to September 30, 2007. Nutrients were globally removed in the SJR-WARMF 2008 Model in order to determine the load reductions (%) in the SJR at Vernalis. The following nutrients were removed by modifying both point and non-point sources in the SJR-WARMF 2008 Model: ammonia (NH_4), nitrate (NO_3), and phosphate (PO_4). The values are calculated according to Equation 1.

	Condition	Ammonia (%)[1]	Nitrate (%)[1]	Phosphate (%)[1]	Total Phosphorous (%)[1]	Total Nitrogen (%)[1]
Scenario 1	No NH4	86	5	-1	0	17
Scenario 2	No NO3	-8	97	0	0	62
Scenario 3	No PO4	-8	-1	86	85	-1
Scenario 4	No NH4 and NO3	85	100	-2	0	79
Scenario 5	No NO3 and PO4	-14	96	85	85	61
Scenario 6	No NH4 and PO4	86	5	85	85	17
Scenario 7	No NH4, NO3, and PO4	85	100	84	85	79

[1]A negative value represents an increase of the constituent and a positive value is a decrease in loads at Vernalis compared to the baseline scenario.

Table 4. Secondary output data for the study period of October 1, 1999 to September 30, 2007. Nutrients were globally removed in the SJR-WARMF 2008 Model in order to determine the load reductions (%) in the SJR at Vernalis. The following nutrients were removed by modifying both point and non-point sources in the SJR-WARMF 2008 Model: ammonia (NH_4), nitrate (NO_3), and phosphate (PO_4). The values are calculated according to Equation 1.

	Condition	Dissolved Organic Carbon (%)[1]	Biochemical Oxygen Demand (%)[2]	Total Phytoplankton (%)	Total Dissolved Solids (%)
Scenario 1	No NH4	0	0	32	0
Scenario 2	No NO3	0	0	13	1
Scenario 3	No PO4	0	0	25	0
Scenario 4	No NH4 and NO3	0	0	62	0
Scenario 5	No NO3 and PO4	0	0	31	1
Scenario 6	No NH4 and PO4	0	0	36	0
Scenario 7	No NH4, NO3, and PO4	0	0	62	1

[1]A negative value represents an increase of the constituent and a positive value is a decrease in loads at Vernalis compared to the baseline scenario.
[2]Biochemical Oxygen Demand (BOD) = Carbonaceous Biochemical Oxygen Demand (cBOD)

Table 5. Output data for the study period of October 1, 1999 to September 30, 2007. Various percentages of ammonia (NH_4) and nitrate (NO_3) were removed by modifying both point and non-point sources. The values are calculated according to Equation 1.

Percent of Load Removed[2]	**100**	**75**	**65**	**50**	**35**	**25**
Ammonia (%)	85	67	59	46	32	23
Nitrate (%)	100	77	67	52	37	27
Phosphate (%)[1]	-2	-1	-1	0	0	0
Total Phosphorous (%)	0	0	0	0	0	0
Total Nitrogen (%)	79	61	53	41	29	21
Dissolved Organic Carbon (%)	0	0	0	0	0	0
Biochemical Oxygen Demand[3] **(BOD) (%)**	0	0	0	0	0	0
Total Phytoplankton (%)	62	21	17	12	8	5
Total Dissolved Solids (%)	0	1	1	0	0	0

[1]A negative value represents an increase of the constituent and a positive value is a decrease in loads at Vernalis compared to the baseline scenario.
[2]Ammonia and nitrate were removed at equal percentages for each simulation.
[3]Biochemical Oxygen Demand (BOD) = Carbonaceous Biochemical Oxygen Demand (cBOD)

Table 6. The SJR-WARMF 2008 Model outputs for the study period of October 1, 1999 to September 30, 2007. The total load for sources of nitrogen accounted for at the SJR at Vernalis. Agricultural drains and rivers were individually removed from the simulations to determine the load reduction (%) from the baseline scenario. Load reduction values calculated according to Equation 1.

	Ammonia		Nitrate		Total Nitrogen	
Tributaries or River Removed	**kg**	**% reduction[1]**	**kg**	**% reduction[1]**	**kg**	**% reduction[1]**
Baseline	2,139,277	-	27,620,066	-	42,865,693	-
Salt Slough	2,262,621	-6	26,138,833	5	40,444,842	6
Mud Slough	2,232,686	-4	24,429,703	12	38,824,217	9
Lander Avenue2	2,198,152	-3	26,968,795	2	40,662,143	5
Harding Drain	2,125,672	1	25,430,557	8	40,531,534	5
Los Banos Creek	2,150,322	-1	27,463,397	1	42,424,751	1
Orestimba Creek	2,135,921	0	27,305,747	1	42,388,173	1
Westport Drain	2,135,243	0	26,531,412	4	41,733,460	3
Del Puerto Creek	2,127,714	1	27,587,034	0	42,781,479	0
Ingram Creek	2,030,136	5	27,244,268	1	41,943,266	2
Hospital Creek	2,128,979	0	27,582,988	0	42,696,414	0
Stanislaus River	2,090,271	2	26,265,878	5	40,118,764	6
Tuolumne River	2,119,346	1	23,402,504	15	36,829,693	14
Merced River	2,094,558	2	24,717,580	11	38,646,560	10
Salt Slough, Mud Slough and Lander Avenue	2,358,715	-10	22,199,457	20	34,095,609	20

[1]A negative value represents an increase of the constituent and a positive value is a decrease in loads at Vernalis compared to the baseline scenario.
[2]90% of Lander Avenue was removed. This inflow file represents the initial load input from the upstream region of the SJR. If 100% of the load is removed from the Lander Avenue inflow file the program is unable to compute any results.

Table 7. The SJR-WARMF 2008 Model outputs for the study period of October 1, 1999 to September 30, 2007. The total load for sources of phosphate accounted for at the SJR at Vernalis. Agricultural drains and rivers were individually removed from the simulations to determine the load reduction (%) from the baseline scenario. Load reduction values calculated according to Equation 1.

	Phosphate		Total Phosphorus	
Tributaries or River Removed	**kg**	**% reduction[1]**	**kg**	**% reduction[1]**
Baseline	2,679,001	-	5,614,132	-
Salt Slough	2,653,246	1	5,349,424	5
Mud Slough	2,646,012	1	5,443,553	3
Lander Avenue2	2,593,112	3	5,294,473	6
Harding Drain	2,419,147	10	5,103,928	9
Los Banos Creek	2,622,426	2	5,452,695	3
Orestimba Creek	2,676,588	0	5,566,644	1
Westport Drain	2,662,760	1	5,580,543	1
Del Puerto Creek	2,678,634	0	5,611,005	0
Ingram Creek	2,692,556	-1	5,590,971	0
Hospital Creek	2,653,144	1	5,503,678	2
Stanislaus River	2,616,434	2	5,366,976	4
Tuolumne River	2,591,970	3	5,241,861	7
Merced River	2,643,370	1	5,352,181	5
Salt Slough, Mud Slough and Lander Avenue	2,521,561	6	4,861,646	13

[1]A negative value represents an increase of the constituent and a positive value is a decrease in loads at Vernalis compared to the baseline scenario.

[2]90% of Lander Avenue was removed. This inflow file represents the initial load input from the upstream region of the SJR. If 100% of the load is removed from the Lander Avenue inflow file the program is unable to compute any results.

Table 8. The SJR-WARMF 2008 Model outputs for the study period of October 1, 1999 to September 30, 2007. The total load accounted for at the SJR at Vernalis. Agricultural drains and rivers were individually removed from the simulations to determine the load reduction (%) from the baseline scenario. Load reduction values calculated according to Equation 1.

	Dissolved Organic Carbon		Biological Oxygen Demand (BOD)[3]	
Tributaries or River Removed	**kg**	**% reduction[1]**	**kg**	**% reduction[1]**
Baseline	93,791,783	-	55,678,963	-
Salt Slough	87,302,519	7	51,853,197	7
Mud Slough	86,697,491	8	50,576,198	9
Lander Avenue[2]	79,809,484	15	48,237,848	13
Harding Drain	92,891,944	1	55,100,002	1
Los Banos Creek	92,015,899	2	54,226,773	3
Orestimba Creek	92,977,417	1	55,255,020	1
Westport Drain	93,484,204	0	55,484,301	0
Del Puerto Creek	93,670,638	0	55,612,160	0
Ingram Creek	93,543,868	0	55,478,089	0
Hospital Creek	93,641,228	0	55,398,530	1
Stanislaus River	80,518,289	14	50,670,836	9
Tuolumne River	75,866,537	19	43,174,530	22
Merced River	83,172,730	11	50,319,667	10
Salt Slough, Mud Slough and Lander Avenue	66,222,933	29	39,349,049	29

[1]A negative value represents an increase of the constituent and a positive value is a decrease in loads at Vernalis compared to the baseline scenario.
[2]90% of Lander Avenue was removed. This inflow file represents the initial load input from the upstream region of the SJR. If 100% of the load is removed from the Lander Avenue inflow file the program is unable to compute any results.
[3]Biochemical Oxygen Demand (BOD) = Carbonaceous Biochemical Oxygen Demand (cBOD)

Table 9. The SJR-WARMF 2008 Model outputs for the study period of October 1, 1999 to September 30, 2007. The total load accounted for at the SJR at Vernalis. Agricultural drains and rivers were individually removed from the simulations to determine the load reduction (%) from the baseline scenario. Load reduction values calculated according to Equation 1.

	Total Phytoplankton		Total Dissolved Solids	
Tributaries or River Removed	**kg**	**% reduction[1]**	**kg**	**% reduction[1]**
Baseline	506,170	-	6,912,371,317	-
Salt Slough	342,074	32	5,827,896,490	16
Mud Slough	373,103	26	5,447,620,216	21
Lander Avenue[2]	367,121	27	6,500,135,311	6
Harding Drain	499,725	1	6,788,131,588	2
Los Banos Creek	470,323	7	6,698,030,688	3
Orestimba Creek	498,558	2	6,849,432,974	1
Westport Drain	504,778	0	6,868,929,375	1
Del Puerto Creek	505,687	0	6,901,663,859	0
Ingram Creek	496,261	2	6,858,466,990	1
Hospital Creek	505,143	0	6,903,292,202	0
Stanislaus River	485,106	4	6,587,586,113	5
Tuolumne River	469,499	7	6,395,080,602	7
Merced River	467,788	8	6,634,163,008	4
Salt Slough, Mud Slough and Lander Avenue	120,564	76	3,938,231,830	43

[1]A negative value represents an increase of the constituent and a positive value is a decrease in loads at Vernalis compared to the baseline scenario.
[23]90% of Lander Avenue was removed. This inflow file represents the initial load input from the upstream region of the SJR. If 100% of the load is removed from the Lander Avenue inflow file the program is unable to compute any results.

Table 10. The SJR-WARMF 2008 Model outputs for the study period of October 1, 1999 to September 30, 2007 showing the agricultural drains and river contributing the largest loads (kg) on the SJR at Vernalis.

Rank	Ammonia	Nitrate	Total Nitrogen	Phosphate	Total Phosphorous	Dissolved Organic Carbon	BOD[2]	Total Phytoplankton	Total Dissolved Solids
1	Ingram Creek	Tuolumne River	Tuolumne River	Harding Drain	Harding Drain	Tuolumne River	Tuolumne River	Salt Slough	Mud Slough
2	Harding Drain	Mud Slough	Merced River	Tuolumne River	Tuolumne River	Lander Avenue[1]	Lander Avenue[1]	Lander Avenue[1]	Salt Slough
3	Stanislaus River	Merced River	Mud Slough	Lander Avenue[1]	Salt Slough	Stanislaus River	Merced River	Mud Slough	Tuolumne River
4	Tuolumne River	Harding Drain	Stanislaus River	Stanislaus River	Lander Avenue[1]	Merced River	Mud Slough	Merced River	Lander Avenue[1]

[1]90% of Lander Avenue was removed. This inflow file represents the initial load input from the upstream region of the SJR. If 100% of the load is removed from the Lander Avenue inflow file the program is unable to compute any results.
[2]Biochemical Oxygen Demand (BOD) = Carbonaceous Biochemical Oxygen Demand (cBOD)

Figure 1. The study area being analyzed with the SJR-WARMF 2008 Model.

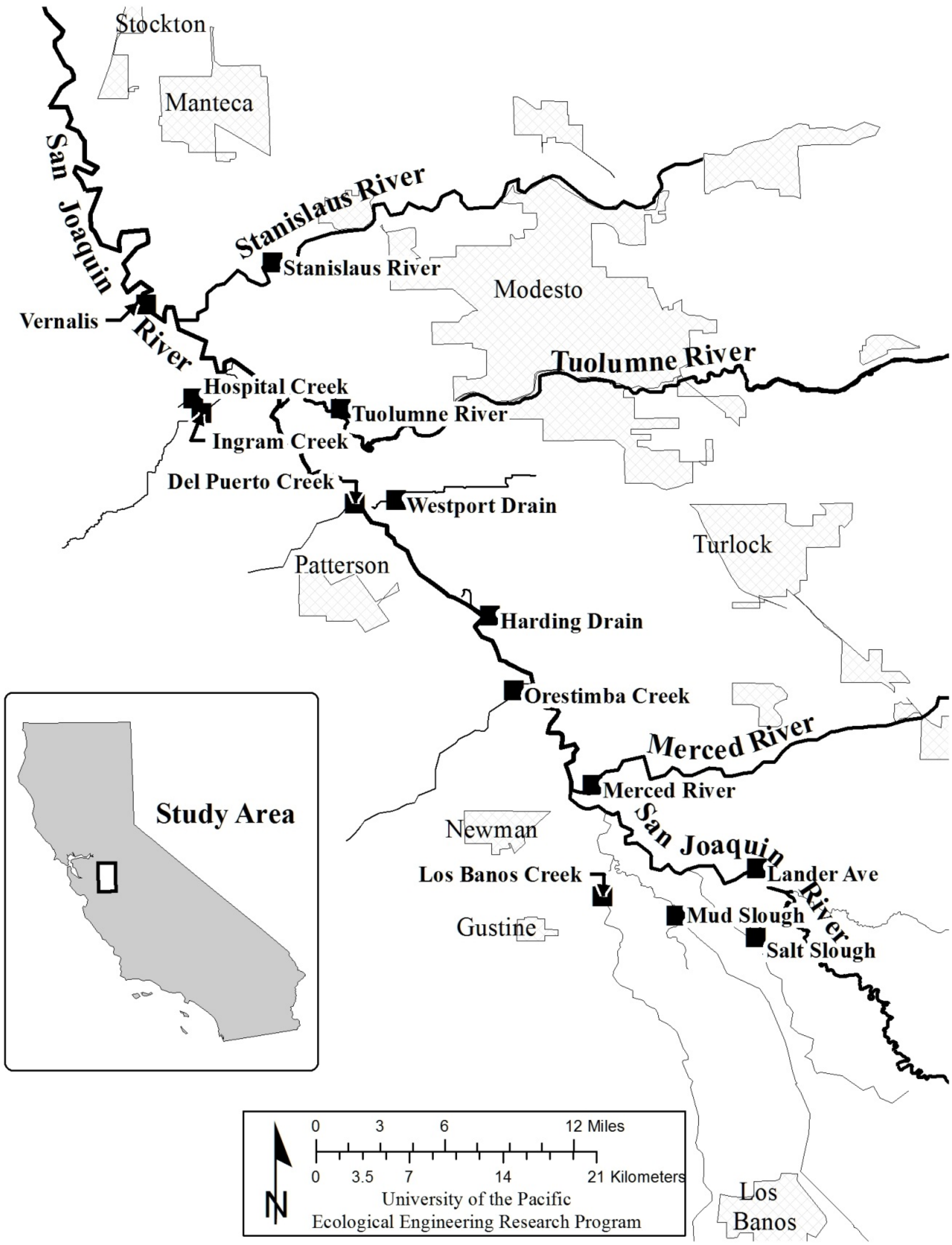

Figure 2. Screenshot of the SJR-WARMF 2008 Model interface.

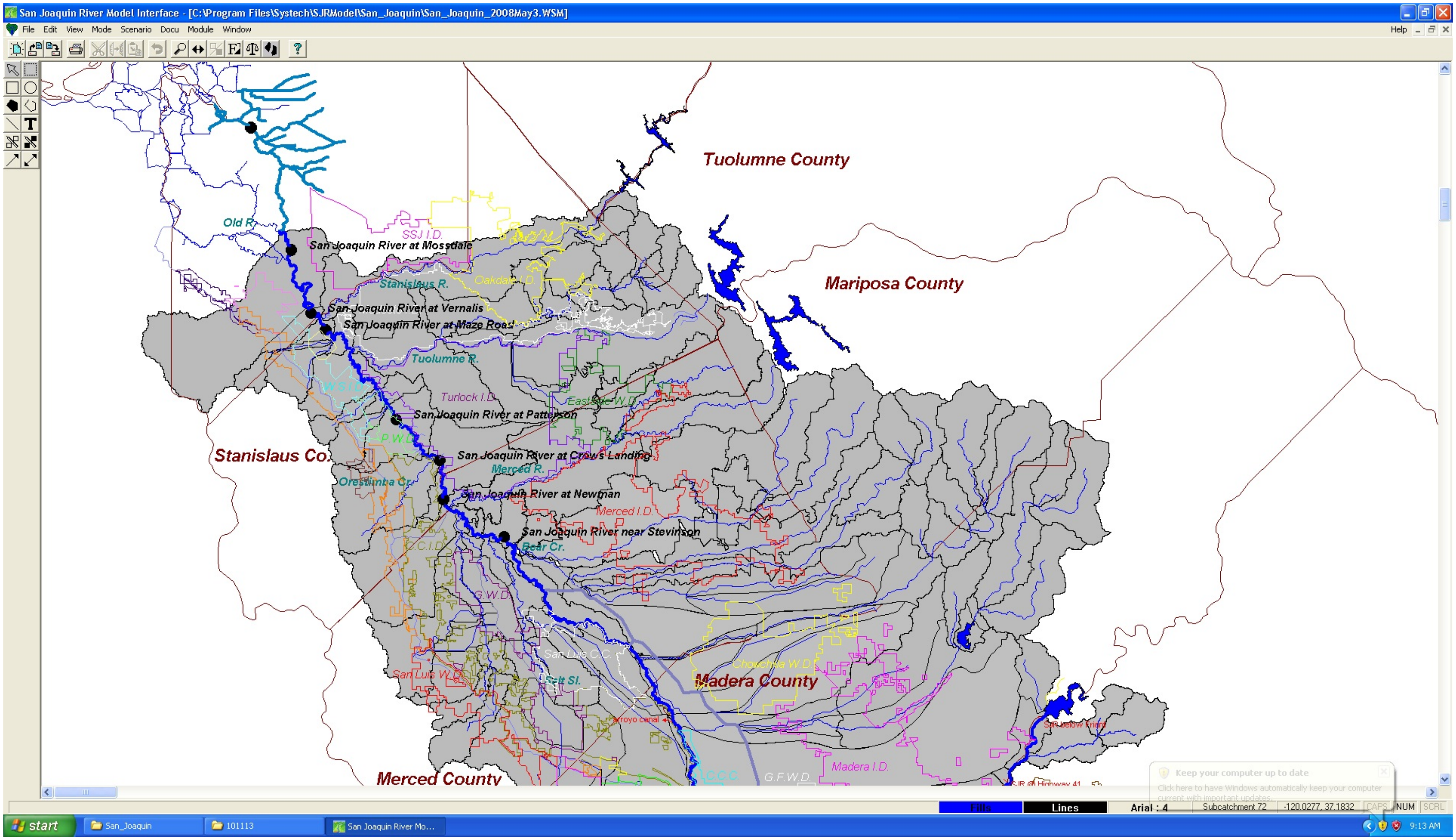

Figure 3. SJR-WARMF 2008 Model simulation of the study period of October 1, 1999 to September 30, 2007 for percent of ammonia removed as a function of a global change of ammonia and nitrate.

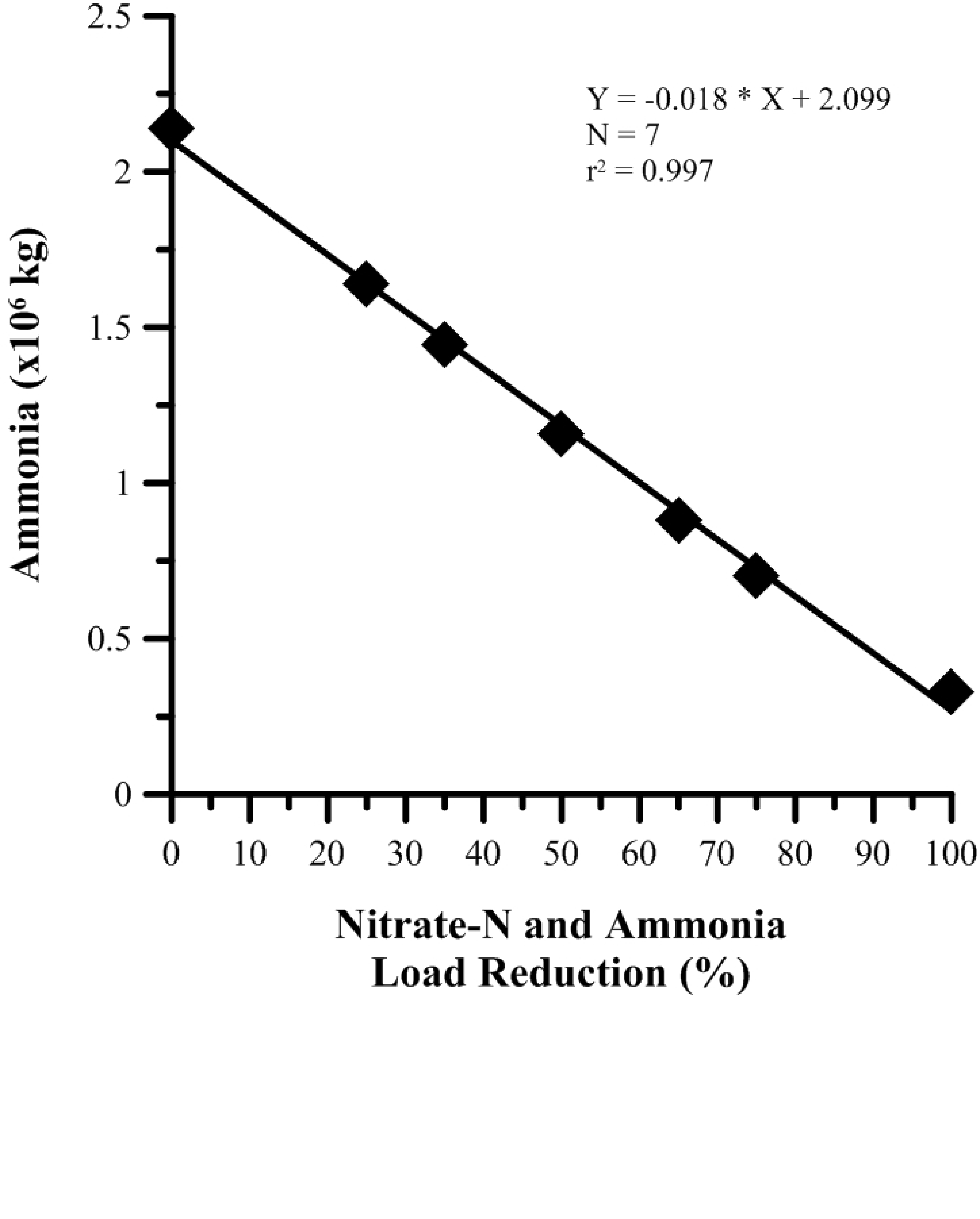

Figure 4. SJR-WARMF 2008 Model simulation of the study period of October 1, 1999 to September 30, 2007 for percent of nitrate removed as a function of a global change of ammonia and nitrate.

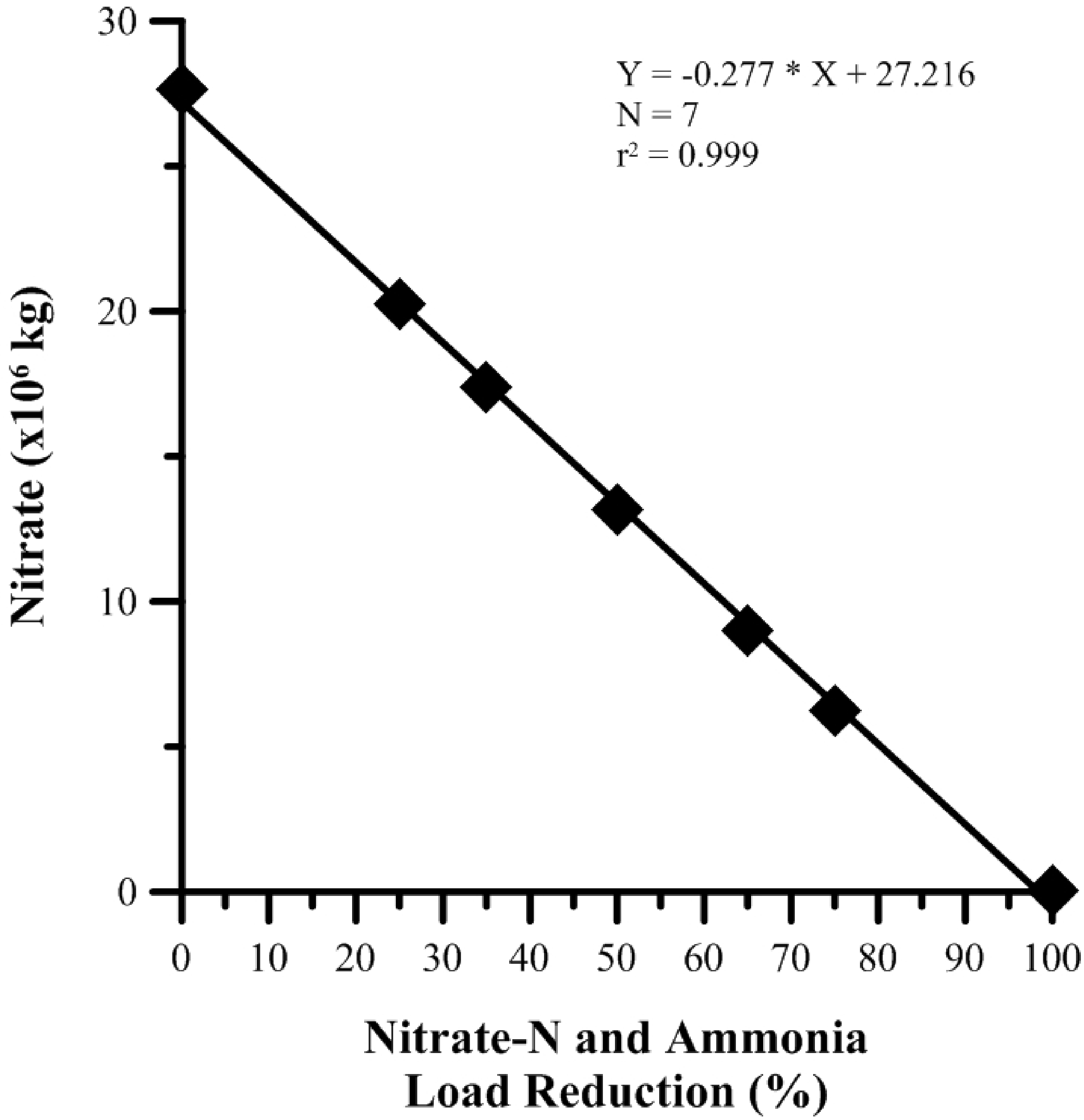

Figure 5. SJR-WARMF 2008 Model simulation of the study period of October 1, 1999 to September 30, 2007 for percent of total nitrogen removed as a function of a global change of ammonia and nitrate.

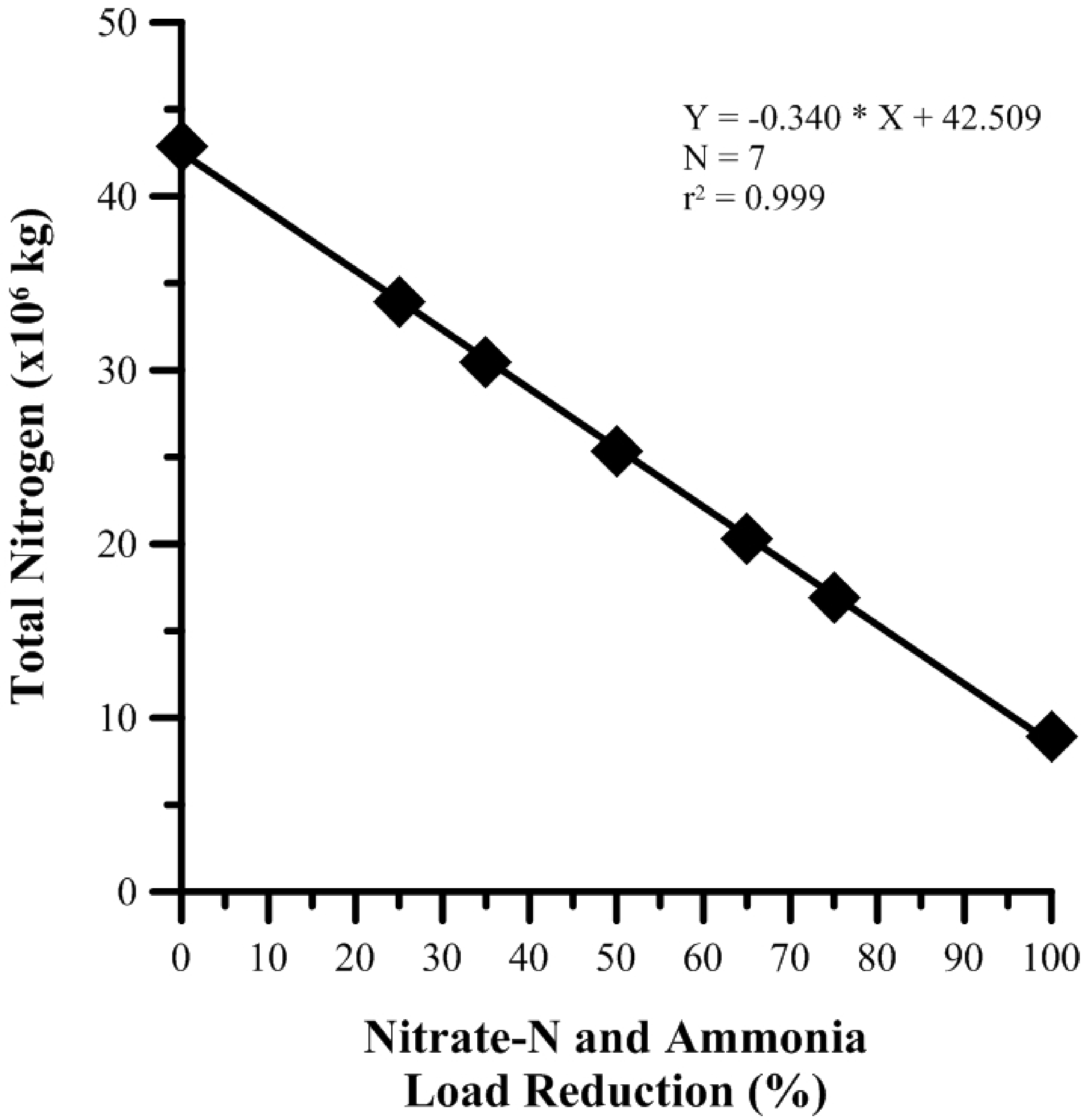

Figure 6. SJR-WARMF 2008 Model simulation of the study period of October 1, 1999 to September 30, 2007 for percent of phytoplankton removed as a function of a global change of ammonia and nitrate.

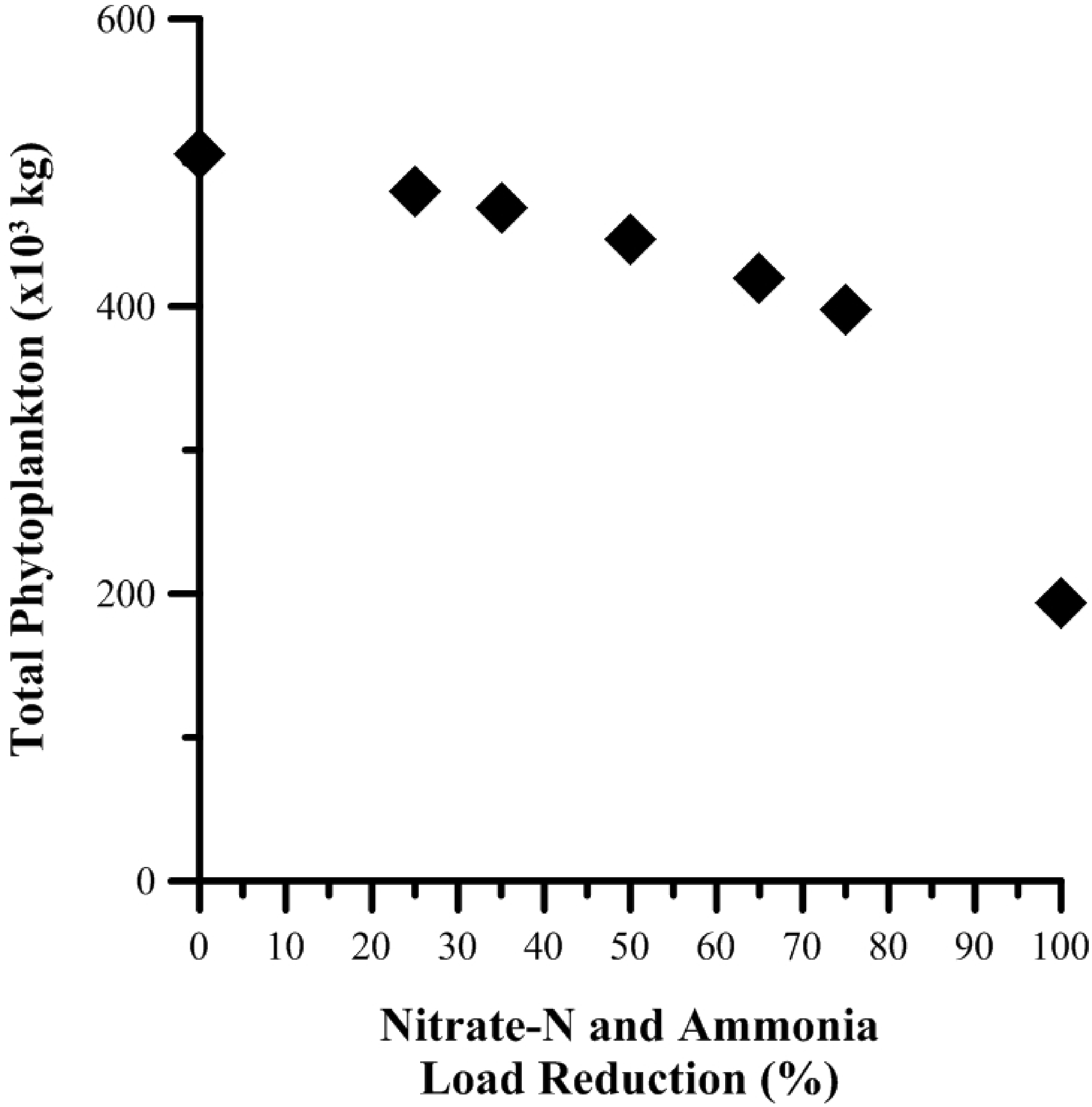

Figure 7. SJR-WARMF 2008 Model simulation of the study period of October 1, 1999 to September 30, 2007 for daily average phytoplankton (kg) as a function of time. Comparison between the baseline simulation and the load removal at Salt Slough simulation.

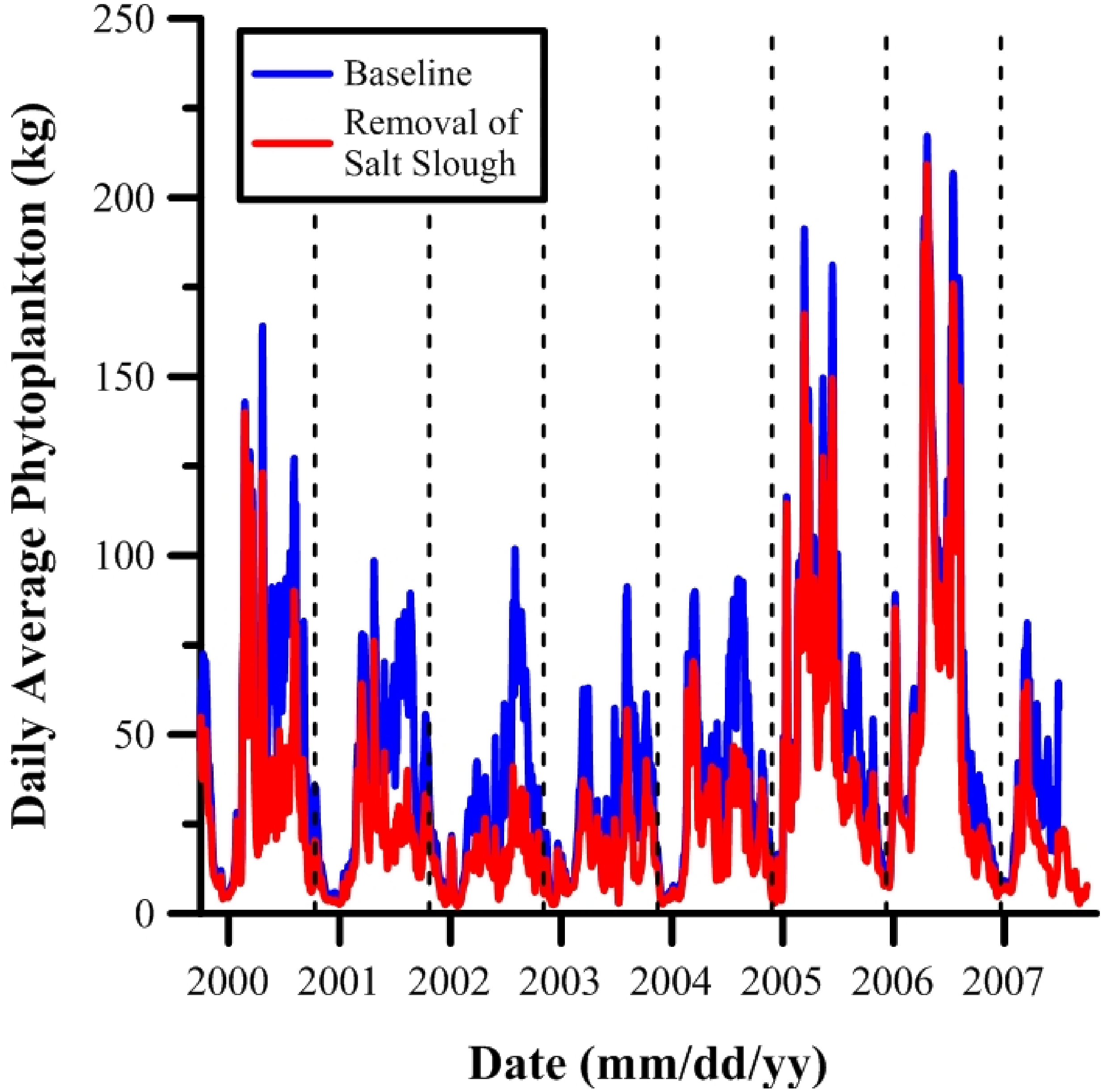

Figure 8. SJR-WARMF 2008 Model simulation of the study period of October 1, 1999 to September 30, 2007 for daily average phytoplankton (kg) as a function of time. Comparison between the baseline simulation and the load removal at Mud Slough simulation.

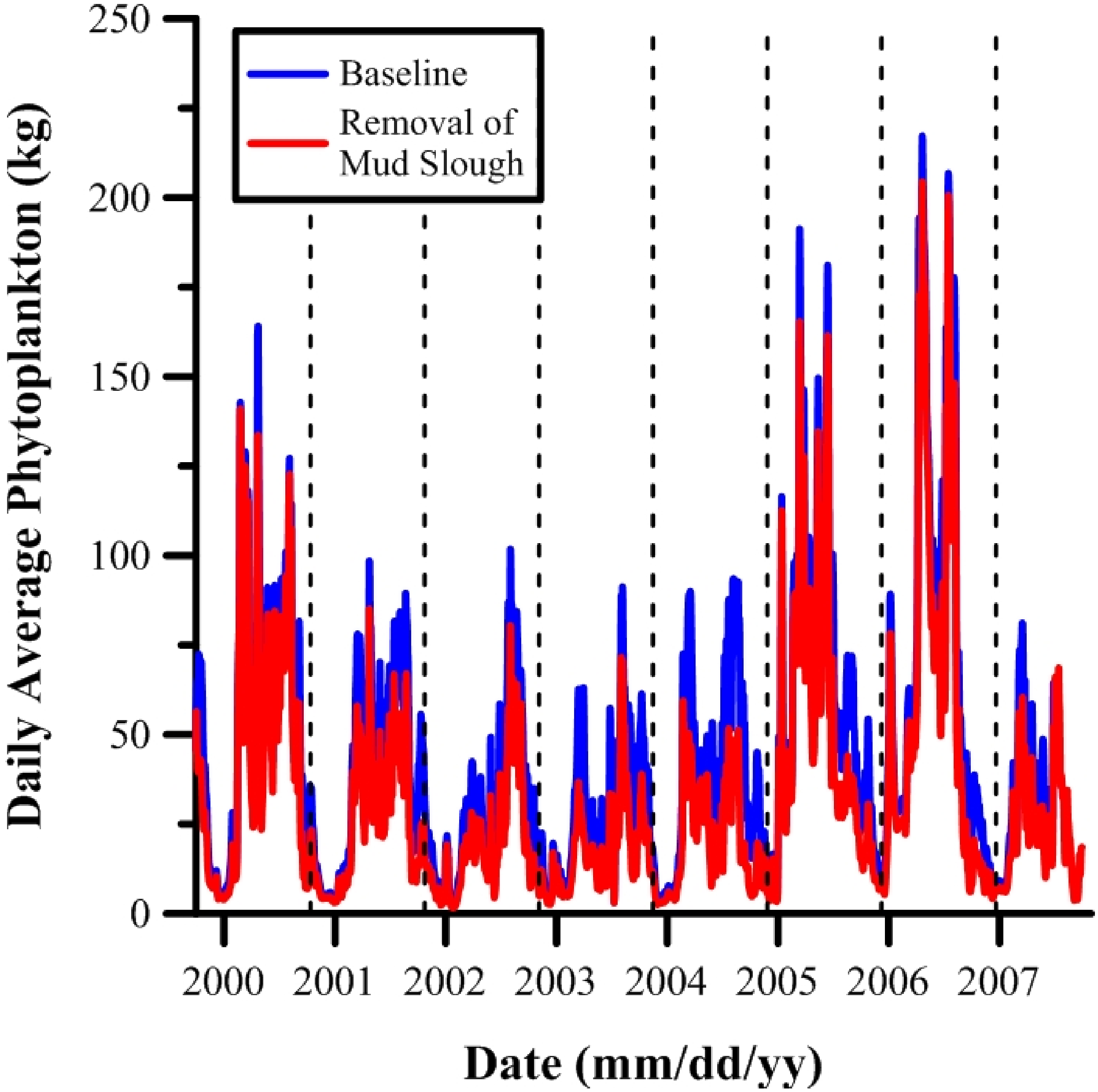

Figure 9. SJR-WARMF 2008 Model simulation of the study period of October 1, 1999 to September 30, 2007 for daily average phytoplankton (kg) as a function of time. Comparison between the baseline simulation and the load removal at Lander Avenue simulation.