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MEMORANDUM

Date: June 28, 2011

To: File: Laguna de Santa Rosa; TMDL Development and Planning

From: Steve Butkus

Subject: Dissolved Oxygen Model Development and Evaluation

The development of the Laguna de Santa Rosa (Laguna) Total Maximum Daily Load (TMDL) for impairment of beneficial uses due to low dissolved oxygen and high nutrients requires a "linkage analysis" (CSWRCB 2005). A linkage analysis describes the method used to establish the relationship between pollutant loading and instream water quality response. The basic goal is to describe the process for establishing a linkage between nutrient loads and the instream dissolved oxygen (DO) conditions. Linkage analyses can vary widely across TMDLs. For example, analyses may include complex watershed and water quality modeling with several steps or simpler spreadsheet mass-balance analyses using only instream monitoring data.

Two water quality models (i.e., lower Santa Rosa Creek and Lake Jonive) were developed according to USEPA (2009) guidance. Model development has five (5) main steps:

1. **Model Selection** determines which available modeling frameworks can best answer the management questions.
2. **Model Development** prepares the selected model with site specific state variables.
3. **Model Calibration** selects those model parameters that best predict the observed conditions. Model calibration involves optimizing model performance based on visual or statistical comparisons of predicted and observed values.
4. **Model Evaluation** is the process for generating information that helps determine the quality of modeling results to serve as the basis for management decisions. Model evaluation includes three main steps:
   - Model corroboration - evaluates the degree to which the model results correspond to reality. Sometimes also referred to as model validation or model verification.
   - Uncertainty analysis - investigates the effects of lack of knowledge and other potential sources of error in the model.
   - Sensitivity analysis – evaluates the effect of assumptions on model results.

5. **Model Application** involves the use of the model to estimate the loading capacity and inform the TMDL allocation process. Model application involves a shift from the hind-casting (testing the model against past observed conditions) used in the model development and evaluation phases to forecasting (predicting a future change) in the application phase. The model variables can be modified for different management scenarios that represent different possible allocation strategies and regulatory alternatives. This memorandum will not describe the application of the models developed as model application has not been completed at this time of writing.

1. MODEL SELECTION

Prior to the selection of the QUAL2Kw model, staff considered using the Water Quality Analysis Simulation Program (WASP) model to construct a branched watershed scale model of the Laguna and Santa Rosa Creek with other large tributaries modeled as point source loads. Due to numerous issues, the use of the WASP model proved to be infeasible for the Laguna TMDLs. More information on the history of model selection can be found in Butkus (2011).

The River and Stream Water Quality Model (QUAL2K) is a receiving waters quality response model supported by the U.S. Environmental Protection Agency (Chapra et al. 2006). The model can help interpret and predict water quality responses to natural phenomena and man-made pollution to support various pollution management decisions. The QUAL2K construct simulates steady state hydraulics in a one-dimensional channel, well-mixed vertically and laterally. The model simulates diel water-quality conditions.

The QUAL2K model was written as open source code for model improvements. One such model upgrade is the QUALKw model version (Pelletier et al. 2006; Pelletier and Chapra 2008). The QUAL2Kw framework includes the following improvements over the QUAL2K model. The QUAL2Kw model:

- Allows for multiple loadings and inflows to any reach.
- Accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. In addition, denitrification is modeled as a first-order reaction that becomes pronounced at low oxygen concentrations.
- Explicitly simulates attached bottom algae.
- Calculates light extinction as a function of algae, detritus and inorganic solids.
- Simlulates both alkalinity and total inorganic carbon. The pH is then simulated based on these two quantities.

Due to these improvements, The QUAL2Kw model framework was selected for development of a model to simulate dissolved oxygen responses for waters in the Laguna watershed. The steady-state hydraulics modeled with the QUALKw model framework is appropriate for Laguna surface waters since the dissolved oxygen linkage analysis will focus on critical low flow periods that typically do not exhibit highly dynamic flows. The largest issue with the use of the QUAL2Kw model framework for application to Laguna surface waters is the inability to simulate the stratification within lentic areas.

However, the stratification observed in Laguna lentic areas is polymictic and typically de-stratifies each evening (Butkus 2010).

2. MODEL DEVELOPMENT

Two QUAL2Kw water quality models were developed to represent the lentic and lotic surface waters. Lower Santa Rosa Creek downstream of the Piner Creek confluence was selected to represent lotic reaches in the lower Laguna watershed. The lower Santa Rosa Creek model was divided into five (5) segments 1-kilometer each in length (Kilometer Miles 0.0 to 5.0). Lake Jonive (Cummings 2004), the open water area south of Occidental Road near Sebastopol, was selected to represent lentic areas of the Laguna. The Lake Jonive model was divided into eighty-one (81) segments 0.01 kilometers each in length (Kilometer Miles 17.30 to 18.11).

The models will be used to simulate various conditions to advise the TMDL allocation process and implementation decisions. Model simulations allow a comparison of current pollutant loading to an estimated historical loading based on land cover that existed prior to European settlement. The estimate of pre-settlement conditions will be used to estimate what water quality conditions may have been prior to major landscape disturbance. The mainstem Laguna prior to European settlement contained large areas of open water even in the summer. Three lakes have been identified from early records: Ballard Lake, Lake Sebring, and Cunningham Lake (Cummings 2004). The Lake Jonive model will be modified to represent these pre-settlement lentic areas.

2.1. Initial and Upstream Concentrations

The model requires specifying initial and upstream conditions for each variable in each segment. Conditions required include the constituent concentrations at the beginning of the simulation period. Median concentration data collected by North Coast Regional Water Quality Control Board (Regional Water Board) staff were used for initial and upstream concentrations in all modeled segments. Regional Water Board staff collected nutrient concentration data from Lower Santa Rosa Creek and Lake Jonive during June and September 2008 (NCRWQCB 2008). The minimum detection limit value was used for sample results reported as not detected. Diel data of dissolved oxygen, water temperature, and pH collected in 2009 were used as initial and upstream conditions (Butkus 2010). Other required input concentrations variables were estimated by the methods shown in Table 1. The values used in the model development are shown in Table 2.

2.2 Stream Flow

The QUAL2Kw model represents stream flow and advective transport as steady-state. The water quality models developed for lower Santa Rosa Creek and Lake Jonive will be applied to simulations representing low flow critical conditions. Modeling steady-state hydraulics is appropriate for critical low flow periods that typically do not exhibit highly dynamic flows.

Mean daily flows for each model were compiled from stream flow gages operating on Lower Santa Rosa Creek at Willowside Road (USGS Gage #1146320) and Lake Jonive at Occidental Road (USGS Gage #11465750). The most commonly-reported statistic for analyses of low flows is based on percentiles (Helsel and Hirsch 2002). TMDL load capacities are often derived based on the "7-day 10-year low flow". This low flow statistic is referred to as the “7Q10”. The 7Q10 is the 10th percentile of the distribution of annual values of Y, where Y is the lowest average of mean daily flows over any consecutive 7-day period for a given year. Several different flow duration periods have been identified to describe the impacts over the entire low flow regime (Pryce 2004).

Although flow-duration and low-flow frequency statistics commonly are computed on an annual basis, they also can be computed on a seasonal or monthly basis. For example, the low flow statistics for the summer dry period could be calculated using just daily mean flows from those dates in the period of record. Table 3 shows that the annual risk equivalent return period for seasonal low flows varies according to the length of the season (WSDOE 1996). For example, the annual low flow statistic for the 7Q10 has an equivalent annual risk of a 7Q20 for a semiannual seasonal period (USEPA 1984).

Daily stream flow values have only been collected at the two stream flow gages for about 10 years. Calculation of flow statistics beyond this period (i.e., 7Q20) would require unacceptable data extrapolation (Searcy 1959). In addition, flows are often recorded at zero flow at the Lake Jonive gage at Occidental Road requiring a conditional probability adjustment for zero flow values (U.S. Interagency Advisory Committee on Water Data 1982).

Estimates of critical flow statistics can be calculated at a gage further downstream that does have an adequate data record. Stream flow values have been measured for over 70 years on the nearby, downstream gage on the Russian River at Hacienda Bridge (USGS Gage #11467000). A statistical regression was conducted using daily mean flows from the Russian River at Hacienda Bridge to allow the calculation of low flow statistics for the gages on the modeled reaches. Daily mean flow data for both gages was paired with flow data from the Russian River gage. The data were natural log-transformed and Pearson linear regression was conducted (Zar 1984). Regressions were statistically significant with a high degree of explained variance for both Santa Rosa Creek (Figure 1) and Lake Jonive (Figure 2).

The regression equations allow comparison of flows measured at the gages on Santa Rosa Creek and Lake Jonive with the return periods of the nearby Russian River. Selected statistics on mean daily flows were calculated for each gage based on the regression equations (Table 4). These low flow statistics were compared to the flows used to calibrate and corroborate the models. The measured flows used for the model development correspond to very large return periods (i.e., nearly an 80-year return period for Santa Rosa Creek). This result may be related to the regression equations y-intercept value which does not accurately represent the lowest flows (Figures 1 and 2).

2.3 Stream Flow Rating Curves

The model requires a depth-flow rating curve for each modeled reach. Depth-flow rating curves were derived from the stream flow gages operating on Lower Santa Rosa Creek (USGS Gage #1466320) and Lake Jonive (USGS Gage #11465750). The USGS rating tables (containing flow and elevation) published for these gages were fitted using nonlinear regression to a power function (i.e, depth = $\alpha Q^{ß}$) for representation in the model (Table 5).

The model also requires velocity-flow rating curves. Velocity-flow rating curves were derived from cross-sectional measurements and the gage depth-flow rating table. Channel cross sectional measurements from Santa Rosa Creek and Lake Jonive were collected for another modeling study (Deas 2007). The cross-section measured at Santa Rosa Creek River Mile 1.59 was used to represent the width profile of Lower Santa Rosa Creek (Figure 3). The cross-section measured at Laguna River Mile 9.79 was used to represent the width profile of Lake Jonive (Figure 4). The published USGS rating tables (containing flow and elevation) were combined with the cross-section area to estimate velocity at varying flows. The estimated velocities and flows were fitted using nonlinear regression to a power function (i.e, velocity = $\alpha Q^{ß}$) for representation in the model (Table 5).

The model also requires the slope of the reach (Table 5). Slopes were measured from the USGS 10-meter digital elevation spatial data (NED, 2006) along the stream thalweg defined by the 1:24K-scale National Hydrography Dataset (NHDPlus, 2007).

2.4 Other Model Constants

The model requires information on several other state variables. The values used for model development of these variables are shown in Table 6. User manual recommendations for sediment and light characteristics were selected. The Ryan-Stolzenbach model was selected for atmospheric attenuation of solar shortwave radiation. The Burtsaert model was selected for downwelling atmospheric longwave infrared radiation. The Brady-Graves-Geyer model was selected for evaporation convection and conduction.

The model requires channel slope to calculate dissolved oxygen reaeration rates. Channel slope for modeled reaches were measured from the USGS 10-meter digital elevation spatial data along the thalweg of the reach modeled.

The model requires a percent shade value to represent the percent of solar radiation that is blocked because of riparian or topographic shade. Information for shade was not available from the reaches modeled. Shade was assumed to be zero for model development for both the Lake Jonive and lower Santa Rosa Creek models. This assumption assumes a worst-case condition that will serve as an inherent margin of safety for the TMDL.

The model requires the wetted-area coverage of benthic algae and oxygen demanding sediments. The proportion of benthic algae coverage to sediment was assumed to be split evenly between both (i.e., 50% to 50%) for Santa Rosa Creek. A larger coverage of sediment was assumed for Lake Jonive since there is more relative open water area.

2.5 Source Loads

The model allows specifying both nonpoint source and point source loads and flows to any model segments. For model development, nonpoint source loads were evenly distributed among each of the model segments, and were represented by the inflow concentrations and flows from the local drainage area to the modeled reaches. Local drainage inflow concentrations were assumed to be the same as the upstream inflow concentrations for model development. Flows from local drainage were estimated by area-weighting. The local drainage area for the modeled segments of Santa Rosa Creek is 3.73% of the drainage area of the stream flow gage operating on Lower Santa Rosa Creek at Willowside Road (USGS Gage #1146320). The local drainage area for the modeled segments of Lake Jonive is 1.84% of the drainage area of stream flow gage operating on Lake Jonive at Occidental Road (USGS Gage #11465750). Local inflows were set at these percentages of the flow measured at these gages.

The City of Santa Rosa treats municipal wastewater from Santa Rosa, Rohnert Park, Cotati, and Sebastopol at the Subregional Water Reclamation System (SWRS) utilizing advanced wastewater treatment. The SWRS is permitted to discharge wastewater only during the non-critical period of October 1 to May 14. In addition, the discharge volume of wastewater is limited based on receiving water flow volume. These permit limitations assure that wastewater is not discharged during critical periods. Therefore, no point source loads were included in the model development since point source discharges are not allowed during critical low flow periods.

2.6 Meteorological Data

The model requires hourly data on air temperature, dew point temperature, wind speed and cloud cover. Solar radiation is estimated from input data based on the time of year, latitude and longitude, cloud cover, and shade. For the Laguna model application, meteorological data were used from the City of Santa Rosa Municipal Services Center Weather Station located at 69 Stony Circle in Santa Rosa. This weather station is near the center of the Laguna watershed and has a half-hourly data record. The model also requires cloud cover, which is not measured at the City of Santa Rosa weather station. Cloud cover was assumed to be zero for model development since the periods of time used for calibration and corroboration were during summer when there is typically little to no precipitation. This assumption assumes a worst-case condition that will serve as an inherent margin of safety for the TMDL.

3. MODEL CALIBRATION

Calibration of the Laguna model to represent observed conditions was conducted by adjusting relevant kinetic model parameters using estimates of input state variables. Adjustments to kinetic model parameters were kept within the range of defined acceptable values (Pelletier and Chapra, 2008). Kinetic model parameters were calibrated as global process constants. Model calibration involved optimizing model performance based on statistical comparison of predicted and observed values. Model calibration was conducted to simulate alkalinity changes due to varying nutrient concentrations and algal use of bicarbonate. Hyporheic exchanges and sediment diagenesis were not simulated. The models were run for more than 3 times the reach travel-time to assure steady-state conditions; model run times that are too short provide results that are too dominated by initial conditions.

The lower Santa Rosa Creek model was calibrated using 3 days of diel data sets for the dates: August 25-27, 2009. The model was run for 20 days to achieve steady state conditions. The Lake Jonive model was calibrated using 5 days of diel data sets for the dates: September 3-7, 2009. The model was run for 1000 days to achieve steady state conditions. The long model run time was required for the Lake Jonive model as a result of the near zero flow (i.e., 0.0001 cms) and resulting high water residence time of the lake during the calibration period selected.

3.1 Calibrated Model Parameters

Model calibration resulted in the selection of the global model parameters of the Lower Santa Rosa Creek model (Tables 7 – 11) and the Lake Jonive model (Tables 12 – 16). The resulting model prediction of diel dissolved oxygen was compared to observed measurements in Lower Santa Rosa Creek (Figures 5 & 6; Table 17) and Lake Jonive (Figures 7 & 8; Table 18). The predicted median dissolved oxygen value of all reaches was used for these comparisons (Figures 5 & 7). The diel pattern of predicted dissolved oxygen generally followed observed values. The comparison of predicted to observed values to the 1:1 line (i.e., predicted DO = observed DO) shows no apparent bias for Lake Jonive calibration (Figure 8). However, the comparison for Santa Rosa Creek appears to show a bias of over predicting dissolved oxygen (Figure 6).

3.2 Calibrated Model Predictive Performance

The predictive performance of the calibrated model was evaluated with a commonly used measure of model error. The Root Mean Square Error (RMSE) is the square root of the variance of the residuals. RMSE indicates the absolute fit of the model predicted values as compared to the measured values. Lower values of RMSE indicate better fit between observed and predicted values. RMSE can be interpreted as the standard deviation of the unexplained variance. RMSE is reported in the same units as the measured data and is a good measure of how accurately the model predicts the model response. The coefficient of variation of the RMSE, CV(RMSE), is defined as the RMSE normalized to (i.e., divided by) the mean of the observed values. It is the same concept as the coefficient of variation except that RMSE replaces the standard deviation.

The predictive performance statistics of the model calibrations are shown in Table 19. The six constituents with the largest relative model error are presented in ranked bar charts (Figures 9 & 10). Most of the constituents were below 5 percent model error, with the exception of the Lower Santa Rosa Creek model calibration, which showed a large model error in predicting hourly dissolved oxygen concentration. However, prediction of the critical daily minimum dissolved oxygen showed small model error in Lower Santa Rosa Creek (0.05 percent model error). The Lake Jonive model calibration showed the largest model errors for phytoplankton, ammonium-N, and nitrate-N concentrations. Prediction of the critical daily minimum dissolved oxygen showed low model error in Lake Jonive (2.3 percent).

4. MODEL EVALUATION

Model evaluation is the process for generating information that helps determine the quality of modeling results to serve as the basis for management decisions (USEPA, 2009). Described below is the evaluation of the two calibrated water quality models that includes: (1) model corroboration, (2) uncertainty analysis, and (3) sensitivity analysis.

4.1 Model Corroboration

The lower Santa Rosa Creek model was corroborated using 3 days of diel data sets for the dates: July 29, 2009, and August 1-2, 2009. The model was run for 20 days to achieve steady state conditions. The resulting model prediction of diel dissolved oxygen was compared to observed measurements in Lower Santa Rosa Creek (Figures 11 & 12; Table 20). The predicted median dissolved oxygen value of all reaches was used for the diel comparison (Figure 11). The diel pattern of predicted dissolved oxygen generally follows observed values, but does not well represent the minimum and maximum observed dissolved oxygen concentrations. Also, the comparison for Santa Rosa Creek appears to show a bias of under-predicting dissolved oxygen (Figure 11). These results are in contrast to the calibration of Lower Santa Rosa Creek which showed an apparent bias of over-predicting dissolved oxygen (Figure 6).

The Lake Jonive model was corroborated using 5 days of diel data sets for the dates: July 22-26, 2009. The model was run for 1000 days to achieve steady state conditions. The resulting model prediction of diel dissolved oxygen was compared to observed measurements in Lake Jonive (Figures 13 & 14; Table 21). The predicted median dissolved oxygen value of all reaches was used for the diel comparisons (Figure 13). The diel pattern of predicted dissolved oxygen generally followed observed values.

Comparison of calibration and corroboration for both models shows that the apparent bias in the Lower Santa Rosa Creek model results was within the variability of the predictive performance of the Lake Jonive model results (Figure 15).

The predictive performance statistics of the model corroborations are shown in Table 22. The six constituents with the largest relative model error are presented in ranked bar charts (Figures 16 & 17). The Lower Santa Rosa Creek model corroboration showed a large model error (>20%) in predicting phytoplankton, organic phosphorus and nitrate nitrogen concentrations (Figure 16). The Lake Jonive model corroboration showed a very high model error (68%) in predicting phytoplankton concentration and relatively high model error for predicting inorganic phosphorus concentrations (Figure 17).

The predictive performance statistics of both the model calibrations and corroborations are shown in Table 23. Most (84%) of the constituents evaluated were below a 10% model error. However, the daily minimum dissolved oxygen is the most important constituent to meet the objectives of the modeling application. Achieving the daily minimum dissolved oxygen concentration needed to meet the requirements of sensitive aquatic life uses will be the numeric target of the TMDL. The prediction of the critical daily minimum dissolved oxygen in Lower Santa Rosa Creek and Lake Jonive showed a very low small model error (<3%) in both calibration and corroboration of the water quality models.

4.2 Model Uncertainty

An uncertainty analysis attempts to describe all the possible results of the model predictions. Uncertainty in model results can be the result of uncertainty in the value used for the state variables (i.e., concentration). These variables are specified in the model as fixed values that may or may not vary over the diel cycle. However, the values used for the variables have inherent uncertainty which could affect the model results.

An uncertainty analysis repeatedly selects input values for the state variables for model simulation to obtain a distribution of the different model results. The selection of the input values is based on the statistical distribution of the input dataset. The Monte Carlo method is commonly used to perform uncertainty analyses. The method first selects a random set of input data values drawn from their individual probability distributions. These values are then used in the simulation model to obtain some model output variable values. This process is repeated many times. The end result is a probability distribution of model output variables.

The Monte Carlo method was applied to evaluate the uncertainty of the calibrated water quality models for Lower Santa Rosa Creek and Lake Jonive. The model was calibrated using the median concentration data collected by the Regional Water Board during June and September 2008 (NCRWQCB 2008). The Monte Carlo method was applied to all of the data collected instead of only the median value that was used in model calibration and corroboration. A uniform distribution was assumed due to the small sample size. The minimum detection limit value was used for samples results reported as not detected. Input concentrations variables were estimated by the methods shown in Table 1. Alkalinity measurements collected in the downstream Russian River were used for the uncertainty analysis (Brown & Sayers-Fay 2007). The values used in the uncertainty analysis model simulations are shown in Tables 24 – 27.

Hourly data of dissolved oxygen, water temperature, and pH collected in 2009 (Butkus 2010) were used as initial and upstream conditions for the uncertainty analysis model simulations. Analytical variability was not available for these variables to conduct uncertainty analysis. Instead, a sensitivity analysis was conducted below for these hourly variables, as described below.

An uncertainty analysis was conducted over the range of critical low flows. The TMDL requires the evaluation of beneficial use impairment during critical conditions. Low flows contribute to the impairment due to low dissolved oxygen concentration. Pryce (2004) reviewed the use of several critical low flow statistics for advising management decisions (Table 28). The flow regression equations developed previously using data from the Russian River at Hacienda Bridge (USGS Gage #11467000) were used to estimate the critical low flow statistics for Lower Santa Rosa Creek and Lake Jonive (Table 28). Uncertainty analysis was conducted for each of these critical low flow values.

4.3 Model Sensitivity

A sensitivity analysis describes how much the model prediction results are affected by changes in model input values. Sensitivity analysis evaluates the importance of assumptions made for unknown variables. Often the variables associated with modeled rate processes (i.e., hydrolysis) are selected through the calibration process rather than being measured.

The sensitivity analysis is useful for management decisions that are advised by model results. Information on the sensitivity of modeling assumptions on model predictions helps inform the relative significance of errors of assumed or estimated values. The significance and interactions among individual model parameters are also useful for future model development. Information gained from sensitivity analysis can be used to identify where efforts to improve models performance should be directed.

A sensitivity analysis was conducted for the assumptions made in development of the water quality models for Lower Santa Rosa Creek and Lake Jonive. The rate process parameters, initial upstream concentrations, and measures of physical features were varied ±50% for each simulation of the Santa Rosa Creek (Table 29) and Lake Jonive (Table 30) calibrated models. Sensitivity analysis was also conducted on the upstream and initial water temperature and dissolved oxygen concentrations. Hourly temperature and dissolved oxygen concentrations were each varied to assess model sensitivity to these inflow state variables. Dissolved oxygen concentration was varied by plus and minus 2 mg/L and water temperature varied by plus and minus 2ºC. TMDL load capacities are often derived based on the 7Q10 critical low flow. The annual low flow statistic for the 7Q10 has an equivalent annual risk of a 7Q20 for a semiannual seasonal period (Table 3; USEPA 1984). Therefore, the estimate of the 7Q20 critical low flow was used for the sensitivity analyses of the Lower Santa Rosa Creek and Lake Jonive models.

The six variables with the largest sensitivity were selected for presenting in the sensitivity analysis results (Figures 42 - 93). The results of sensitivity analyses are described visually in tornado diagrams and spider plots. Both tornado diagrams and spider plots are useful to present how sensitive the model predicted concentrations are to the input parameters and state variables of the model.

Tornado plots are a ranked horizontal bar chart with the categories ordered from the largest range at the top of the chart to the smallest range at the bottom. Tornado plots are useful for comparing the relative importance of the input variables. Spider plots present the variables with zero sensitivity as a horizontal line. The slope of the line represents the range of the input variable by showing the degree of sensitivity of the predicted concentrations to each input parameter or state variable.

Sensitivity analysis plots for the Lower Santa Rosa Creek model show sediment oxygen demand and bottom algae respiration were the most sensitive parameters for predicting dissolved oxygen (Figures 42 - 47). Upstream concentrations of each variable were consistently the most sensitive variable (Figures 48 – 63).

Sensitivity analysis plots for the Lake Jonive model show phytoplankton and bottom algae respiration and growth were the most sensitive parameters for predicting dissolved oxygen (Figures 64 - 69). Phytoplankton growth and respiration was the most sensitive variable for most of the state variables (Figures 70 – 85).

Sensitivity analysis plots for the upstream and initial water temperature and dissolved oxygen concentrations are shown for Lower Santa Rosa Creek (Figures 86 – 89) and Lake Jonive (Figures 90 – 93). These plots present the relative deviation from the calibration concentration expressed as a percentage.

The Lower Santa Rosa Creek model was most sensitive to changes in upstream dissolved oxygen for predictions of dissolved oxygen concentrations, but with a low relative deviation of around 1% (Figures 86 - 87). The Lower Santa Rosa Creek model was most sensitive to changes in upstream temperature for predictions of nitrate-N, phytoplankton, and dissolved oxygen concentrations. Relative deviations for prediction of minimum, maximum, and mean dissolved oxygen concentrations were below 5% (Figures 88 - 89).

The Lake Jonive model was most sensitive to changes in upstream dissolved oxygen for predictions of minimum and maximum dissolved oxygen and phytoplankton concentrations, but with a very low relative deviation of <0.2% (Figures 90 - 91). The Lake Jonive model was most sensitive to changes in upstream temperature for predictions of nitrate-N and phytoplankton. Relative deviations for prediction of dissolved oxygen concentrations were below 1% (Figures 92 - 93).

REFERENCES

AES, 2004. Technical Memorandum – Graton Rancheria: Effect of High-Quality Wastewater Effluent on Aquatic Habitats. Prepared for the Federated Indians of Graton Rancheria by Analytical Environmental Services, Sacramento, CA.

Brown, M. and Sayers-Fay, A. 2007. Technical Memorandum D-5 – Santa Rosa IRWP – Discharge Compliance Project: Winter-Spring 2006 Evaluation of Recycled Water and Receiving Water Copper, Lead, and Nickel. Prepared for the City of Santa Rosa by Robertson-Bryan, Inc.

Butkus, 2010. Water Quality Dynamics within the Laguna de Santa Rosa Watershed. North Coast Regional Water Quality Control Board. Memorandum to the File: Laguna de Santa Rosa; TMDL Development & Planning dated 25 March 2010. Santa Rosa, CA.

Butkus, 2011. Water Quality Model Development History for the Laguna de Santa Rosa TMDL. Memorandum to the File: Laguna de Santa Rosa; TMDL Development & Planning dated 31 May 2011. Santa Rosa, CA.

Chapra, S.C., Pelletier, G.J. and Tao, H. 2006. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.04: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

Chapra, 1997. *Surface Water–Quality Modeling*. McGraw-Hill Companies, Inc. New York, NY.

Covar, A. P. 1976. "Selecting the Proper Reaeration Coefficient for Use in Water Quality Models." Presented at the U.S. EPA Conference on Environmental Simulation and Modeling, April 19-22, 1976, Cincinnati, OH.

CSWRCB, 2005. A Process for Addressing Impaired Waters in California. S.B. 669 Guidance approved by resolution 2005-0050. California State Water Resources Control Board (CSWRCB), Sacramento, CA.

Cummings, J. 2004. Draining and Filling the Laguna de Santa Rosa. Copyrighted Reference publication at Sebastopol Public Library, Sebastopol CA.

Deas, M. 2007. Laguna de Santa Rosa and Russian River Flow and Water Quality Model Summary. Technical Memorandum D-6. Santa Rosa IRWP – Discharge Compliance Project. Prepared for the City of Santa Rosa by Merritt Smith Consulting.

Emery, R.M., Welch, E.B., and Christman, R.F. 1971. The Total Organic Carbon Analyzer and its Application to Water Research. Journal Water Pollution Control Fed. 43, 1834.

Helsel, D.R. and Hirsch, R.M. 2002. Techniques of Water-Resources Investigations of the United States Geological Survey: Book 4, Hydrologic Analysis and Interpretation; Chapter A3 – Statistical Methods. U.S. Geological Survey. Available at: http://water.usgs.gov/pubs/twri/twri4a3/

Linsley, R.K. Jr., Kohler M.A. and Paulhus, J.L.H. 1982. *Hydrology for Engineers.* 3rd Edition. McGraw-Hill Companies, Inc. New York, NY.

National Elevation Dataset (NED), 2006, *NED Data Dictionary*, U. S. Geological Survey, Available at http://ned.usgs.gov/ned/downloads/documents/

National Hydrography Dataset Plus (NHDPlus). User Guide. U.S. Environmental Protection Agency & U.S. Geological Survey, 2997. Available at: http://www.horizon-systems.com/nhdplus/data/NHDPLUS_UserGuide.pdf

NCRWQCB, 2008. Laguna de Santa Rosa TMDL – 2008 Source Analysis Monitoring Report. North Coast Regional Water Quality Control Board. Santa Rosa, CA. December 2008.

Ontario Ministry of Natural Resources (OMNR), 1994. Natural Channel Systems, An Approach to Management and Design, Queen's Printer for Ontario, Ontario Ministry of Natural Resources, Peterborough, Ontario, 103p.

Pelletier, G.J. and Chapra, S.C. 2008. QUAL2Kw User Manual (version 5.1). A modeling framework for simulation of river and stream water quality. Washington State Dept of Ecology Publication No. 08-03-xxx. Olympia, WA.

Pelletier, G.J., Chapra, S.C. and H. Tao. 2006. QUAL2Kw – A Framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. Environmental Modeling & Software 21:419-425.

Pyrce, R. 2004. Hydrological Low Flow Indices and their Uses. WSC Report No. 04-2004, Watershed Science Centre, Peterborough, Ontario, Canada.
K9J 7B8

Searcy, J.K., 1959, Flow-duration curves, Manual of hydrology—Part 2. Low-flow techniques: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Smakhtin, V.Y., 2001. Low flow hydrology: a review. Journal of Hydrology, 240: 147-186.

South Dakota Department of Environment and Natural Resources, 1998. Mixing zone and dilution implementation procedures. Available at <http://www.state.sd.us/denr/denr.html>.

USEPA 1984. Technical guidance manual for performing waste load allocations. Book IX. Innovative waste load allocations. Contratc Number 68-01-6904. U.S. Environmental Protection Agency, Washington, DC.

USEPA, 2009. Guidance on the Development, Evaluation, and Application of Environmental Models. Publ. No. EPA/100/K-09/003. Council for Regulatory Environmental Modeling, U.S. Environmental Protection Agency, Washington, DC.

U.S. Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Reston, Virginia, U.S. Geological Survey, Office of Water Data Coordination, Hydrology Committee Bulletin 17B, 183 p.

WSDOE, 1996. Total Maximum Daily Load Development Guidelines. Publication No. 97-315. Washington State Department of Ecology, Olympia, WA.

Zacharias, S., Heatwole, C.D., and Coakley, C.W. 1996. Robust quantitative techniques for validating pesticide transport models. Transactions of the ASAE 39(1):47-54.

TABLES

Table 1. Source of Initial and Upstream Concentration Data Used in Model Development

Constituent	Method	Citation
Temperature	Measured in 2009 – diel data	Butkus, 2010
Dissolved Oxygen	Measured in 2009 – diel data	Butkus, 2010
pH	Measured in 2009– diel data	Butkus, 2010
Conductivity	Measured in 2009 – diel data	Butkus, 2010
Alkalinity	Median measured in Russian River	Brown & Sayers-Fay, 2007
	Mean measured in the Laguna	AES, 2004
$CBOD_u$	Derived from 5-day BOD	Pelletier & Chapra, 2008
Organic-N	Derived from ammonium-N & total Kjeldahl-N measured in 2008	Standard Methods 4500-N
Ammonium-N	Measured in 2008	NCRWQCB, 2008
Nitrate-N	Measured in 2008	NCRWQCB, 2008
Organic-P	Derived from inorganic-P & total-P measured in 2008	Assume all particulate-P is Organic-P
Inorganic-P	Measured in 2008	NCRWQCB, 2008
Phytoplankton	Derived from chlorophyll *a* measured in 2008	Standard Methods 100200 I(1)
Particulate Organic Matter	Derived from 5-day BOD measured in 2008	1) Assume same particulate fraction as in total-P 2) Emery et al 1971 for TOC derived from 5-day BOD
Inorganic Solids	Derived from conductivity measured in 2009	Chapra, 1997

Table 2. Initial and Upstream Concentration Data Used in Model Development

Constituent	Units	Santa Rosa Creek		Lake Jonive	
		Calibration	Corroboration	Calibration	Corroboration
Temperature	ºC	16.58 – 18.97	18.65 – 20.06	21.75 – 24.95	22.60 – 25.46
Dissolved Oxygen	mg/L	5.88 – 6.81	4.93 – 5.57	1.61 – 10.67	4.33 – 7.67
pH	standard units	7.72 – 7.79	7.73 – 7.77	7.88 – 8.64	7.65 – 7.93
Conductivity	µmhos	650	650	621	621
Alkalinity	mg $CaCO_3$/L	150	150	202	202
$CBOD_u$	mgO_2/L	4.38	4.38	14.6	14.6
Organic-N	µgN/L	130	130	2150	2150
Ammonium-N	µgN/L	80	80	460	460
Nitrate-N	µgN/L	30	30	30	30
Organic-P	µgP/L	10	10	180	180
Inorganic-P	µgP/L	100	100	330	330
Phytoplankton	µg/L	0.536	0.536	26.867	26.867
Particulate Organic Matter	mg/L	1	1	47	47
Inorganic Solids	mg/L	379	379	331	331

Table 3. Annual Risk Equivalent Return Period for Different Seasons.

Season	**Annual Risk Equivalent Return Period (years)**
Annual	10
Semiannual	20
Quarterly	38
Monthly	114

Table 4. Stream Flow Statistics from Gages on Modeled Reaches

Flow Statistic	**Santa Rosa Creek at Willowside Road**		**Lake Jonive at Occidental Road**	
	flow (cfs)	flow (cms)	flow (cfs)	flow (cms)
7Q1	7.68	0.2174	1.90	0.0539
7Q2	3.85	0.1091	0.68	0.0191
7Q5	2.74	0.0775	0.40	0.0114
7Q10	2.22	0.0629	0.30	0.0084
7Q20	1.96	0.0554	0.24	0.0069
7Q20	1.94	0.0549	0.24	0.0068
7Q50	1.66	0.0471	0.19	0.0054
7Q100	1.08	0.0306	0.10	0.0028
Calibration Mean Daily Flow	1.6	0.0453	0.05	0.0014
Corroboration Mean Daily Flow	1.1	0.0311	0.005*	0.0001

Table 1. The measured 7-day flow equaled zero. Since QUAL2Kw requires some flow to operate, zero flows were substituted with ½ the lowest measureable flow from the USGS Gage Rating Table

Table 5. Channel Characteristics of Modeled Reaches

Reach	**Depth Rating Curve**		**Velocity Rating Curve**		**Slope**
	Coefficient (α)	**Exponent (ß)**	**Coefficient (α)**	**Exponent (ß)**	
Santa Rosa Creek	0.2422	0.1522	0.0322	0.2354	$2.09\text{x}10^{3}$
Lake Jonive	1.6258	0.1680	0.0006	0.4910	$1.64\text{x}10^{3}$

Table 6. Other Constants Used in Model Development

Reach Constant	Units	Santa Rosa Creek	Lake Jonive
Sediment Thermal Conductivity	W/m/ºC	1.6	1.6
Sediment Thermal Diffusivity	cm^2/second	0.0059	0.0059
Sediment Zone Thickness	cm	10	10
Photosynthetically Available Radiation	dimensionless	0.47	0.47
Background Light Extinction	/m	0.2	0.2
Linear Chlorophyll Light Extinction	1/m-(µgA/L)	0.0088	0.0088
Nonlinear Chlorophyll Light Extinction	1/m-$(\mu gA/L)^{2/3}$	0.054	0.054
ISS Light Extinction	1/m-(mgD/L)	0.052	0.052
Detritus Light Extinction	1/m-(mgD/L)	0.174	0.174
Macrophyte Light Extinction	1/m-(gD/m^3)	0.015	0.015
Atmospheric Transmission Coefficient	dimensionless	0.8	0.8
Longwave Emissivity Parameter	dimensionless	1.24	1.24
Cloud Cover Solar Radiation Attenuation	dimensionless	0.65	0.65
Cloud Cover Sky Emissivity Adjustment	dimensionless	0.17	0.17
Channel Slope along Thalweg	dimensionless	0.002094	
Shade – Riparian and Topographic	%	0	0
Bottom Algae Coverage	%	50	33
Sediment Oxygen Demand Coverage	%	50	67

Table 7. Dissolved Oxygen Parameters of the Calibrated Lower Santa Rosa Creek Model

Dissolved Oxygen Parameter	Value	Unit
Reaeration temperature correction – Covar (1976) model	1.024	unitless
Oxygen for carbon oxidation	2.69	gO_2/gC
Oxygen for NH_4 nitrification	4.57	gO_2/gN
Oxygen inhibition parameter $CBOD_u$ oxidation – Exponential model	0.60	L/mgO_2
Oxygen inhibition parameter nitrification – Exponential model	0.60	L/mgO_2
Oxygen enhance parameter denitrification – Exponential model	0.60	L/mgO_2
Oxygen inhibibition parameter phytoplankton respiration – Exponential model	0.60	L/mgO_2
Oxygen enhance parameter bottom algae respiration – Exponential model	0.60	L/mgO_2
$CBOD_u$ oxidation rate	10^{-3}	/d
$CBOD_u$ oxidation rate temperature correction	1.047	unitless
Sediment oxygen demand	2.6	$gO_2/m^2/d$

Table 8. Nutrient Parameters of the Calibrated Lower Santa Rosa Creek Model

Nutrient Parameter	Value	Unit
Organic N hydrolysis rate	10^{-3}	/d
Organic N hydrolysis temperature correction	1.069	unitless
Ammonium-N Nitrification rate	10^{-2}	/d
Ammonium-N Nitrification temperature correction	1.011	unitless
Nitrate-N denitrification rate	10^{-6}	/d
Nitrate-N denitrification temperature correction	1.044	unitless
Nitrate-N denitrification sediment transfer coefficient	0.6	m/d
Nitrate-N denitrification sediment transfer coefficient temperature correction	1.053	unitless
Organic-P hydrolysis rate	10^{-3}	/d
Organic-P hydrolysis temperature correction	1.002	unitless
Sediment-P oxygen attenuation constant	0.0	mgO_2/L
Sediment-P flux	0	$mgP/m^2/d$
Sediment-N flux	0.8	$mgN/m^2/d$

Table 9. Phytoplankton Parameters of the Calibrated Lower Santa Rosa Creek Model

Phytoplankton Parameter	Value	Unit
Maximum growth rate	4.1	/d
Growth rate temperature correction	1.001	unitless
Respiration rate	0.7	/d
Respiration rate temperature correction	1.000	unitless
Death rate	0.0	/d
Nitrogen half saturation constant	50	µgN/L
Phosphorus half saturation constant	30	µgP/L
Inorganic carbon half saturation constant	1.3×10^{-5}	moles/L
Light half saturation constant	100	langleys/d
Ammonia preference	25	µgN/L
Phytoplankton settling velocity	10^{-2}	m/d

Table 10. Benthic Algae Parameters of the Calibrated Lower Santa Rosa Creek Model

Benthic Algae Parameters	**Value**	**Unit**
Maximum growth rate – First order model	1.29	$gD/m^2/d$
Growth rate temperature correction	1.015	
Carrying capacity - First-order model	200	gD/m^2
Basal respiration rate	0.1	/d
Photo-respiration rate parameter	0.6	unitless
Photo-respiration rate parameter temperature correction	1.000	unitless
External nitrogen half saturation constant	150	ugN/L
External phosphorus half saturation constant	50	ugP/L
Inorganic carbon half saturation constant	$1.3x10^{-5}$	moles/L
Light half saturation constant	50	langleys/d
Ammonia preference	50	ugN/L
Subsistence quota for nitrogen	72	mgN/gD
Subsistence quota for phosphorus	10	mgP/gD
Maximum uptake rate for nitrogen	350	mgN/gD/d
Maximum uptake rate for phosphorus	50	mgP/gD/d
Internal nitrogen half saturation ratio	1.05	unitless
Internal phosphorus half saturation ratio	1.05	unitless

Table 11. Miscellaneous Parameters of the Calibrated Lower Santa Rosa Creek Model

Parameter	**Value**	**Unit**
Detritus Dissolution rate	10^{-3}	/d
Detritus Dissolution rate Temp correction	1.000	unitless
Partial pressure of carbon dioxide	375	ppm
Carbon stoichiometry	40	gC
Nitrogen stoichiometry	7.2	gN
Phosphorus stoichiometry	1	gP
Dry weight stoichiometry	100	g Detritus
Chlorophyll stoichiometry	0.5	g Algae

Table 12. Dissolved Oxygen Parameters of the Calibrated Lake Jonive Model

Dissolved Oxygen Parameter	**Value**	**Unit**
Reaeration temperature correction – Covar (1976) model	1.024	unitless
Oxygen for carbon oxidation	2.69	gO_2/gC
Oxygen for NH_4 nitrification	4.57	gO_2/gN
Oxygen inhibition parameter $CBOD_u$ oxidation - Exponential model	0.60	L/mgO_2
Oxygen inhibition parameter nitrification - Exponential model	0.60	L/mgO_2
Oxygen enhance parameter denitrification - Exponential model	0.60	L/mgO_2
Oxygen inhibition parameter phytoplankton respiration - Exponential model	0.60	L/mgO_2
Oxygen enhance parameter bottom algae respiration – Exponential model	0.60	L/mgO_2
$CBOD_u$ oxidation rate	10^{-6}	/d
$CBOD_u$ oxidation rate temperature correction	1.014	unitless
Sediment oxygen demand	10	$gO_2/m^2/d$

Table 13. Nutrient Parameters of the Calibrated Lake Jonive Model

Nutrient Parameter	Value	Unit
Organic N hydrolysis rate	$1.5x10^{-3}$	/d
Organic N hydrolysis temperature correction	1.048	unitless
Ammonium-N Nitrification rate	0.08	/d
Ammonium-N Nitrification temperature correction	1.019	unitless
Nitrate-N denitrification rate	10^{-4}	/d
Nitrate-N denitrification temperature correction	1.044	unitless
Nitrate-N denitrification sediment transfer coefficient	0.6	m/d
Nitrate-N denitrification sediment transfer coefficient temperature correction	1.042	unitless
Organic-P hydrolysis rate	10^{-3}	/d
Organic-P hydrolysis temperature correction	1.000	unitless
Sediment-P oxygen attenuation constant	1.0	mgO_2/L
Sediment-P flux	0.9	$mgP/m^2/d$
Sediment-N flux	100	$mgN/m^2/d$

Table 14. Phytoplankton Parameters of the Calibrated Lake Jonive Model

Phytoplankton Parameter	Value	Unit
Maximum growth rate	4.1	/d
Growth rate temperature correction	1.042	unitless
Respiration rate	0.2	/d
Respiration rate temperature correction	1.057	unitless
Death rate	0.01	/d
Death rate temperature correction	1.065	unitless
Nitrogen half saturation constant	50	µgN/L
Phosphorus half saturation constant	30	µgP/L
Inorganic carbon half saturation constant	$1.3x10^{-5}$	moles/L
Light half saturation constant	100	langleys/d
Ammonia preference	25	µgN/L
Phytoplankton settling velocity	0.01	m/d

Table 15. Benthic Algae Parameters of the Calibrated Lake Jonive Model

Benthic Algae Parameters	Value	Unit
Maximum growth rate – First order model	8	$gD/m^2/d$
Growth rate temperature correction	1.004	
Carrying capacity - First-order model	300	gD/m^2
Basal respiration rate	0.1	/d
Photo-respiration rate parameter	0.6	unitless
Photo-respiration rate parameter temperature correction	1.058	unitless
External nitrogen half saturation constant	150	ugN/L
External phosphorus half saturation constant	50	ugP/L
Inorganic carbon half saturation constant	$1.3x10^{-5}$	moles/L
Light half saturation constant	50	langleys/d
Ammonia preference	50	ugN/L
Subsistence quota for nitrogen	72	mgN/gD
Subsistence quota for phosphorus	10	mgP/gD
Maximum uptake rate for nitrogen	350	mgN/gD/d
Maximum uptake rate for phosphorus	50	mgP/gD/d
Internal nitrogen half saturation ratio	1.05	unitless
Internal phosphorus half saturation ratio	1.05	unitless

Table 16. Miscellaneous Parameters of the Calibrated Lake Jonive Model

Parameter	Value	Unit
Inorganic suspended solids settling velocity	10^{-6}	m/d
Detritus Dissolution rate	$1.2x10^{-3}$	/d
Detritus Dissolution rate Temp correction	1.001	unitless
Partial pressure of carbon dioxide	375	ppm
Carbon stoichiometry	40	gC
Nitrogen stoichiometry	7.2	gN
Phosphorus stoichiometry	1	gP
Dry weight stoichiometry	100	g Detritus
Chlorophyll stoichiometry	0.5	g Algae

Table 17. Comparison of Predicted Median and Observed Dissolved Oxygen Concentrations in Lower Santa Rosa Creek during the Model Calibration Period

Hour	Predicted Median	7/29/2009	8/1/2009	8/2/2009
0:00	5.08	5.19	5.22	5.35
1:00	5.03	5.11	5.13	5.27
2:00	4.99	5.02	5.03	5.25
3:00	4.91	4.94	4.97	5.20
4:00	4.88	4.86	4.96	5.13
5:00	4.85	4.78	4.94	5.10
6:00	4.81	4.82	4.94	5.07
7:00	4.79	4.82	4.96	5.06
8:00	4.78	4.80	4.94	5.08
9:00	4.88	4.78	4.93	5.06
10:00	4.95	4.78	5.08	5.09
11:00	5.02	4.87	5.08	5.14
12:00	5.17	4.93	5.01	5.03
13:00	5.24	4.91	5.21	4.93
14:00	5.30	4.88	5.19	5.03
15:00	5.40	4.93	5.19	5.21
16:00	5.45	5.00	5.23	5.26
17:00	5.48	5.05	5.45	5.25
18:00	5.53	5.20	5.94	5.16
19:00	5.53	5.50	5.74	5.24
20:00	5.51	5.37	5.75	5.43
21:00	5.36	5.30	5.69	5.57
22:00	5.28	5.17	5.53	5.51
23:00	5.21	5.07	5.41	5.42

Table 18. Comparison of Predicted Median and Observed Dissolved Oxygen Concentrations in Lake Jonive during the Model Calibration Period

Hour	Predicted Median	9/3/2009	9/4/2009	9/5/2009	9/6/2009	9/7/2009
0:00	4.29	3.79	3.82	4.29	4.31	4.39
1:00	3.55	3.01	3.26	3.85	3.55	4.08
2:00	3.11	2.83	2.81	3.11	3.30	3.86
3:00	2.62	2.39	2.58	2.85	2.62	3.59
4:00	2.41	1.98	2.08	2.42	2.41	3.42
5:00	2.08	1.87	1.94	2.28	2.08	3.18
6:00	1.90	1.74	1.72	2.14	1.90	2.97
7:00	1.61	1.56	1.61	1.99	1.56	2.90
8:00	1.80	1.62	1.59	1.91	1.80	3.27
9:00	2.08	2.08	1.92	2.06	2.60	3.81
10:00	3.82	2.74	2.36	3.82	4.32	4.92
11:00	4.48	3.35	4.53	3.82	4.48	4.54
12:00	5.09	3.74	5.99	6.63	4.56	5.09
13:00	5.44	5.44	6.42	9.29	4.88	5.05
14:00	6.80	5.59	6.80	8.87	5.05	6.94
15:00	7.28	7.24	7.28	9.20	5.31	8.11
16:00	8.44	8.44	8.14	9.32	5.71	9.95
17:00	10.28	10.28	7.41	11.18	5.42	11.20
18:00	10.67	10.67	7.01	10.82	4.73	12.81
19:00	8.26	8.26	6.42	8.69	4.13	11.66
20:00	6.61	6.61	6.02	7.78	4.19	9.73
21:00	5.73	5.73	5.66	6.81	5.03	8.14
22:00	5.48	5.08	5.48	6.11	5.24	7.14
23:00	4.89	4.33	4.89	5.10	4.67	6.39

Table 19. Calibrated Model Predictive Performance Statistics

Constituent	Unit	Lower Santa Rosa Creek		Lake Jonive	
		RMSE	CV(RMSE)	RMSE	CV(RMSE)
DO Hourly Mean	mg/L	1.214	23.6%	1.248	19.4%
DO Daily Mean	mg/L	0.004	0.1%	0.015	0.3%
DO Daily Maximum	mg/L	0.011	0.2%	0.090	1.0%
DO Daily Minimum	mg/L	0.003	0.0%	0.034	2.3%
$CBOD_u$	mg/L	0.004	0.1%	0.004	0.0%
Organic-N	µg/L	0.115	0.1%	269.012	8.4%
NH_4-Nitrogen	µg/L	1.192	1.5%	43.518	8.4%
NO_3-Nitrogen	µg/L	0.568	2.0%	2.682	21.6%
Organic-P	µg/L	0.010	0.1%	121.330	23.3%
Inorganic-P	µg/L	0.042	0.0%	17.172	14.4%
Phytoplankton	µg/L	0.016	3.1%	8.250	21.9%
Particulate Organic Matter	mg/L	0.001	0.1%	4.362	7.0%

Table 20. Comparison of Predicted Median and Observed Dissolved Oxygen Concentrations in Lower Santa Rosa Creek during the Model Corroboration Period

Hour	Predicted Median DO (mg/L)	Sampling Date		
		8/25/2009	8/26/2009	8/27/2009
		DO (mg/L)	DO (mg/L)	DO (mg/L)
0:00	6.37	6.77	6.73	6.73
1:00	6.34	6.69	6.64	6.64
2:00	6.32	6.59	6.54	6.59
3:00	6.29	6.47	6.40	6.49
4:00	6.27	6.32	6.26	6.36
5:00	6.26	6.15	6.13	6.26
6:00	6.25	6.01	6.00	6.14
7:00	6.25	5.92	5.90	6.06
8:00	6.24	5.88	5.86	6.01
9:00	6.29	5.88	5.87	5.99
10:00	6.34	5.99	5.95	6.02
11:00	6.39	6.13	6.10	6.12
12:00	6.50	6.34	6.28	6.25
13:00	6.55	6.48	6.42	6.40
14:00	6.59	6.70	6.62	6.33
15:00	6.66	6.66	6.70	6.33
16:00	6.68	6.83	6.70	6.33
17:00	6.70	6.95	6.78	6.34
18:00	6.70	6.86	6.81	6.75
19:00	6.69	6.84	6.77	6.67
20:00	6.65	6.85	6.79	6.14
21:00	6.54	6.80	6.84	5.82
22:00	6.49	6.79	6.82	6.12
23:00	6.45	6.76	6.78	6.40

Table 21. Comparison of Predicted and Observed Dissolved Oxygen Concentrations in Lake Jonive during the Model Corroboration Period

Hour	Predicted Median DO (mg/L)	Sampling Date				
		7/22/2009	7/23/2009	7/24/2009	7/25/2009	7/26/2009
		DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)
0:00	5.63	5.63	5.48	5.37	6.60	6.66
1:00	5.55	5.32	5.55	5.06	6.61	6.74
2:00	5.36	5.16	5.21	5.36	6.36	5.97
3:00	5.47	5.01	4.62	5.47	5.98	5.96
4:00	5.10	4.90	4.44	5.10	5.56	5.57
5:00	4.59	4.59	4.52	4.47	5.55	5.52
6:00	4.48	4.47	4.48	4.43	5.37	5.56
7:00	4.33	4.26	4.13	4.33	5.36	5.15
8:00	4.56	4.56	4.44	4.37	5.07	5.28
9:00	4.86	4.86	4.50	4.68	5.39	5.67
10:00	5.30	5.13	5.30	5.03	6.23	6.62
11:00	6.10	5.55	6.10	6.05	6.90	7.74
12:00	6.77	6.39	6.77	6.66	7.03	7.61
13:00	7.32	6.75	7.23	7.32	7.55	7.93
14:00	7.67	7.43	7.23	7.67	8.20	8.52
15:00	7.59	7.59	7.47	7.24	7.90	8.03
16:00	7.63	7.63	7.70	7.27	7.90	7.50
17:00	7.59	7.53	7.59	6.82	7.81	8.16
18:00	7.44	7.61	7.08	6.54	7.46	7.44
19:00	6.89	6.90	6.52	6.38	6.89	7.18
20:00	6.61	6.61	6.91	6.30	6.42	8.41
21:00	6.51	6.57	6.51	6.17	6.01	8.29
22:00	6.68	5.98	6.61	6.68	6.87	7.84
23:00	6.37	5.88	5.82	6.37	6.66	7.65

Table 22. Corroborated Model Predictive Performance Statistics

Constituent	Unit	Lower Santa Rosa Creek		Lake Jonive	
		RMSE	CV(RMSE)	RMSE	CV(RMSE)
DO Hourly Mean	mg/L	0.082	1.7%	0.098	1.6%
DO Daily Mean	mg/L	0.004	0.1%	0.010	0.2%
DO Daily Maximum	mg/L	0.019	0.3%	0.028	0.3%
DO Daily Minimum	mg/L	0.009	0.2%	0.023	0.6%
$CBOD_u$	mg/L	0.005	0.1%	0.002	0.01%
Organic-N	µg/L	0.139	0.1%	229.2	12.4%
Ammonium-N	µg/L	4.091	5.4%	19.05	3.7%
Nitrate-N	µg/L	1.432	5.2%	1.000	3.0%
Organic-P	µg/L	0.011	0.1%	5.802	3.0%
Inorganic-P	µg/L	0.067	0.1%	116.8	22.6%
Phytoplankton	µg/L	0.039	6.1%	5.519	67.5%
Particulate Organic Matter	mg/L	0.001	0.1%	3.696	8.8%

Table 23. Comparison of Calibrated and Corroborated Model Predictive Performance Statistics

Constituent	Lower Santa Rosa Creek CV(RMSE)		Lake Jonive CV(RMSE)	
	Calibration	**Corroboration**	**Calibration**	**Corroboration**
DO Hourly Mean	23.6%	19.4%	1.7%	1.6%
DO Daily Mean	0.1%	0.1%	0.3%	0.2%
DO Daily Maximum	0.2%	0.3%	1.0%	0.3%
DO Daily Minimum	0.0%	0.2%	2.3%	0.6%
$CBOD_u$	0.1%	0.1%	0.0%	0.01%
Organic-N	0.1%	0.1%	8.4%	12.4%
Ammonium-N	1.5%	5.4%	8.4%	3.7%
Nitrate-N	2.0%	5.2%	21.6%	3.0%
Organic-P	0.1%	0.1%	23.3%	3.0%
Inorganic-P	0.0%	0.1%	14.4%	22.6%
Phytoplankton	3.1%	6.1%	21.9%	67.5%
Particulate Organic Matter	0.1%	0.1%	7.0%	8.8%

Table 24. Lower Santa Rosa Creek Constituent Values Used for Uncertainty Analysis

Constituent	Unit	Sampling Date			
		6/11/2008	**9/11/2008**	**9/17/2008**	**9/29/2008**
$CBOD_u$	mg/L	4.38	4.38	4.38	4.38
Ammonium-N	µg/L	0.07	0.07	0.15	0.09
Nitrate-N	µg/L	0.03	0.06	0.02	0.03
Organic-N	µg/L	0.13	0.13	0.05	0.21
Inorganic-P	µg/L	0.10	0.12	0.10	0.09
Organic-P	µg/L	0	0.01	0	0.03
Particulate Organic Matter	mg/L	0	2.991	0	9.721

Table 25. Lake Jonive Constituent Values Used for Uncertainty Analysis

Constituent	Unit	Sampling Date			
		6/18/2008	**9/11/2008**	**9/17/2008**	**9/29/2008**
$CBOD_u$	mg/L	5.84	20.44	8.76	20.44
Ammonium-N	µg/L	0.08	0.58	0.68	0.33
Nitrate-N	µg/L	0.01	0.01	0.04	0.07
Organic-N	µg/L	0.82	5.42	1.02	3.27
Inorganic-P	µg/L	0.42	0.30	0.25	0.36
Organic-P	µg/L	0.09	0.37	0.20	0.15
Particulate Organic Matter	mg/L	9.354	107.273	36.114	57.133

Table 26. Conductivity and Phytoplankton Estimates used for Uncertainty Analysis

Sample Date	Sample Location	Conductivity (µmhos)	Phytoplankton (ug/L)
8/27/2008	Lake Jonive Site 1	648	24.589
8/27/2008	Lake Jonive Site 2	642	24.12
8/27/2008	Lake Jonive Site 3	650	30.418
8/27/2008	Lake Jonive Site 4	636	29.547
8/27/2008	Lake Jonive Site 5	622	26.867
9/2/2008	Lake Jonive Site 1	657	-
9/2/2008	Lake Jonive Site 2	657	-
9/2/2008	Lake Jonive Site 3	656	-
9/2/2008	Lake Jonive Site 4	642	-
9/2/2008	Lake Jonive Site 5	613	-
9/23/2008	Lake Jonive Site 1	631	12.06
9/23/2008	Lake Jonive Site 2	621	20.1
9/23/2008	Lake Jonive Site 3	631	10.72
9/23/2008	Lake Jonive Site 4	631	8.978
9/23/2008	Lake Jonive Site 5	485	2.68
10/1/2008	Lake Jonive Site 1	612	-
10/1/2008	Lake Jonive Site 2	620	-
10/1/2008	Lake Jonive Site 3	618	-
10/1/2008	Lake Jonive Site 4	609	-
10/1/2008	Lake Jonive Site 5	571	-
10/22/2008	Lake Jonive Site 1	612	26.867
10/22/2008	Lake Jonive Site 2	612	166.16
10/22/2008	Lake Jonive Site 3	608	32.227
10/22/2008	Lake Jonive Site 4	606	59.027
10/22/2008	Lake Jonive Site 5	600	134
9/4/2008	Santa Rosa Creek at Willowside Road	661	0.402
9/24/2008	Santa Rosa Creek at Willowside Road	652	4.02
9/30/2008	Santa Rosa Creek at Willowside Road	648	-
10/21/2008	Santa Rosa Creek at Willowside Road	608	0.536

Table 27. Alkalinity Measurements used for Uncertainty Analysis

Sampling Date	Alkalinity (mg $CaCO_3$/L)
2/14/2006	110
3/15/2006	62
4/17/2006	77
5/10/2006	120

Table 28. Critical Low Flow Statistics

Flow Statistic	Lower Santa Rosa Creek (cms)	Lake Jonive (cms)	Critical Flow Application
7Q1	0.2174	0.0539	Dry weather flow (Smakhtin, 2001)
7Q2	0.1091	0.0191	Habitat maintenance flow (OMNR, 1994)
7Q5	0.0775	0.0114	Warmwater aquatic life protection (SDDENR, 1998)
7Q10	0.0629	0.0084	
7Q20	0.0554	0.0069	Ecosystem maintenance flow (OMNR et al 2002)
7Q25	0.0549	0.0068	Coldwater aquatic life protection (SDDENR, 1998)
7Q50	0.0471	0.0054	
7Q100	0.0306	0.0028	

Table 29. Lower Santa Rosa Creek Sensitivity Analysis Parameters

Parameter	Unit	Calibration value	Plus 50% value	Minus 50% value
Rate Processes				
$CBOD_u$ oxidation rate	/d	$1.0x10^{-3}$	$1.5x10^{-3}$	$5.0x10^{-4}$
Organic-N hydrolysis rate	/d	$1.0x10^{-3}$	$1.5x10^{-3}$	$5.0x10^{-4}$
Ammonium-N nitrification rate	/d	$1.0x10^{-2}$	$1.5x10^{-2}$	$5.0x10^{-3}$
Nitrate-N denitrification rate	/d	$1.0x10^{-6}$	$1.5x10^{-6}$	$5.0x10^{-7}$
Organic-P hydrolysis rate	/d	$1.0x10^{-3}$	$1.5x10^{-3}$	$5.0x10^{-4}$
Phytoplankton maximum growth rate	/d	4.10	6.15	2.05
Phytoplankton respiration rate	/d	0.70	1.05	0.35
Phytoplankton death rate	/d	0.0	0.01	-
Bottom algae maximum growth rate	/d	1.290	1.935	0.645
Bottom algae basal respiration rate	/d	0.1	0.15	0.05
Bottom algae photo-respiration rate	/d	0.6	0.9	0.3
Detritus dissolution rate	/d	$1.0x10^{-3}$	$1.5x10^{-3}$	$5.0x10^{-4}$
Sediment oxygen demand	$gO_2/m^2/d$	2.6	3.9	1.3
Ammonium sediment flux	$mgN/m^2/d$	0.8	1.2	0.4
Phosphate sediment flux	$mgP/m^2/d$	0	0.1	-
Upstream & Diffuse Inflow Concentrations				
Hourly Dissolved Oxygen	mg/L	5.42 – 6.13	+ 2.0	- 2.0
Hourly Water Temperature	ºC	17.65 – 19.45	+ 2.0	- 2.0
Conductivity	µmhos	650	975	325
Inorganic Solids	mg/L	379	569	190
$CBOD_u$	mg/L	4.38	6.57	2.19
Organic-N	µg N/L	130	195	65
Ammonium-N	µg N/L	80	120	40
Nitrate-Nitrogen	µg N/L	30	45	15
Organic-P	µg P/L	10	15	5
Inorganic-P	µg P/L	100	150	50
Phytoplankton	µg/L	0.536	0.804	0.268
Particulate Organic Matter	mg/L	1.0	1.5	0.5
Alkalinity	mg $CaCO_3$/L	150	225	75
Physical Features				
Bottom Algae Coverage	%	50%	25%	75%
SOD Coverage	%	50%	25%	75%
Shade	%	0%	100%	-

Table 30. Lake Jonive Sensitivity Analysis Parameters

Parameter	Unit	Calibration value	Plus 50% value	Minus 50% value
Rate Processes				
$CBOD_u$ oxidation rate	/d	1.0×10^{-6}	1.5×10^{-6}	5.0×10^{-7}
Organic-N hydrolysis rate	/d	1.5×10^{-3}	2.3×10^{-3}	8.0×10^{-4}
Ammonium-N nitrification rate	/d	8.0×10^{-2}	1.2×10^{-1}	4.0×10^{-2}
Nitrate-N denitrification rate	/d	1.0×10^{-4}	1.5×10^{-4}	5.0×10^{-5}
Organic-P hydrolysis rate	/d	1.0×10^{-3}	1.5×10^{-3}	5.0×10^{-4}
Phytoplankton maximum growth rate	/d	4.1	6.15	2.05
Phytoplankton respiration rate	/d	0.2	0.3	0.1
Phytoplankton death rate	/d	0.01	0.015	0.005
Bottom algae maximum growth rate	/d	8	12	4
Bottom algae basal respiration rate	/d	0.1	0.15	0.05
Bottom algae photo-respiration rate	/d	0.6	0.9	0.3
Detritus dissolution rate	/d	1.2×10^{-3}	1.8×10^{-3}	6.0×10^{-4}
Sediment oxygen demand	$gO_2/m^2/d$	10	15	5
Ammonium sediment flux	$mgN/m^2/d$	100	150	50
Phosphate sediment flux	$mgP/m^2/d$	0.9	1.35	0.45
Upstream & Diffuse Inflow Concentrations				
Hourly Dissolved Oxygen	mg/L	3.28 – 8.34	+ 2.0	- 2.0
Hourly Water Temperature	ºC	22.18 – 24.77	+ 2.0	- 2.0
Conductivity	µmhos	621	932	311
Inorganic Solids	mg/L	331	497	166
$CBOD_u$	mg/L	14.6	21.9	7.3
Organic-N	µg N/L	2150	3225	1075
Ammonium-N	µg N/L	460	690	230
Nitrate-N	µg N/L	30	45	15
Organic-P	µg P/L	180	270	90
Inorganic-P	µg P/L	330	495	165
Phytoplankton	µg/L	26.867	40.301	13.434
Particulate Organic Matter	mg/L	47	70.5	23.5
Alkalinity	mg $CaCO_3$/L	202	303	101
Physical Features				
Bottom Algae Coverage	%	33%	50%	17%
SOD Coverage	%	67%	101%	34%
Cloud Cover	%	0%	100%	-
Wind Speed	m/s	0.2 – 3.3	5	0

FIGURES

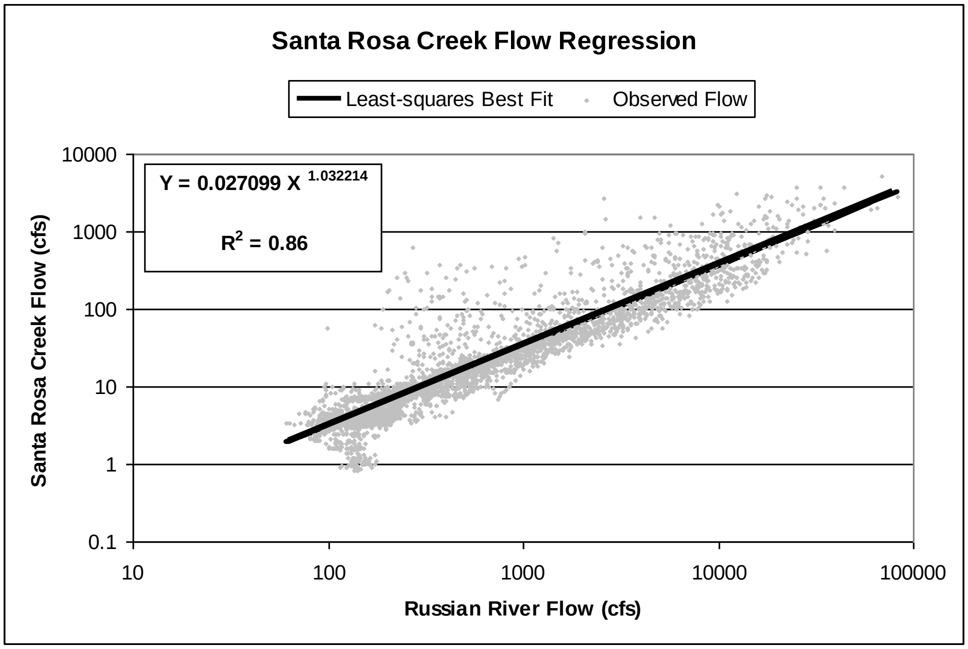

Figure 1. Relationship Between Mean Daily Flows measured at Santa Rosa Creek (USGS Gage #1146320) and the Russian River (USGS Gage #11467000)

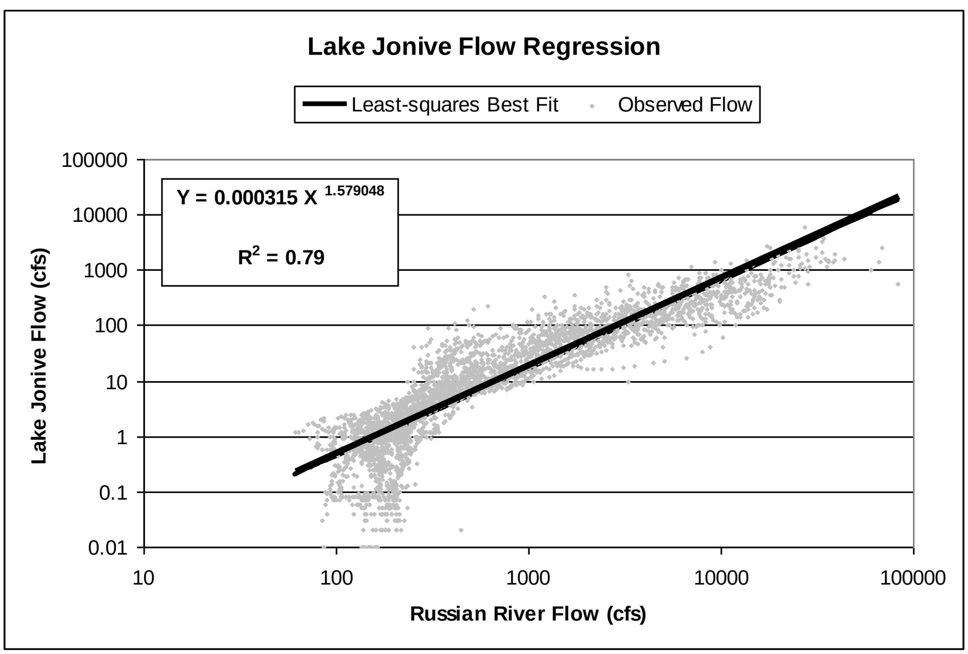

Figure 2. Relationship Between Mean Daily Flows measured at Lake Jonive (USGS Gage #11465750) and the Russian River (USGS Gage #11467000)

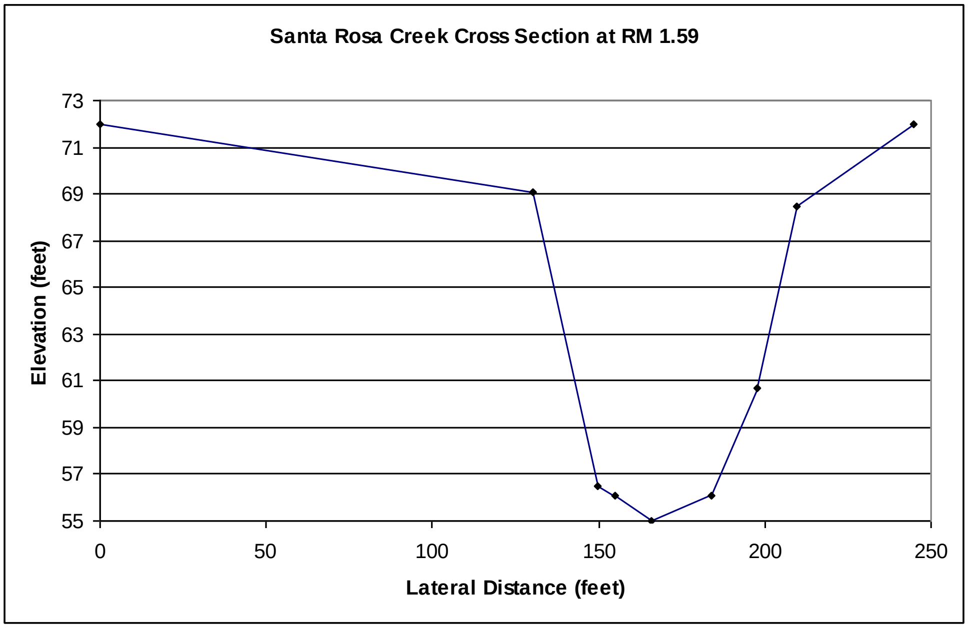

Figure 3. Cross Section Profile of Santa Rosa Creek at River Mile 1.59 (Deas, 2007)

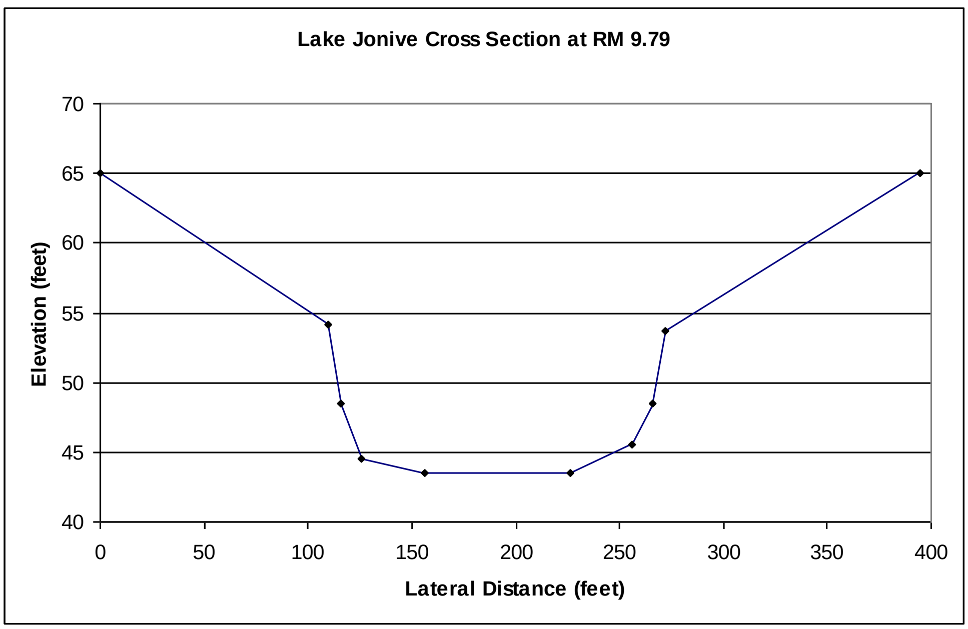

Figure 4. Cross Section Profile of Lake Jonive at River Mile 1.59 (Deas, 2007)

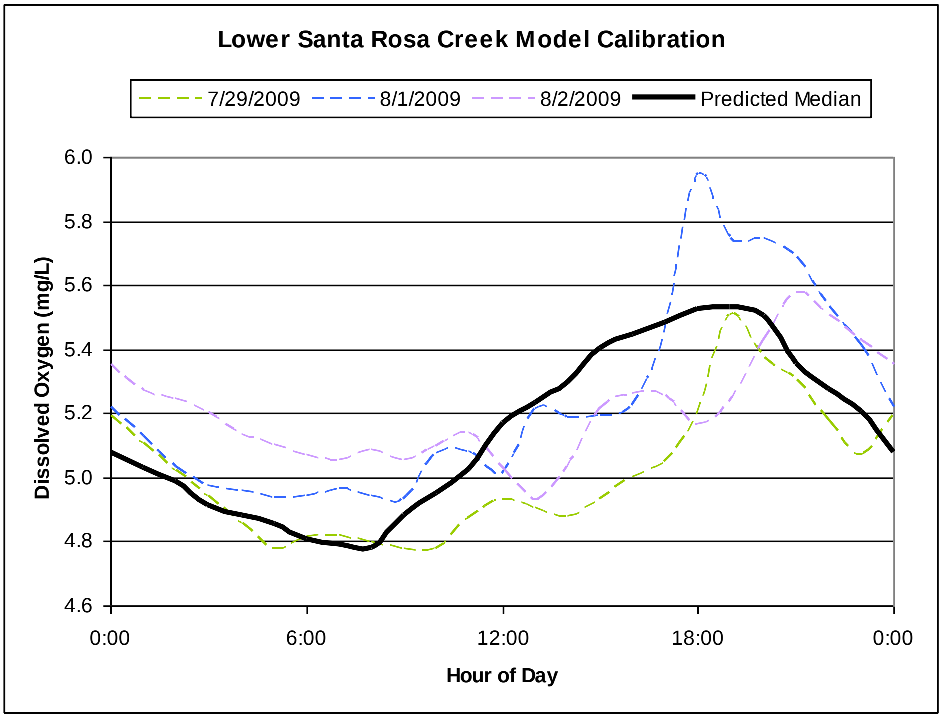

Figure 5. Comparison of Diel Predicted and Observed Dissolved Oxygen Concentrations in Lower Santa Rosa Creek during the Model Calibration Period

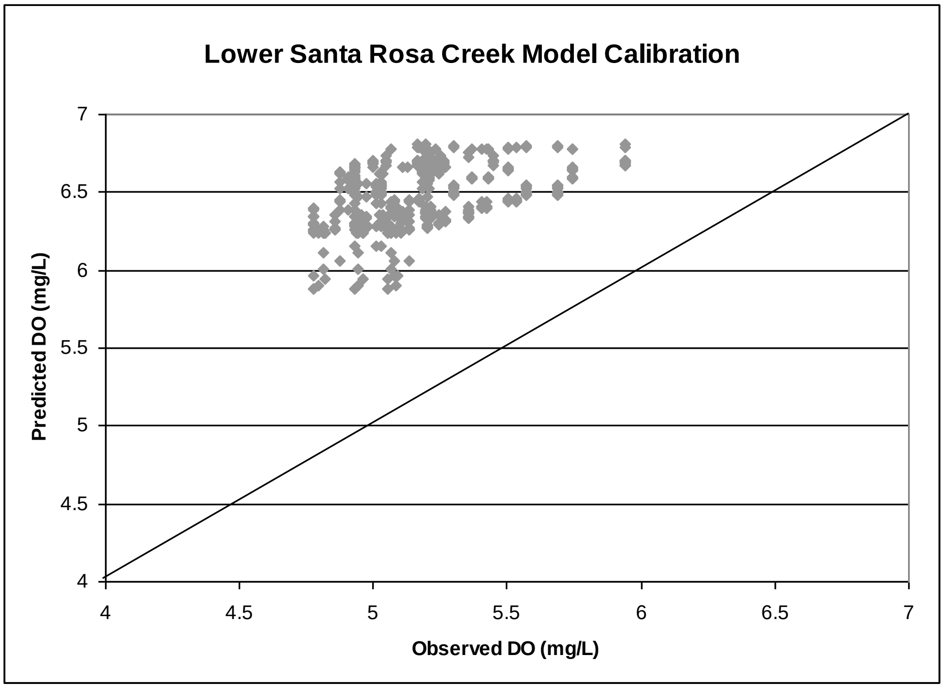

Figure 6. Comparison of Predicted and Observed Dissolved Oxygen Concentrations in Lower Santa Rosa Creek during the Model Calibration Period

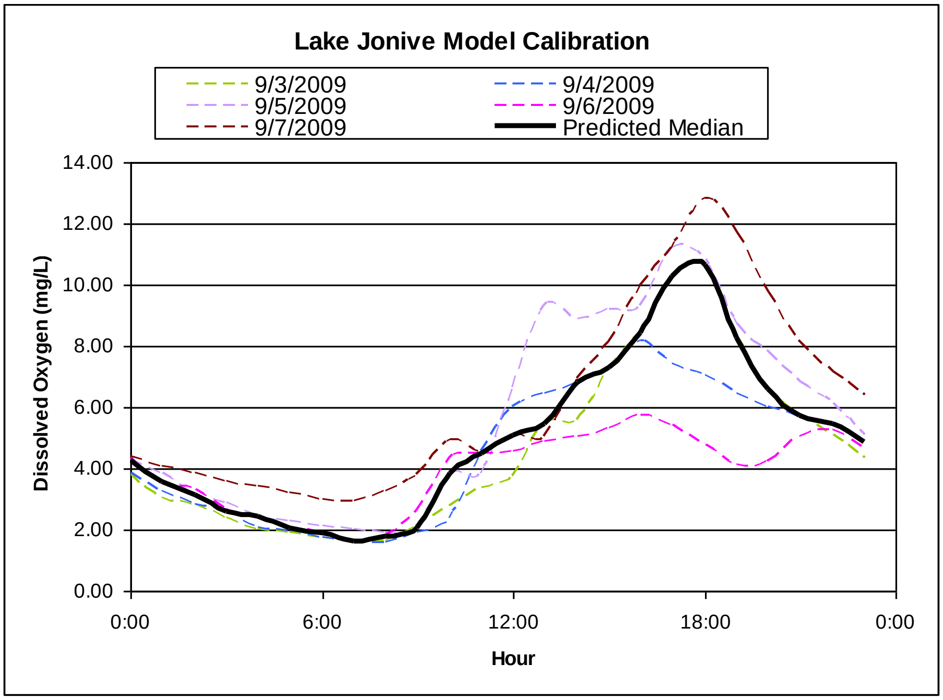

Figure 7. Comparison of Diel Predicted and Observed Dissolved Oxygen Concentrations in Lake Jonive during the Model Calibration Period

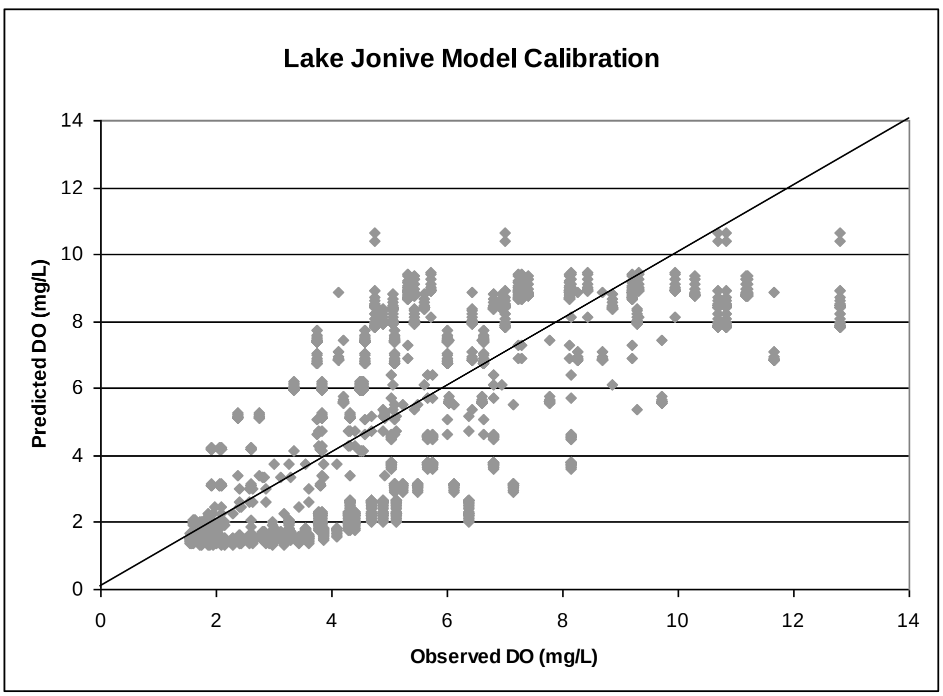

Figure 8. Comparison of Predicted and Observed Dissolved Oxygen Concentrations in Lake Jonive during the Model Calibration Period

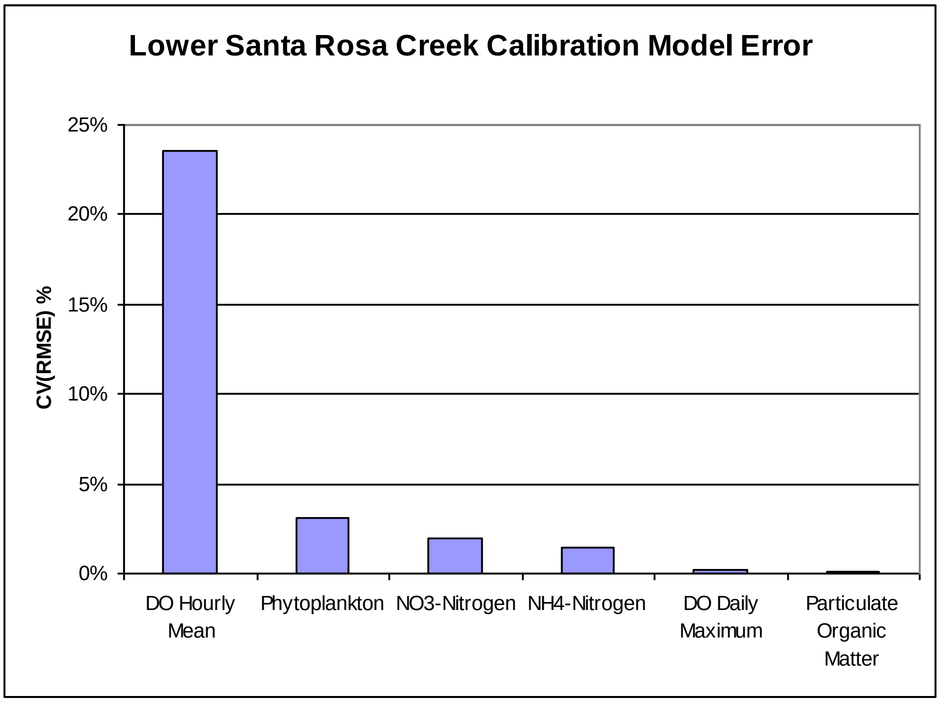

Figure 9. Lower Santa Rosa Creek Calibration Model Error

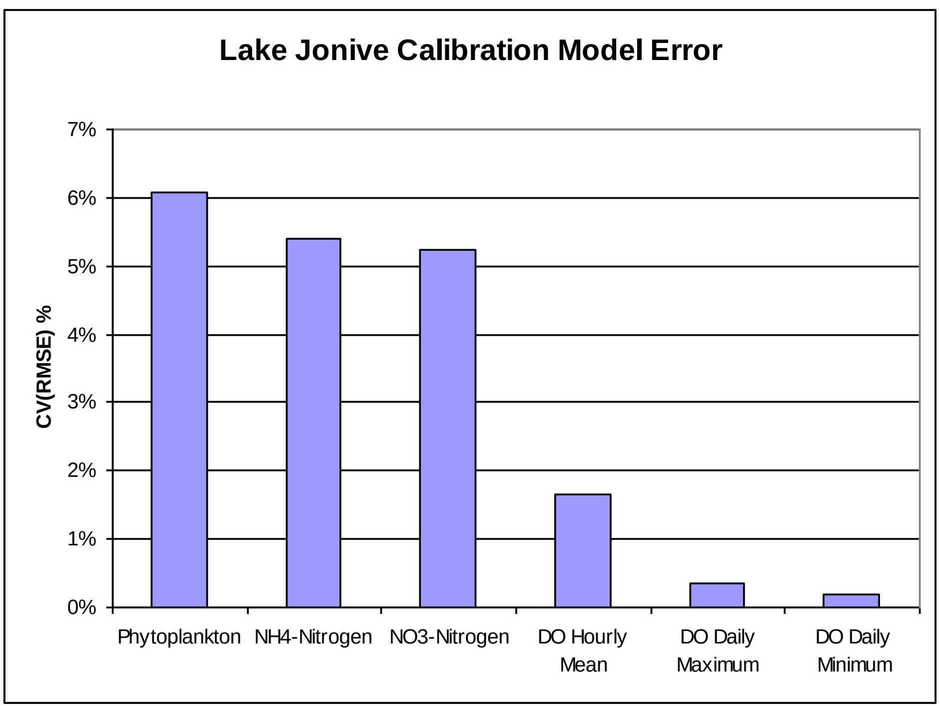

Figure 10. Lake Jonive Calibration Model Error

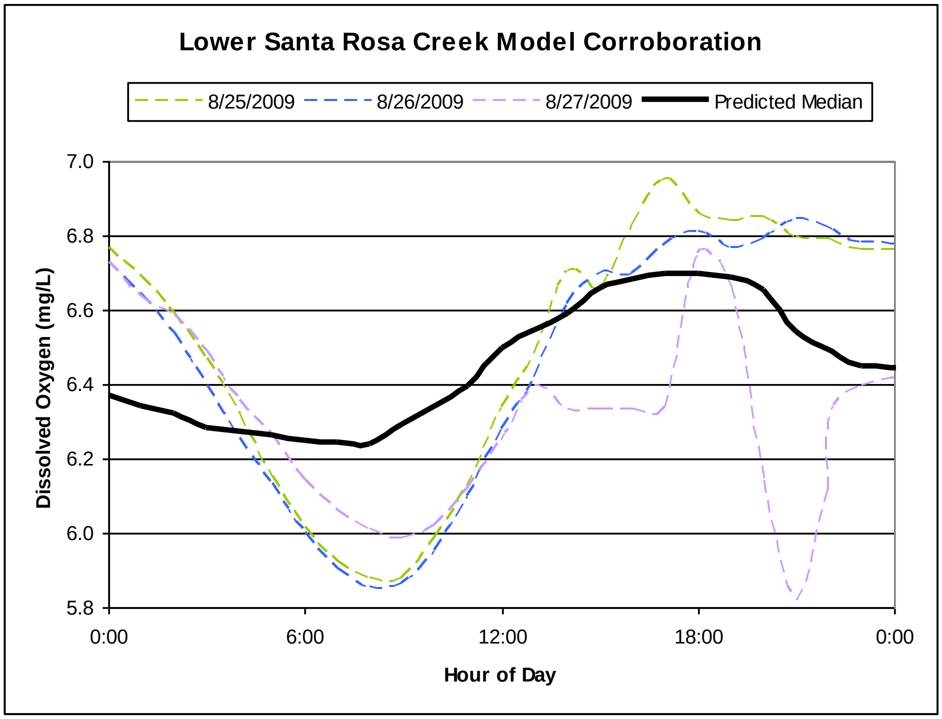

Figure 11. Comparison of Predicted and Observed Dissolved Oxygen Concentrations in Lower Santa Rosa Creek during the Model Corroboration Period

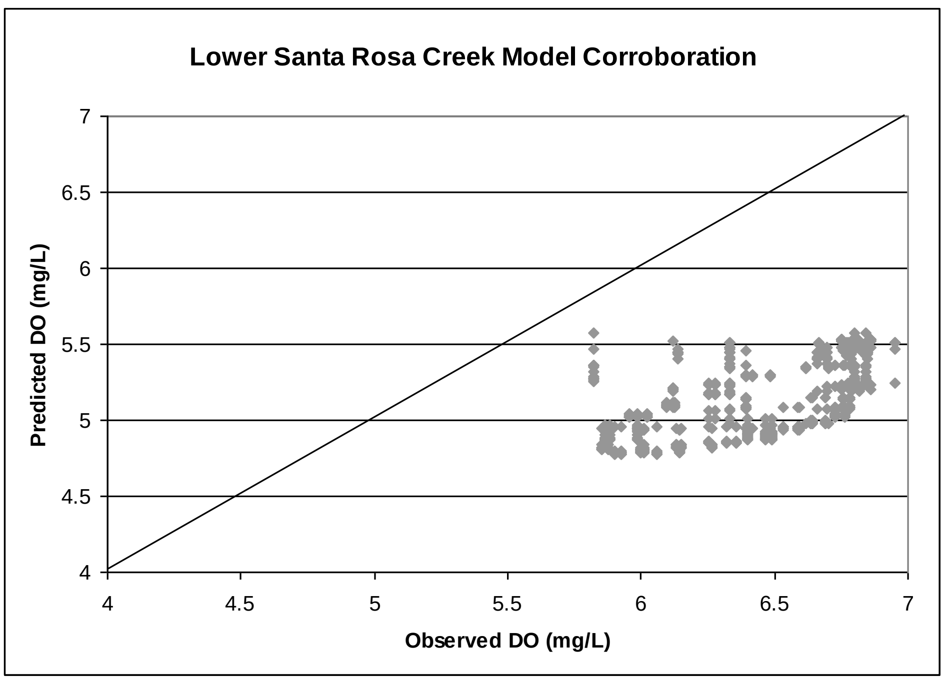

Figure 12. Comparison of All Predicted and Observed Dissolved Oxygen Concentrations in Lower Santa Rosa Creek during the Model Corroboration Period

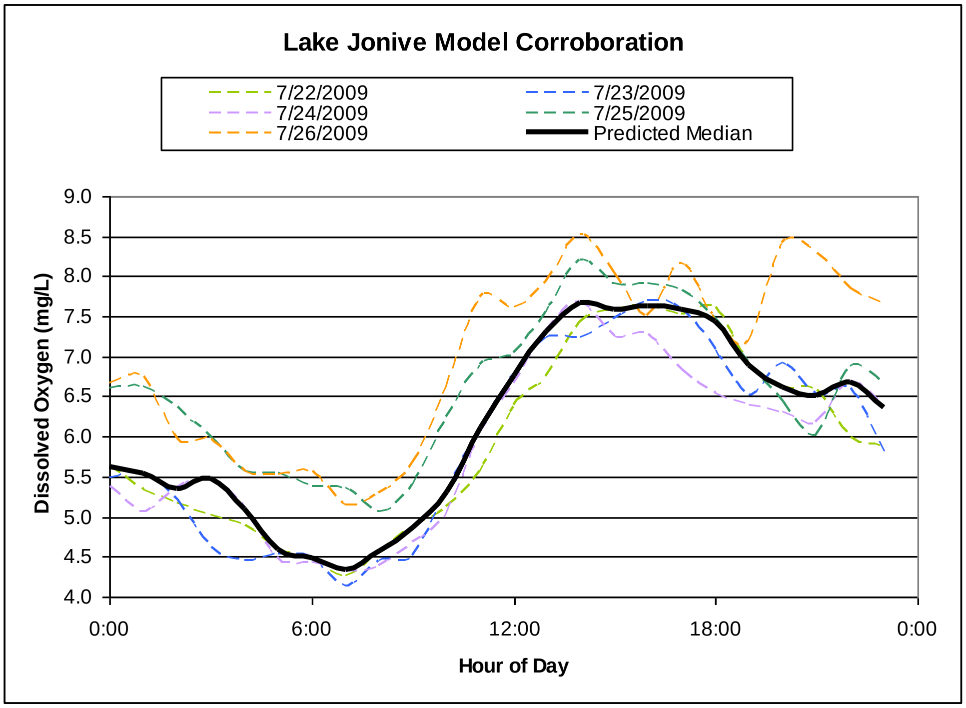

Figure 13. Hourly Comparison of Predicted and Observed Dissolved Oxygen Concentrations in Lake Jonive during the Model Corroboration Period

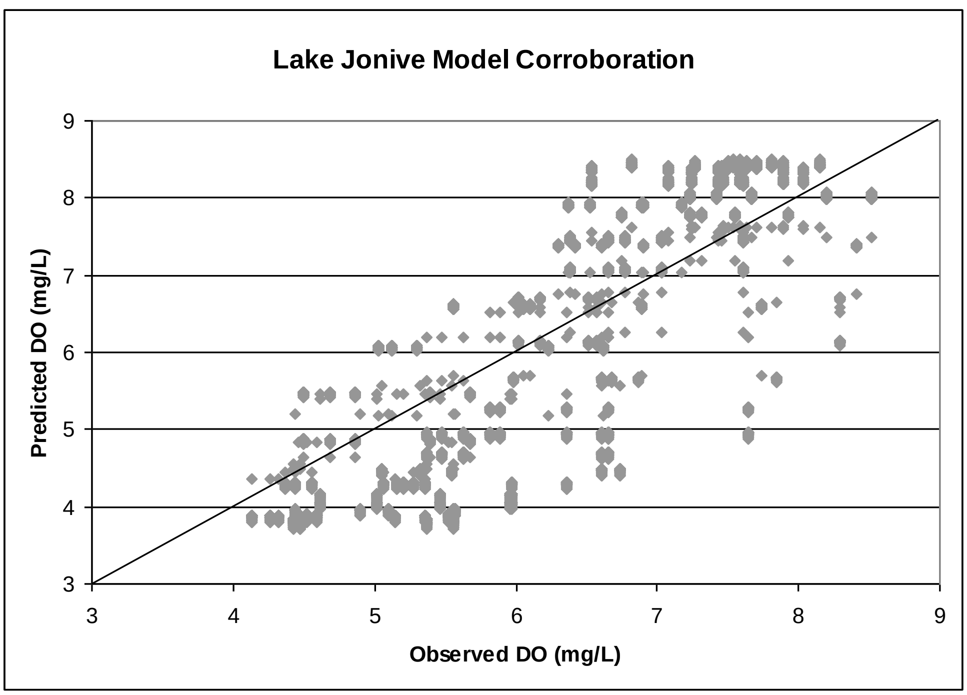

Figure 14. Comparison of Predicted and Observed Dissolved Oxygen Concentrations in Lake Jonive during the Model Corroboration Period

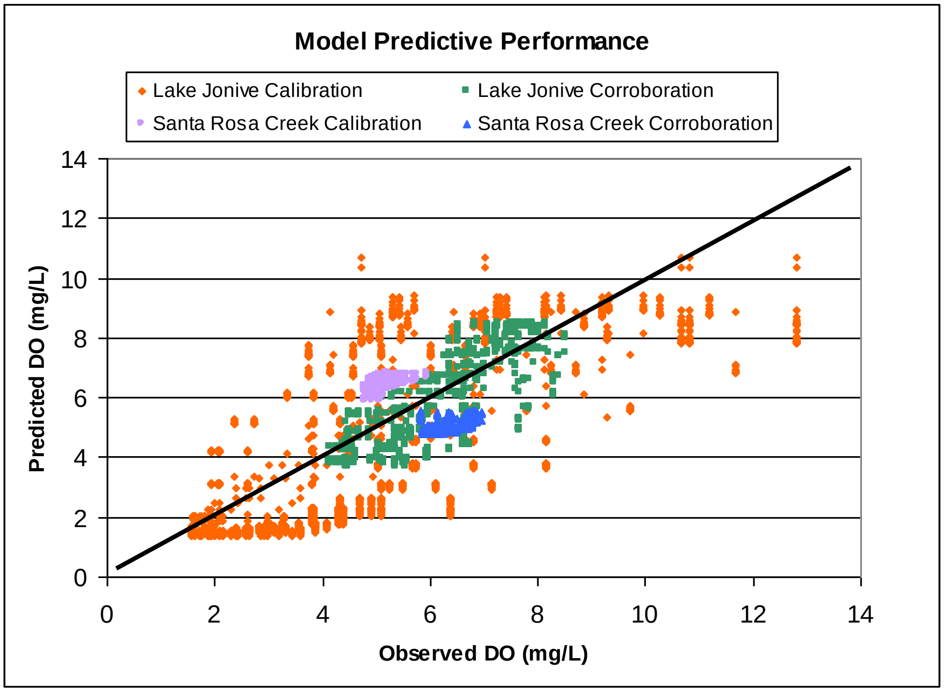

Figure 15. Comparison of the Predictive Performance of Developed Models

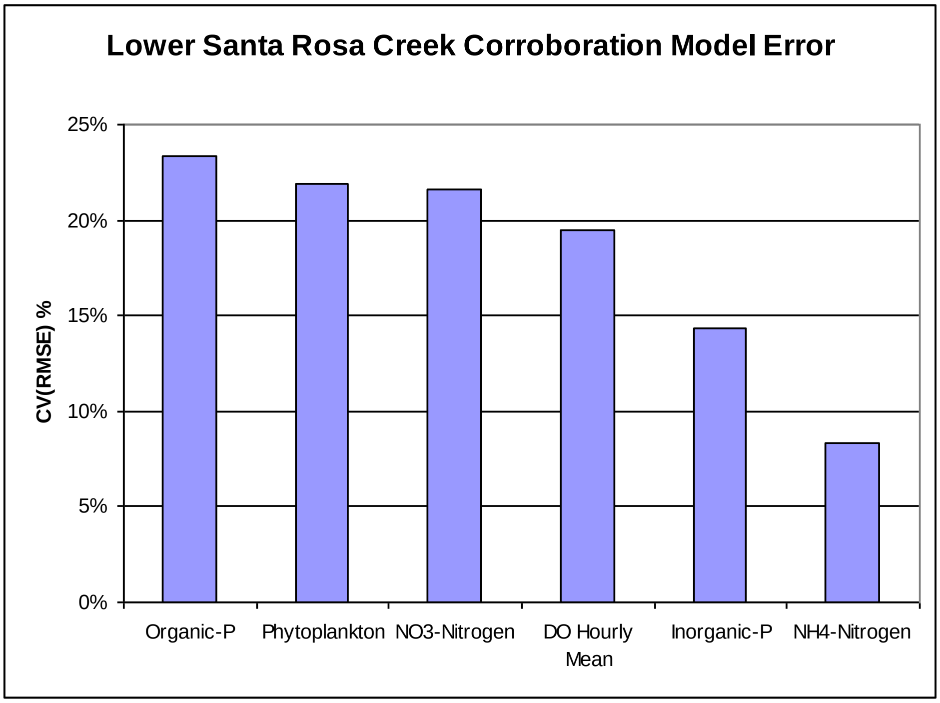

Figure 16. Lower Santa Rosa Creek Corroboration Model Error

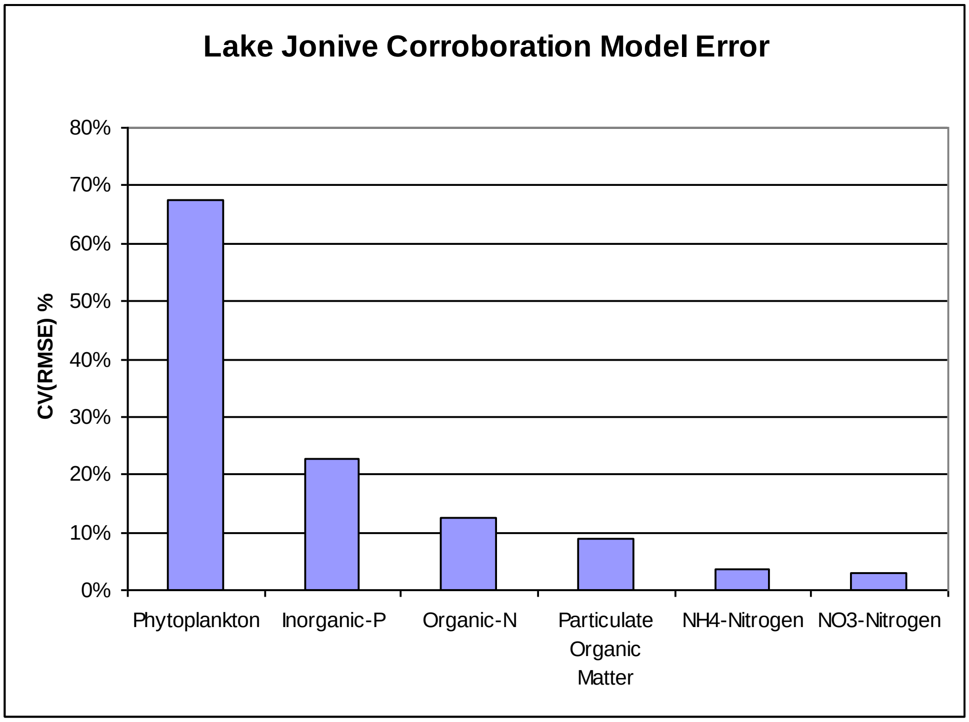

Figure 17. Lake Jonive Corroboration Model Error

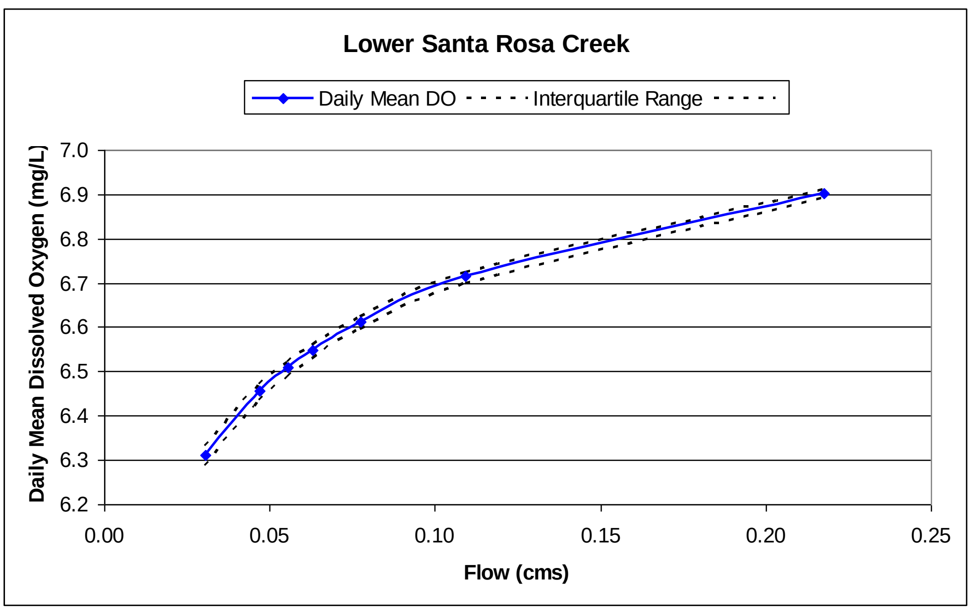

Figure 18. Lower Santa Rosa Creek Model Prediction Uncertainty for Daily Mean Dissolved Oxygen Concentration

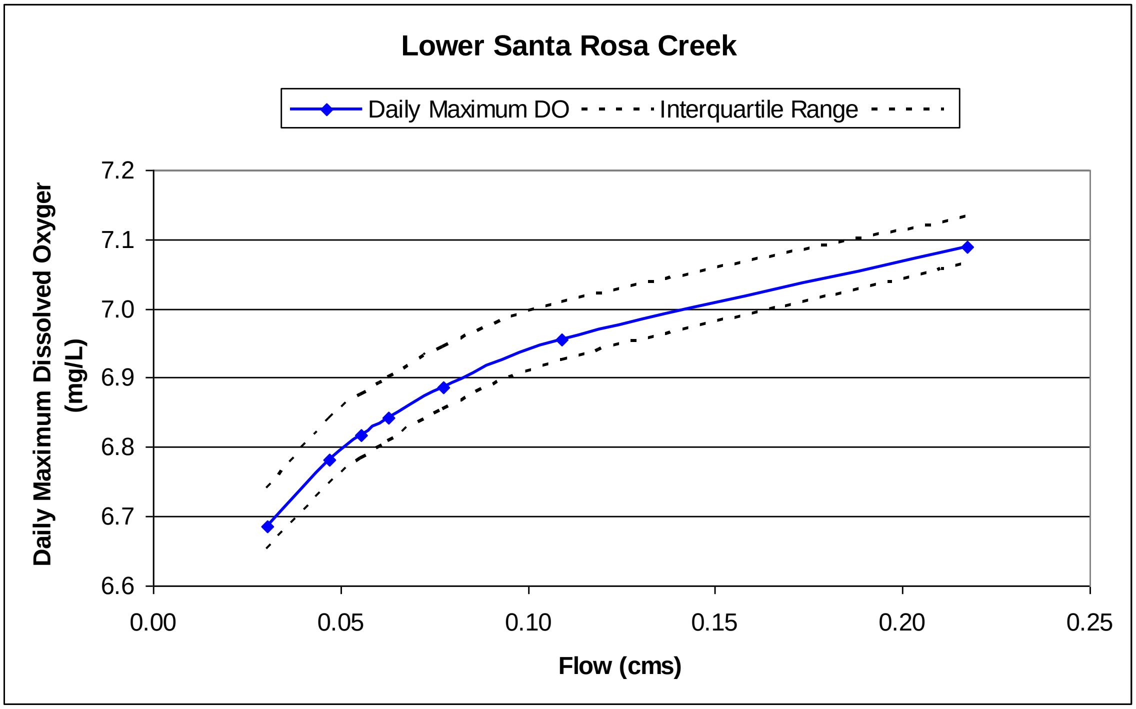

Figure 19. Lower Santa Rosa Creek Model Prediction Uncertainty for Daily Maximum Dissolved Oxygen Concentration

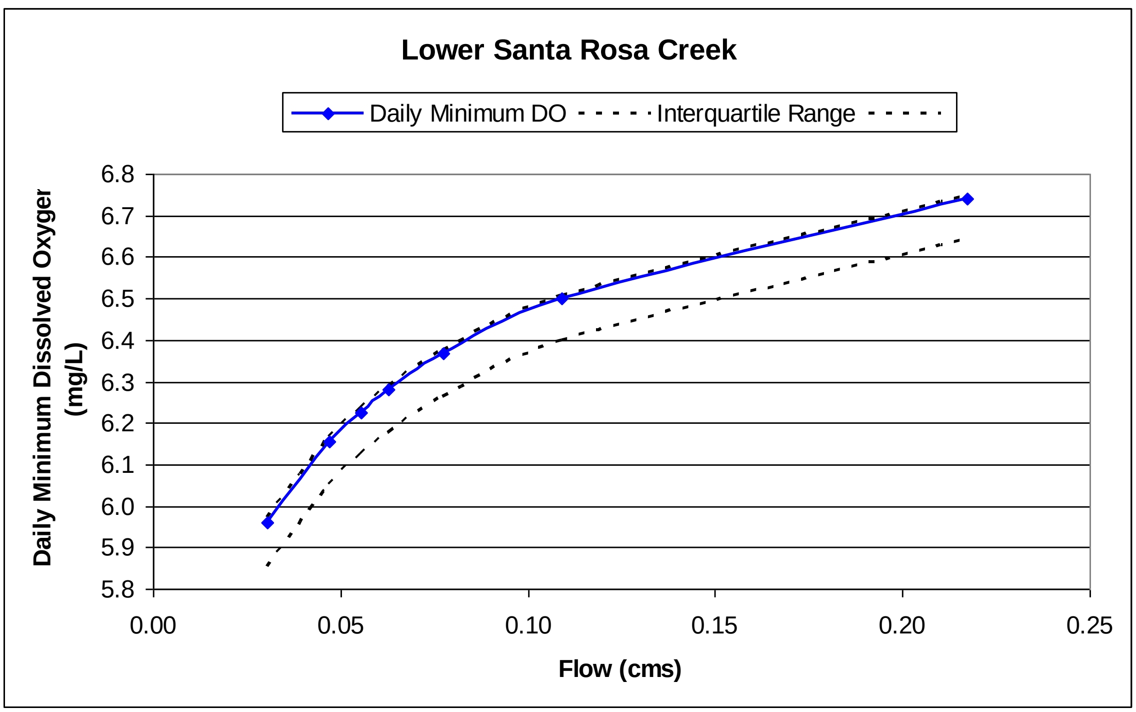

Figure 20. Lower Santa Rosa Creek Model Prediction Uncertainty for Daily Minimum Dissolved Oxygen Concentration

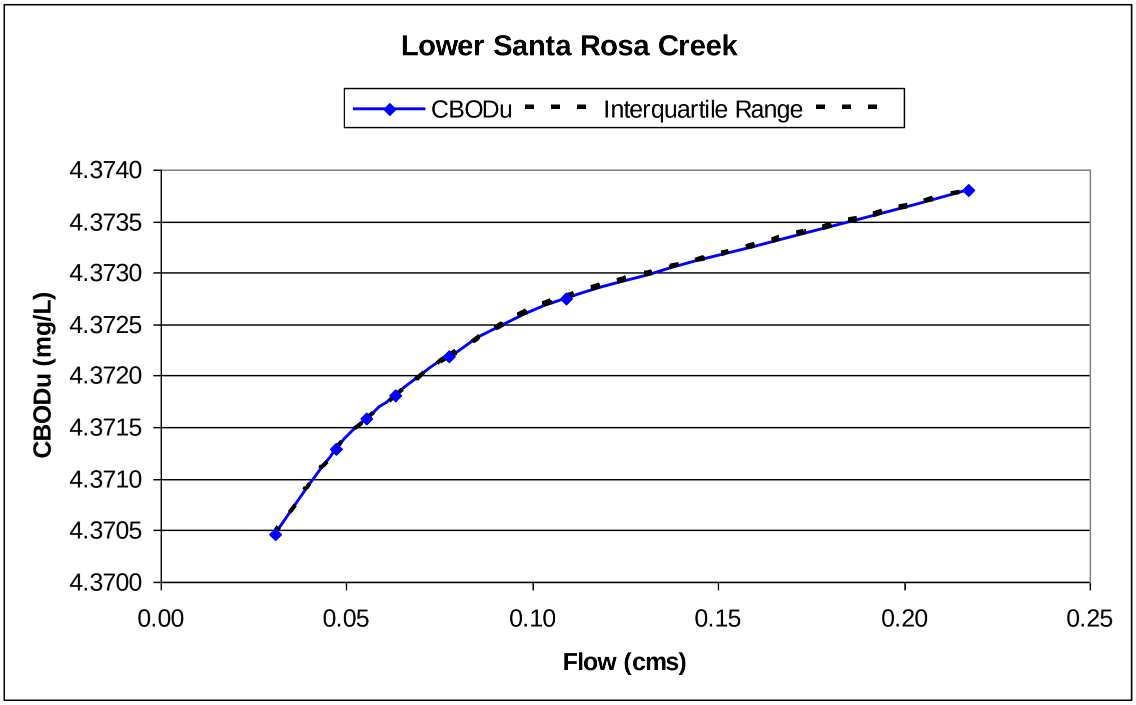

Figure 21. Lower Santa Rosa Creek Model Prediction Uncertainty for $CBOD_u$ Concentration

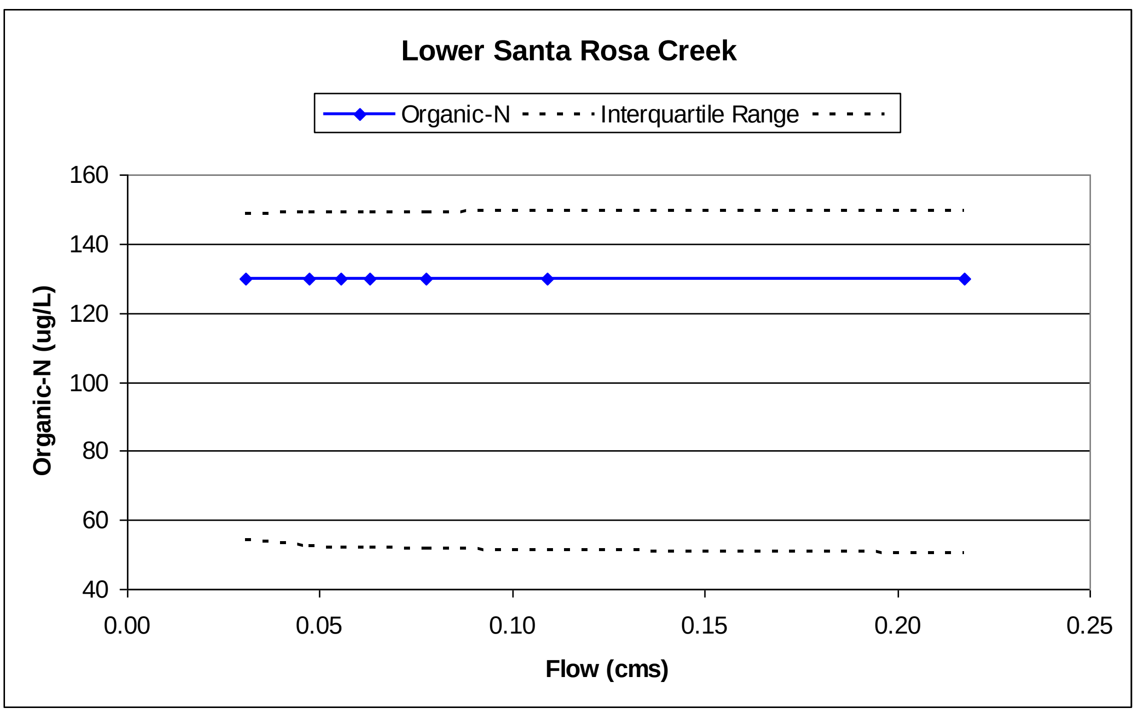

Figure 22. Lower Santa Rosa Creek Model Prediction Uncertainty for Organic Nitrogen Concentration

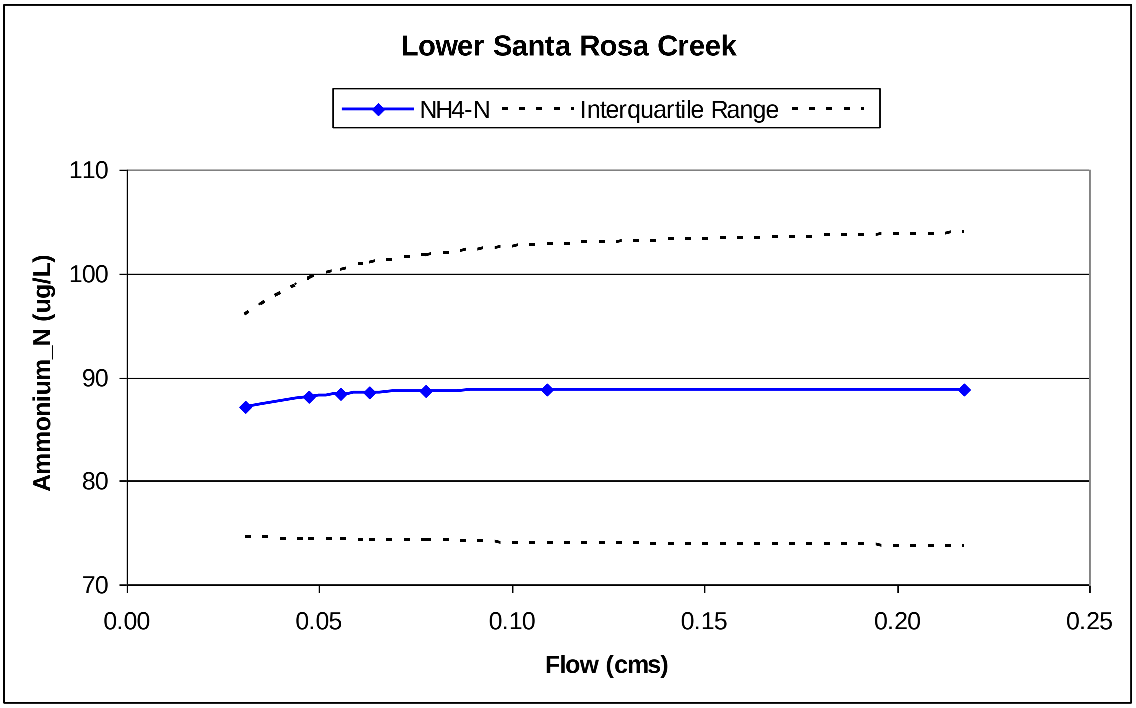

Figure 23. Lower Santa Rosa Creek Model Prediction Uncertainty for Ammonium Nitrogen Concentration

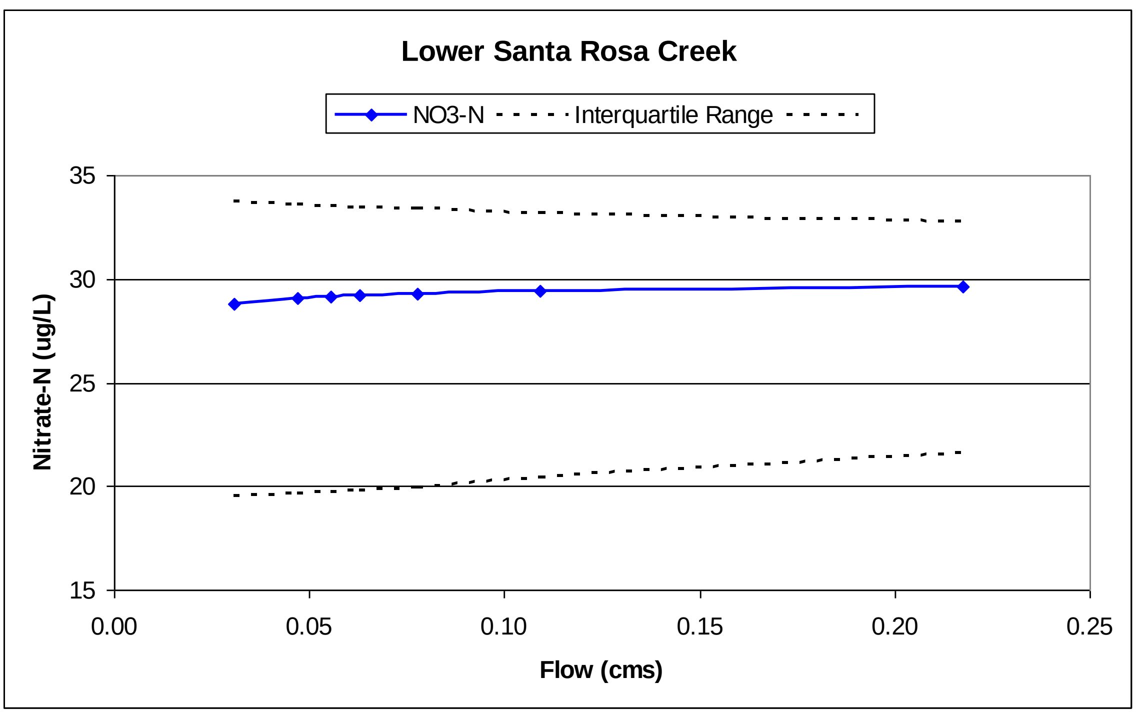

Figure 24. Lower Santa Rosa Creek Model Prediction Uncertainty for Nitrate Nitrogen Concentration

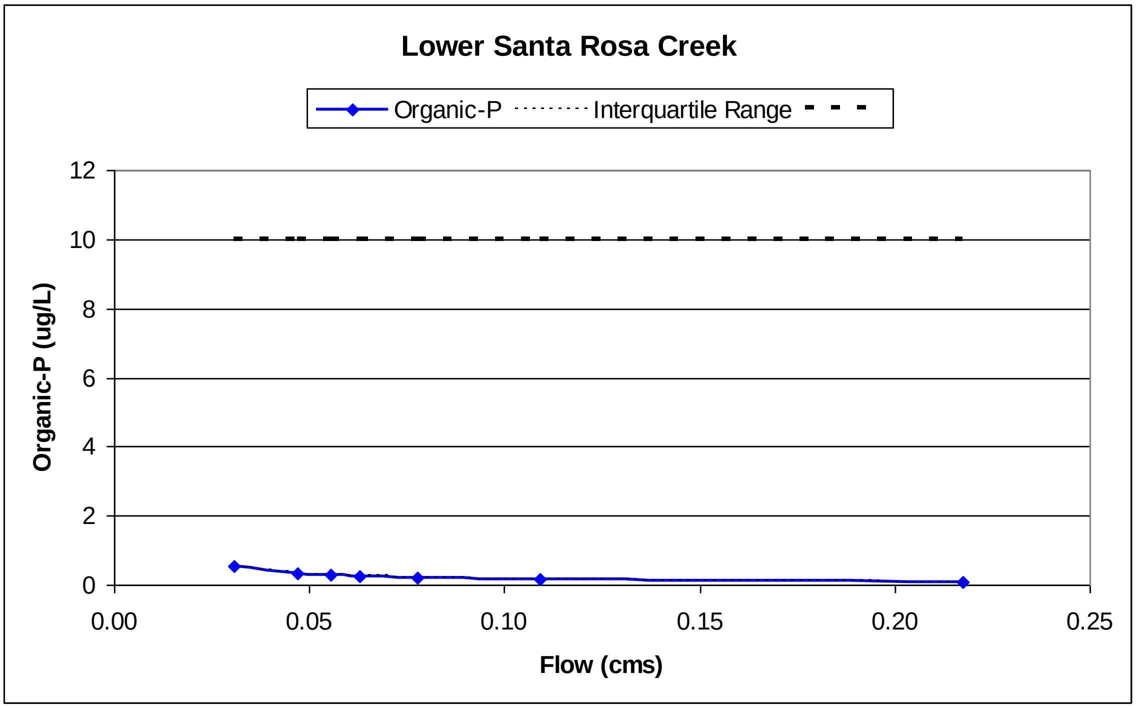

Figure 25. Lower Santa Rosa Creek Model Prediction Uncertainty for Organic Phosphorus Concentration

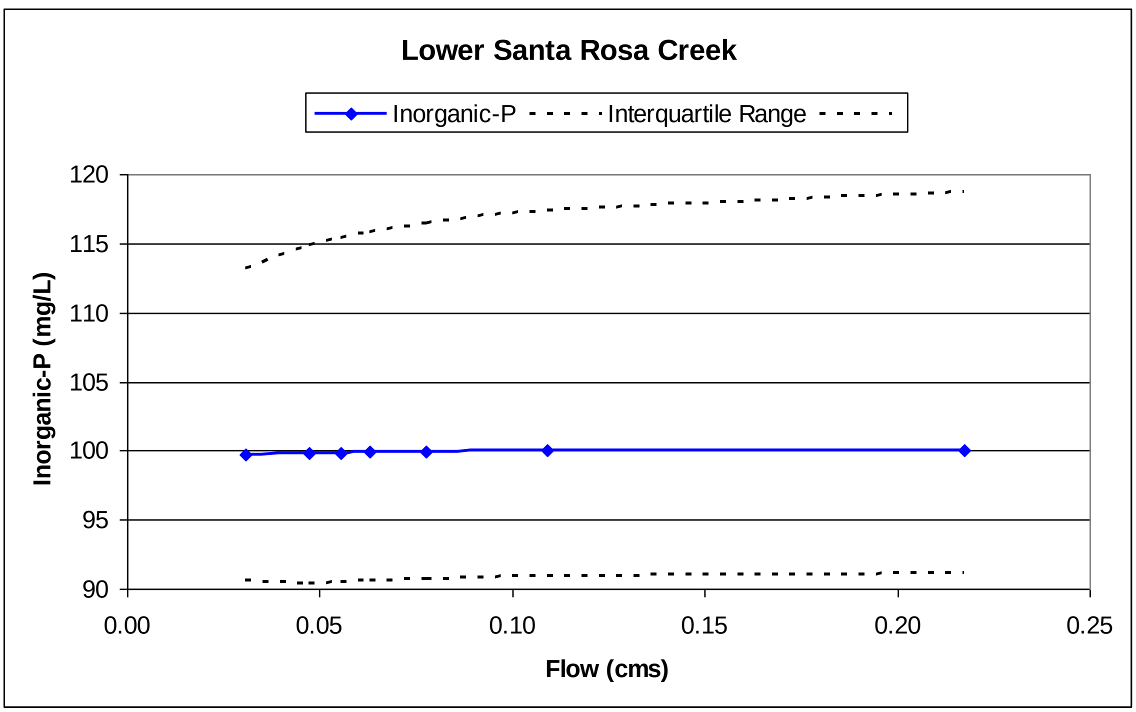

Figure 26 Lower Santa Rosa Creek Model Prediction Uncertainty for Inorganic Phosphorus Concentration

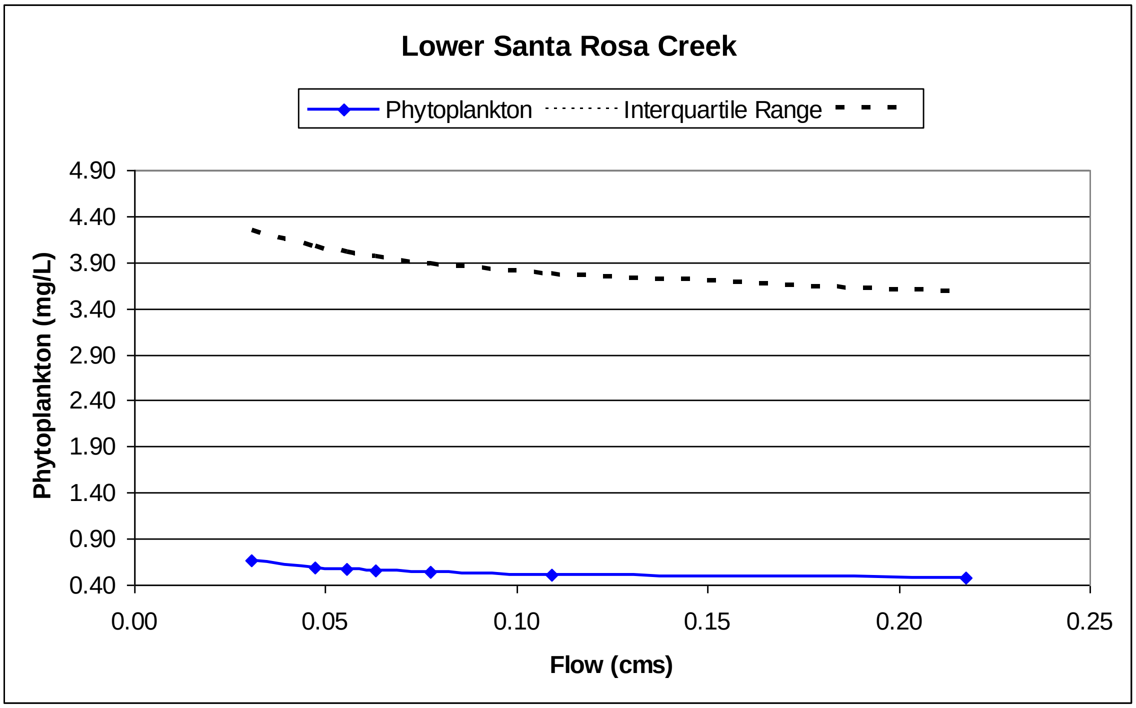

Figure 27. Lower Santa Rosa Creek Model Prediction Uncertainty for Phytoplankton Concentration

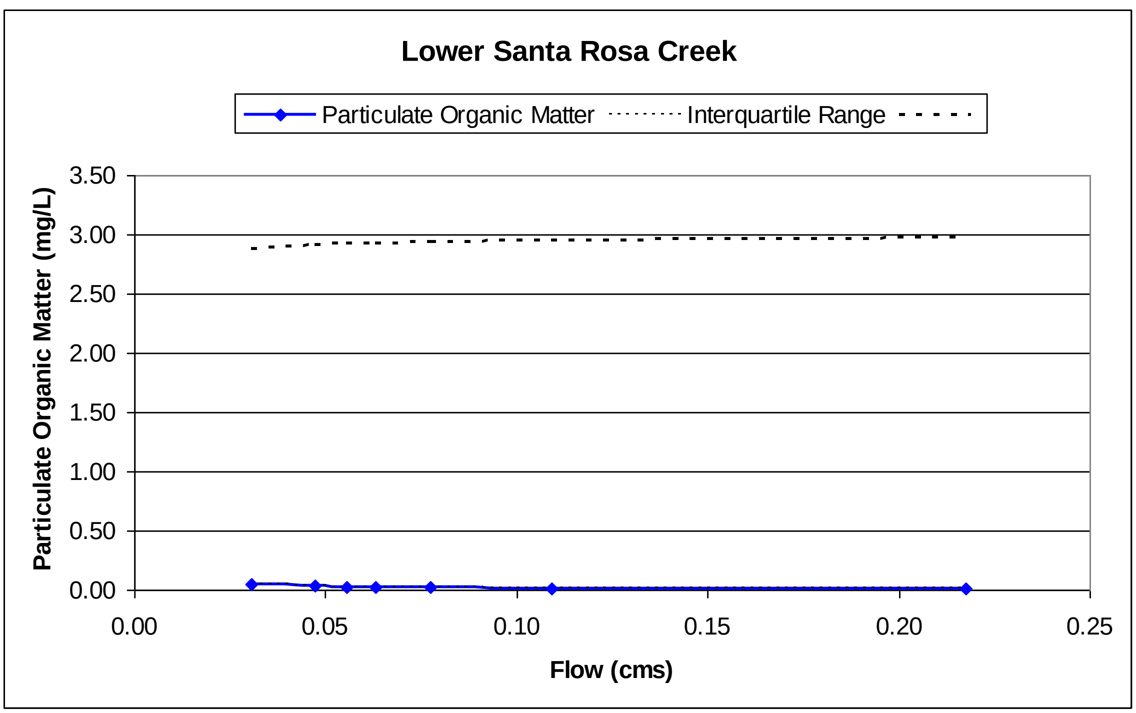

Figure 28. Lower Santa Rosa Creek Model Prediction Uncertainty for Particulate Organic Matter Concentration

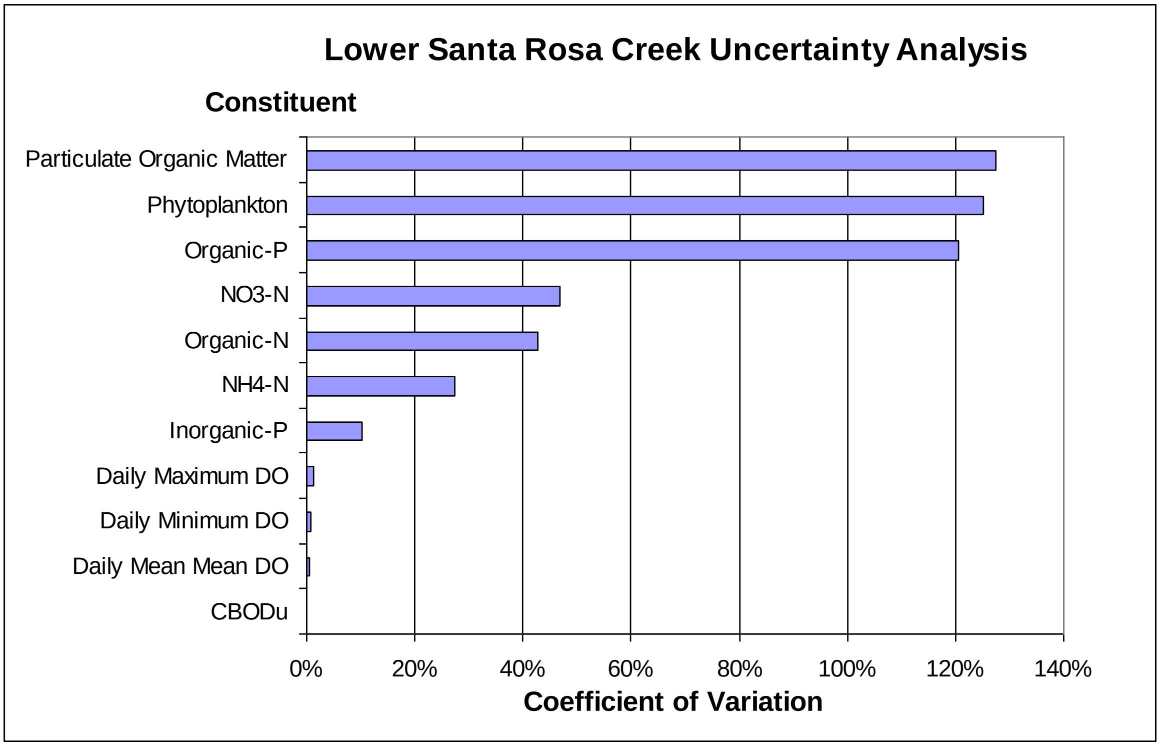

Figure 29. Lower Santa Rosa Creek Model Uncertainty Error

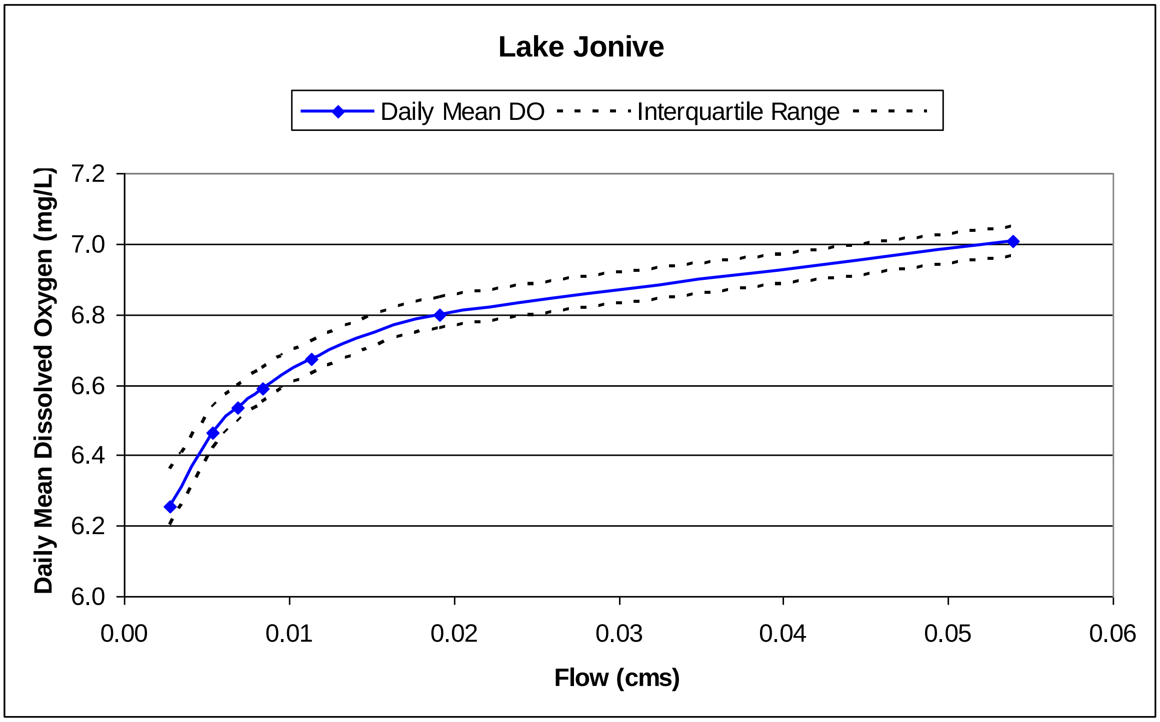

Figure 30. Lake Jonive Model Prediction Uncertainty for Daily Mean Dissolved Oxygen Concentration

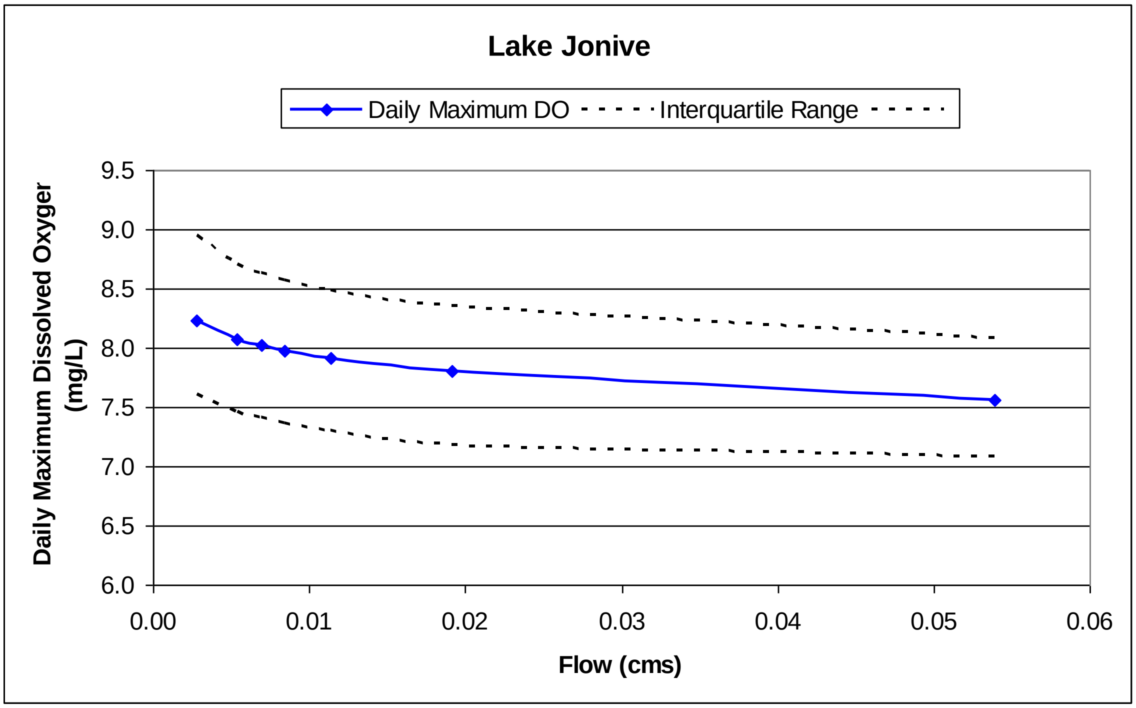

Figure 31. Lake Jonive Model Prediction Uncertainty for Daily Maximum Dissolved Oxygen Concentration

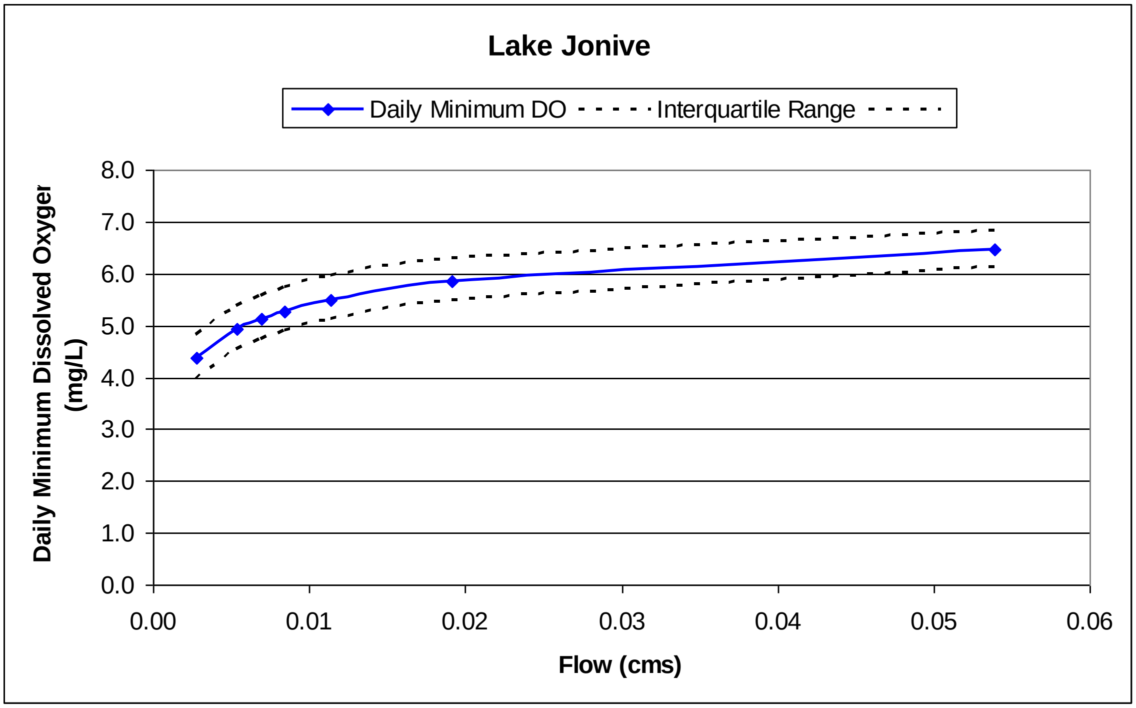

Figure 32. Lake Jonive Model Prediction Uncertainty for Daily Minimum Dissolved Oxygen Concentration

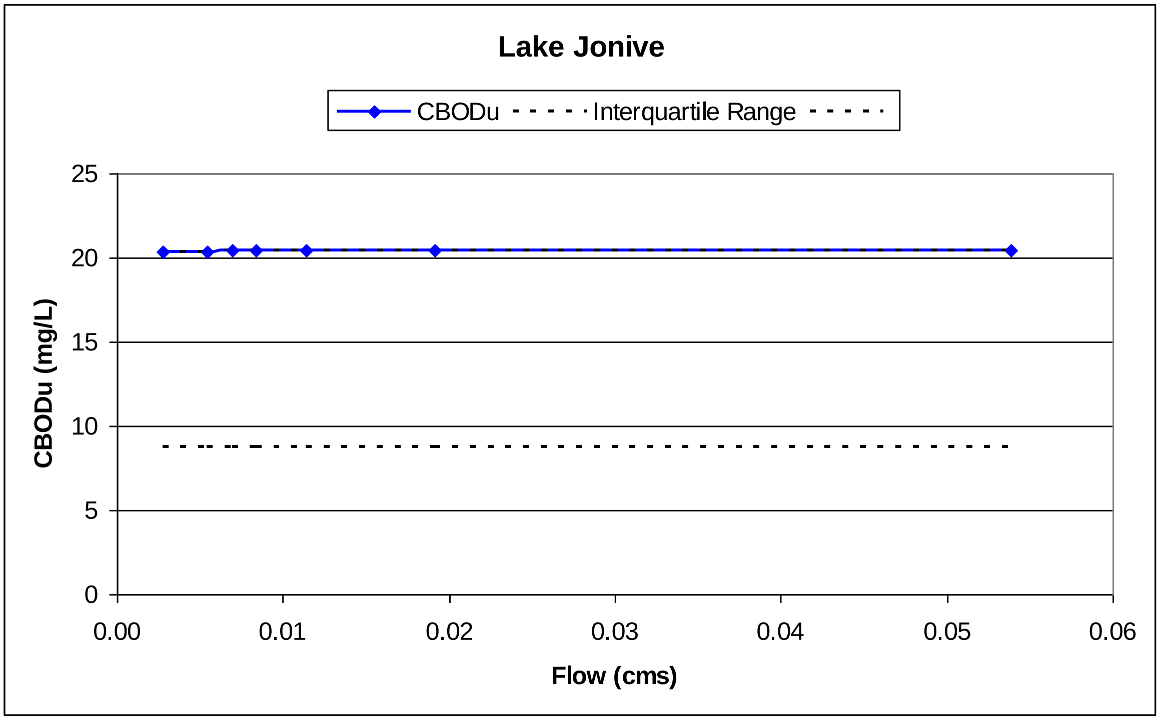

Figure 33. Lake Jonive Model Prediction Uncertainty for $CBOD_u$ Concentration

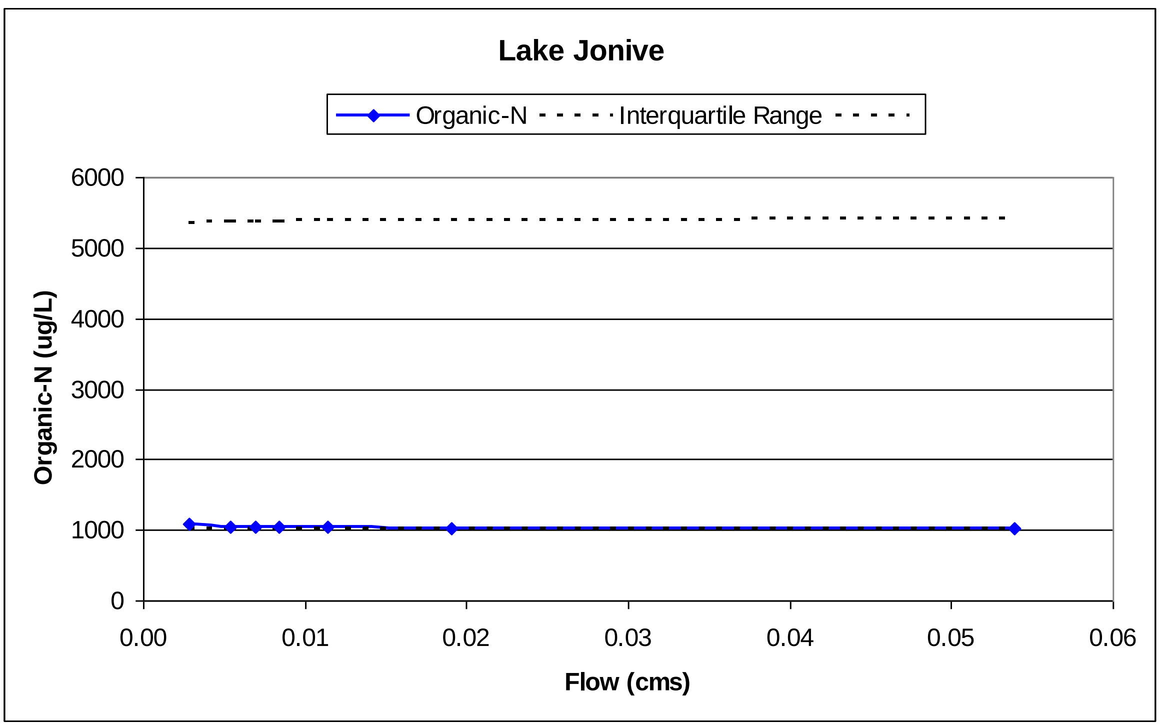

Figure 34. Lake Jonive Model Prediction Uncertainty for Organic Nitrogen Concentration

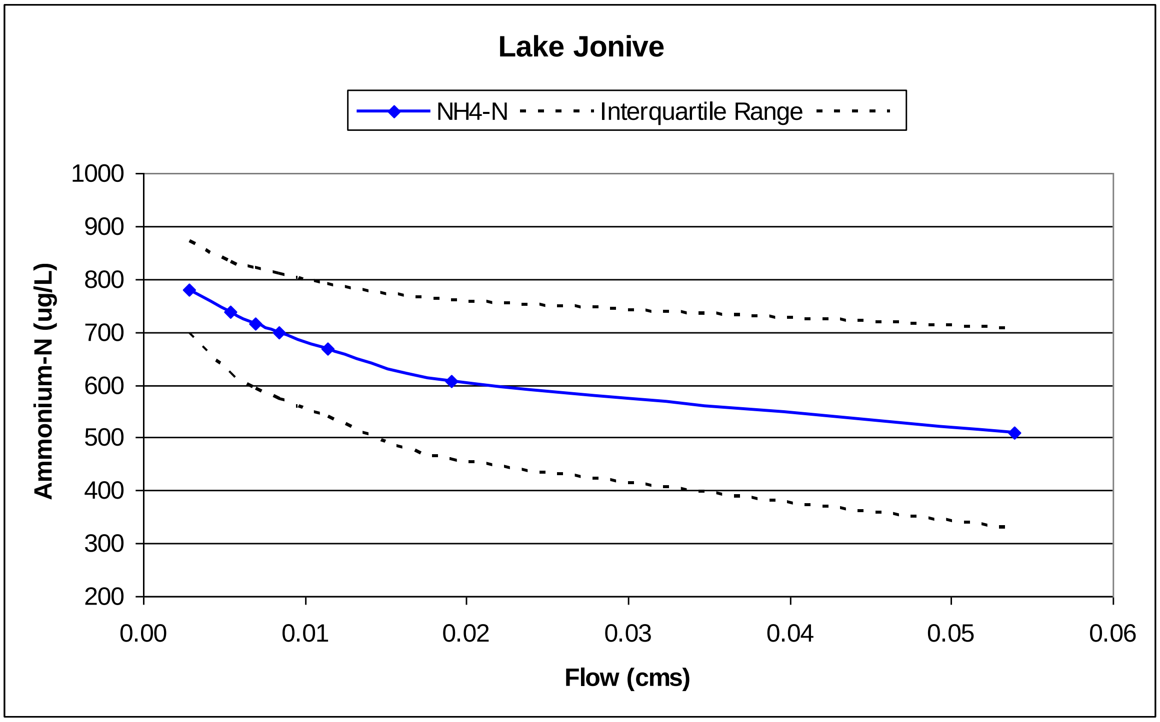

Figure 35. Lake Jonive Model Prediction Uncertainty for Ammonium Nitrogen Concentration

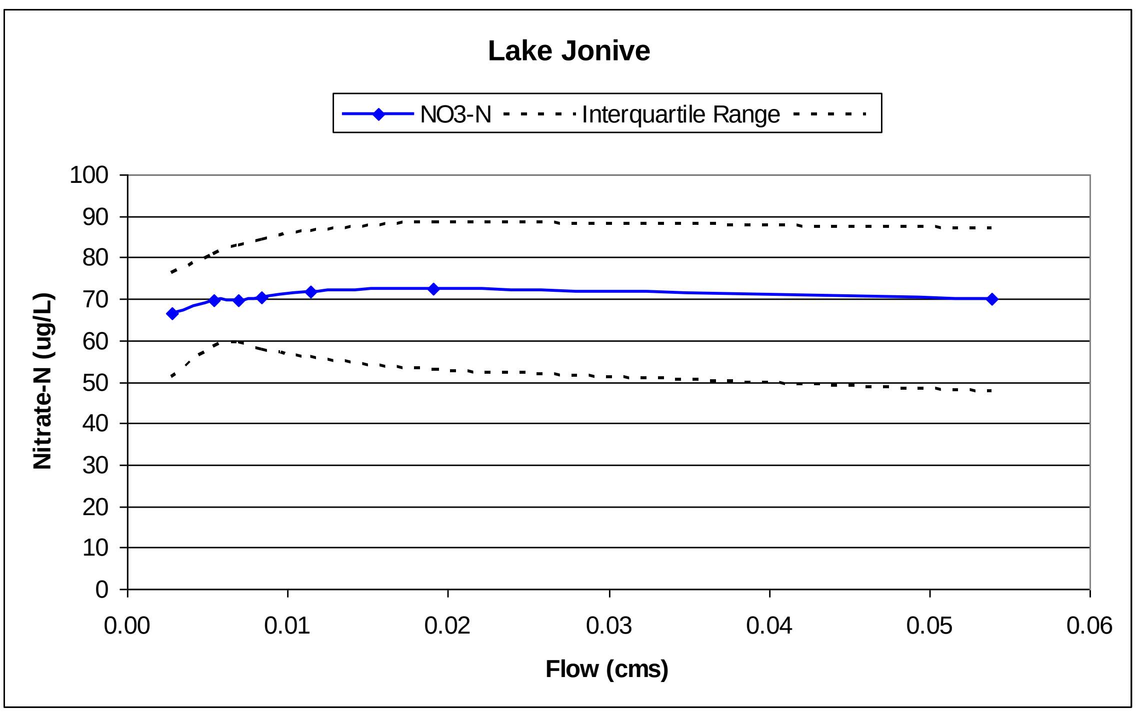

Figure 36. Lake Jonive Model Prediction Uncertainty for Nitrate Nitrogen Concentration

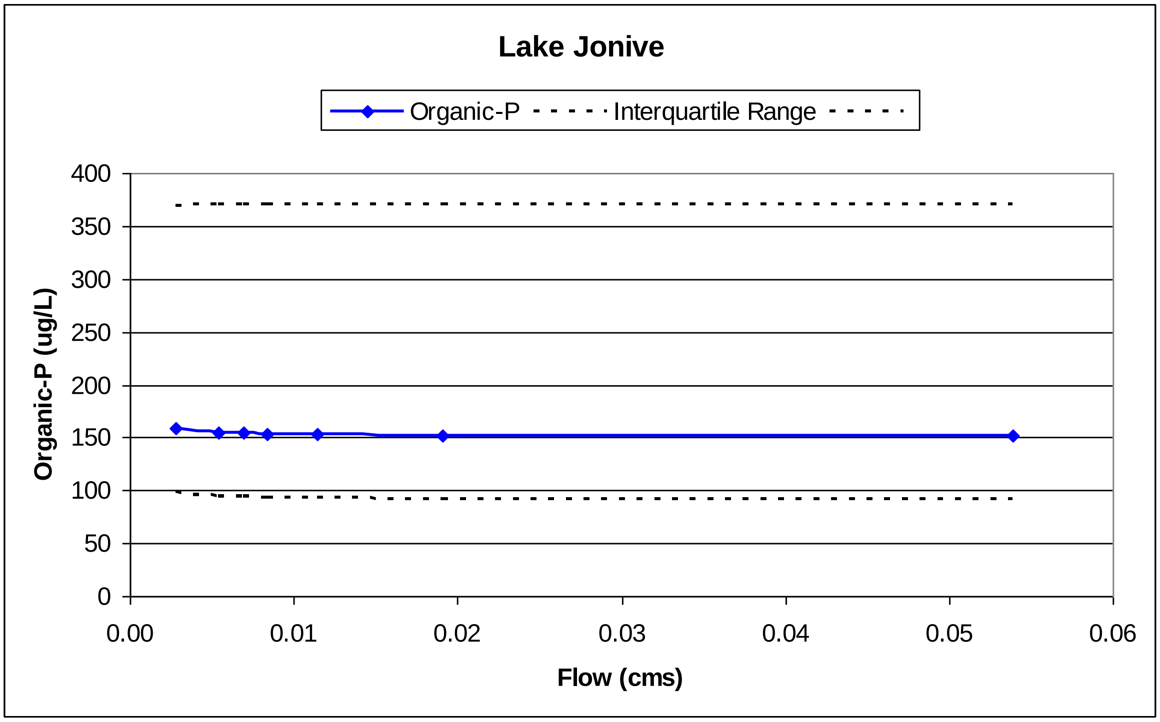

Figure 37. Lake Jonive Model Prediction Uncertainty for Organic Phosphorus Concentration

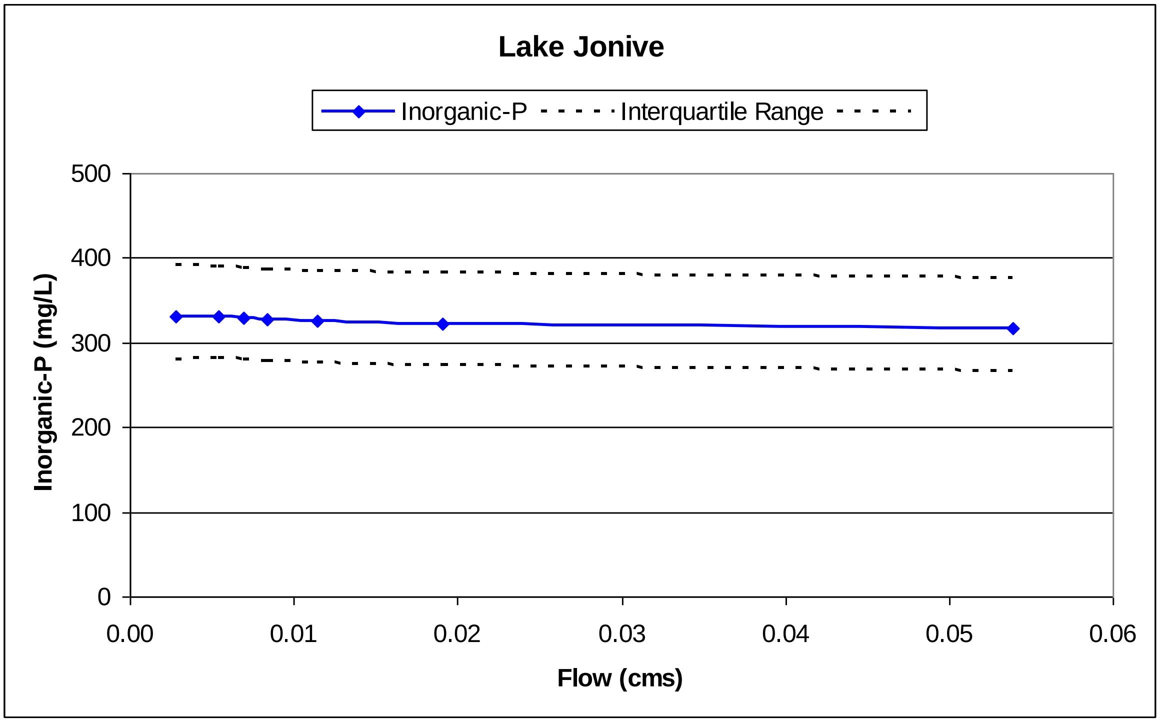

Figure 38. Lake Jonive Model Prediction Uncertainty for Inorganic Phosphorus Concentration

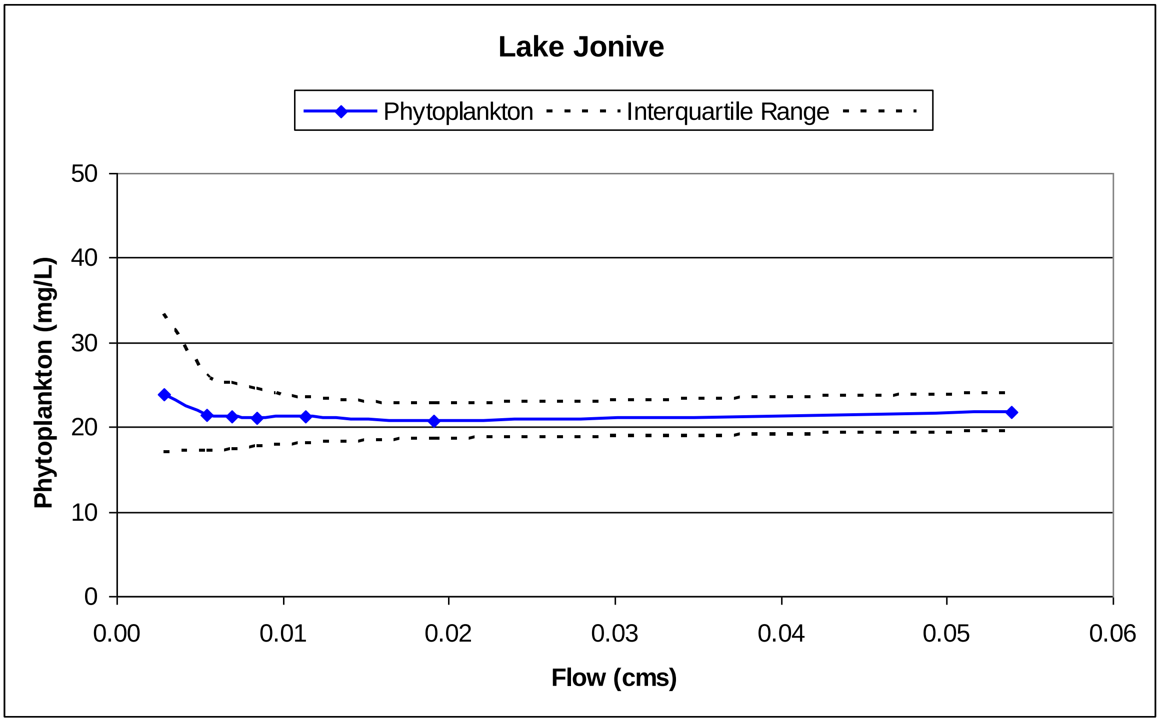

Figure 39. Lake Jonive Model Prediction Uncertainty for Phytoplankton Concentration

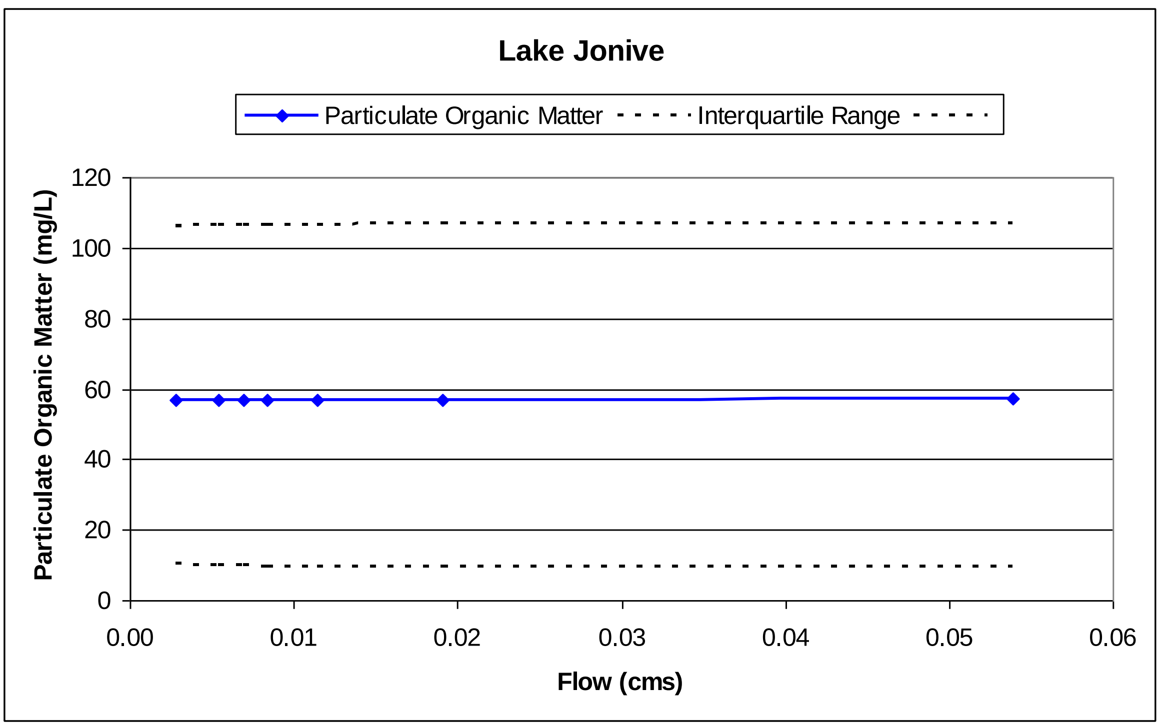

Figure 40. Lake Jonive Model Prediction Uncertainty for Particulate Organic Matter Concentration

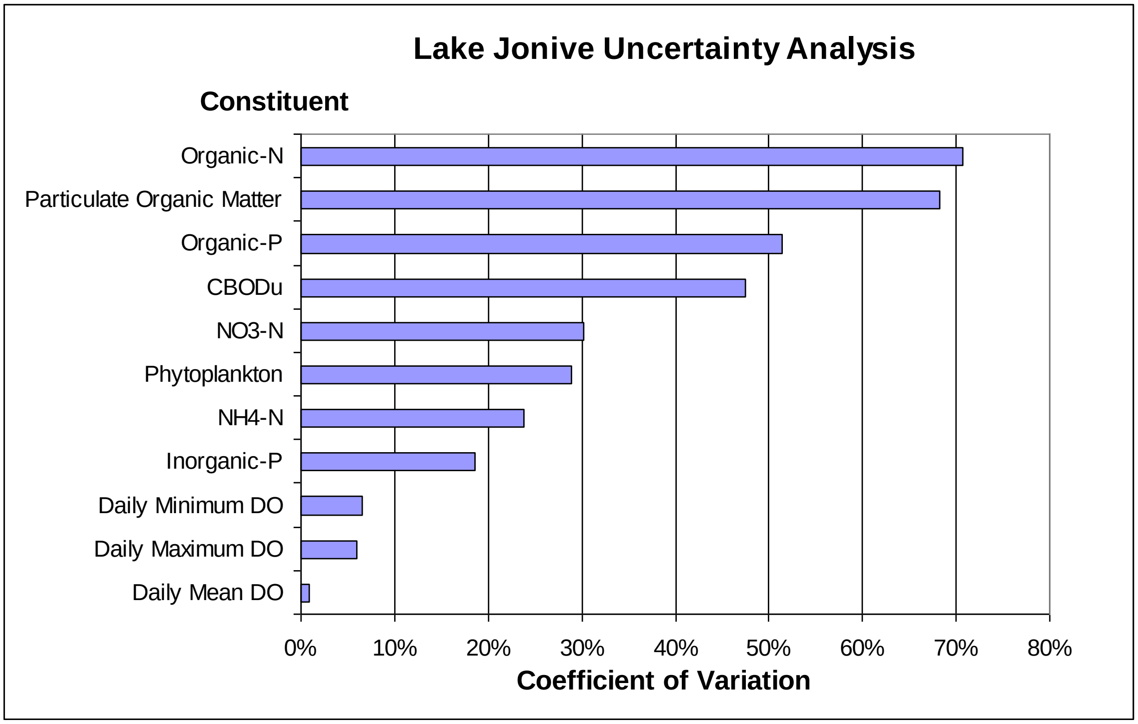

Figure 41. Lake Jonive Model Uncertainty Error

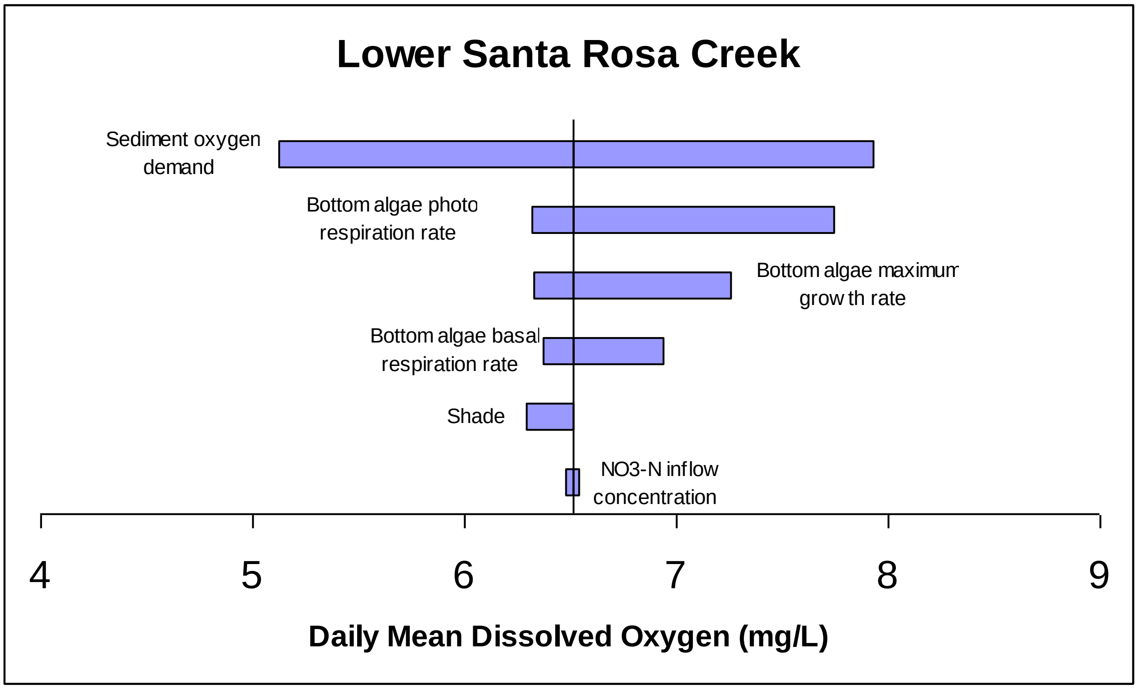

Figure 42. Lower Santa Rosa Creek Daily Mean Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

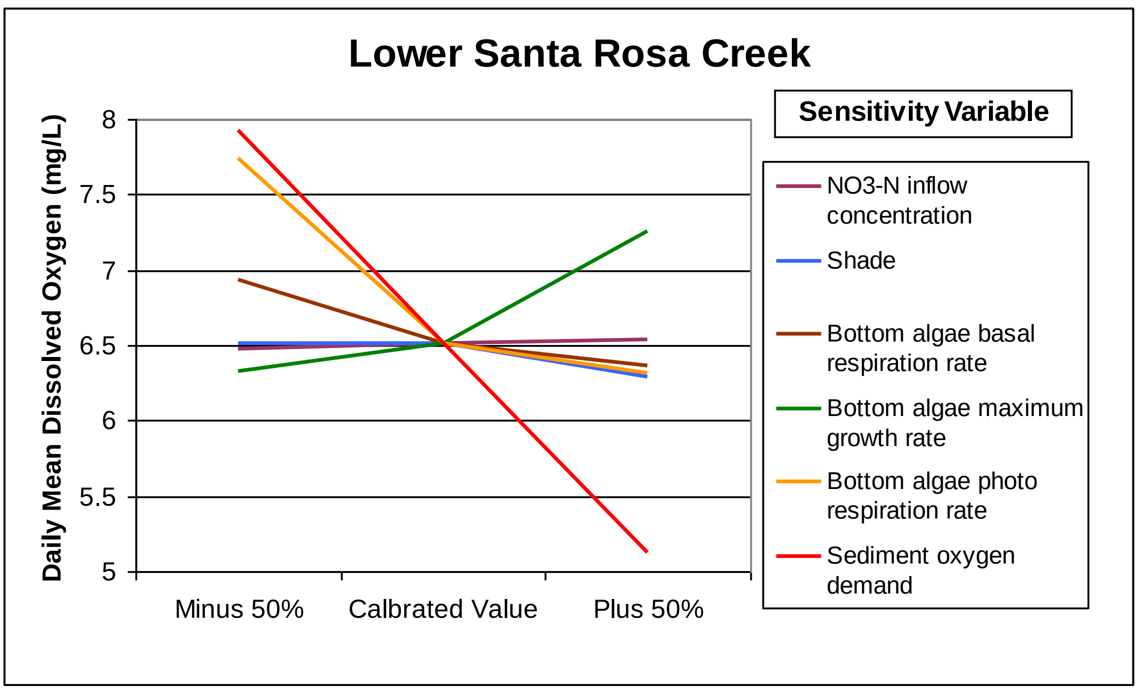

Figure 43. Lower Santa Rosa Creek Daily Mean Dissolved Oxygen Concentration Model Sensitivity Spider Plot

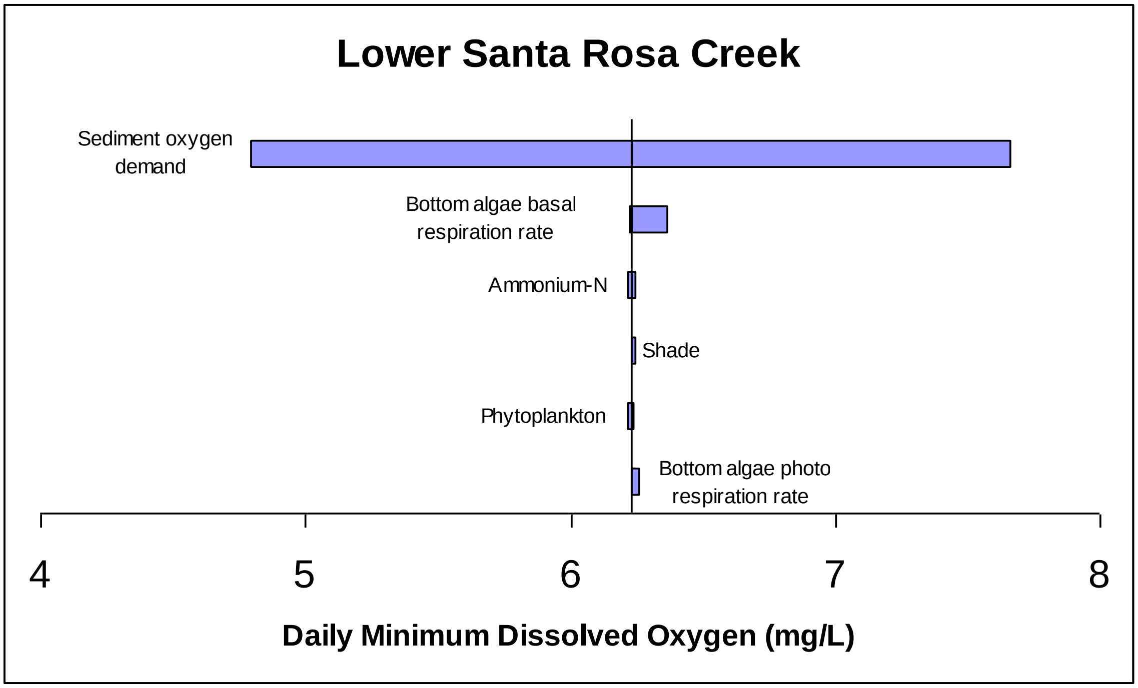

Figure 44. Lower Santa Rosa Creek Daily Minimum Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

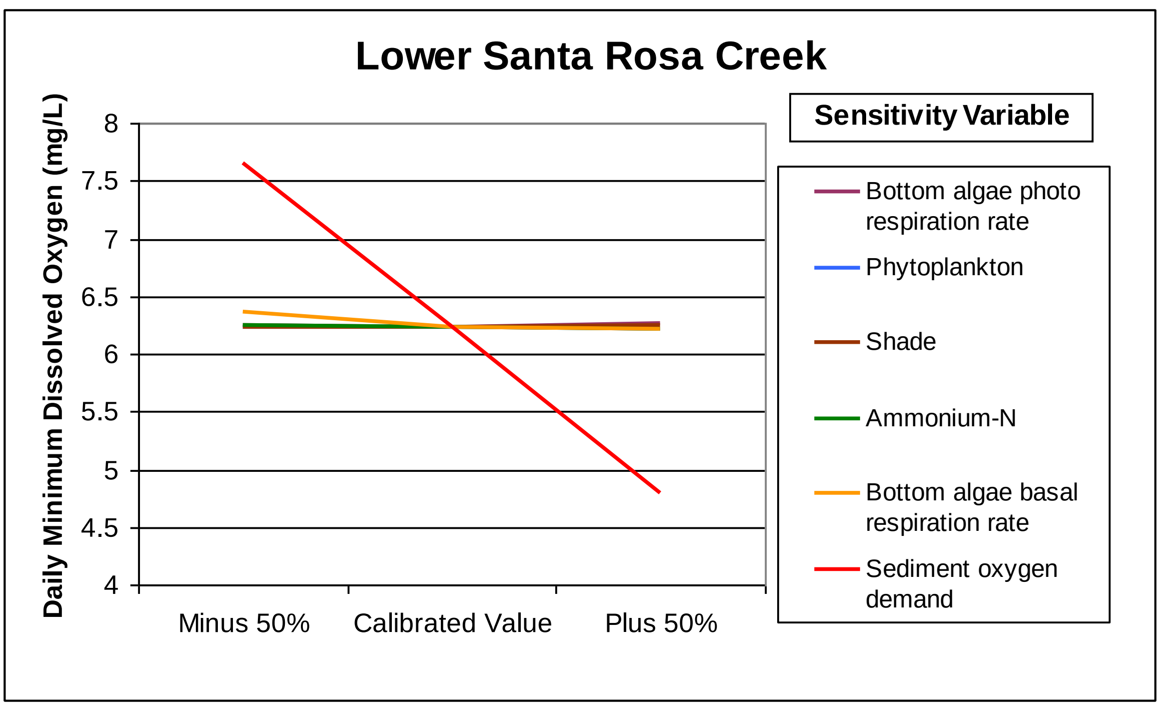

Figure 45. Lower Santa Rosa Creek Daily Mimimum Dissolved Oxygen Concentration Model Sensitivity Spider Plot

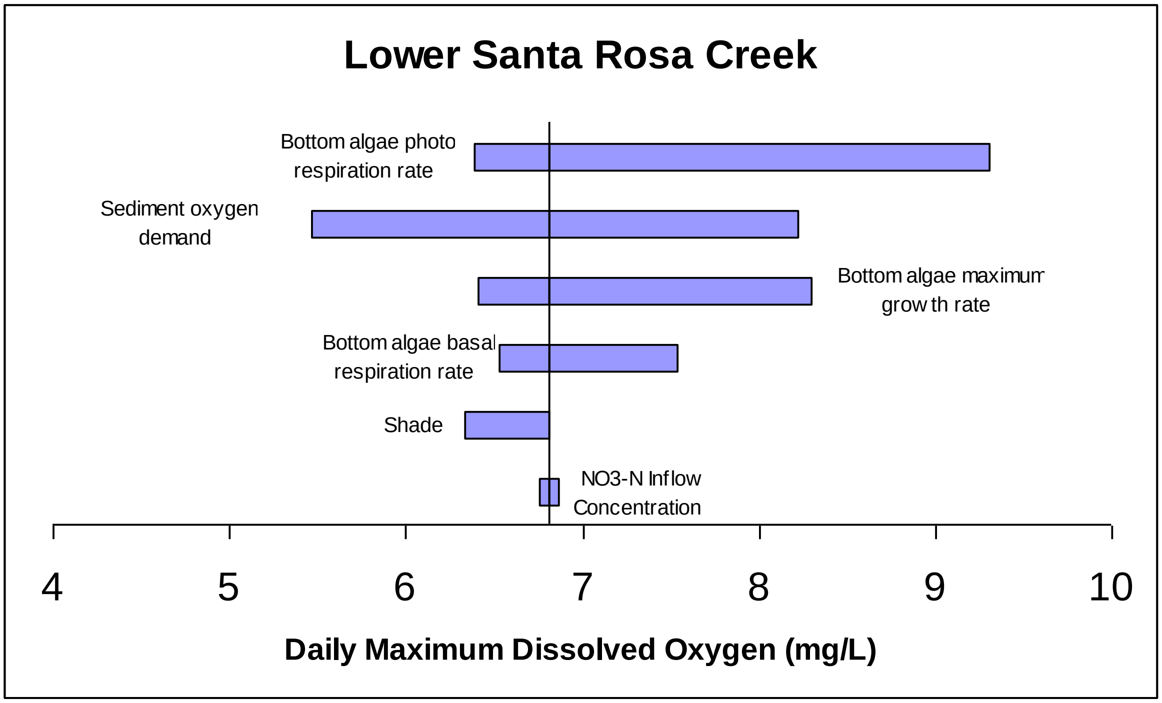

Figure 46. Lower Santa Rosa Creek Daily Maximum Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

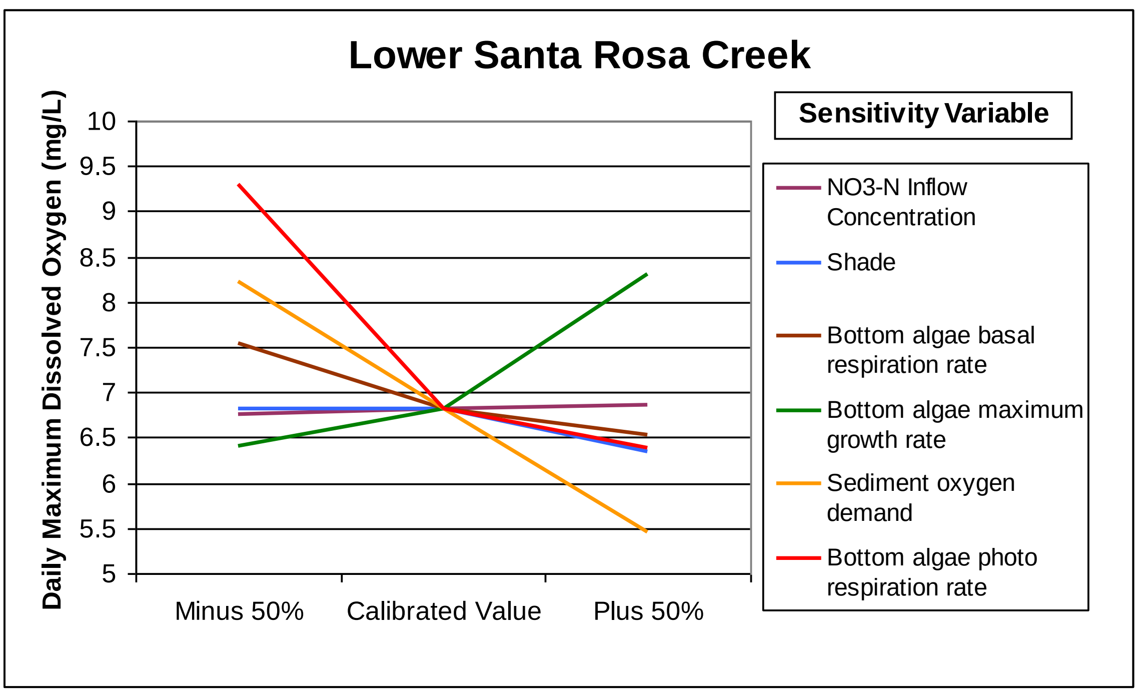

Figure 47. Lower Santa Rosa Creek Daily Maximum Dissolved Oxygen Concentration Model Sensitivity Spider Plot

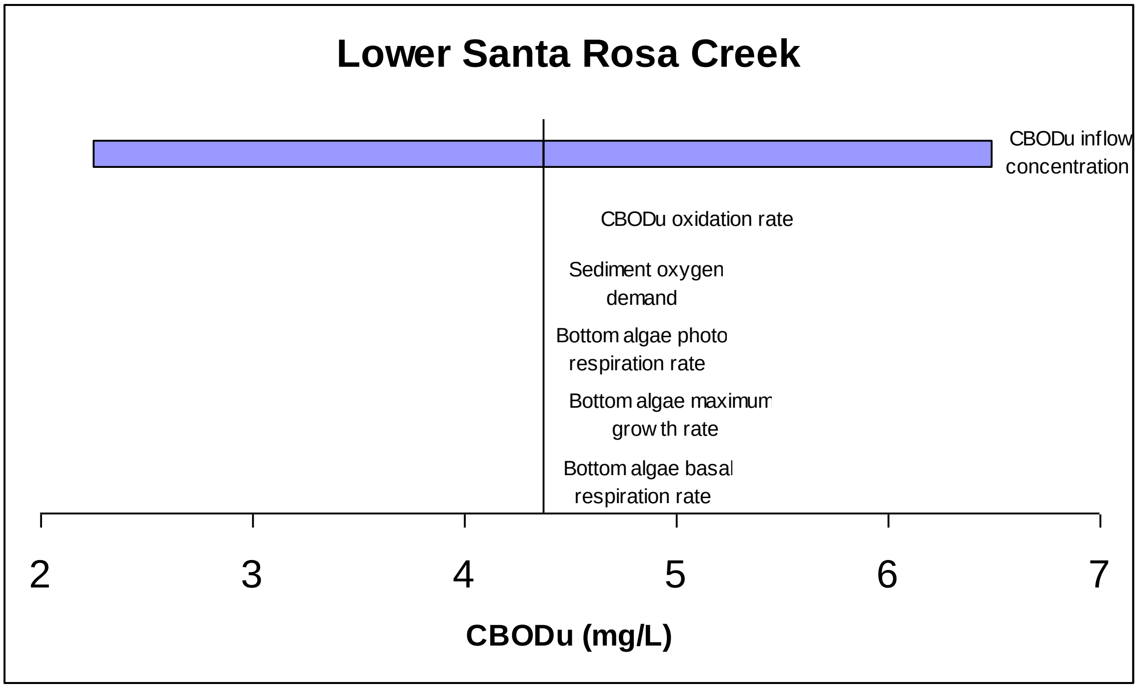

Figure 48. Lower Santa Rosa Creek $CBOD_u$ Concentration Model Sensitivity Tornado Plot

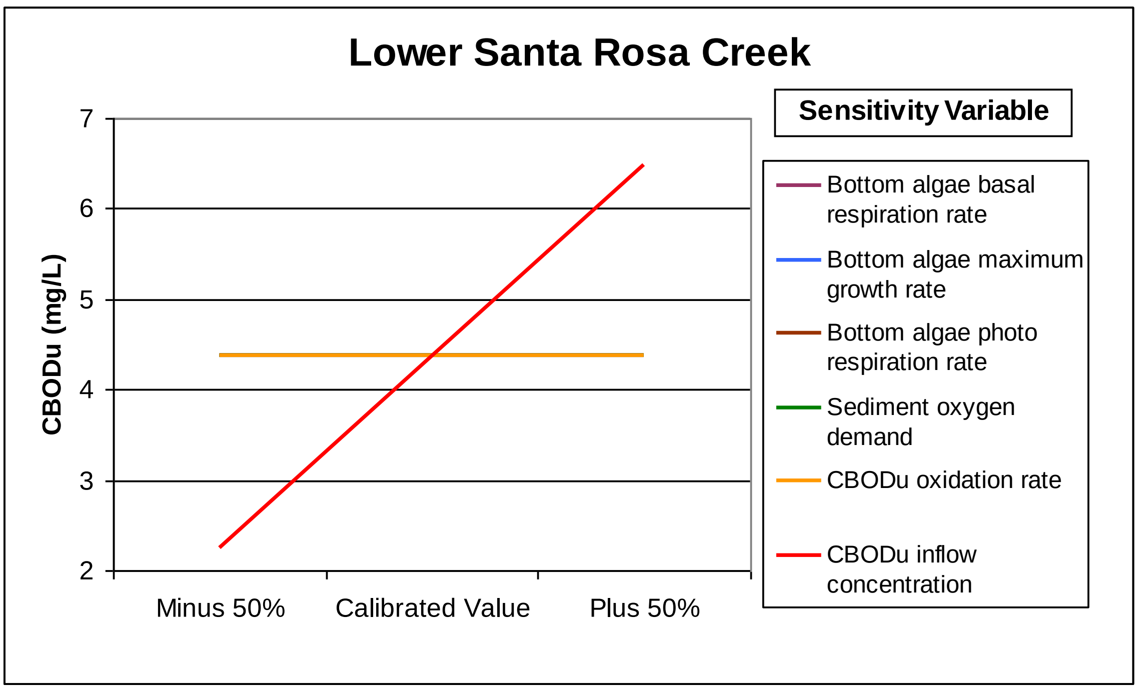

Figure 49. Lower Santa Rosa Creek $CBOD_u$ Concentration Model Sensitivity Spider Plot

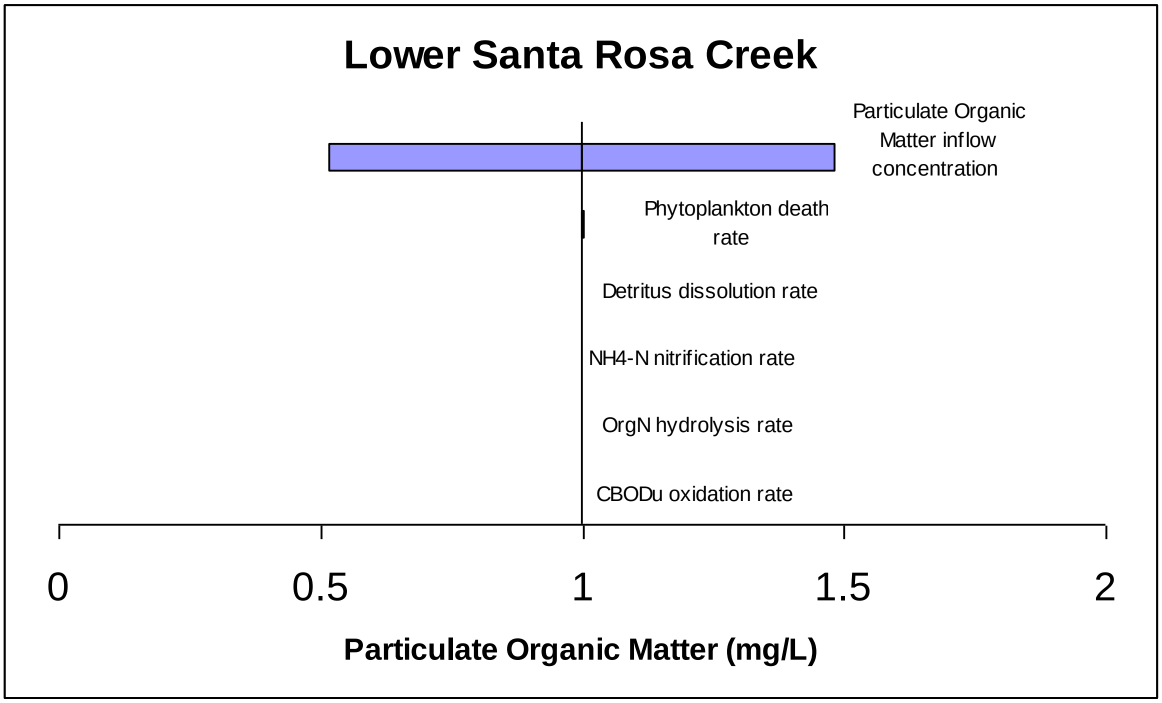

Figure 50. Lower Santa Rosa Creek Particulate Organic Matter Concentration Model Sensitivity Tornado Plot

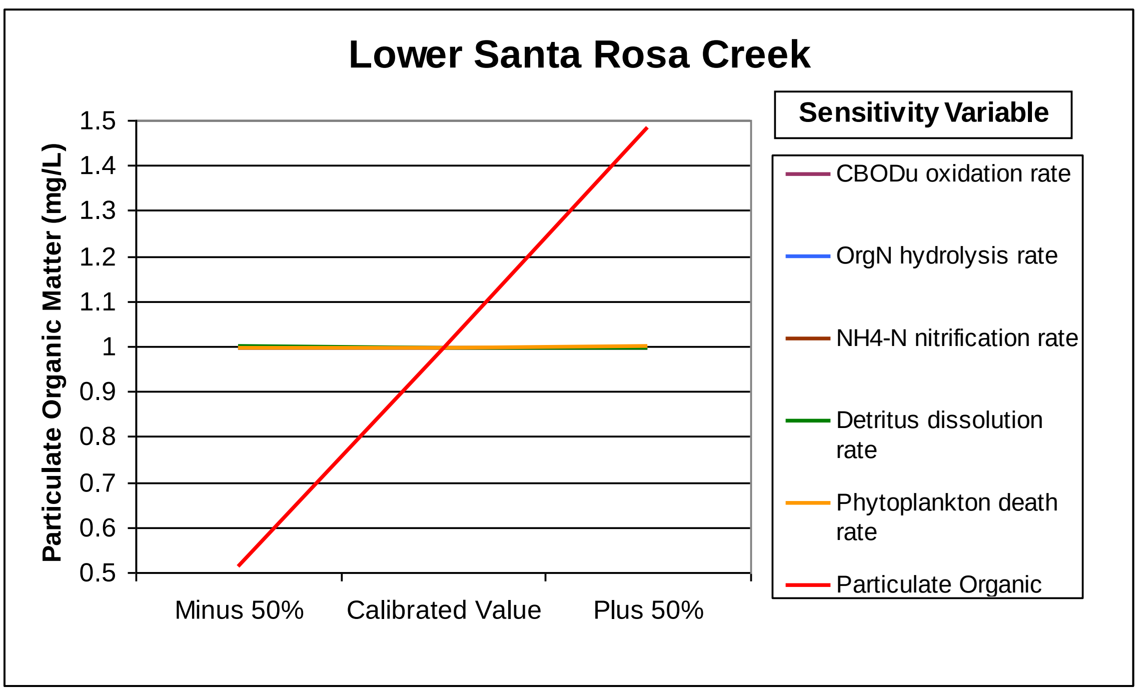

Figure 51. Lower Santa Rosa Creek Particulate Organic Matter Concentration Model Sensitivity Spider Plot

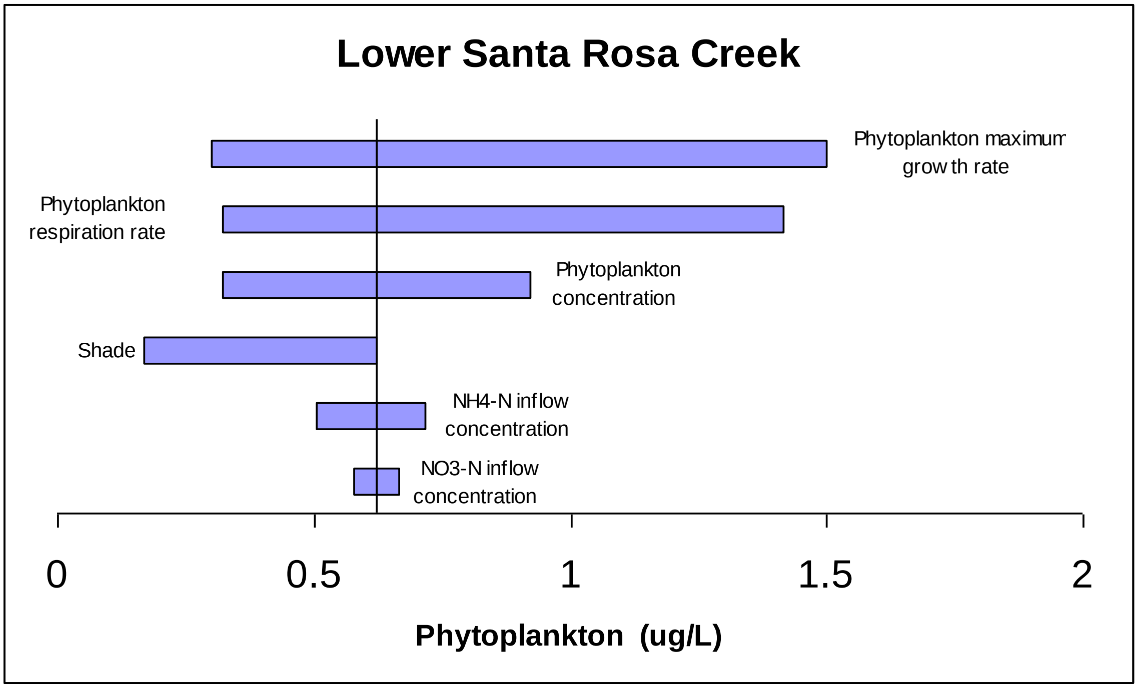

Figure 52. Lower Santa Rosa Creek Phytoplankton Concentration Model Sensitivity Tornado Plot

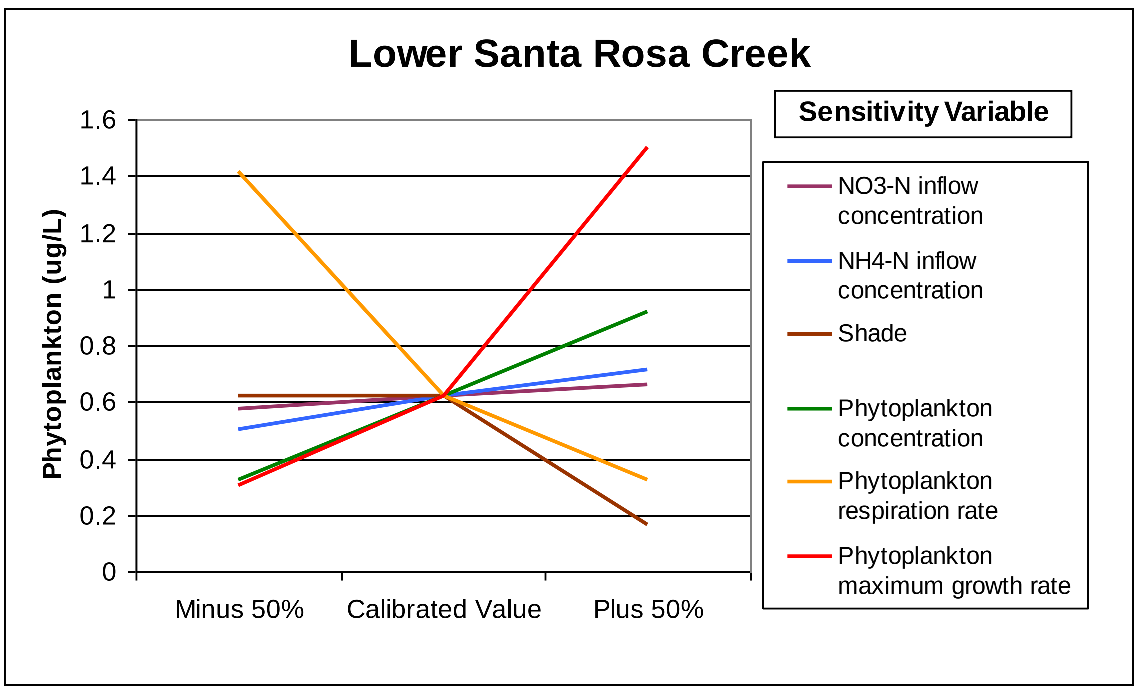

Figure 53. Lower Santa Rosa Creek Phytoplankton Concentration Model Sensitivity Spider Plot

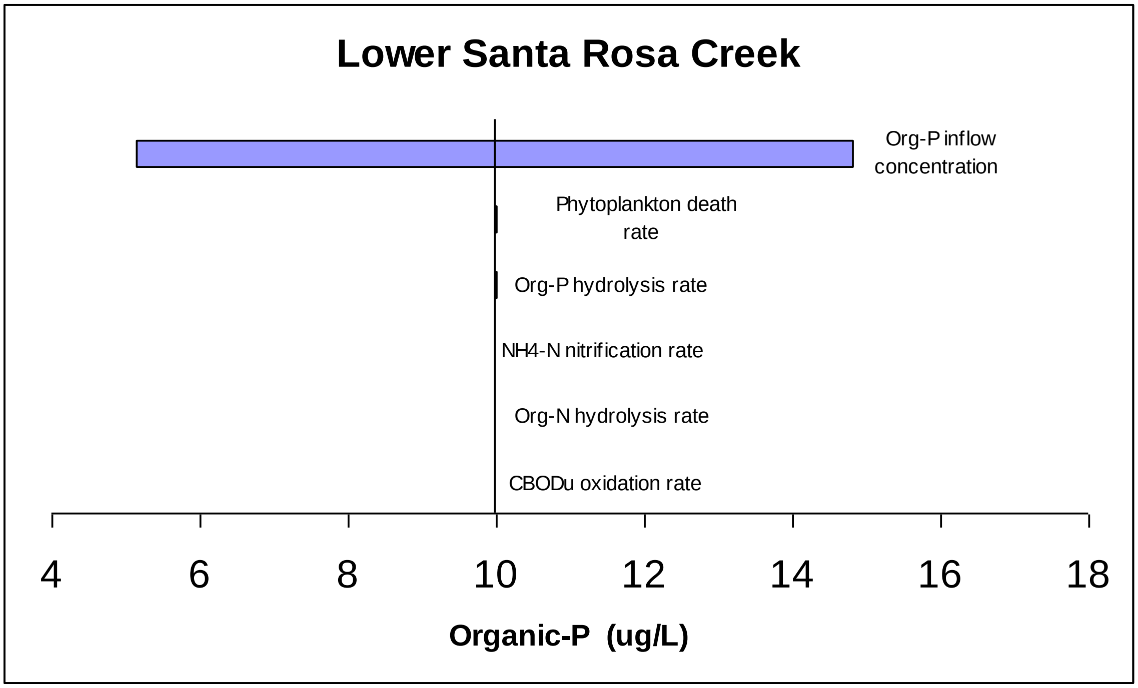

Figure 54. Lower Santa Rosa Creek Organic-P Concentration Model Sensitivity Tornado Plot

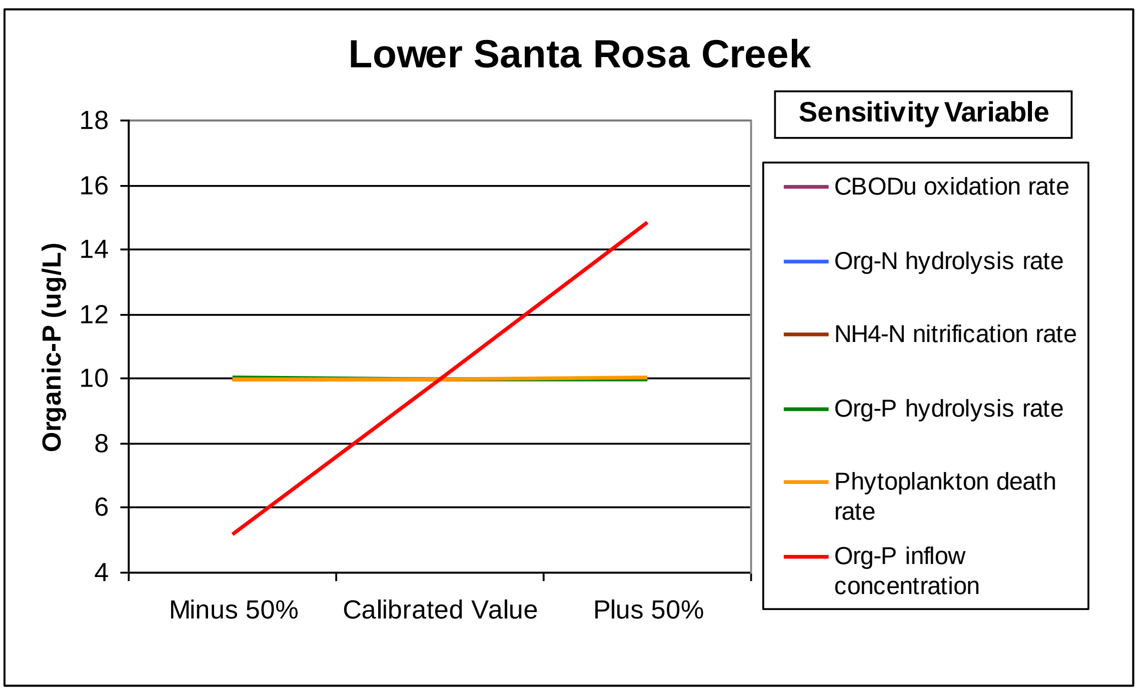

Figure 55. Lower Santa Rosa Creek Organic-P Concentration Model Sensitivity Spider Plot

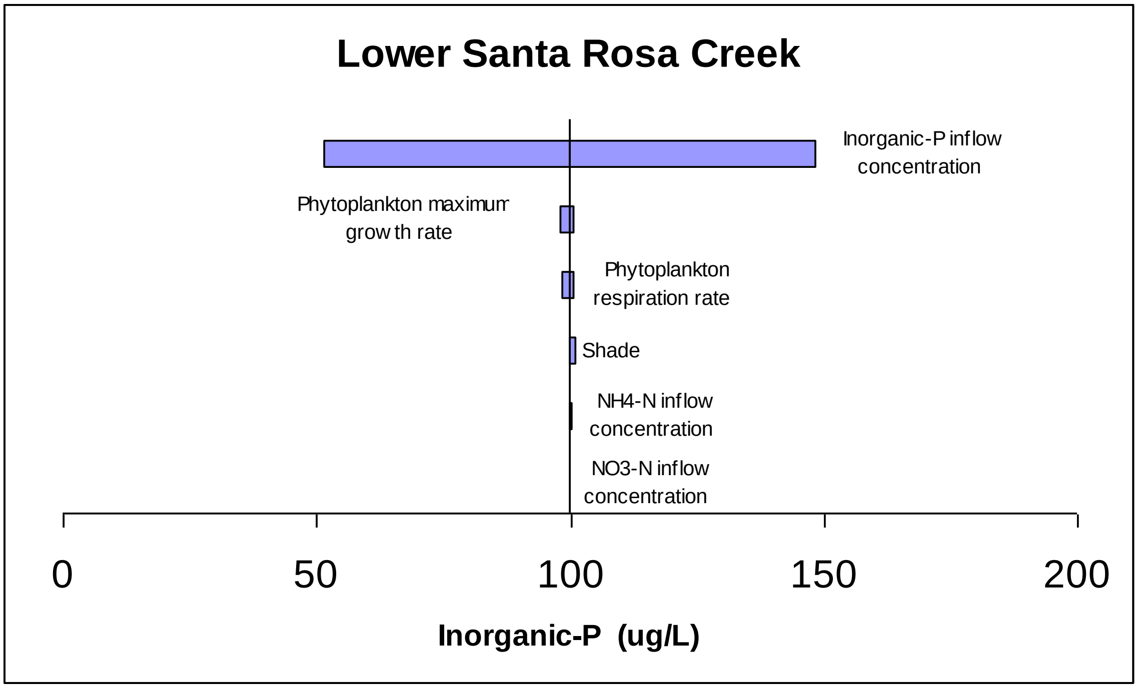

Figure 56. Lower Santa Rosa Creek Inorganic-P Concentration Model Sensitivity Tornado Plot

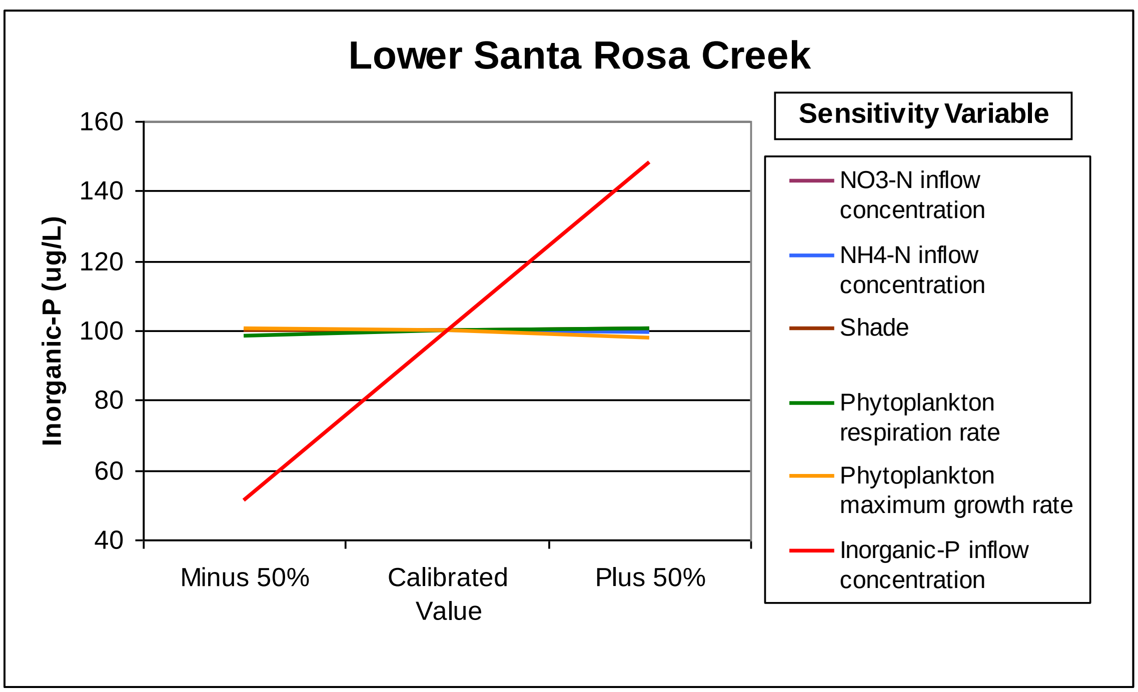

Figure 57. Lower Santa Rosa Creek Inorganic-P Concentration Model Sensitivity Spider Plot

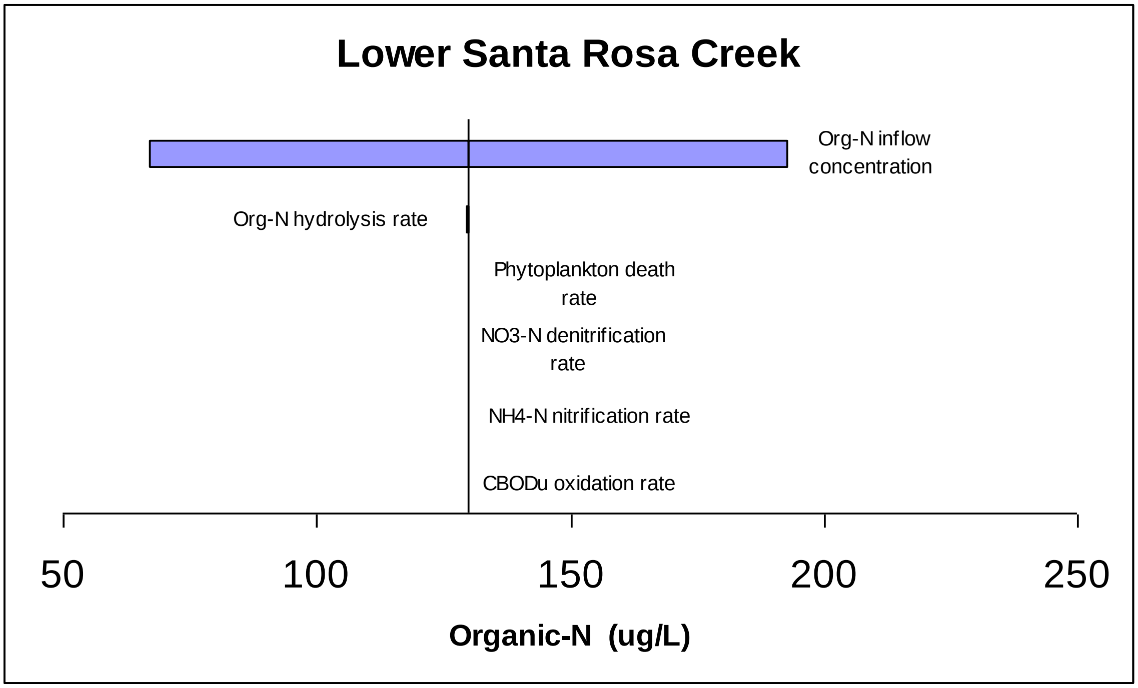

Figure 58. Lower Santa Rosa Creek Organic-N Concentration Model Sensitivity Tornado Plot

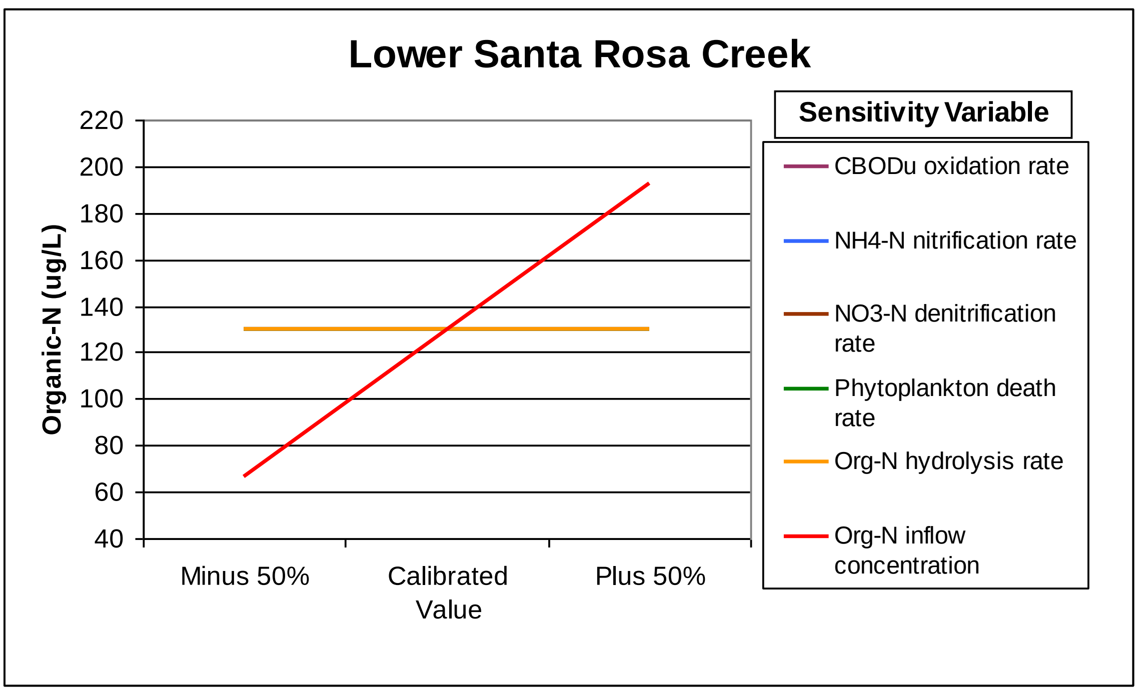

Figure 59. Lower Santa Rosa Creek Organic-N Concentration Model Sensitivity Spider Plot

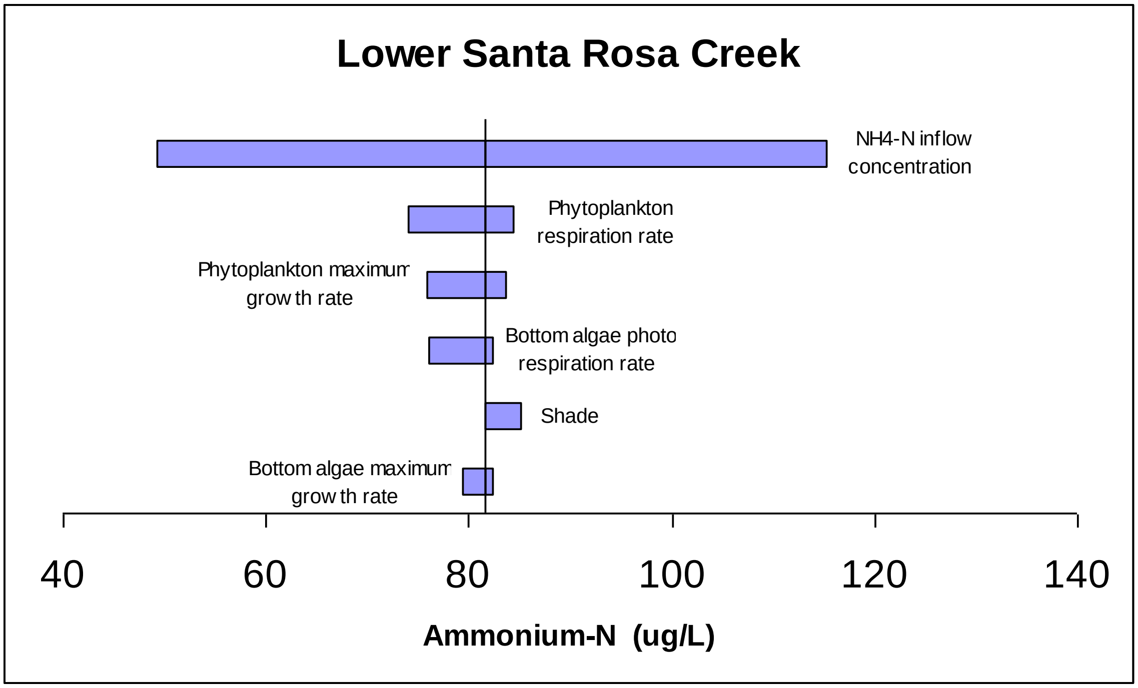

Figure 60. Lower Santa Rosa Creek Ammonium-N Concentration Model Sensitivity Tornado Plot

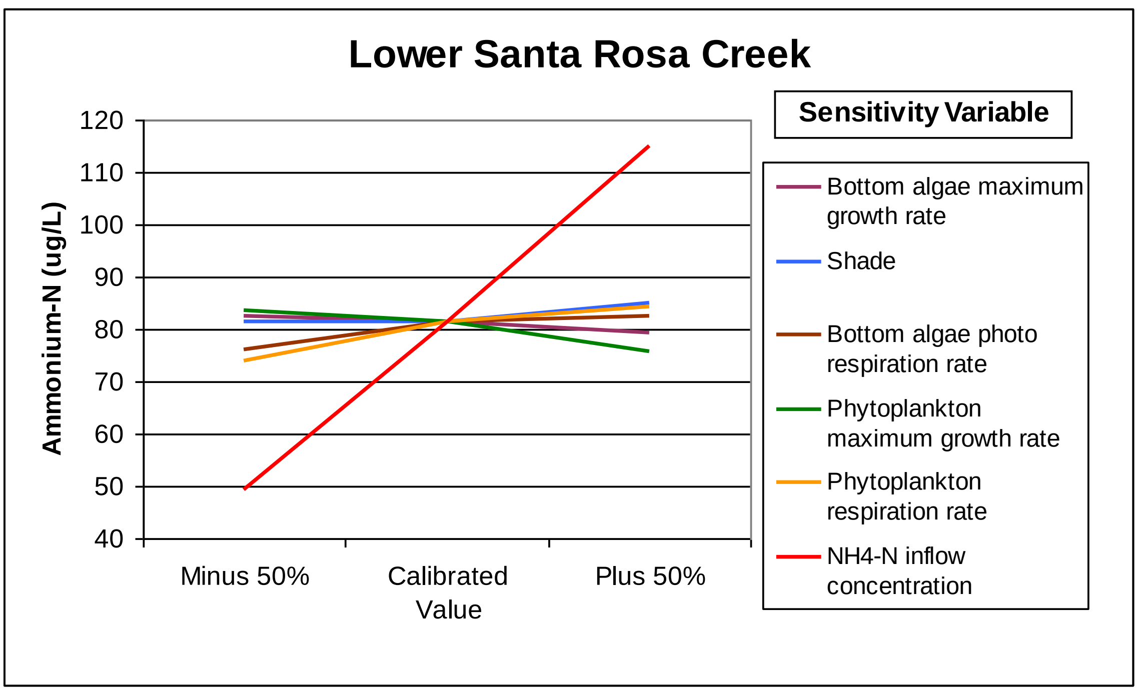

Figure 61. Lower Santa Rosa Creek Ammonium-N Concentration Model Sensitivity Spider Plot

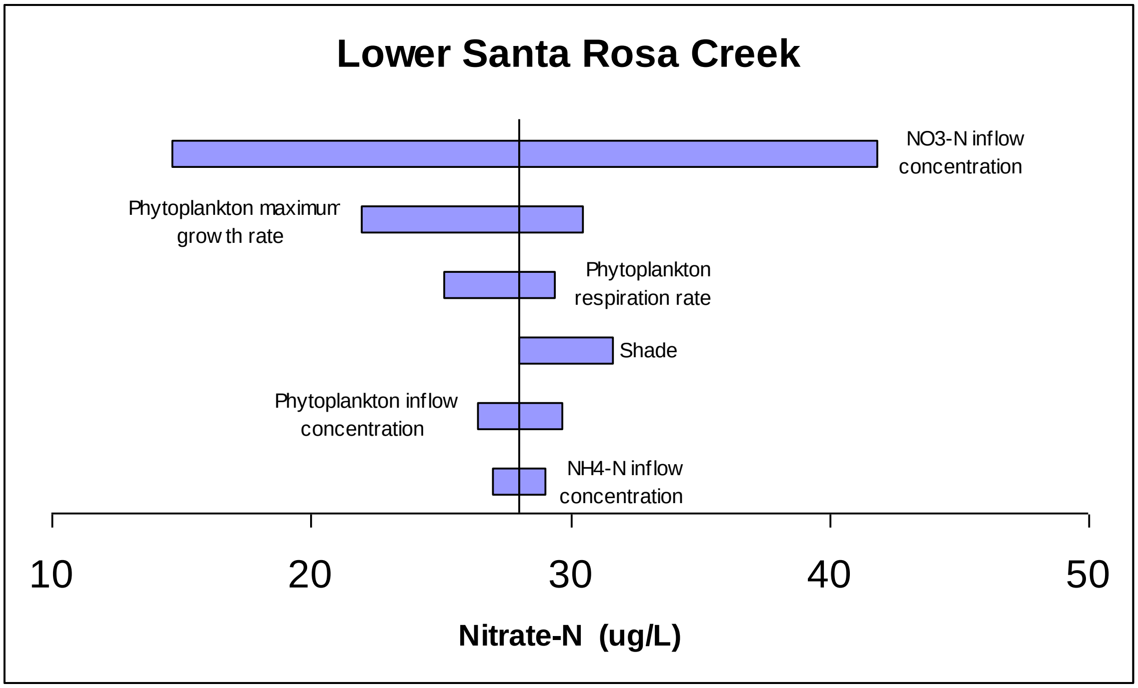

Figure 62. Lower Santa Rosa Creek Nitrate-N Concentration Model Sensitivity Tornado Plot

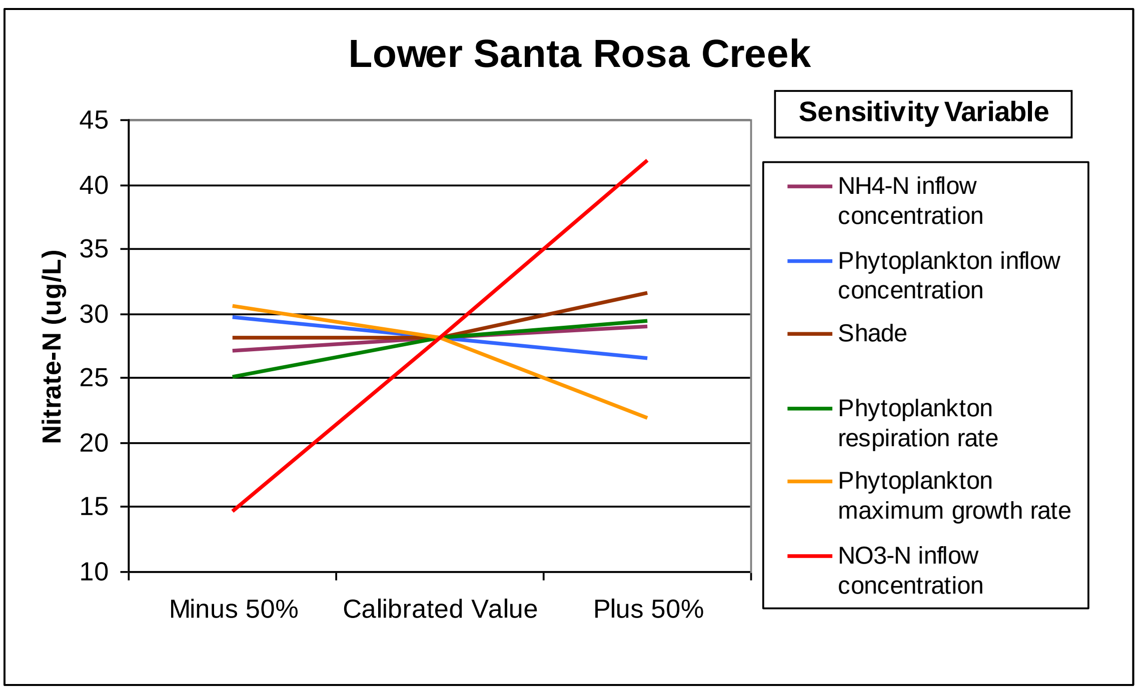

Figure 63. Lower Santa Rosa Creek Nitrate-N Concentration Model Sensitivity Spider Plot

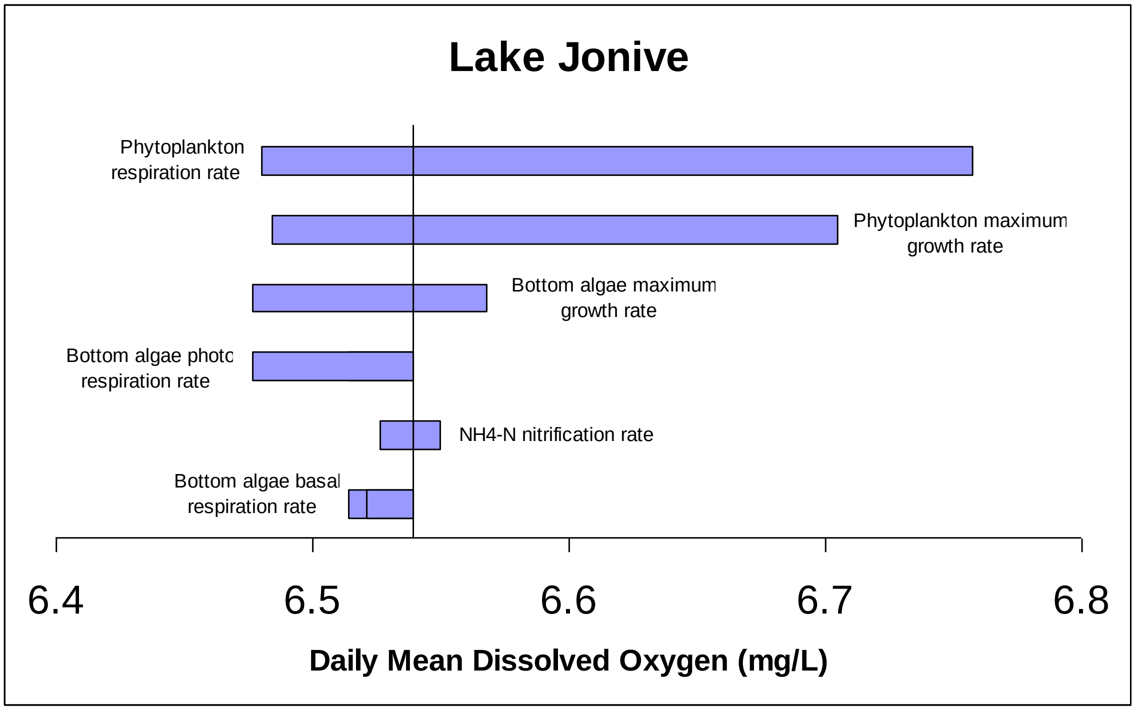

Figure 64. Lake Jonive Daily Mean Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

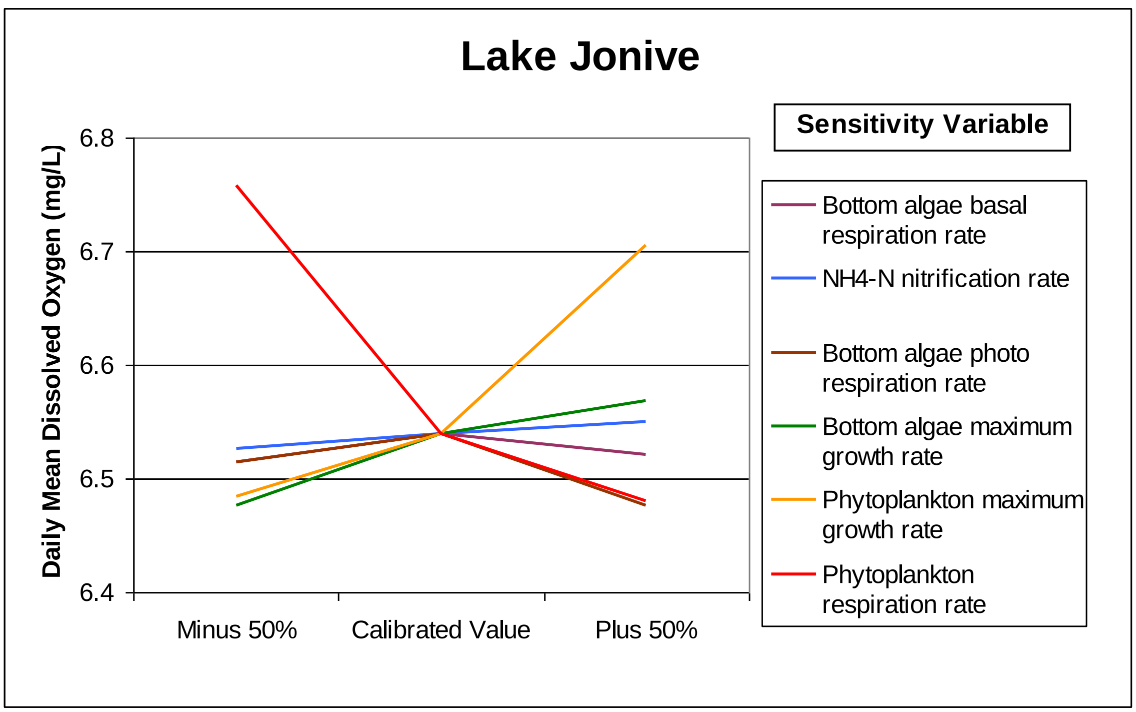

Figure 65. Lake Jonive Daily Mean Dissolved Oxygen Concentration Model Sensitivity Spider Plot

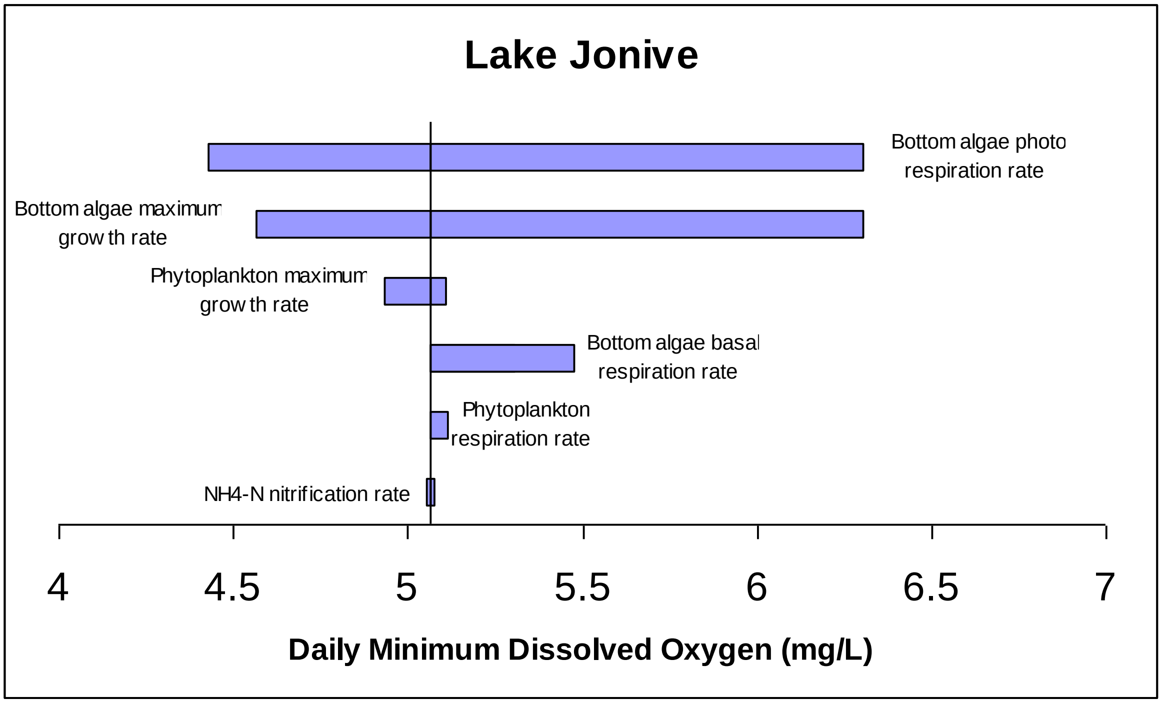

Figure 66. Lake Jonive Daily Minimum Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

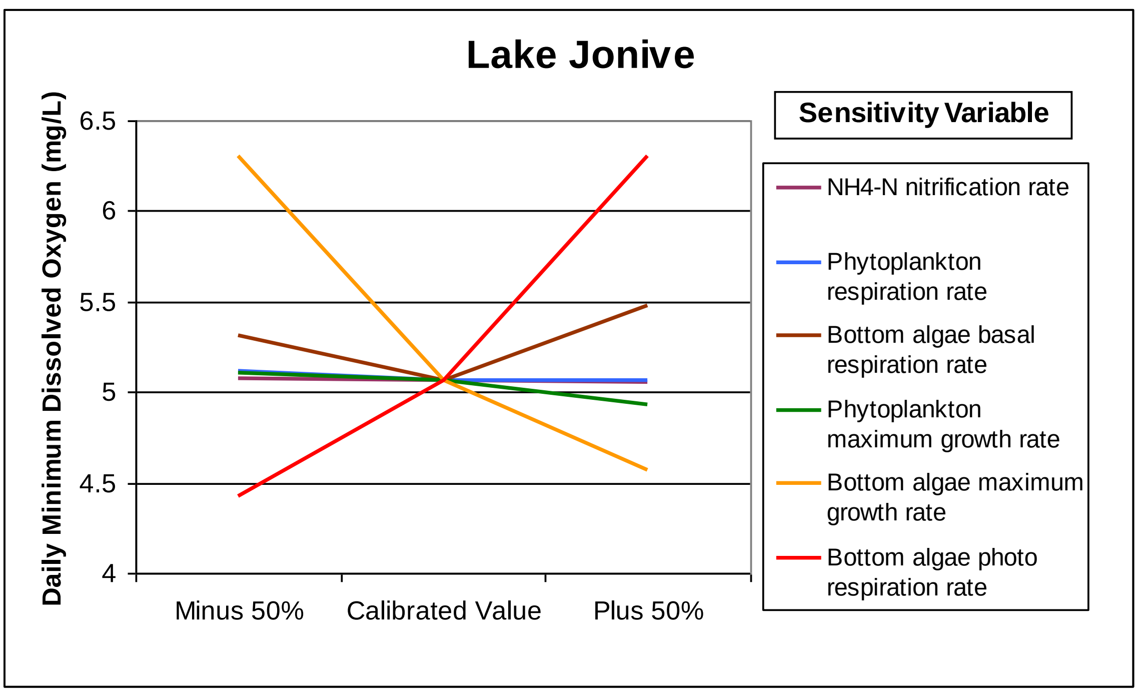

Figure 67. Lake Jonive Daily Minimum Dissolved Oxygen Concentration Model Sensitivity Spider Plot

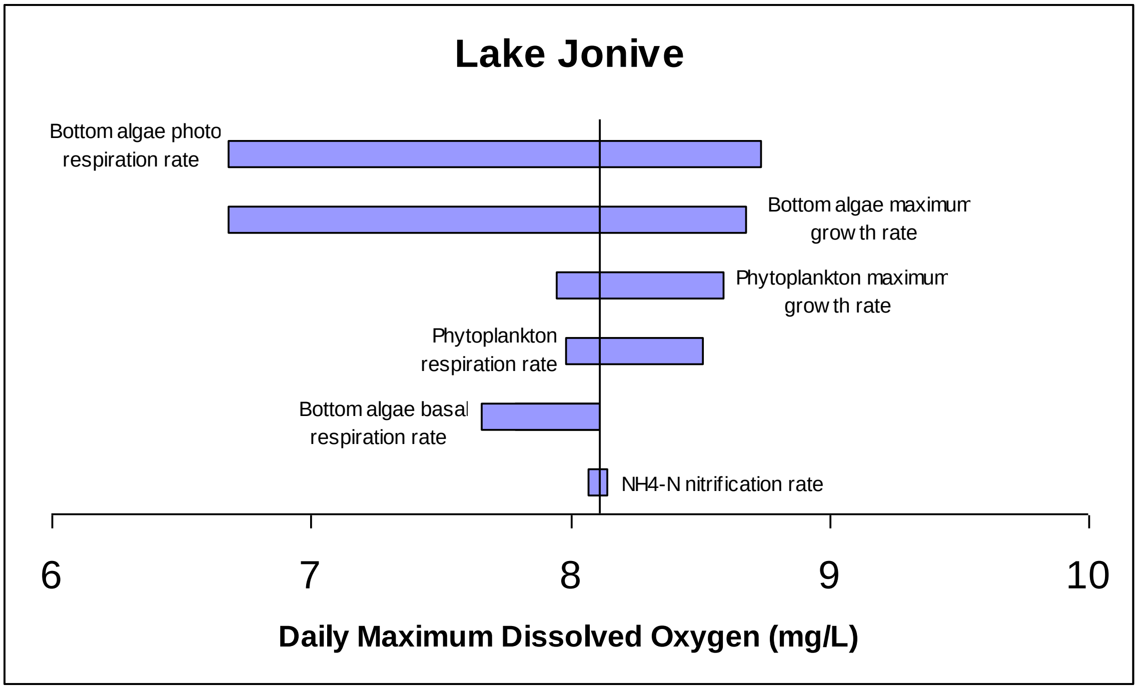

Figure 68. Lake Jonive Daily Maximum Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

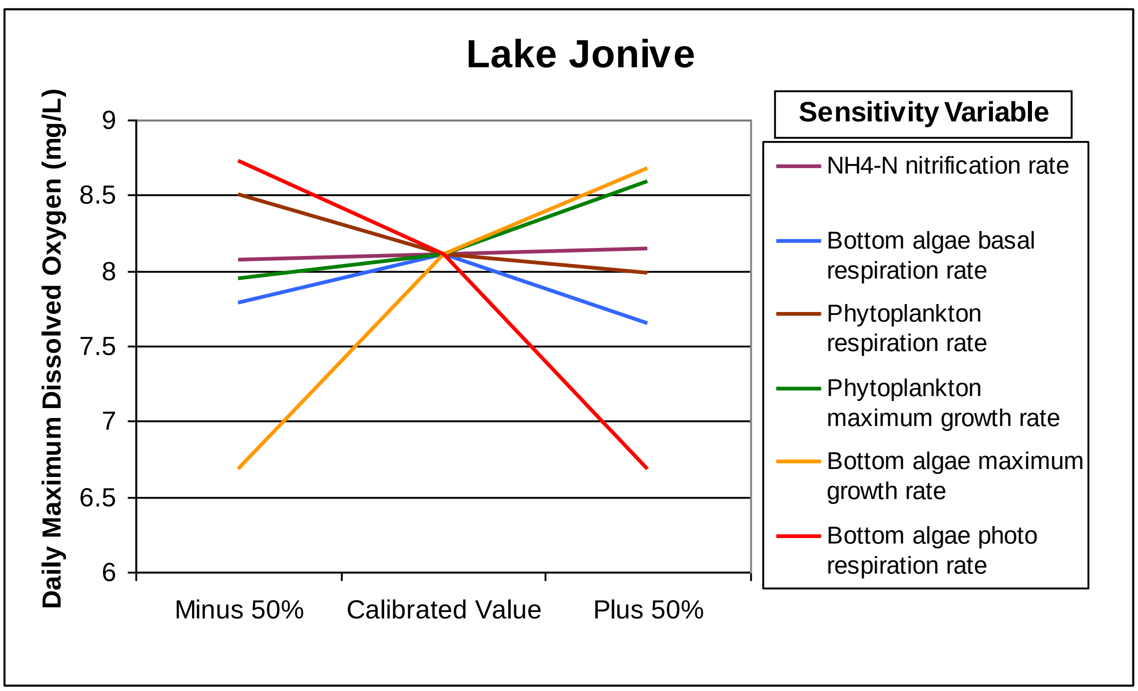

Figure 69. Lake Jonive Daily Maximum Dissolved Oxygen Concentration Model Sensitivity Spider Plot

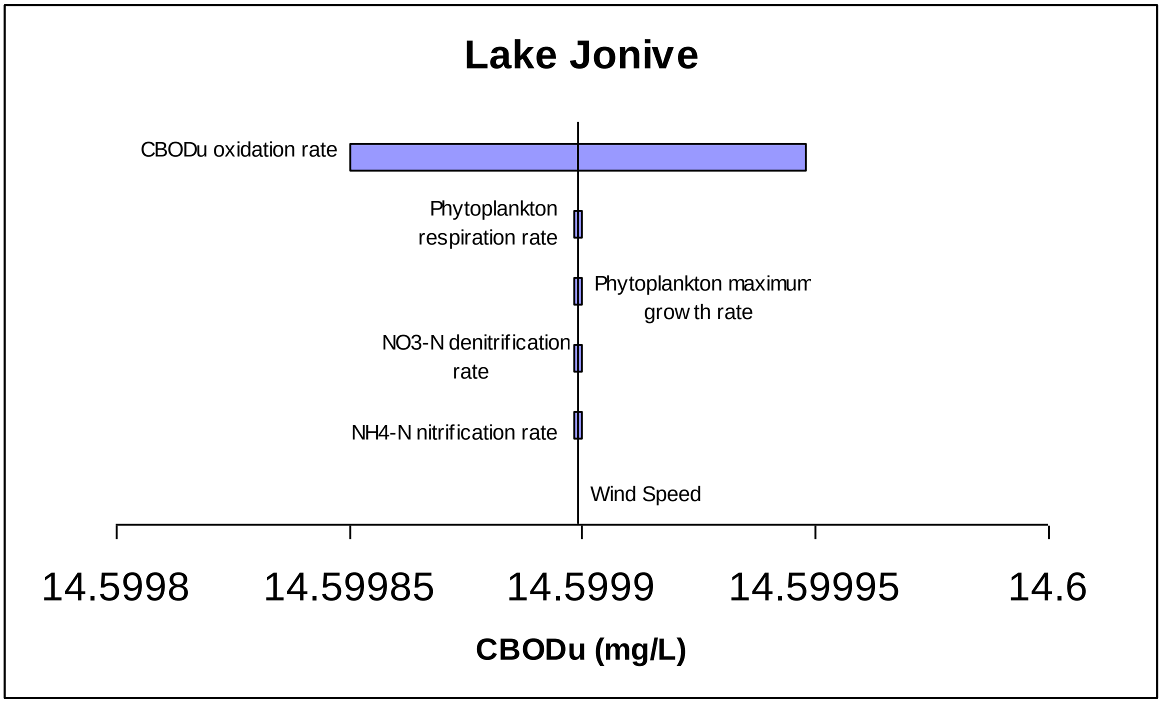

Figure 70. Lake Jonive $CBOD_u$ Concentration Model Sensitivity Tornado Plot

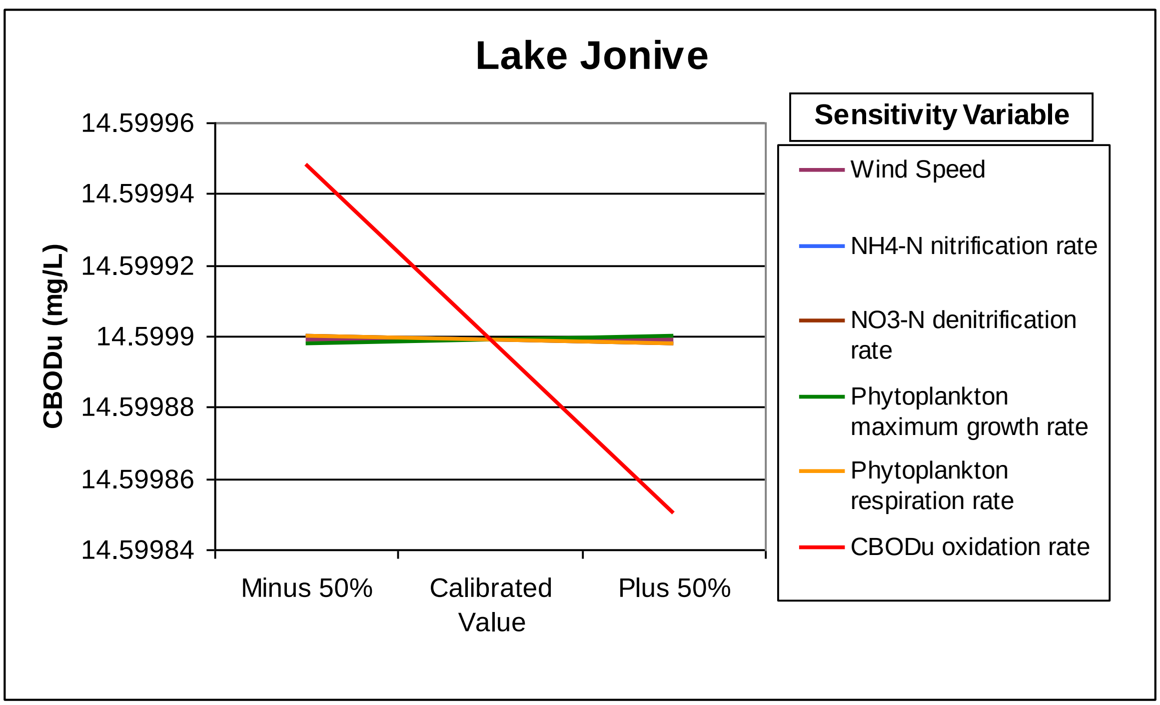

Figure 71. Lake Jonive $CBOD_u$ Concentration Model Sensitivity Spider Plot

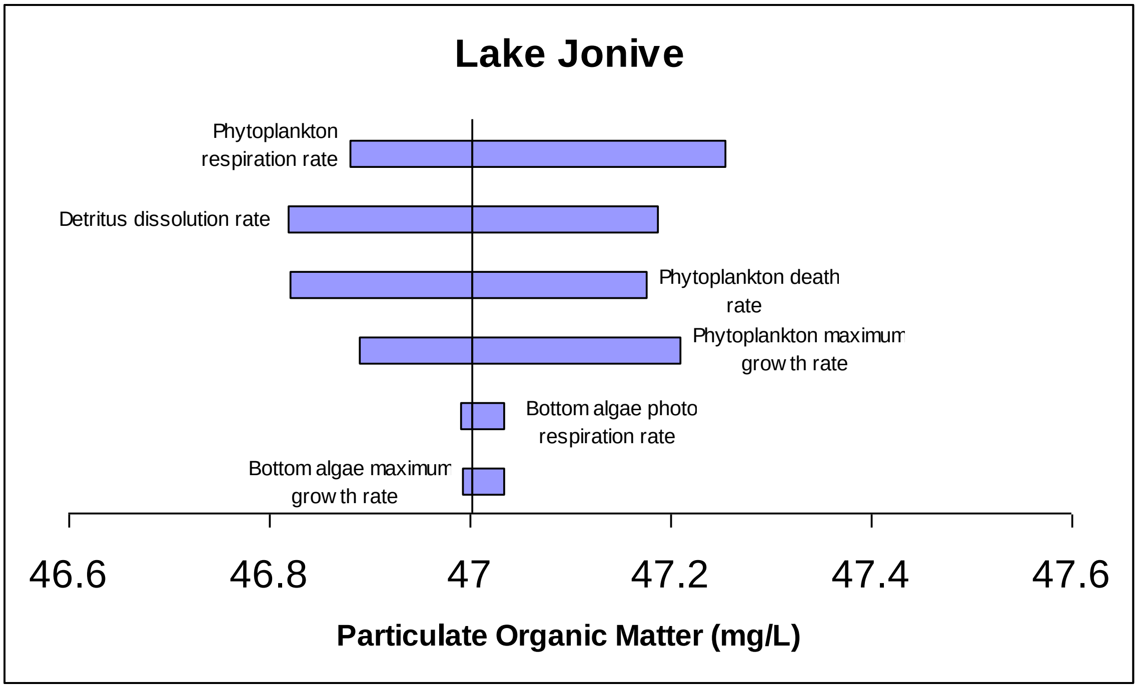

Figure 72. Lake Jonive Particulate Organic Matter Concentration Model Sensitivity Tornado Plot

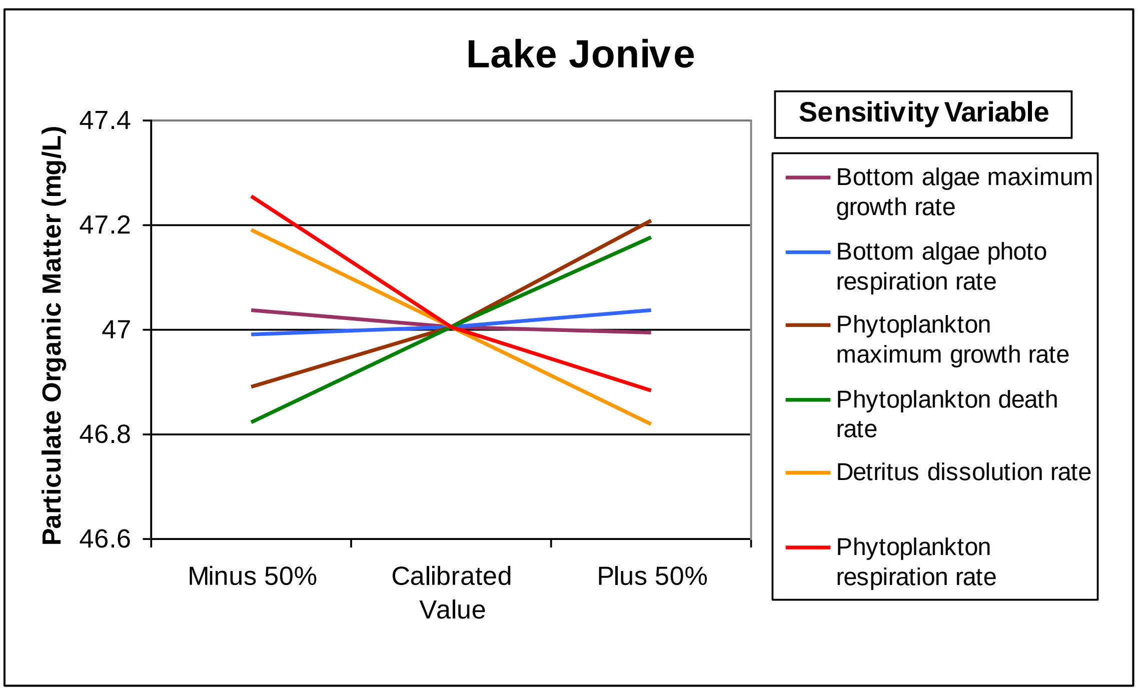

Figure 73. Lake Jonive Particulate Organic Matter Concentration Model Sensitivity Spider Plot

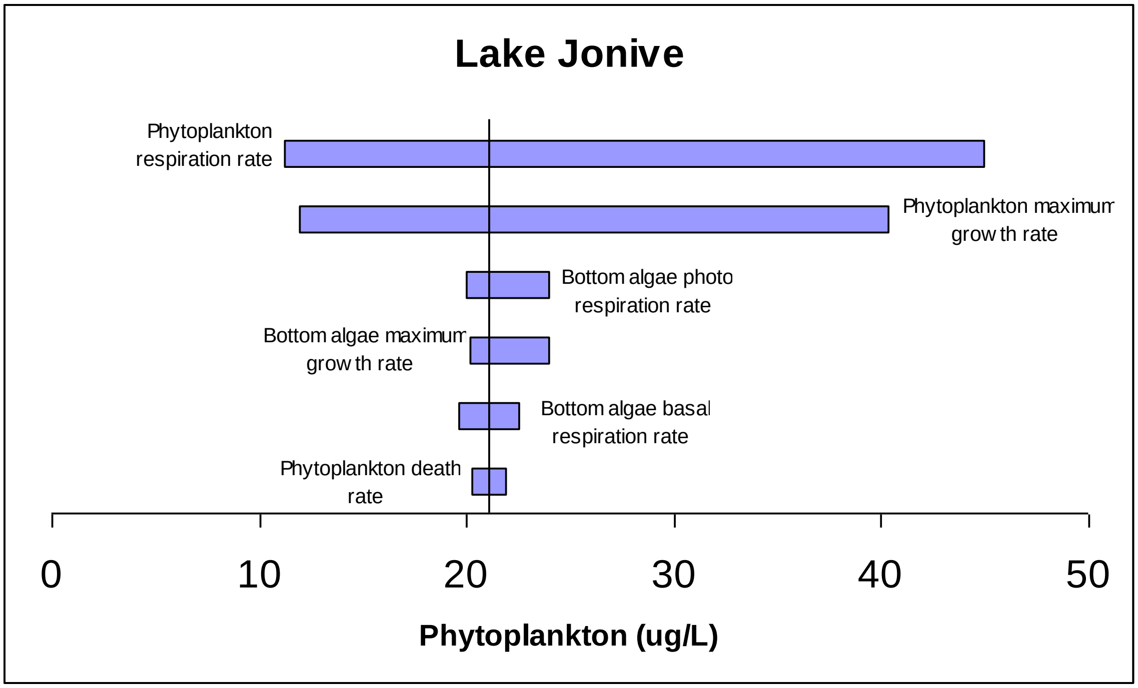

Figure 74. Lake Jonive Phytoplankton Concentration Model Sensitivity Tornado Plot

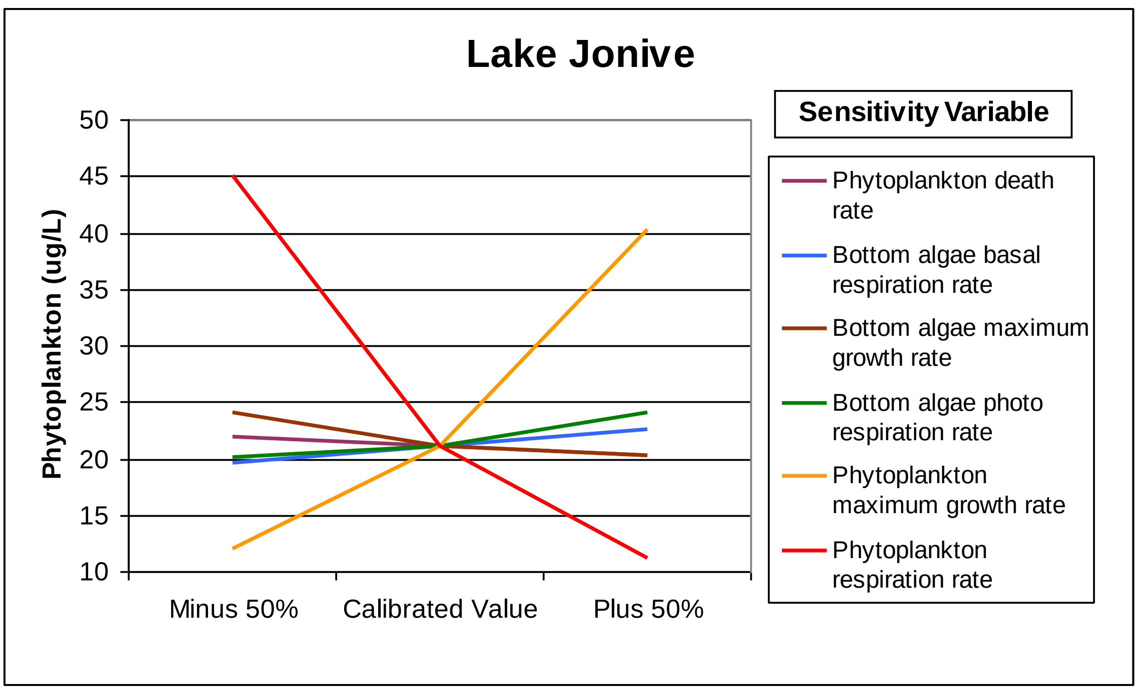

Figure 75. Lake Jonive Phytoplankton Concentration Model Sensitivity Spider Plot

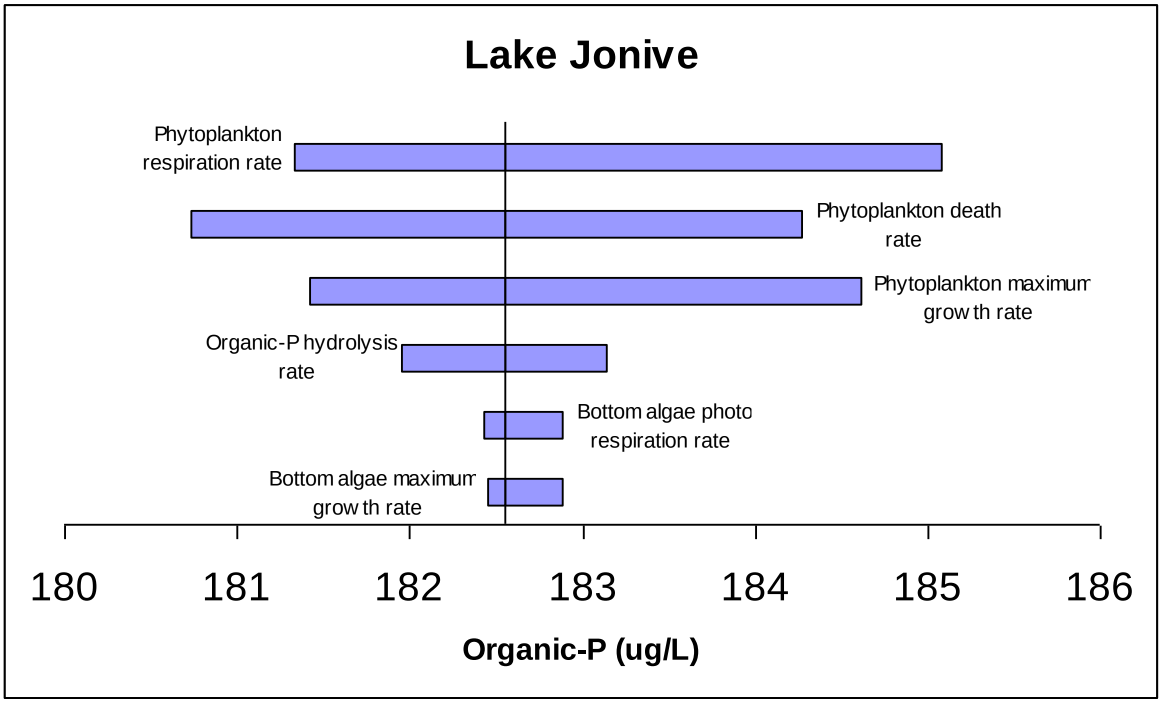

Figure 76. Lake Jonive Organic-P Concentration Model Sensitivity Tornado Plot

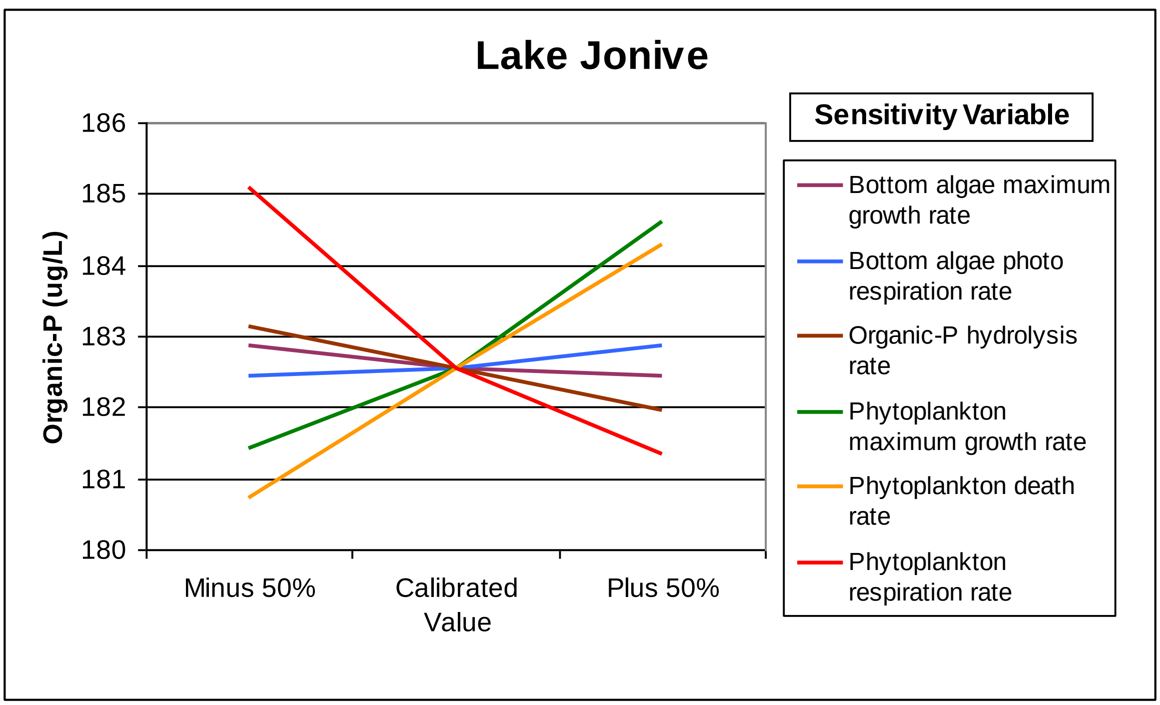

Figure 77. Lake Jonive Organic-P Concentration Model Sensitivity Spider Plot

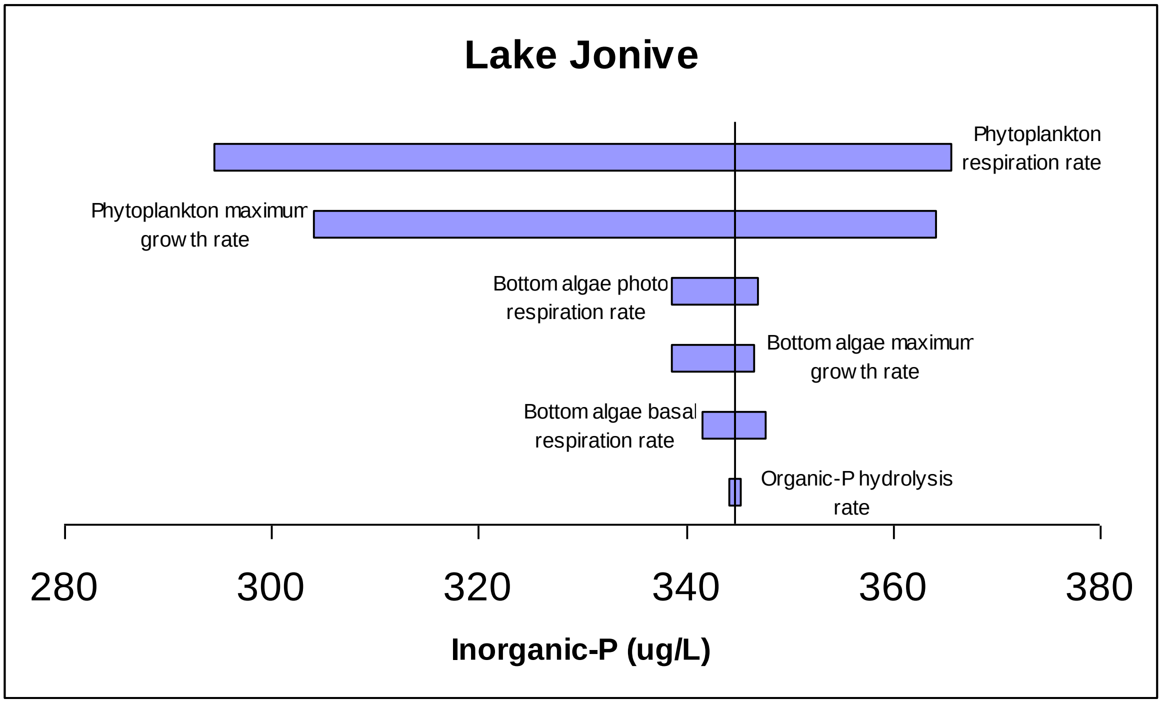

Figure 78. Lake Jonive Inorganic-P Concentration Model Sensitivity Tornado Plot

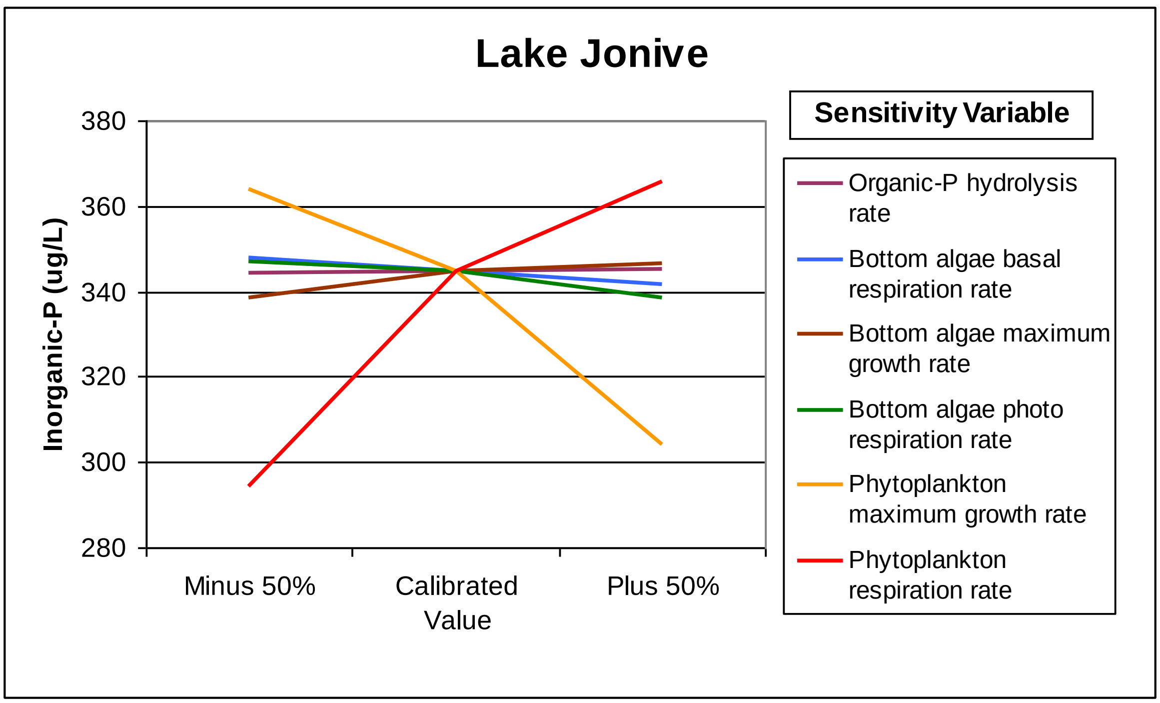

Figure 79. Lake Jonive Inorganic-P Concentration Model Sensitivity Spider Plot

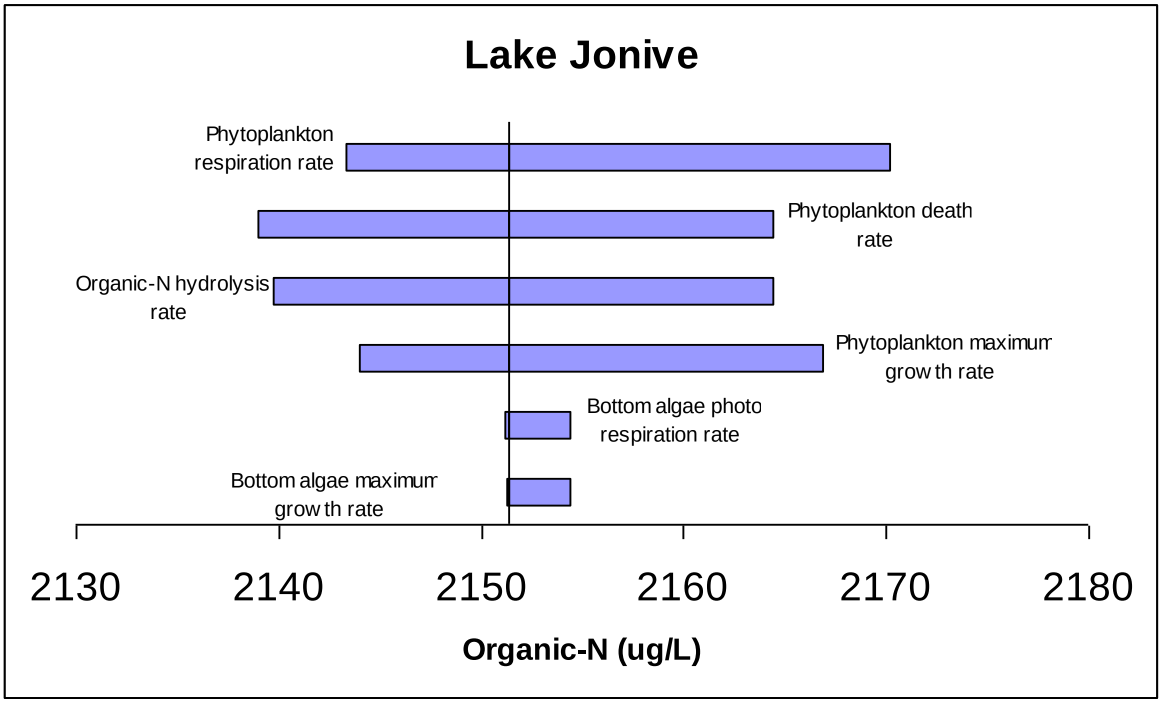

Figure 80. Lake Jonive Organic-N Concentration Model Sensitivity Tornado Plot

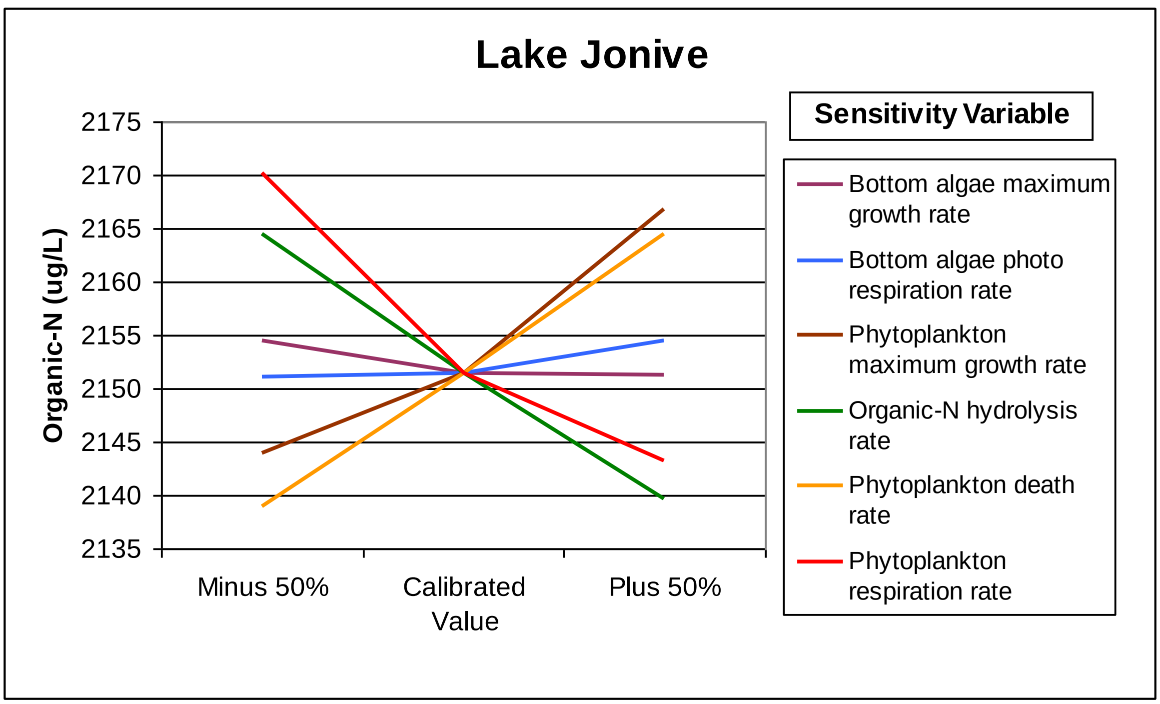

Figure 81. Lake Jonive Organic-N Concentration Model Sensitivity Spider Plot

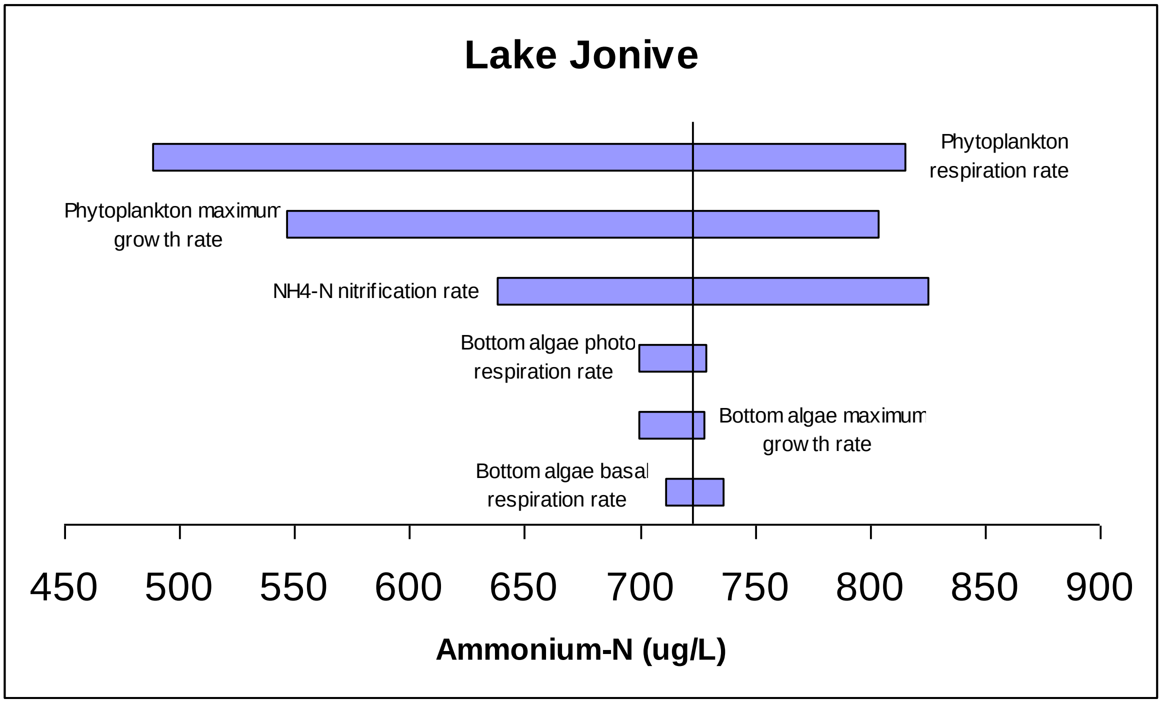

Figure 82. Lake Jonive Ammonium-N Concentration Model Sensitivity Tornado Plot

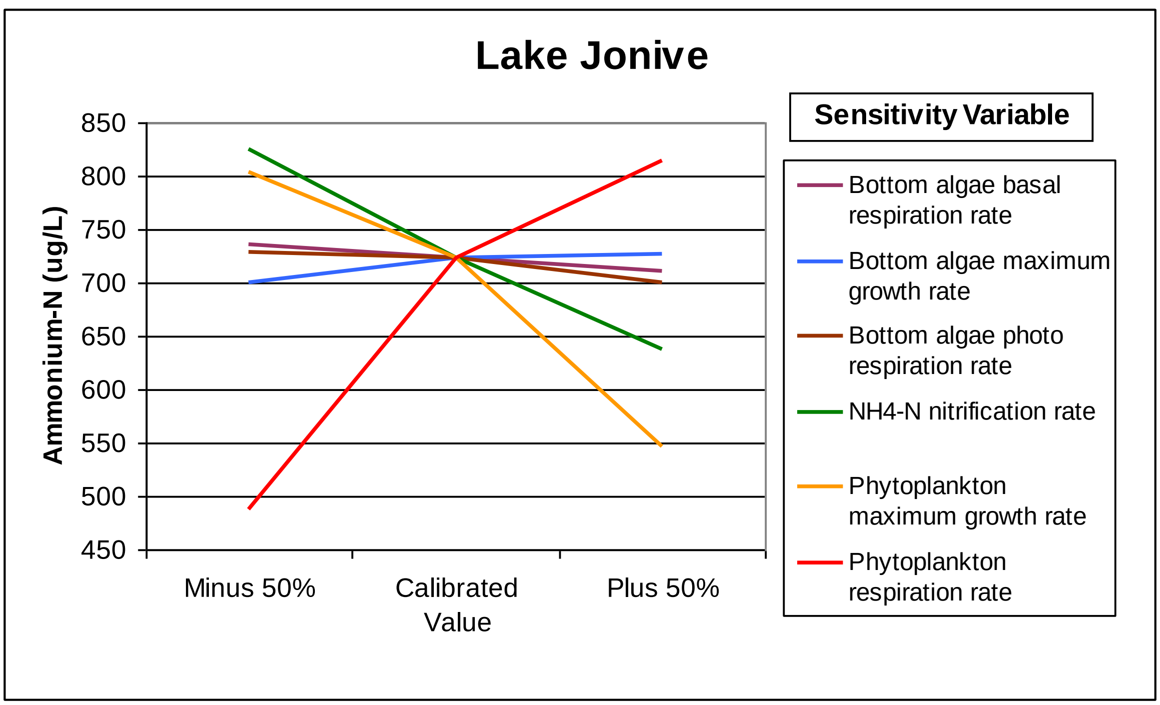

Figure 83. Lake Jonive Ammonium-N Concentration Model Sensitivity Spider Plot

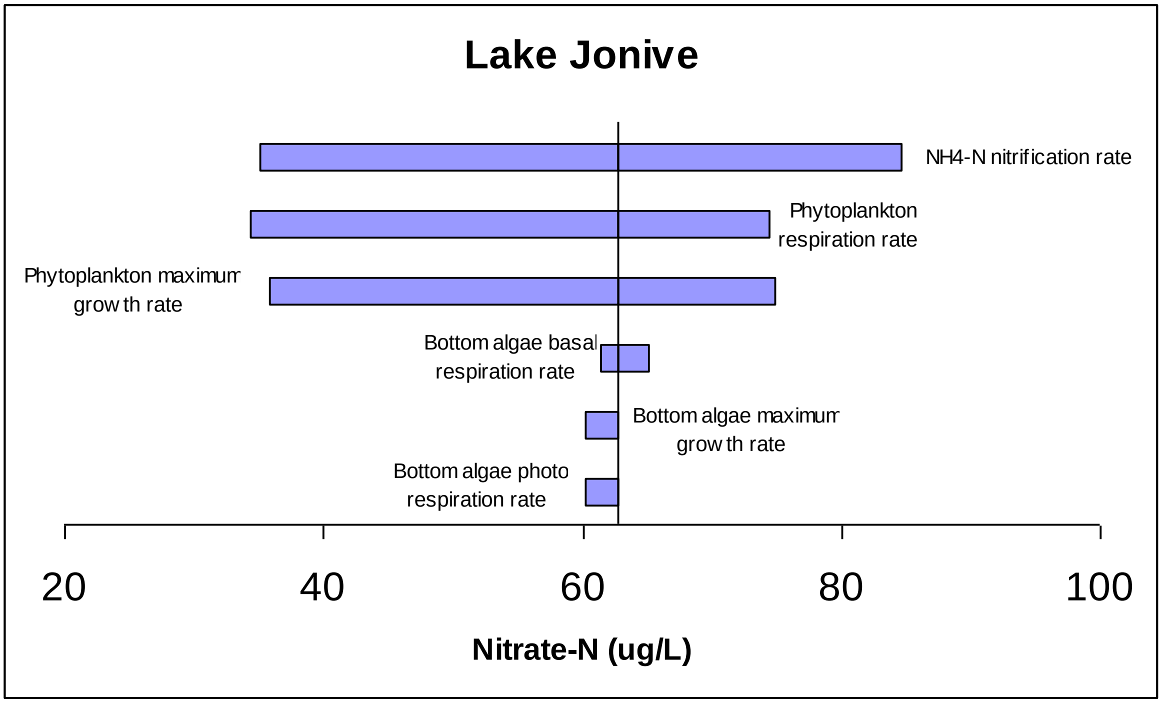

Figure 84. Lake Jonive Nitrate-N Concentration Model Sensitivity Tornado Plot

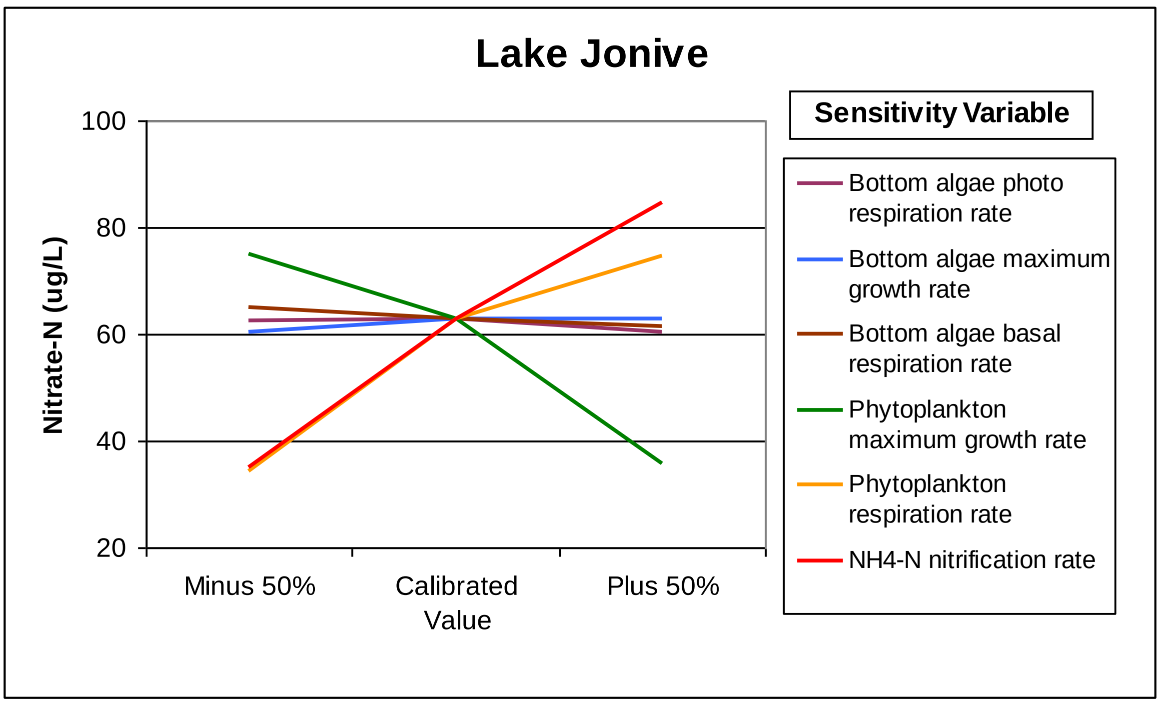

Figure 85. Lake Jonive Nitrate-N Concentration Model Sensitivity Spider Plot

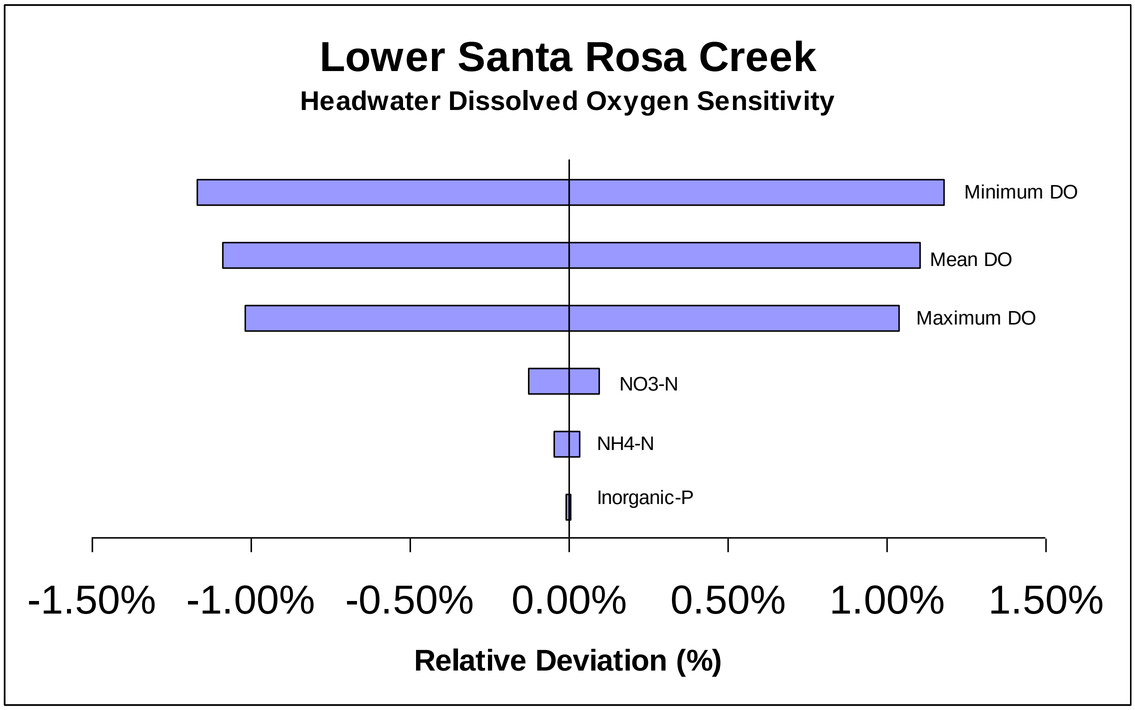

Figure 86. Lower Santa Rosa Creek Hourly Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

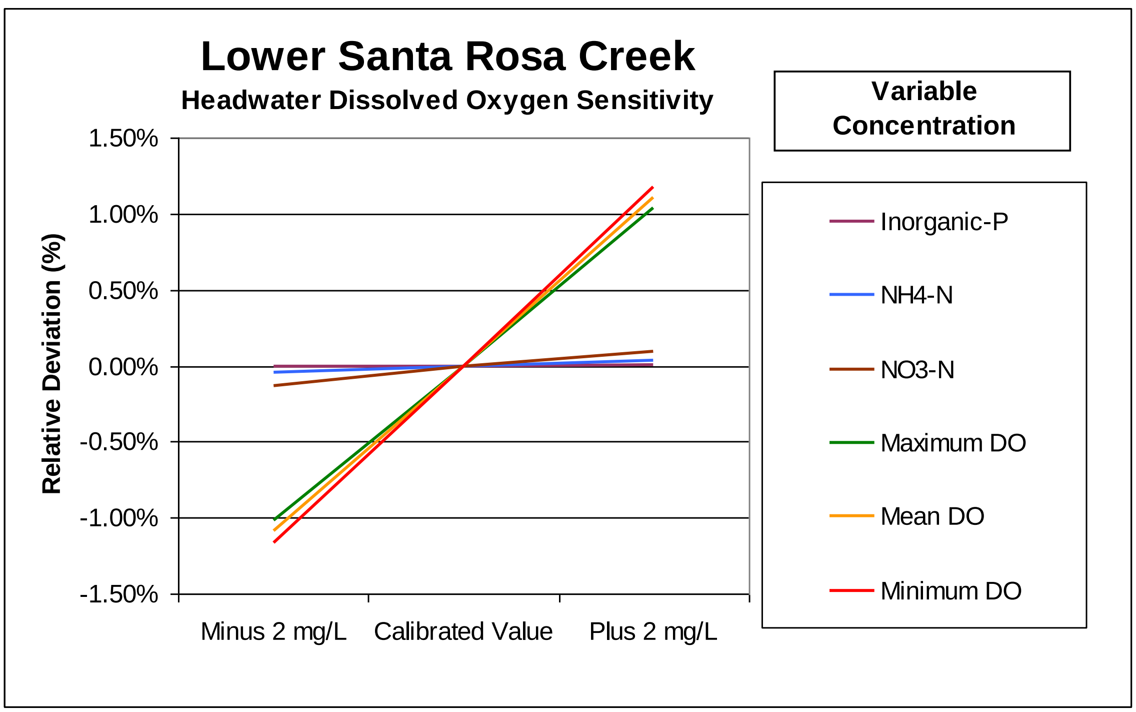

Figure 87. Lower Santa Rosa Creek Hourly Dissolved Oxygen Concentration Model Sensitivity Spider Plot

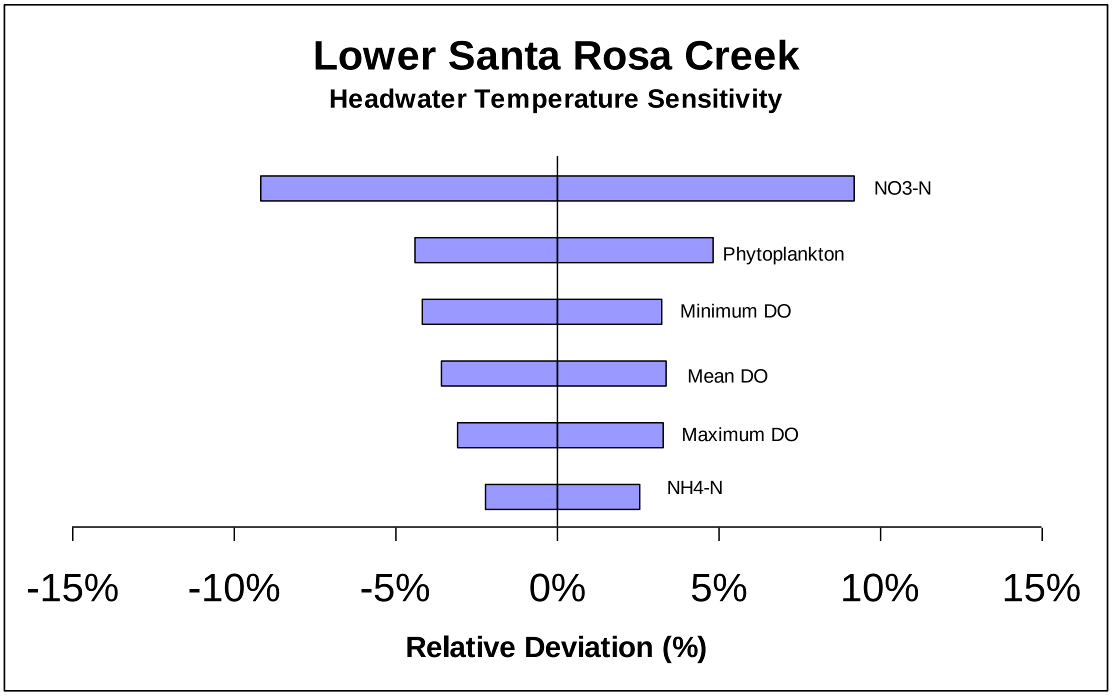

Figure 88. Lower Santa Rosa Creek Hourly Water Temperature Model Sensitivity Tornado Plot

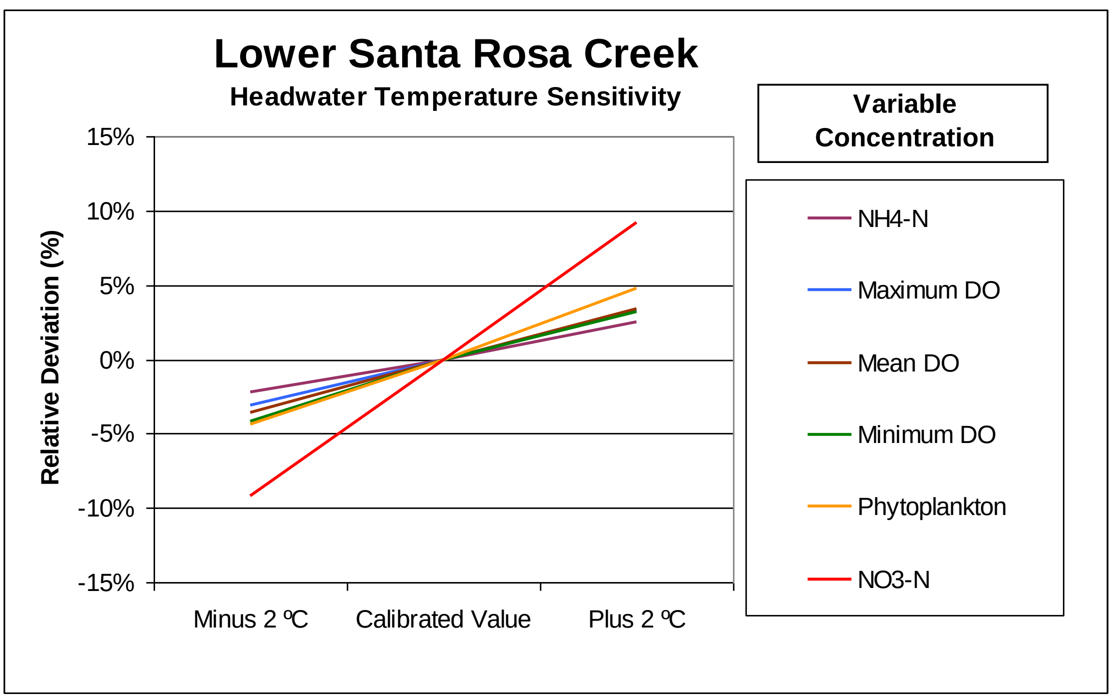

Figure 89. Lower Santa Rosa Creek Hourly Water Temperature Model Sensitivity Spider Plot

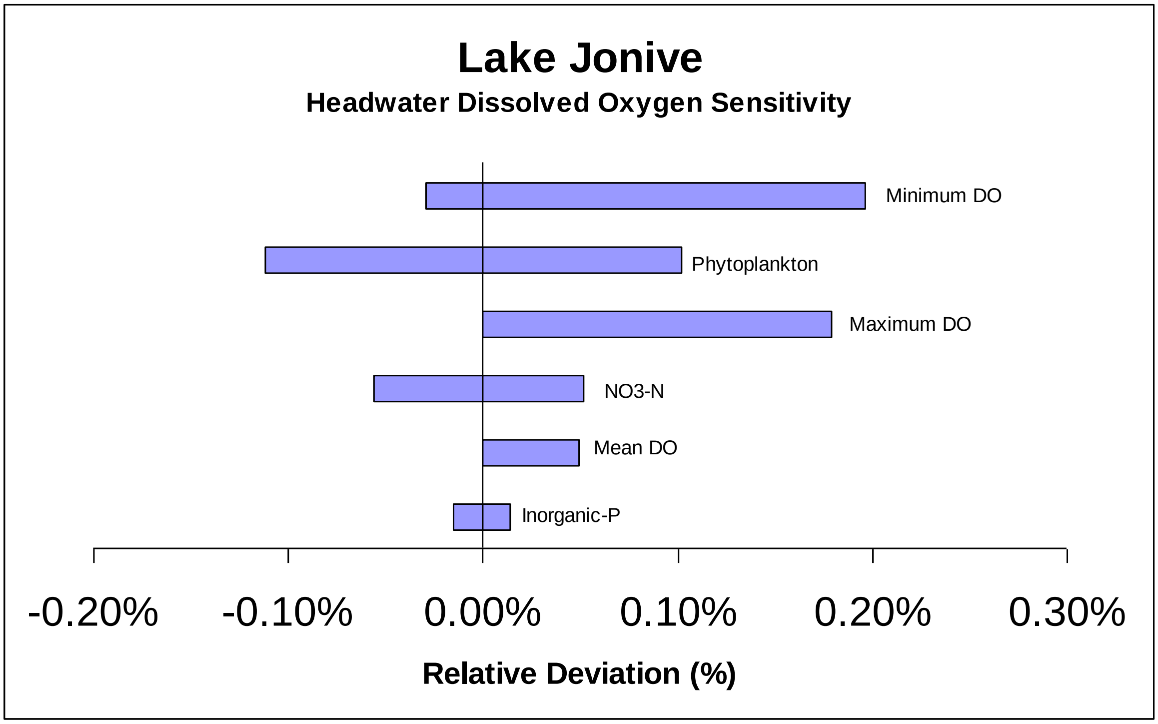

Figure 90. Lake Jonive Hourly Dissolved Oxygen Concentration Model Sensitivity Tornado Plot

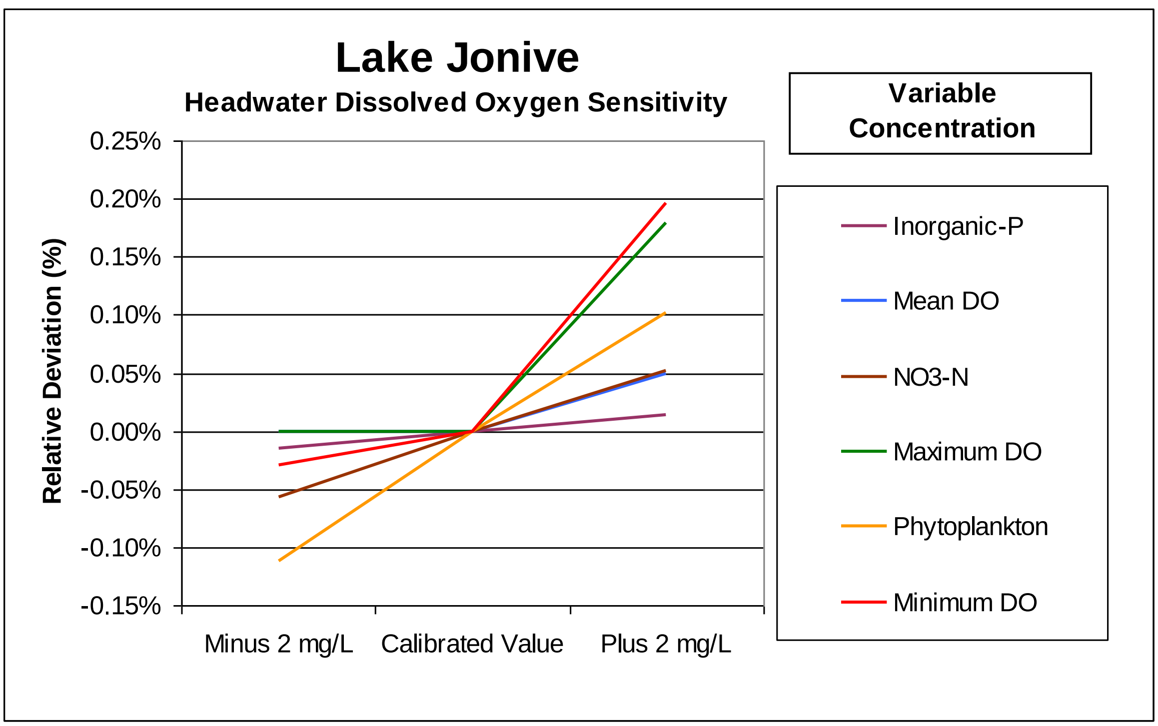

Figure 91. Lake Jonive Hourly Dissolved Oxygen Concentration Model Sensitivity Spider Plot

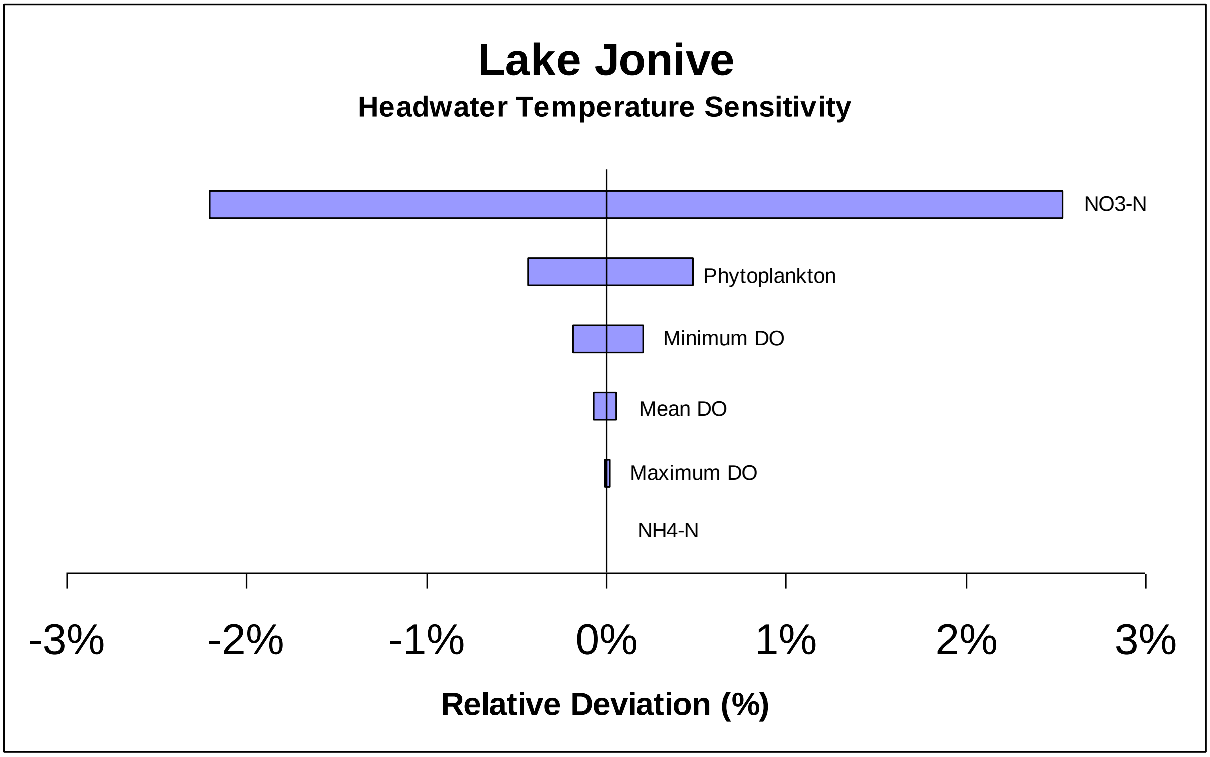

Figure 92. Lake Jonive Hourly Water Temperature Model Sensitivity Tornado Plot

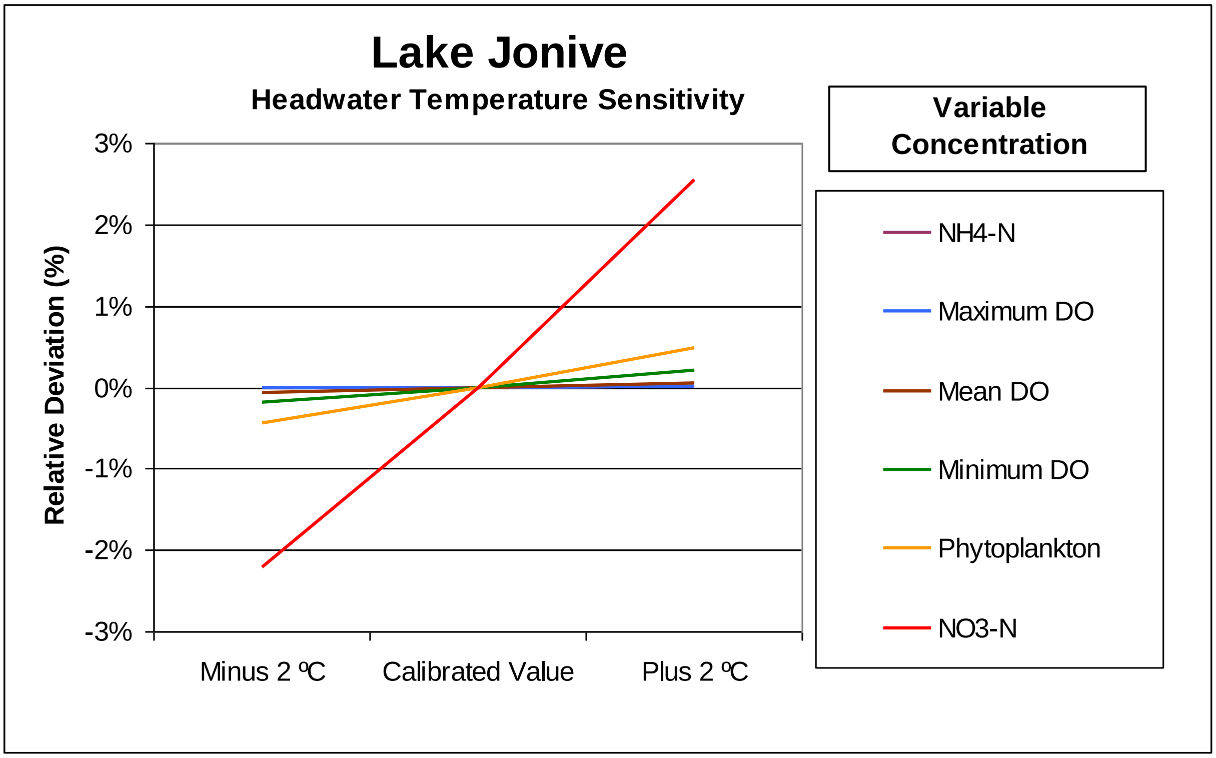

Figure 93. Lake Jonive Hourly Water Temperature Model Sensitivity Spider Plot