Santa Margarita River Watershed Model and Lower River Nutrient Response Models

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1.0 INTRODUCTION

1.1 HISTORY OF THE SANTA MARGARITA RIVER WATERSHED MODEL

A watershed simulation model has been developed for the Santa Margarita watershed as a tool to estimate sources of nutrient loads within the watershed, calculate the timing and amounts of nutrient loads delivered to the Santa Margarita Estuary, support development of Water Quality Improvement Plans, and provide input to more detailed receiving water models of the Santa Margarita mainstem. The model is implemented using the USEPA-supported Hydrologic Simulation Program-FORTRAN (HSPF) model (Bicknell et al., 2014).

HSPF is a comprehensive, EPA-supported and widely applied watershed modeling package that can simulate water quantity and quality for a wide range of pollutants. HSPF was selected for this study because of its capability to assess the impact of point and nonpoint sources in a large watershed with varying land cover and management conditions. The HSPF model has been applied throughout the US and has a long history of application for nutrient management, Total Maximum Daily Load, and water supply protection studies.

HSPF divides the larger watershed into smaller sub-basins, each of which is conceptualized as a group of various land uses routed to a representative stream reach. The sub-basins are linked together by the stream reach network to represent the larger watershed drainage. A variety of instream modules describe flow, sediment transport, and water quality kinetics for nutrients, dissolved oxygen, algae, and other components, including exchanges with the sediment bed and kinetic transformations simulated at an hourly time step.

Upland land processes are simulated in HSPF on a unit area basis and multiplied by area to provide input to the stream reach simulation, with separate modules for pervious and directly connected impervious areas. These include routines to dynamically simulate the water budget, sediment erosion and transport, and water quality constituents. Hydrology is modeled as a water balance in multiple surface and soil layer storage compartments. Interception, infiltration, evapotranspiration, interflow, groundwater loss, and overland flow processes are considered. Sediment production is based on detachment and/or scour from a soil matrix and transport by overland flow in pervious areas, whereas solids buildup and washoff is simulated for impervious areas. Nutrient loads from the land surface are represented either by buildup/washoff processes or as a function of sediment transport, while the pervious land simulation also incorporates transport via interflow and shallow groundwater.

The Santa Margarita River (SMR) watershed HSPF model has been developed incrementally over a number of years and with a variety of focus areas. The initial model was developed in 2013 (hydrology) and updated in 2014 (Phase 2, water quality calibration) based on then available data (Tetra Tech, 2013; 2014). This model was calibrated for flow, sediment, and nutrients (total nitrogen [N] and phosphorus [P]) and covered the entire watershed from the estuary to the remote upstream tributaries. This model ran through the end of water year 2010 and used older land use information from 2005 and 2009 in conjunction with precipitation data from a relatively small set of rain gauges.

The 2014 version of the watershed model provided a reasonable representation of flow, sediment, and nutrient concentrations in the Santa Margarita River and loading and transport from the river to the Santa Margarita estuary; however, as with any model, there was a degree of uncertainty in the representation of watershed processes that could potentially be reduced. The wet weather simulation was primarily limited by a lack of detail in the spatial representation of precipitation in the watershed, where areas of significant topographic relief were represented by a limited number of individual rain gauges. The dry weather simulation was primarily limited by a lack of detail on the complex interactions between surface water and groundwater in the basin. Additional updates were carried out in conjunction with the 2016 load allocation estimates, including work to integrate groundwater exchanges in the lower Santa Margarita mainstem with the Camp Pendleton groundwater model for water years 2008-2010 (Sutula et al., 2016a).

Another major update was completed in April 2017, primarily to support development of County of San Diego Water Quality Improvement Plans (Tetra Tech, 2017). This update was authorized for the Santa Margarita River mainstem below U.S. Geological Survey (USGS) gage 11044000 at the head of the Gorge (situated below the confluence of Murrieta and Temecula Creeks and below the Comprehensive Water Rights Management Agreement [CWRMA] discharge), as well as all tributaries discharging into the mainstem below this point (Figure 1-1). The portions of the watershed model upstream of USGS gage 11044000 in Riverside County were not updated. A few additional updates and corrections to the model were completed in May 2017.

Major changes for the 2017 model included the following: First, the model land use within San Diego County was updated to the most recent available (2015) coverage and auxiliary information provided by the County was used to identify and delineate the area in nurseries, which appear to be significant contributors to nutrient loads in Rainbow Creek. Second, the model simulation, which previously ended in 2010, was extended through September of 2016. Thirdly, the issue of sparse rain gauge information over the full time period of the model was addressed through the use of gridded precipitation data that combines rain gauge calibration, Doppler radar information, and regressions against topography to provide a more accurate spatial representation of rainfall distribution. Finally, the watershed model was integrated with an updated version of the groundwater model of the aquifers on Camp Pendleton that had been extended through water year 2016 by Stetson Engineers. The revised groundwater model has now been used to simulate loading of N and P from the aquifer back to the river in resurfacing groundwater.

In addition to bringing the model up through water year 2016, these enhancements allowed significant improvements in the model representation of hydrology, covering both wet and extremely dry periods. Improvements in the hydrologic simulation in turn support more accurate estimation of load delivery to the Estuary as well as better representation of low flow conditions within the stream network.

It is important to note that the watershed model within Riverside County has not been updated except for the headwaters of tributaries (e.g., De Luz, Sandia, and Rainbow Creeks) that originate in Riverside County and flow to the Santa Margarita River within San Diego County (Figure 1-2). This required specifying a boundary condition at the head of the gorge. The simulation model of the watershed upstream of this point runs only through September 2010 and thus does not cover the full simulation period of the updated 2017 model. Flows at the boundary for water year 2011 and later are available from the USGS gage, but nutrient concentrations and loads at the boundary must be inferred from sparse monitoring data.

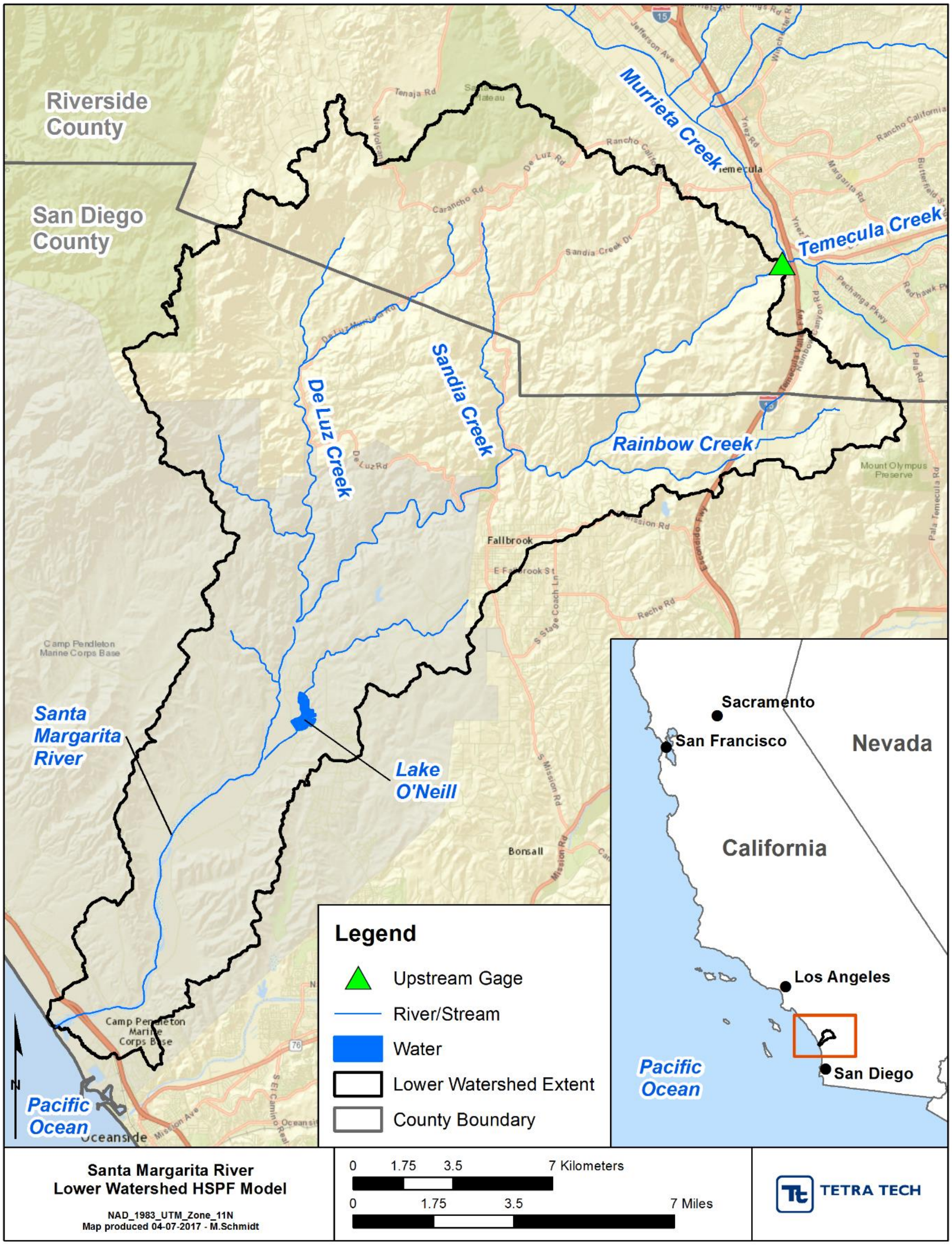


Figure 1-1. Area Represented in the 2017 Santa Margarita River Watershed Model Update

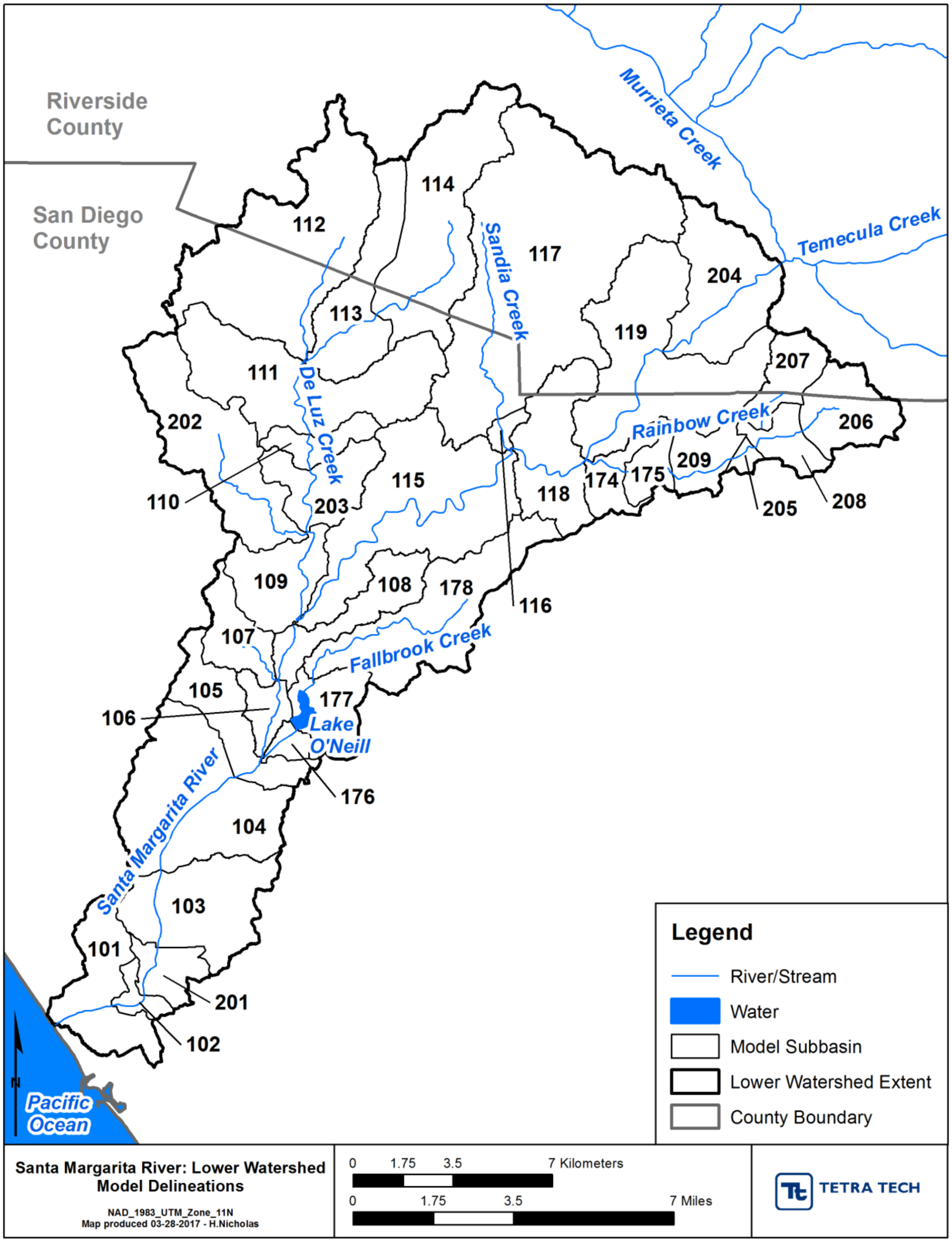


Figure 1-2. Areas Simulated in the 2017 Santa Margarita River Watershed Model

Note: Numbers refer to HSPF model subbasins.

1.2 SCOPE OF CURRENT EFFORT

A new round of updates to the HSPF model described in this report was designed to support detailed receiving water simulations of water quality and algal growth to determine the conditions necessary to support beneficial uses within the lower Santa Margarita River mainstem, defined as the portion of the river from the confluence with DeLuz Creek to the estuary (Figure 1-3). In addition to direct simulations of water quality using HSPF, more detailed receiving water models have been developed using the WASP (Wool et al., 2001; Ambrose and Wool, 2009; Martin and Wool, 2017) and QUAL2Kw (Pelletier and Chapra, 2008) models, which require inputs generated from the HSPF model.

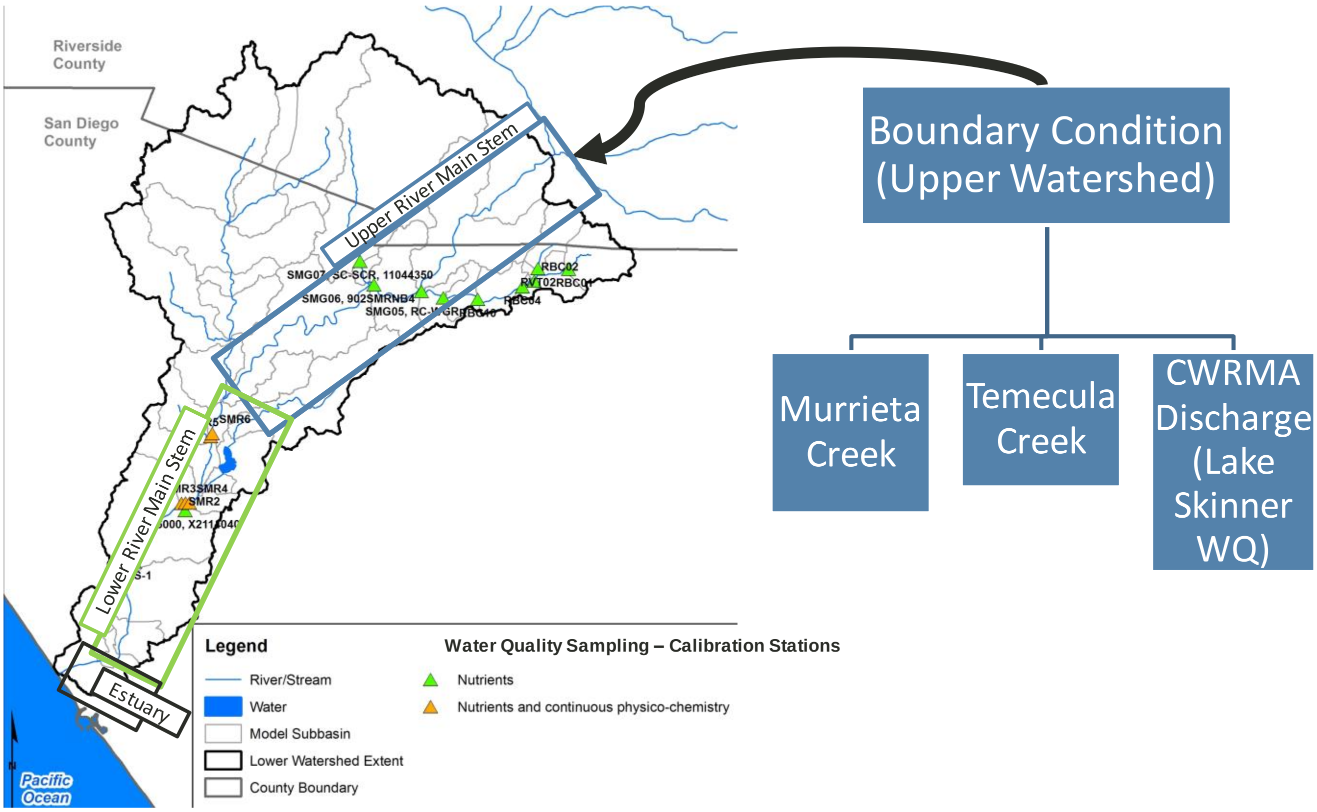


Figure 1-3. Santa Margarita River Upper and Lower River Mainstem Domains

The WASP model is used for continuous simulation for the perennial reach above the Camp Pendleton diversion and QUAL2Kw is used for the simulation of critical conditions throughout the Lower SMR. WASP (EUTRO module) is the tool now being used in the estuary to address algal growth and the DO balance, and is an appropriate tool for areas (and time periods) where perennial flow and a reasonable depth is maintained. In general, the time step in WASP must be no greater than the minimum segment travel time or pollutant residence time, so extremely short time steps or very small segments would be required for shallow flow, while complete drying is not addressed, rendering this approach inappropriate for continuous simulation of intermittent or very shallow reaches. HSPF can provide the hydraulic and pollutant load time series input to WASP.

QUAL2Kw is used to develop a representation of critical conditions (with diel variability) of DO and algal responses. The QUAL2Kw model is a modified version of the QUAL2K model (Chapra et al., 2012). It is a one-dimensional model that simulates the diel heat budget, diel water quality, phytoplankton, bottom algae, pH, and the full DO balance. The kinetic representation of water quality is similar to that in the current version of WASP.

The model is implemented for steady flow conditions and is typically used to evaluate one or more sets of critical conditions under which maximum impacts are expected – usually a combination of low flows, high algal biomass, and high thermal inputs. It also includes a detailed analysis of shading impacts. The focus on critical conditions means that periods of no flow or extreme high flows that may occur during a continuous simulation do not affect model application, making this model a good choice for evaluation of the intermittent reaches of the river.

Both WASP and QUAL2Kw provide detailed simulations of eutrophication and dissolved oxygen response that depend on concentrations of individual forms of nutrients. Therefore, the existing HSPF model was updated to provide representation of ammonium N (NH_4), nitrite N (NO_2), nitrate N (NO_3), and orthophosphate P (PO_4), as well as labile and refractory organic forms of N and P, rather than just total N and total P. The HSPF model was also expanded to provide process-based simulation of benthic algae, water temperature, alkalinity, inorganic carbon, and pH. Linkage to the Camp Pendleton groundwater model was also revised and improved. These refinements to the model in turn required recalibration of HSPF, which is enhanced by newly available monitoring data collected by SCCWRP in 2015 and 2016 (Sutula et al., 2016b).

2.0 HSPF WATERSHED MODEL

2.1 MODEL DEVELOPMENT – UPSTREAM BOUNDARY CONDITION

The current update of the model does not include revision of the simulation of the watershed above the confluence of Murrieta and Temecula Creeks in Riverside County. Accordingly, measured flows and estimated constituent loads at the upstream end of the Santa Margarita River gorge within Riverside County are taken as boundary conditions for the current model update. In contrast, the 2014 model simulated flows above the gorge, but suffered from uncertainties due to the lack of detailed information on surface-ground water exchanges in the Murrieta – Temecula aquifer area. For the 2017 model, water quality at the boundary after the end of the 2014 modeling period (9/30/2009) was based on monthly average results for wet and dry weather conditions. The approach of using monthly averages did not match observed conditions in the Santa Margarita mainstem very well and was therefore updated for this effort.

2.1.1 Flow, Sediment, and Nutrient Loads

The boundary condition for the Lower Santa Margarita River model is established at the head of the gorge. Continuous flow monitoring is available, but nutrient loads need to be established from limited monitoring data. The 2014 model of the upstream watershed (Tetra Tech, 2014) has not been recalibrated and ends in 2010. Further, available evidence suggests that concentrations at the boundary have declined significantly since the 1995-2009 period used to calibrate the upper watershed model. Therefore, the older model should not be used for specification of the boundary condition for the recent period.

Murrieta and Temecula Creeks join to form the Santa Margarita River at the head of the gorge (refer to Figure 1-3 above). The CWRMA discharge enters the Santa Margarita just below the confluence of Murrieta and Temecula creeks. USGS gage 11044000 is on the mainstem just below the CWRMA release. SCCWRP stations G1 and G2 are on the SMR downstream of the USGS gage; GA and GB are on the SMR upstream of the CWRMA release. SCCWRP also monitored on Temecula Creek and Murrieta Creek just above the confluence. A gage on Murrieta Creek (11043000) is a small distance upstream; there is no downstream gage on Temecula Creek.

As part of their MS4 permit requirements, Riverside Co. also has (somewhat limited) monitoring of water quality in Murrieta and Temecula Creeks and in the mainstem below the CWRMA discharge.

The CWRMA release consists of Colorado Project water via Lake Skinner and the quality of the CWRMA water reflects the water quality measured in Lake Skinner. Water quality monitoring in the mainstem SMR and on Murrieta and Temecula Creeks is limited and sporadic. In contrast, the CWRMA release has known flows and has water quality that is buffered by Lake Skinner and thus varies relatively slowly in time. It thus makes sense to back out and re-add the CWRMA releases.

To do this, we define C and Q as concentration and flow rate, respectively, with subscripts M, T, C, and G representing Murrieta Creek, Temecula Creek, CWRMA releases, and Gorge (mainstem below CWRMA). “M+T” represents the flow and concentration in the mainstem Santa Margarita just above the CWRMA discharge. In this discussion, “T” is used to represent the contribution from Temecula Creek itself, the small amount of direct drainage to the mainstem upstream of the CWRMA pipe, and resurfacing ground water at the head of the gorge at an uncertain location (about 0.5 cfs). Finally, let G represent gaged flow, with appropriate gage number as a subscript.

Q_C is known. We can establish the other flows in the system as follows. The estimate for Q_M is approximate because it does not account for exchanges downstream of the Murrieta Creek gage.

$$Q_G = G_{11044000}$$

$$Q_{M+T} = Q_G - Q_C$$

$$Q_M \approx G_{11043000}$$

$$Q_T = Q_{M+T} - Q_M$$

The boundary condition (represented by subscript B) concentration in the gorge is related to the upstream contributing components as:

$$C_B = [C_M Q_M + C_T Q_T + C_C Q_C]/G_{11044000}$$

Where there are observations in the gorge, the contributions from M and T can be inferred by subtracting the CWRMA load:

$$C_{M+T} = [C_G G_{11044000} – C_C Q_C]/[G_{11044000} – Q_C]$$

Where we have estimates of C_M and C_T we can also estimate C_{M+T} from upstream information

$$C_{M+T} = [C_M Q_M + C_T Q_T]/[Q_M + Q_T]$$

We use available upstream and downstream monitoring information to estimate as many points for C_{M+T} in the 2010-2017 time period as possible. These are assigned to wet or dry conditions, and used to calculate daily average values for C_{M+T} to fill in the sparse data. We then reconstruct the boundary series (using the more reliable CWRMA estimates as a separate input) as

$$C_G = [C_{M+T} Q_{M+T} + C_C Q_C]/G_{11044000},$$

substituting actual measured C_G on days where it is available. This procedure for establishing the upstream boundary condition is still likely to result in considerable uncertainty in the representation of upstream loads after September 2010.

2.1.2 DO and Water Temperature

Commencing in December 1999, USGS began reporting daily minimum and maximum water temperatures and maximum, minimum, and median DO concentrations at gage 11044000. 15-minute temperature and DO data are available from 10/1/2007 on. These data were interpolated and the units adjusted to provide inputs of hourly flow volume (AF) and heat input (BTUs relative to freezing) for the HSPF model.

2.1.3 Other Constituents

Boundary condition inputs are also needed for other constituents that are either not frequently monitored or typically below detection limits. We assume ultimate carbonaceous BOD at 2.5 mg/L, alkalinity of 184 mg/L, total inorganic carbon (TIC) of 184 mg/L as $CaCO_3$, and dissolved CO_2 of 2.76 mg/L (yielding an equilibrium pH of approximately 7.7, consistent with observations).

2.2 MODEL DEVELOPMENT - GROUNDWATER EXCHANGES

The Santa Margarita River flows through an area of alluvial aquifers on Camp Pendleton (Figure 2-1). Depending on conditions, the river both loses water to and gains water from the aquifers, and these exchanges play a major role in determining the flow and associated nutrient loads that reach the Santa Margarita Estuary. In the earlier phases of the model (Tetra Tech, 2013), these exchanges were represented by a rough approximation. Stetson Engineers subsequently developed a MODFLOW groundwater model of the aquifers and preliminary results for 2008 – 2010 were incorporated into the HSPF model (Sutula et al., 2016b). The groundwater model was since recalibrated and extended through 2016, allowing an improved representation of interactions with surface flows.

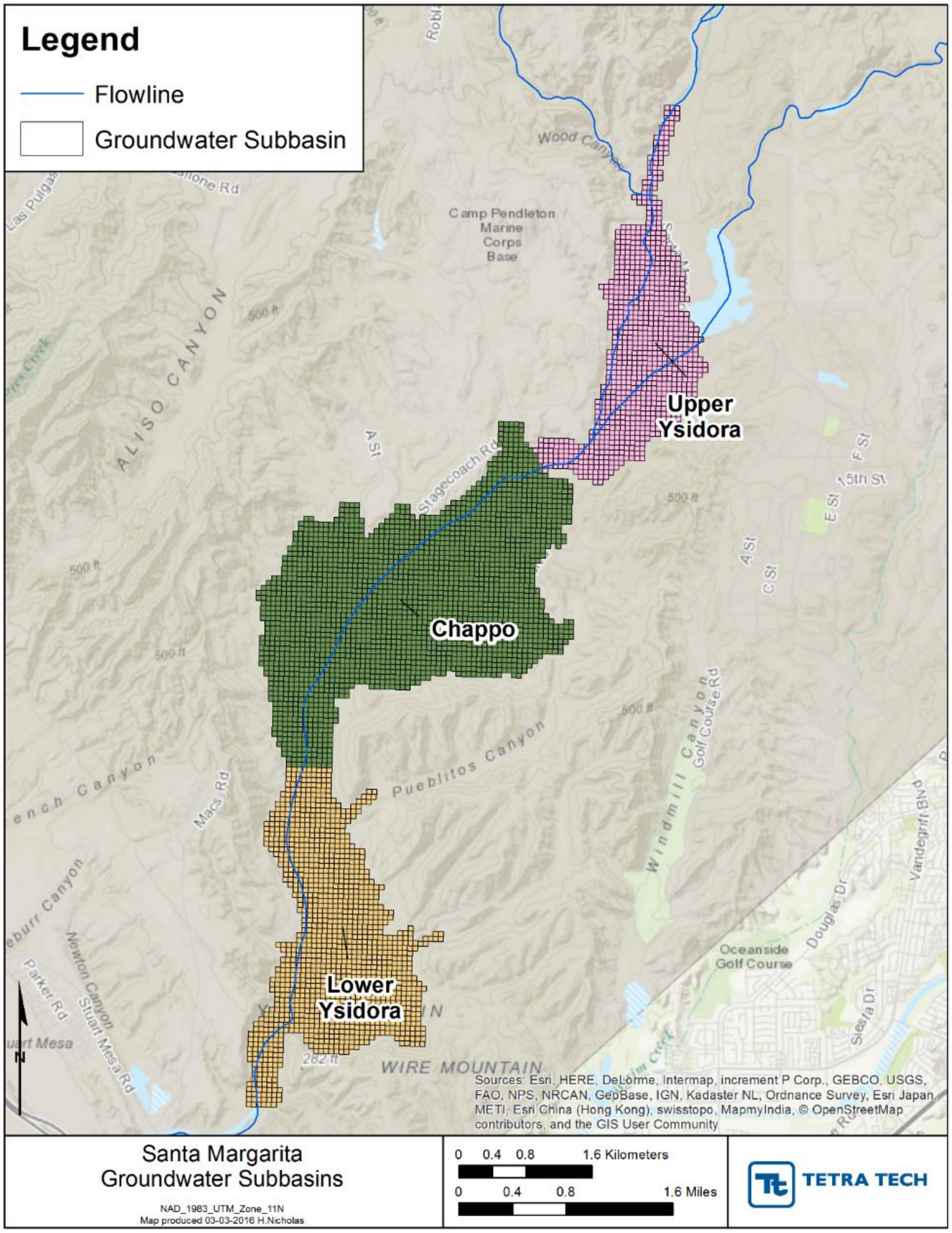


Figure 2-1. Santa Margarita River Alluvial Aquifers in the Vicinity of USMC Camp Pendleton

2.2.1 Updated Surface Water and Groundwater Exchange

Tetra Tech (2017) attempted a direct integration of the HSPF and MODFLOW models. An important part of the MODFLOW model is simulation of exchanges between the aquifer and surface water cells. The MODFLOW model operates at a monthly time interval (referred to as a “stress period”) and for each month estimates streambed recharge and streambed discharge, which is sufficient for developing an aquifer water budget but does not provide a detailed prediction of streamflow or exchanges between the river and aquifer at the hourly time step required by the watershed model. Stetson Engineers subsequently developed further refinements to the groundwater model calibration (Figure 2-2) and also predicted transport of N and P through the groundwater system, prompting a refinement of the model integration.

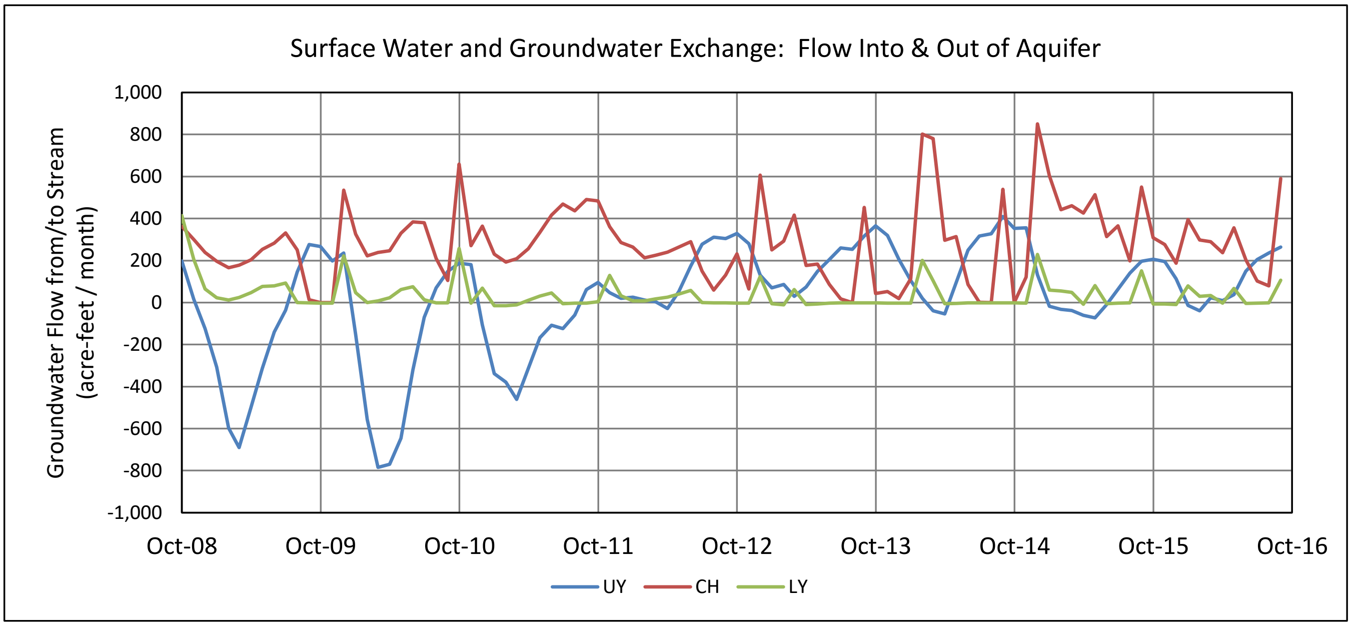


Figure 2-2. MODFLOW Simulated Exchanges between Santa Margarita River and Aquifer (

Figure provided by Stetson Engineers. Note that flow from stream to aquifer is positive. UY = Upper Ysidora, CH = Chappo, LY = Lower Ysidora groundwater basin.

The basics of the model integration are described in detail in Tetra Tech (2017). One major difficulty is engendered by the mismatch in time steps when interpreting the loss of water from the river to the aquifer. Summer flow in the Santa Margarita River is quite low and varies from day to day. If the monthly losses from river to aquifer are interpreted as a constant rate the total loss will be underestimated as the model will attempt to apply some of the loss during periods when insufficient water is available. A related concern applies to the Camp Pendleton Diversion. While this diversion is gaged there may be small shifts in timing between the actual diversion and availability of simulated flows in the river, resulting in an underestimation.

To address these issues we applied an iterative approach. First small adjustments were made to the reported diversions so their timing better matches simulated water availability in the river in excess of the flow of 3 cfs that passes through the sediment sluice gate. With this adjustment, the model was able to increase the simulated diversion amount from 97.0 to 99.8% of the gaged diversion.

Once the diversion simulation was adjusted, four sequential iterations (upstream to downstream) were applied to optimize the timing of losses from each of the four affected reaches (106, 105, 104, and 103) of the river to the aquifer within the monthly stress periods. This enables essentially 100% of the predicted losses from the river to the aquifer to be achieved. The groundwater model is developed for water years 2008 – 2016 and direct integration is only available for this period. As was done previously, we developed a surrogate model representation for the period prior to October 2007.

2.2.2 Groundwater Quality

Stetson Engineers used the groundwater modeling to simulate the mass balance of inorganic N (as NO_3-N) and inorganic P (as PO_4-P) in the alluvial aquifers along the lower Santa Margarita River. The groundwater model evaluates N inputs from the recharge ponds and other land-based sources, along with outputs in produced water and seepage back to the river on a monthly time step. Losses of nutrients from the river to the aquifer are automatically simulated in HSPF through the flow loss time series described in Section 2.2.1. Loads in seepage from the aquifer back to the river are specified based on the Stetson output, which covers water years 2008-2016. These loads are added to the river at a constant rate per month, converted to an hourly basis. Prior to WY 2008 we used the average concentrations in seepage for the 2008-2016 period to approximate loads (Table 2-1).

Table 2-1. Average Nutrient Concentrations in Resurfacing Groundwater from Lower Santa Margarita Alluvial Aquifer from Stetson Model, WY 2008 – 2016

Aquifer Segment	Upper Ysidora (Reach 106)	Upper Ysidora (Reach 105)	Chappo (Reach 104)	Lower Ysidora (Reach 103)
NO_3-N (mg/L)	2.038	2.051	0.397	0.374
PO_4-P (mg/L)	0.073	0.069	0.087	0.102

The groundwater model assumes no transformations of nutrient forms during transit. To match instream observed concentrations we adjusted the nutrients in seepage from the aquifer during calibration to be 10% NH_4-N, 40% NO_3-N, and 50% organic N.

2.3 HYDROLOGY ADJUSTMENTS

Simulation of hydrology in the revised model is largely unchanged from Tetra Tech (2017), except for the areas downstream of the Camp Pendleton diversion, where there is a USGS gage at Ysidora (11046000). One modification was made to the Sandia Creek simulation as well (gage 11044350), which is upstream of the Ysidora gage but enters the mainstem just downstream of the Santa Margarita at FPUD sump gage (see Figure 2-3).

For Sandia Creek, the original model had a small addition to baseflow to account for apparent groundwater loading from outside the local watershed. This addition resulted in over-prediction of low flows during the recent drought and the associated nitrate loads resulted in over-prediction of dry weather nitrate in the lower mainstem. This speculative component of the water balance was removed from the model to provide a better fit to observed flows in the 2015 -2016 period that is the focus of the current work.

The adjustments to hydrology produced little change, with the exception of Sandia Creek (Table 2-2). The current model fit in the lower river, Santa Margarita River at Ysidora, is shown in Figure 2-4. For Sandia Creek, the model fit when examined over the period 2000 – 2016 is slightly worse than previous, but fit during the 2015 –

2016 period that is the focus of the nutrient response modeling is better. Detailed results are updated here only for Sandia Creek,

Table 2-2. Summary of Hydrologic Calibration (2000-2016)

Flow Gage	Error in Total Volume	NSE, Daily Flow	NSE, Monthly Flow
11044300, Santa Margarita River at FPUD Sump	3.41%	0.780	0.871
11046000, Santa Margarita River at Ysidora	-2.20%	0.865	0.890
11044800, De Luz Creek near De Luz	7.06%	0.695	0.777
11044250, Rainbow Creek near Fallbrook	-3.93%	0.637	0.910
11044350, Sandia Creek near Fallbrook	-9.40%	0.694	0.869
11045300, Fallbrook Creek near Fallbrook	2.13%	0.725	0.927

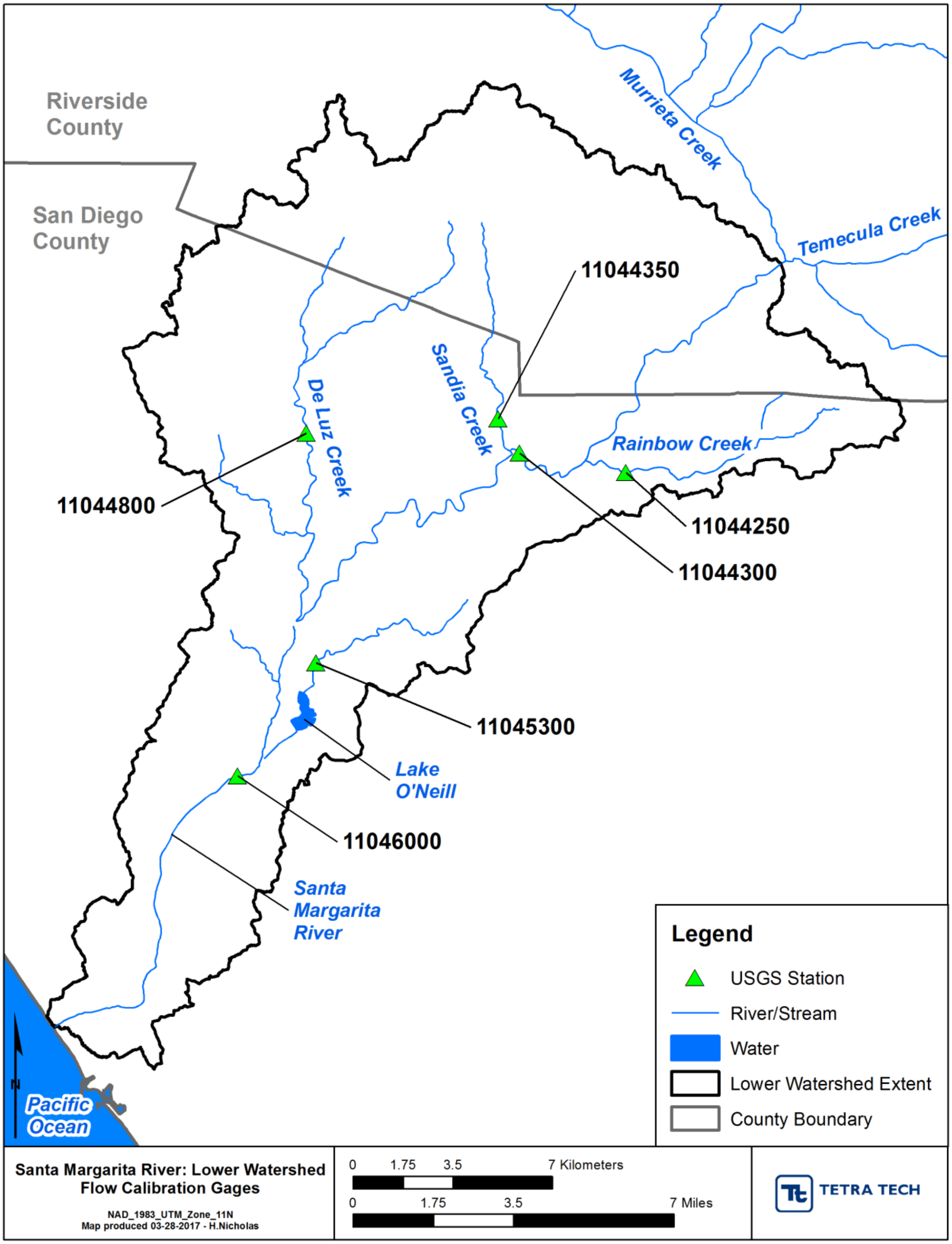


Figure 2-3. Flow Gage Locations

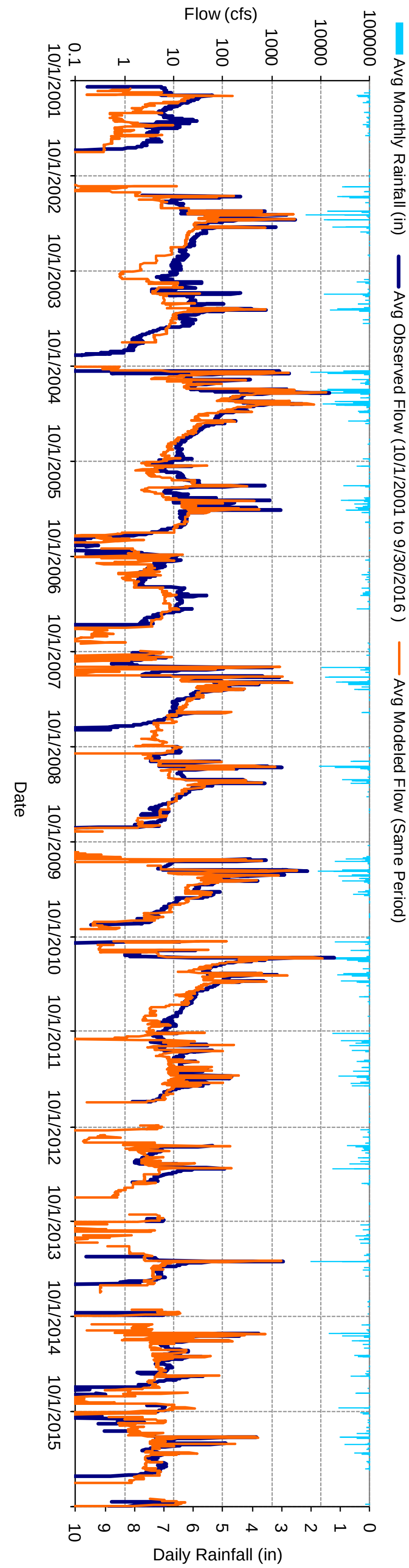


Figure 2-4. Mean daily flow: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

2.3.1 Sandia Creek near Fallbrook

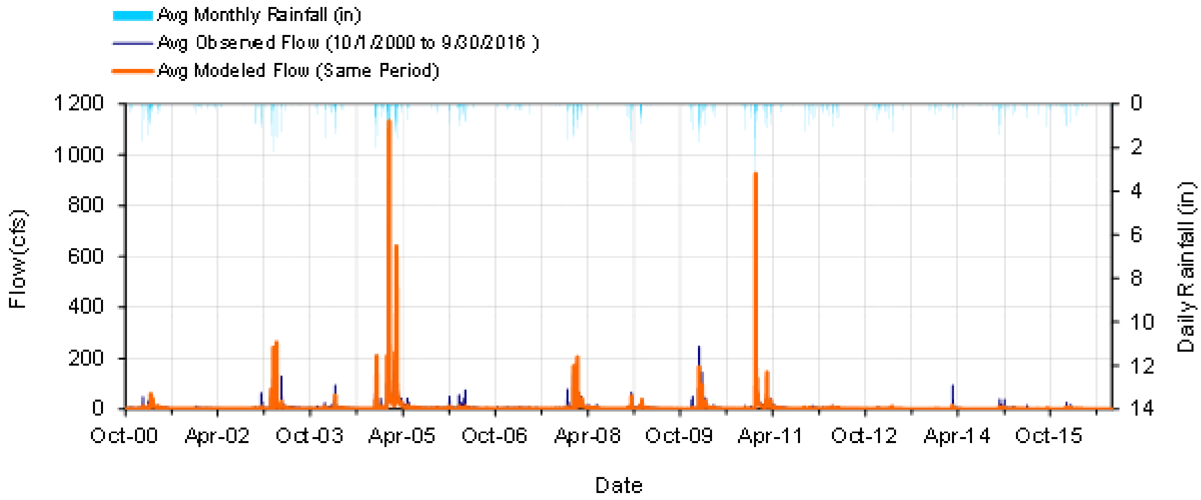


Figure 2-5. Mean daily flow: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

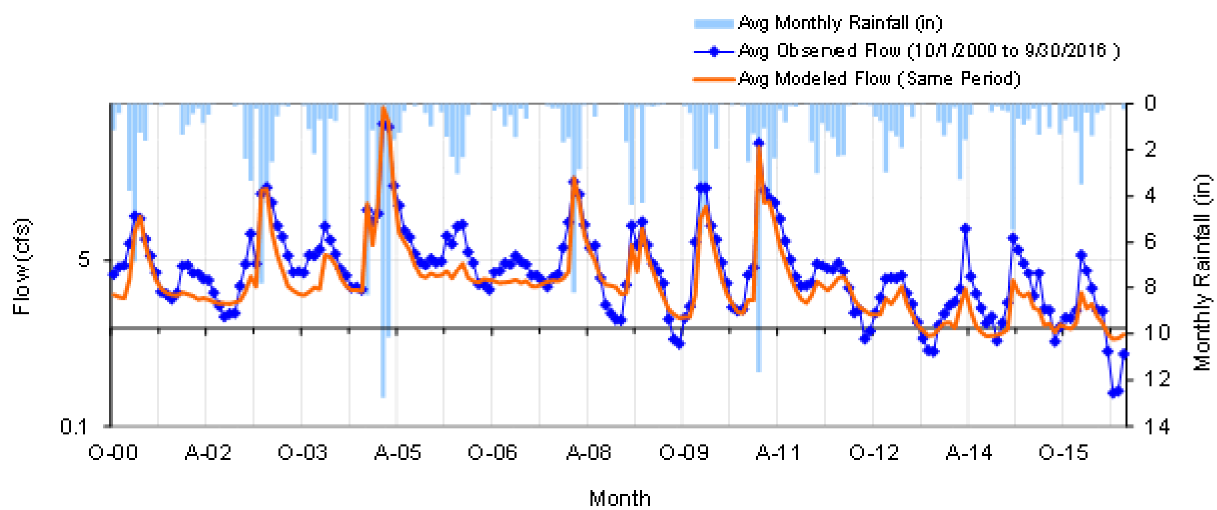


Figure 2-6. Mean monthly flow: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

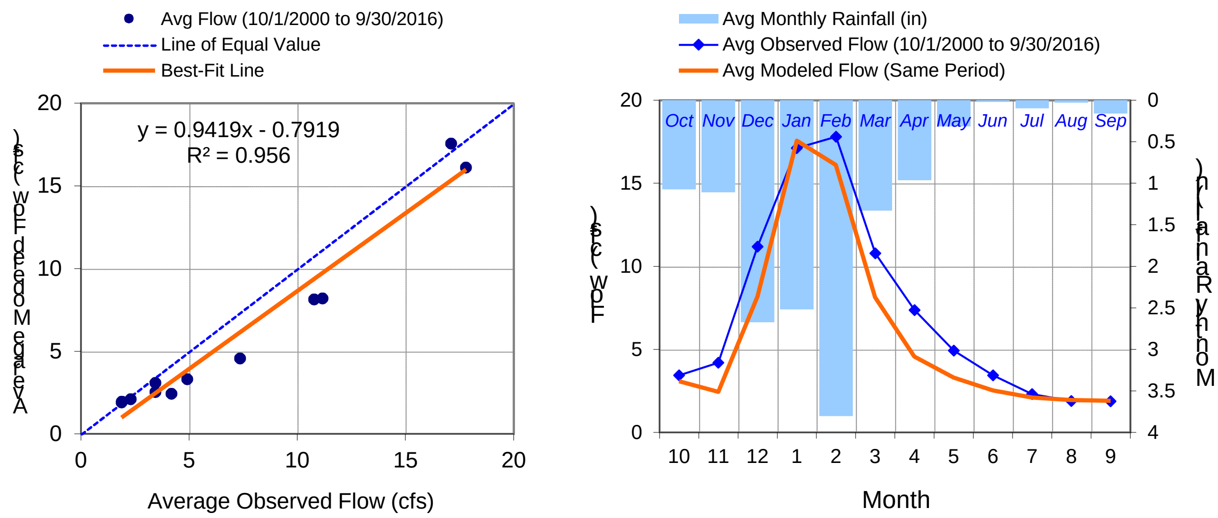


Figure 2-7. Seasonal regression and temporal aggregate: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

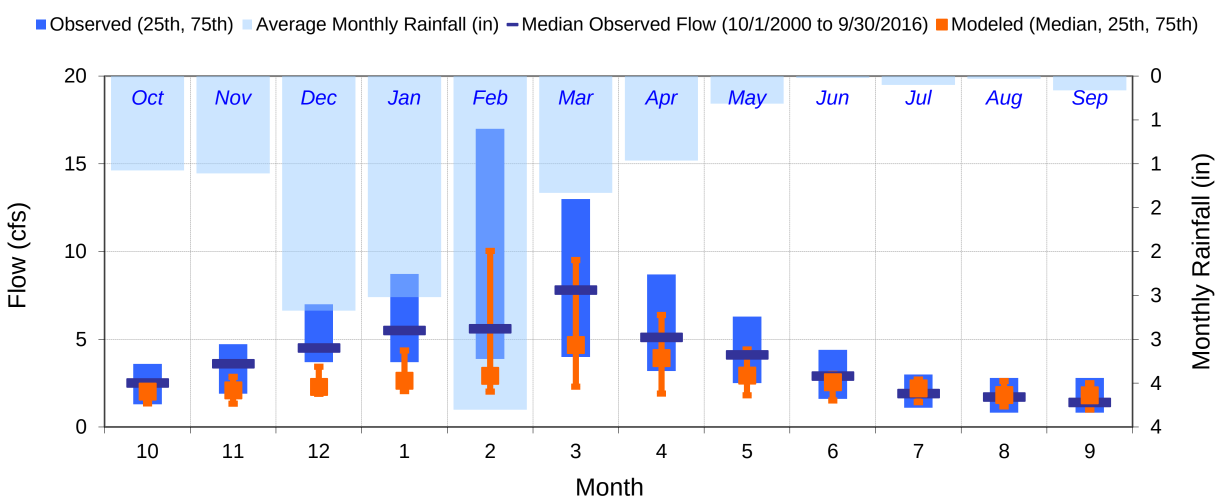


Figure 2-8. Seasonal medians and ranges: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

Table 2-3. Seasonal summary: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	3.44	2.50	1.30	3.60	3.08	2.02	1.34	2.40
Nov	4.19	3.60	1.90	4.73	2.43	2.09	1.33	2.86
Dec	11.18	4.50	3.70	7.00	8.19	2.29	1.89	3.43
Jan	17.12	5.50	3.70	8.73	17.56	2.65	2.04	4.37
Feb	17.80	5.60	3.88	17.00	16.10	2.92	2.02	10.04
Mar	10.78	7.80	4.00	13.00	8.13	4.69	2.30	9.52
Apr	7.36	5.10	3.20	8.70	4.56	3.93	1.91	6.40
May	4.92	4.10	2.50	6.30	3.30	2.93	1.81	4.43
Jun	3.44	2.90	1.60	4.40	2.52	2.57	1.51	3.03
Jul	2.31	1.90	1.10	3.00	2.10	2.21	1.42	2.72
Aug	1.90	1.70	0.82	2.80	1.94	1.84	1.17	2.62
Sep	1.88	1.40	0.82	2.80	1.89	1.81	0.99	2.50

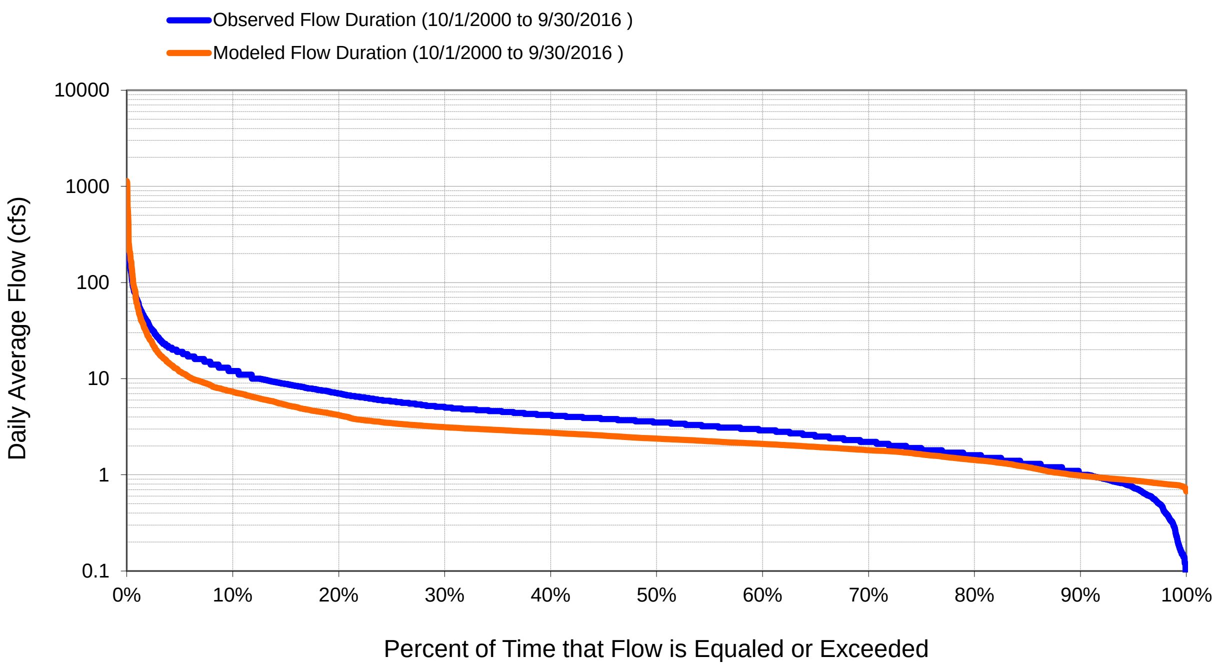


Figure 2-9. Flow exceedence: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

Table 2-4. Summary statistics: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

HSPF Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM DSN 5117 16-Year Analysis Period: 10/1/2000 - 9/30/2016 Flow volumes are (inches/year) for upstream drainage area 4/4/18 9:39 v23c, version optimized to better replicate 2015-16		USGS 11044350 SANDIA C NR FALLBROOK CA Hydrologic Unit Code: 18070302 Latitude: 33.42447348 Longitude: -117.249202 Drainage Area (sq-mi): 21.1		
Total Simulated In-stream Flow:	**3.83**	Total Observed In-stream Flow:		**4.60**
Total of simulated highest 10% flows:	**2.39**	Total of Observed highest 10% flows:		**2.48**
Total of Simulated lowest 50% flows:	**0.51**	Total of Observed Lowest 50% flows:		**0.62**
Simulated Summer Flow Volume (months 7-9):	**0.32**	Observed Summer Flow Volume (7-9):		**0.33**
Simulated Fall Flow Volume (months 10-12):	**0.74**	Observed Fall Flow Volume (10-12):		**1.02**
Simulated Winter Flow Volume (months 1-3):	**2.21**	Observed Winter Flow Volume (1-3):		**2.41**
Simulated Spring Flow Volume (months 4-6):	**0.55**	Observed Spring Flow Volume (4-6):		**0.84**
Total Simulated Storm Volume:	**1.15**	Total Observed Storm Volume:		**1.13**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):		**0.04**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	**-16.86**	**10**		
Error in 50% lowest flows:	**-18.21**	**10**		
Error in 10% highest flows:	-3.81	15		
Seasonal volume error - Summer:	-2.57	30		
Seasonal volume error - Fall:	-27.06	30		
Seasonal volume error - Winter:	-8.53	30		
Seasonal volume error - Spring:	**-33.94**	**30**		
Error in storm volumes:	1.92	20		
Error in summer storm volumes:	**-69.42**	**50**		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.693	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.548	as E or E' approaches 1.0		
Monthly NSE	0.864			

2.4 WATER QUALITY DATA

Tetra Tech (2014, 2017) describes in detail the calibration of the Santa Margarita River watershed model for sediment and nutrients, using monitoring data collected through 2010. The current effort provides an adjustment and recalibration of the model using new data collected through the end of water year 2016 and incorporating the refinements to the hydrology calibration described above.

Water quality data have been collected at many locations and under many different programs in the Santa Margarita River watershed. Section 3 in Tetra Tech (2014) provided a summary of the data that are available for 1990 – 2013, while Tetra Tech (2017) gave an interim update through 2016. This section further updates data available through 2016 that is used in the current nutrient response modeling effort.

The summary provided here includes data collected from 2004 to 2017 and conducted by County of San Diego, USMC Camp Pendleton (MCBCP), Southern California Coastal Water Research Project (SCCWRP), and Rainbow Creek Total Maximum Daily Load monitoring (RBC TMDL), as well as water temperature data from a USGS station. Table 2-5 summarizes nutrient sample counts for 2014-2016 (the period of interest for the lower river nutrient response modeling) at locations within the Santa Margarita River watershed downstream of the confluence of Murrieta and Temecula Creeks. Parameters of interest for the model update include temperature, pH, dissolved oxygen (DO), alkalinity, and chlorophyll *a*. Therefore, sample counts for these data from old sampling (2004 – 2015) and new sampling (2015 – 2017) are provided as well. The locations of the monitoring stations are indicated in Figure 2-10.

While there are a number of sampling locations in the watershed, many have a limited number of samples. In some cases, a station only had one sample for certain parameters across the indicated period. Stations most useful for watershed model calibration are those that have a relatively large number of samples and cover a range of flow conditions. Individual or small sets of observations are less useful because there is typically a large component of random variability in water quality measurements. Continuous sampling of temperature, pH, and DO was completed at a number of stations along the Santa Margarita River and the sampling periods are indicated in Table 2-5. This continuous sampling is particularly useful for model calibration and was primarily completed at stations along the lower river in 2015 and 2016 and then at stations along the upper river in 2017.

There were 5 stations along the lower river that sampled continuous physico-chemistry in 2015, and 1 of these stations near the Old Hospital (SMR6) also sampled continuous physico-chemistry in 2016. Similarly, there were 4 stations along the upper river that sampled continuous physico-chemistry in 2017.

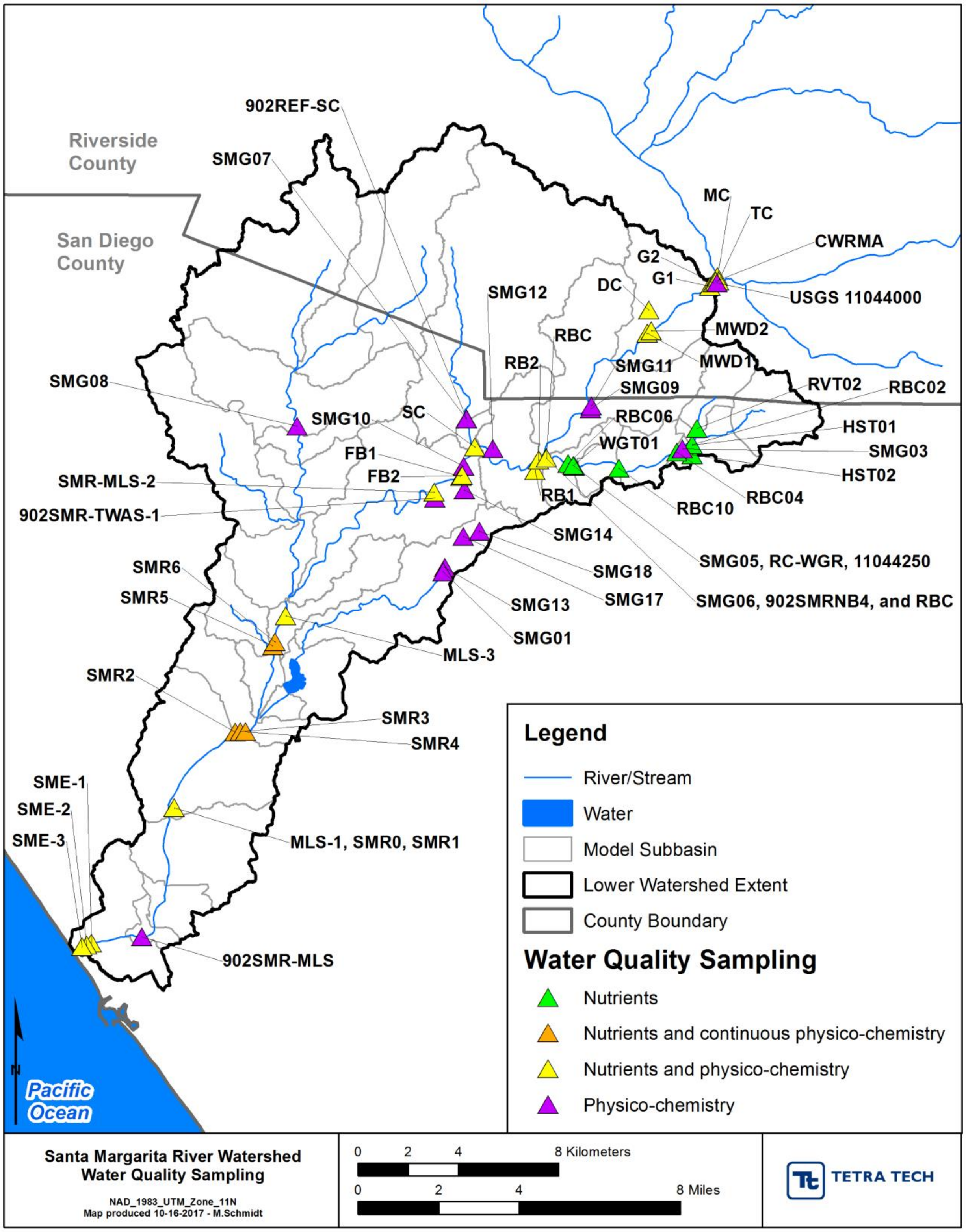


Figure 2-10. Water Quality Sample Locations

Table 2-5. Water quality sample counts from the Santa Margarita River Watershed

Station ID	Location	Sampling Program	Nutrient Sample Count 2014-2016	Old Sampling (from 2004 – 2015)					New Sampling (from 2015 – 2017)				
				Temperature	DO	pH	Alkalinity	Chlorophyll-a	Temperature	DO	pH	Alkalinity	Chlorophyll-a
HST01	Brow Ditch to Rainbow Creek at Huffstatler Street. 33.41526 - 117.15204	RBC TMDL	9										
HST02	Pipe from a nursery along Huffstatler Street. 33.41174 - 117.15196	RBC TMDL	9										
RBC02	Rainbow Creek @ Huffstatler Street. 33.41544 - 117.15199	RBC TMDL	33										
RBC04	Rainbow Creek @ Old Highway 395. 33.41272 - 117.15853	RBC TMDL	33										
RBC06	Rainbow Creek @ 2219 Willow Glen Road. 33.40859 - 117.20523	RBC TMDL	33										
RBC10	Rainbow Creek @ MWD Road Crossing. 33.40696 -117.18344	RBC TMDL	15										
RVT02	Chica tributary @ 1st Street. 33.42126 - 117.14983	RBC TMDL	8										
SMG05, RC-WGR, 11044250	Rainbow Creek @ Willow Glen Road. 33.40757 - 117.20253	RBC TMDL, SMRWQ Stetson, County of San Diego DWM	36			4		1					
902REF-SC	33.4247 - 117.24903	County of San Diego Receiving Waters						1					
902SMR-TWAS-1	33.39602 - 117.26237	County of San Diego Receiving Waters						1					

Station ID	Location	Sampling Program	Nutrient Sample Count 2014-2016	Old Sampling (from 2004 – 2015)					New Sampling (from 2015 – 2017)				
				Temperature	DO	pH	Alkalinity	Chlorophyll-a	Temperature	DO	pH	Alkalinity	Chlorophyll-a
SMG07	33.4246 -117.24904	County of San Diego MS4 Target Dry and DWM				13	5						
SMG08	33.42184 -117.32179	County of San Diego MS4 Target Dry and DWM				8	5						
SMG09	33.42839 -117.19561	County of San Diego DWM				14	2						
SMG10	33.4075 -117.25018	County of San Diego DWM				13	2						
SMG11	33.42936 -117.19531	County of San Diego MS4 Target Dry					1						
SMG12	33.41396 -117.23754	County of San Diego MS4 Target Dry					1						
SMG13	33.371 -117.25819	County of San Diego MS4 Target Dry					1						
SMG14	33.39892 -117.24979	County of San Diego MS4 Target Dry					1						
SMG17	33.38223 -117.25015	County of San Diego MS4 Target Dry					1						
SMG18	33.38407 -117.24336	County of San Diego MS4 Target Dry					1						
SMG01	33.36944 -117.25883	County of San Diego DWM				6							
SMG03	33.4139 -117.1561	County of San Diego DWM				4							

Station ID	Location	Sampling Program	Nutrient Sample Count 2014-2016	Old Sampling (from 2004 – 2015)					New Sampling (from 2015 – 2017)				
				Temperature	DO	pH	Alkalinity	Chlorophyll-a	Temperature	DO	pH	Alkalinity	Chlorophyll-a
SMG06, 902SMRNB4, and RBC	Rainbow Creek @ Stage Coach Lane. 33.41056 -117.21477	RBC TMDL, SMRWQ Stetson, SCCWRP, County of San Diego DWM	43			4							
WGT01	Pinckney Tributary @ Willow Glen Road. 33.40784 -117.20309	RBC TMDL	34										
MLS-1, SMR0, SMR1	MLS-1. 33.284 -117.374	MCBCP_2015-2016_MWSWWQMR, SCCWRP	8	20	3	23	20		2	2	2	2	2
SMR-MLS-2	De Luz Road Bridge over Santa Margarita Bridge. 33.398142 -117.26273	San Diego County long term and transitional monitoring, MCBCP_ 2015-2016_MWSWWQMR	6	20	12	20	25		1	1	1	1	
902SMR-MLS	33.237481 -117.387623	San Diego County long term and transitional monitoring		4		4	4						
MLS-3	33.353333, -117.326389	MCBCP_2015-2016_MWSWWQMR	3	1	1	1	1		2	2	2	2	
SME-1	Inlet of the embayment 33.23512, -117.40929	MCBCP_2015-2016_MWSWWQMR	3	7	7	7		7	1	1	1		1
SME-2	Mid-point of estuary 33.23436, -117.41127	MCBCP_2015-2016_MWSWWQMR	3	7	7	7		7	1	1	1		1
SME-3	Near the outlet of the embayment 33.23378, -117.41329	MCBCP_2015-2016_MWSWWQMR	3	7	7	7		7	1	1	1		1

Station ID	Location	Sampling Program	Nutrient Sample Count 2014-2016	Old Sampling (from 2004 – 2015)					New Sampling (from 2015 – 2017)				
				Temperature	DO	pH	Alkalinity	Chlorophyll-a	Temperature	DO	pH	Alkalinity	Chlorophyll-a
SMR-U	Reach upstream of De Luz Road Arizona crossing. 33.363064, -117.320461	MCBCP_2015-2016_MWSWWQMR	3	1	1	1		1	1	1	1		1
LPC	Reach in Las Pulgas/Flores Creek, approximately 150 feet east of Basilone Road 33.348333, -117.40333	MCBCP_2015-2016_MWSWWQMR		1	1	1		1	1	1	1		1
LPC-U	Reach in Las Pulgas/Flores Creek, approximately 0.25 mile east of Basilone Road 33.350877, -117.40125	MCBCP_2015-2016_MWSWWQMR							1	1	1		1
DC	Devils Creek. 33.464055 -117.170571	SCCWRP	12										15
FB	Unknown	SCCWRP	8						Continuous sampling: 3/14/2017 – 3/20/2017 5/1/2017 – 5/15/2017				12
FB1	Fallbrook Reach 1. 33.403861 -117.251214	SCCWRP	5										10
FB2	Fallbrook reach 2. 33.404209 -117.250867	SCCWRP	4									3	9
G	Unknown	SCCWRP	3						Continuous sampling: 3/30/17 – 4/2/2017 6/15/2017 – 7/7/2017				3
G1	Gorge Reach 1. 33.472561 -117.144391	SCCWRP	4										9
G2	Gorge Reach 2. 33.473825 -117.142828	SCCWRP	4										9
GG	Unknown	SCCWRP	4									2	10
MWD	Unknown	SCCWRP	8						Continuous sampling: 4/1/2017 – 8/8/2017				17
MWD1	The Crossing Reach 1.	SCCWRP	4									4	4

Station ID	Location	Sampling Program	Nutrient Sample Count 2014-2016	Old Sampling (from 2004 – 2015)					New Sampling (from 2015 – 2017)				
				Temperature	DO	pH	Alkalinity	Chlorophyll-a	Temperature	DO	pH	Alkalinity	Chlorophyll-a
	33.455589 - 117.171385												
MWD2	The Crossing Reach 2. 33.456564 - 117.169596	SCCWRP	4										4
RB	Unknown	SCCWRP	9						Continuous sampling: 3/16/2017 – 3/20/2017 5/3/2017 – 5/9/2017				12
RB1	Rainbow Above Confluence. 33.406051 - 117.219396	SCCWRP	4									1	9
RB2	Rainbow Below confluence. 33.409774 - 117.21788	SCCWRP	4									2	9
SC	Sandia Creek. 33.4145 - 117.245403	SCCWRP	10										15
MC	Murrieta Creek 33.476162 - 117.14121	SCCWRP	10										15
RBC	Rainbow Creek 33.410508 - 117.214598	SCCWRP	10										15
TC	Temecula Creek 33.474504 - 117.140722	SCCWRP	10										15
CWRMA	Comprehensive Water Rights Management Agreement discharge 33.474376 - 117.141941	SCCWRP	2										7
SMR2	33.31141 - 117.34799	SCCWRP	12						Continuous sampling: 6/10/2015 - 6/12/2015 5/27/2015 - 6/01/2015				4
SMR3	33.31162 - 117.34567	SCCWRP	19						Continuous sampling: 4/14/2015 - 4/20/2015 7/6/2015 - 7/9/2015 2/24/2015 - 2/27/2015				10

Station ID	Location	Sampling Program	Nutrient Sample Count 2014-2016	Old Sampling (from 2004 – 2015)					New Sampling (from 2015 – 2017)				
				Temperature	DO	pH	Alkalinity	Chlorophyll-a	Temperature	DO	pH	Alkalinity	Chlorophyll-a
SMR4	33.31156 - 117.34359	SCCWRP	16						Continuous sampling: 1/23/2015 - 1/29/2015 7/6/2015 - 7/9/2015				7
SMR5	33.34253 - 117.33185	SCCWRP	17						Continuous sampling: 1/23/2015 - 1/24/2015 4/14/2015 - 4/20/215 6/10/2015 - 6/12/2015 7/13/2015 - 7/16/2015 5/27/2015 - 6/02/2015				8
SMR6	33.34401 - 117.33095	SCCWRP	21						Continuous sampling: 1/23/2015 - 1/24/2015 4/14/2015 - 4/20/2015 5/27/2015 - 6/02/2015 5/26/2016 - 8/25/2016				11
USGS 11044000	Santa Margarita R NR Temecula 33.473889 - 117.141389	USGS		Daily sampling: 12/15/1999 – 9/30/2016 Hourly sampling: 10/1/2007 – 9/30/2016									

2.5 NUTRIENT MODEL UPDATES

1.1.1 Upland Nutrient Loads

Upland nutrient loading rates for land uses in the study area are presented in Table 2-6. These represent nutrient loads combined from surface and subsurface flow pathways. Changes from Tetra Tech (2017) are small. For most land uses, simulated average annual yields (Table 2-6) are of similar magnitude to rates specified in the Rainbow Creek TMDL, which range from 0.18 - 0.70 lb/ac/yr for TP and 2.2 – 3.4 lb/ac/yr for TN. For the whole watershed area downstream of the confluence of Murrieta and Temecula Creeks, the upland nutrient loads average 0.26 lb/ac TP and 1.78 lb/ac TN.

Table 2-6. Simulated TN and TP Loading Rates for Revised HSPF Model

Land Use/Cover	Total Nitrogen Yield (lb/ac/yr)	Total Phosphorus Yield (lb/ac/yr)
CALTRANS	2.430	0.275
Chaparral, scrub	0.988	0.194
Commerical, institutional	1.375	0.104
Forest	0.452	0.137
Grassland, herbaceous	0.412	0.156
Horse ranches	2.766	0.461
Industrial	2.086	0.164
Irrigated agriculture	5.696	0.742
Non-irrigated agriculture	0.694	0.344
Nurseries	16.902	1.630
Open and recreation	1.825	0.207
Orchards, vineyards	4.727	0.453
Parks and recreation	2.085	0.248
Residential (pervious)	1.990	0.285
Road, freeway	2.008	0.356
Transitional	2.057	0.807
Water	4.483	0.012
Impervious	1.652	0.438

1.1.2 Stream Nutrient Recalibration Results

Graphical representations and tabular statistics are presented for stream calibration locations. In general, quantitative statistics are only presented when the sample count equals or exceeds 30, as discussed in Tetra Tech (2017), Section 5.2. Exceptions were made for sites on the lower Santa Margarita River and for Sandia Creek where monitoring data is sparse but important to review.

Nutrient parameters are varied by land use, but are held constant across all weather zones due to the relative shortage of monitoring data in locations other than the Rainbow Creek drainage. Results are variable, but generally reasonable for TN and TP given the relative lack of storm event sampling in recent years. Strong spatial and temporal shifts are evident at many of the Rainbow Creek stations, likely representing differences in operation of individual nurseries and orchards combined with changes in management practices over time. Many samples are from extreme low flow conditions, where highly variable results can be expected from water that is near stagnant conditions and likely experiencing transient algal blooms.

It should be noted that some of the observed data are of suspect quality. Rainbow Creek monitoring during 2005-2007 was obtained using field colorometric strips rather than via laboratory analyses, likely resulting in poor precision (Weston, 2017). Some of the concentration data obtained during the 1990s is also either suspect or influenced by unknown external factors, as noted in Tetra Tech (2014). For example, the station on the Santa Margarita River at Fallbrook PUD shows nitrate N concentrations consistently in the range of 10 mg/L in 1995-1996, followed by an abrupt downward shift to the 2 mg/L range in 1997 and thereafter. Results at the downstream stations on the mainstem (Ysidora and MLS-1) appear credible, suggesting the model is appropriate for use in evaluating loads to the estuary.

Due to the nature of most recent water quality monitoring, the revisions to the nutrient calibration primarily apply to low flow, dry weather conditions, which coincide with critical conditions for eutrophication. Under these conditions, observed water quality primarily reflects groundwater discharge and irrigation return flows. Nutrient loads associated with wet weather events must primarily be inferred from monitoring prior to 2000, so there was not a firm basis to alter those aspects of the calibration from the prior effort. Overall statistics comparing observed and simulated concentrations and loads for nutrients are thus generally of similar quality to those presented previously in Tetra Tech (2014), although using a somewhat different selection of monitoring sites.

Little recent monitoring has occurred on De Luz and Sandia Creeks. For the Santa Margarita mainstem, concentrations simulated by the model are strongly influenced by the upstream boundary condition below the confluence of Murrieta and Temecula Creeks, which is subject to a high degree of uncertainty as described in Section 2.1.

The following sections present detailed results by station, arranged in approximate upstream to downstream order. Only the (re-)calibration period (WY 2008 – WY 2016) is shown as it contains the 2015-2016 period for which the detailed nutrient response models were developed, due to availability of monitoring data. See sections 2.5.2.10 and 2.5.2.11 for the key locations to the nutrient response modeling.

2.5.1.1 Chica Tributary of Rainbow Creek at 1st Street (RVT02)

Chica Creek is a small tributary stream to upper Rainbow Creek. During periods of extended dry weather Chica Creek ponds, retaining flow and nutrients that would otherwise be discharged to Rainbow Creek. Water quality sampling near the mouth of Chica Creek began in the mid-2000s and samples were collected a few times each year through 2016. Accompanying flow records confirm that sampling was primarily conducted during dry weather and, at times, the creek was at a standstill. Observed TN and TP concentrations were steadily high, averaging 24.7 mg/L and 0.60 mg/L, respectively, despite the largely rural characteristics of the drainage area.

Table 2-7. Water Quality Calibration Statistics for Chica Tributary at 1st Street (RVT02)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3-N**	**TN**	**SRP**	**TP**
Count	71	55	72	74	74	73	74
Concentration Average Error	-73.69%	-16.29%	-15.12%	-72.13%	-69.29%	-39.63%	-43.97%
Concentration Median Error	-15.95%	16.67%	14.49%	-62.37%	-60.01%	-27.57%	-31.11%
Load Average Error	-86.84%	-88.08%	-88.12%	-89.52%	-89.21%	-80.53%	-82.49%
Load Median Error	-8.47%	-2.71%	-2.65%	-47.02%	-42.71%	-25.71%	-27.14%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

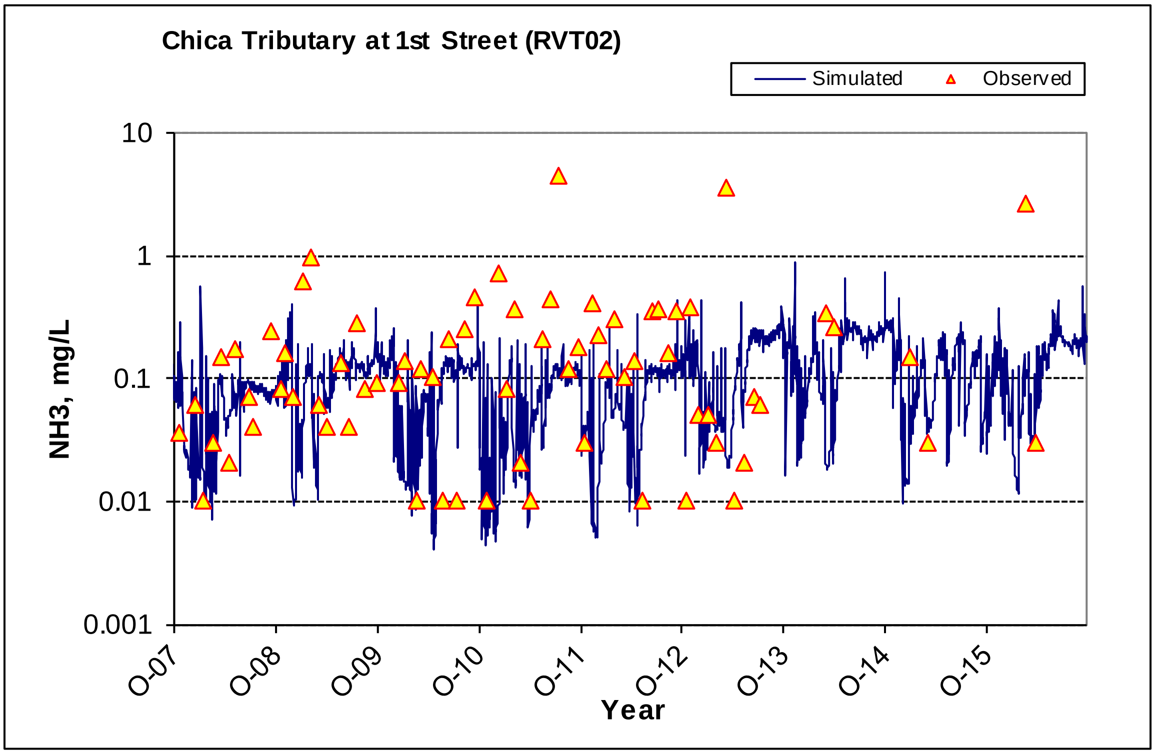


Figure 2-11. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Chica Tributary at 1st Street (RVT02)

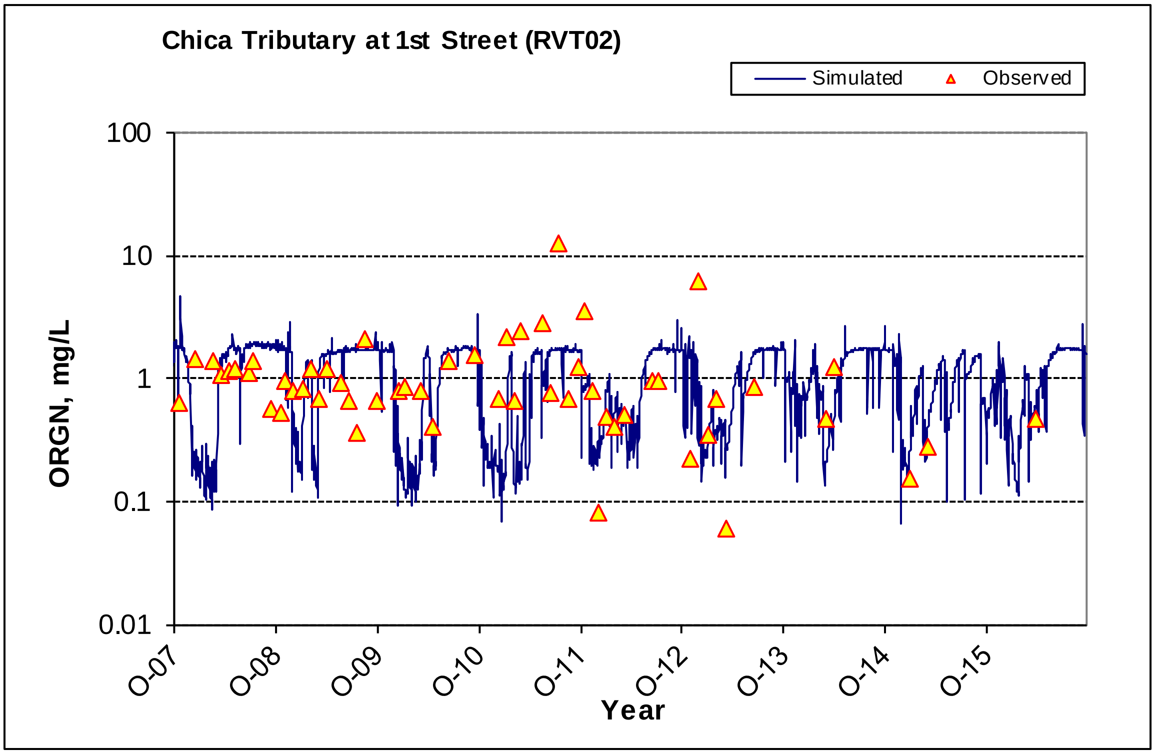


Figure 2-12. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Chica Tributary at 1st Street (RVT02)

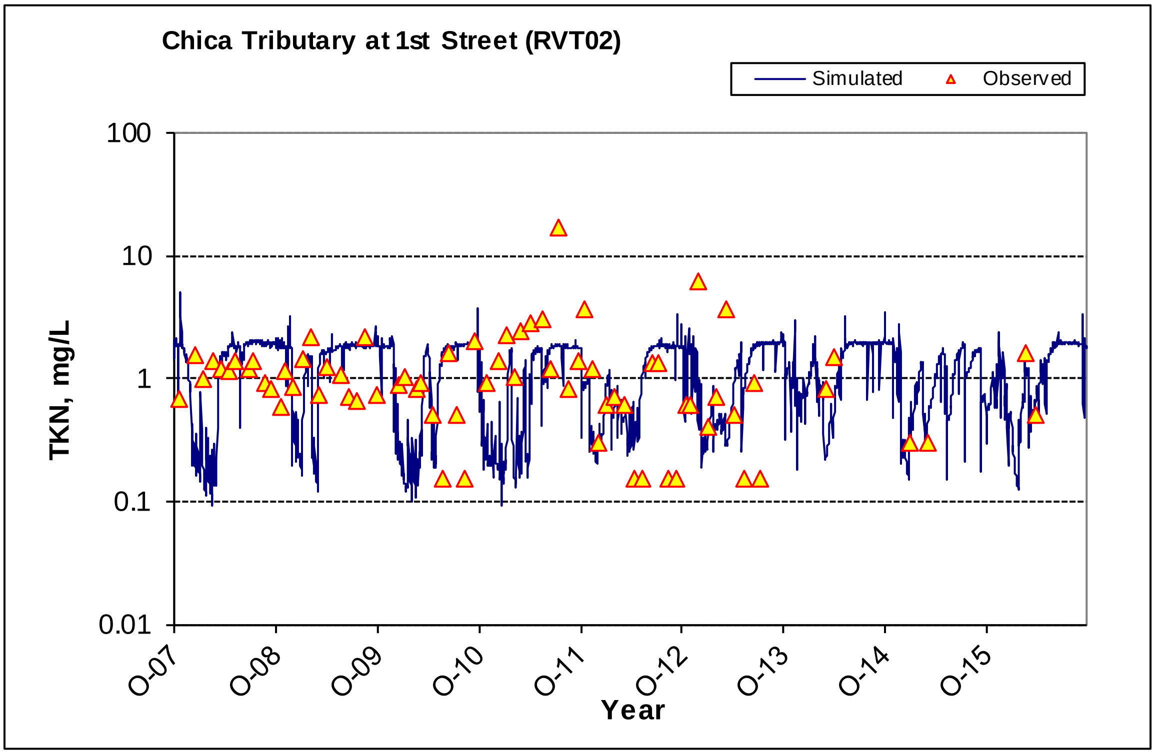


Figure 2-13. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Chica Tributary at 1st Street (RVT02)

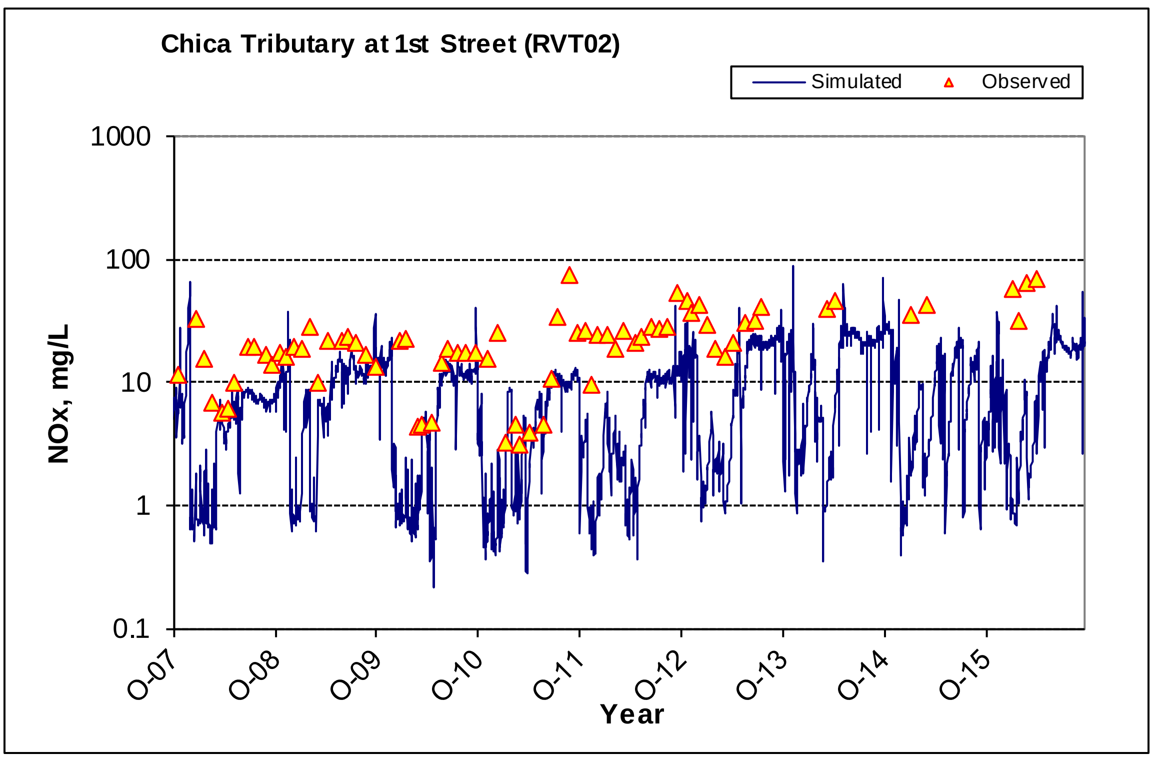


Figure 2-14. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Chica Tributary at 1st Street (RVT02)

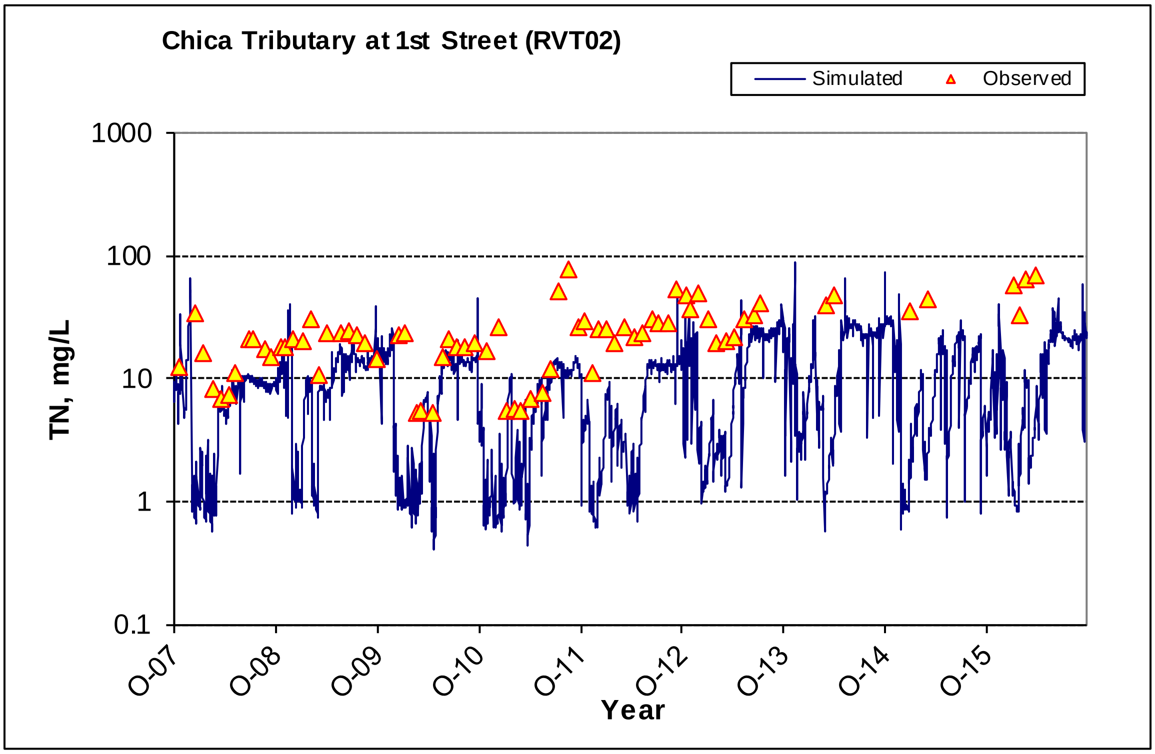


Figure 2-15. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Chica Tributary at 1st Street (RVT02)

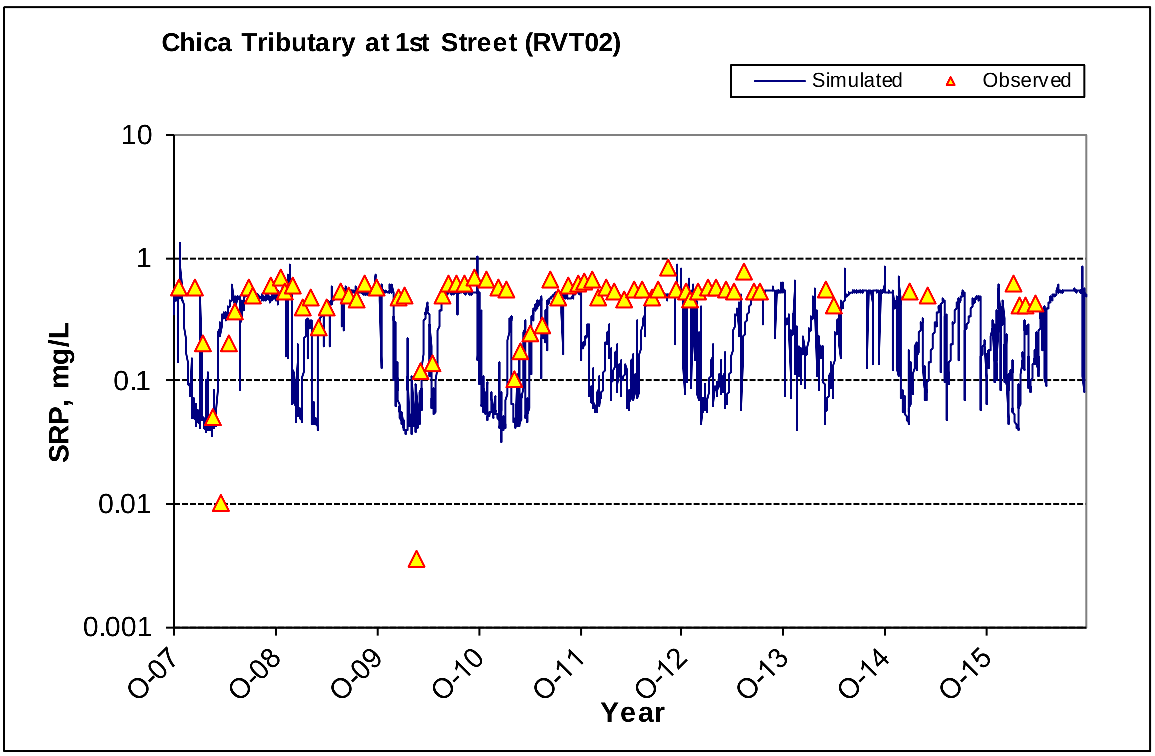


Figure 2-16. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Chica Tributary at 1st Street (RVT02)

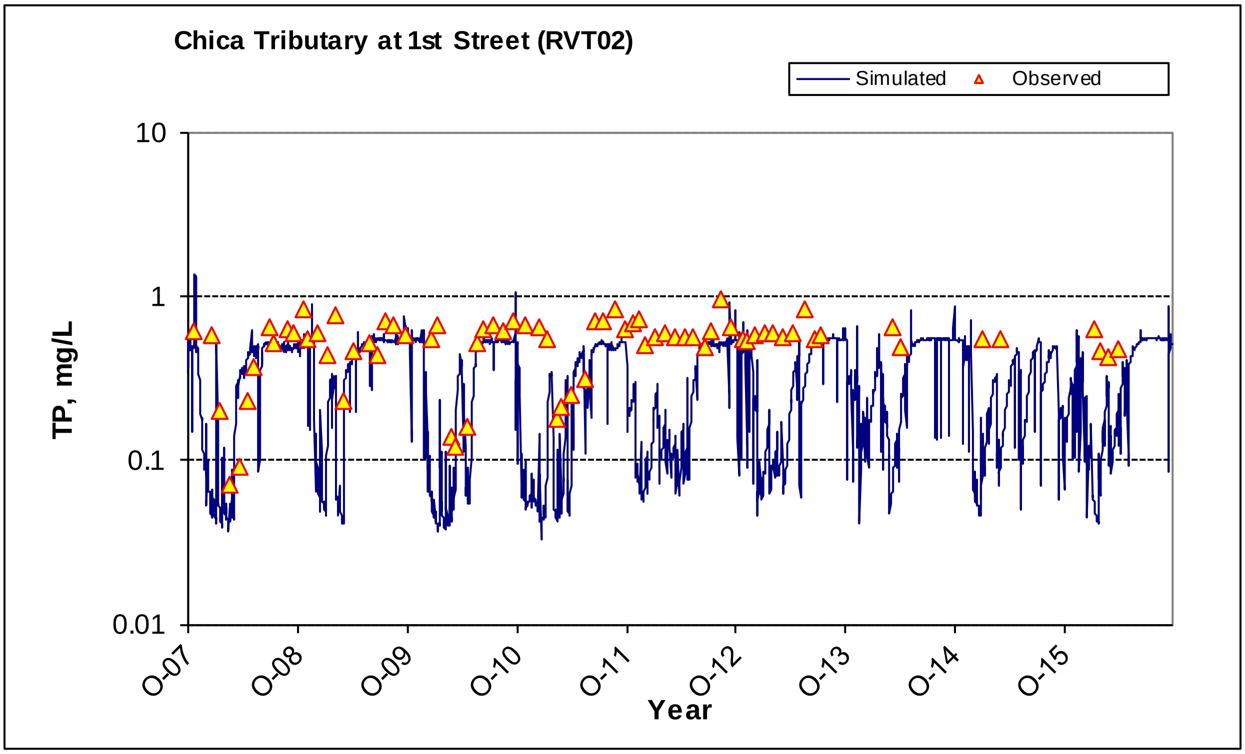


Figure 2-17. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Chica Tributary at 1st Street (RVT02)

1.1.2.1 Rainbow Creek at Jubilee Way (RBC01)

Jubilee Way is the most upstream sampling site on Rainbow Creek. Nutrient data was collected at this location from the mid-2000s to 2011. Nitrogen and phosphorus concentrations vary widely in the headwaters of Rainbow Creek. Recorded soluble reactive P concentrations, for example, range from as low as 0.002 mg/L to as high as 0.32 mg-P/L. Sample counts for all nutrient species are less than 30, so formal statistics are not presented. Nonetheless, this sampling site was useful for characterizing water quality conditions in the headwaters of Rainbow Creek.

Table 2-8. Water Quality Calibration Statistics at Rainbow Creek at Jubilee Way (RBC01)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3 -N**	**TN**	**SRP**	**TP**
Count	20	14	20	20	20	20	20

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

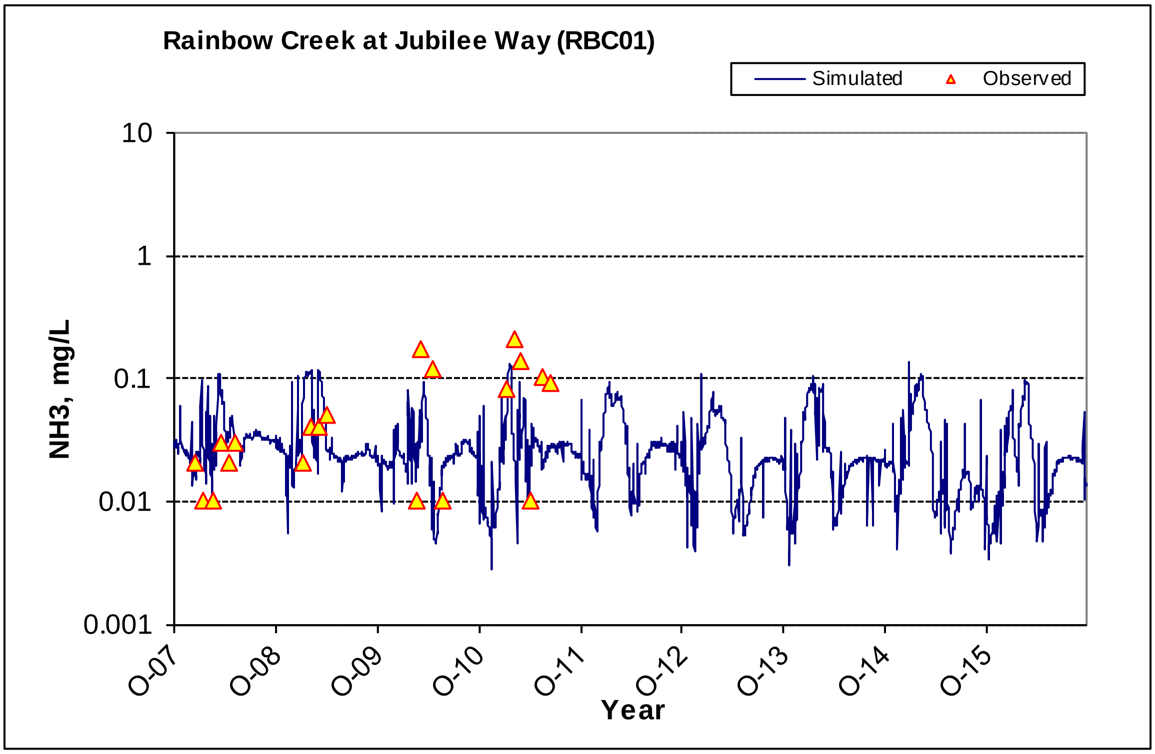


Figure 2-18. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Jubilee Way (RBC01)

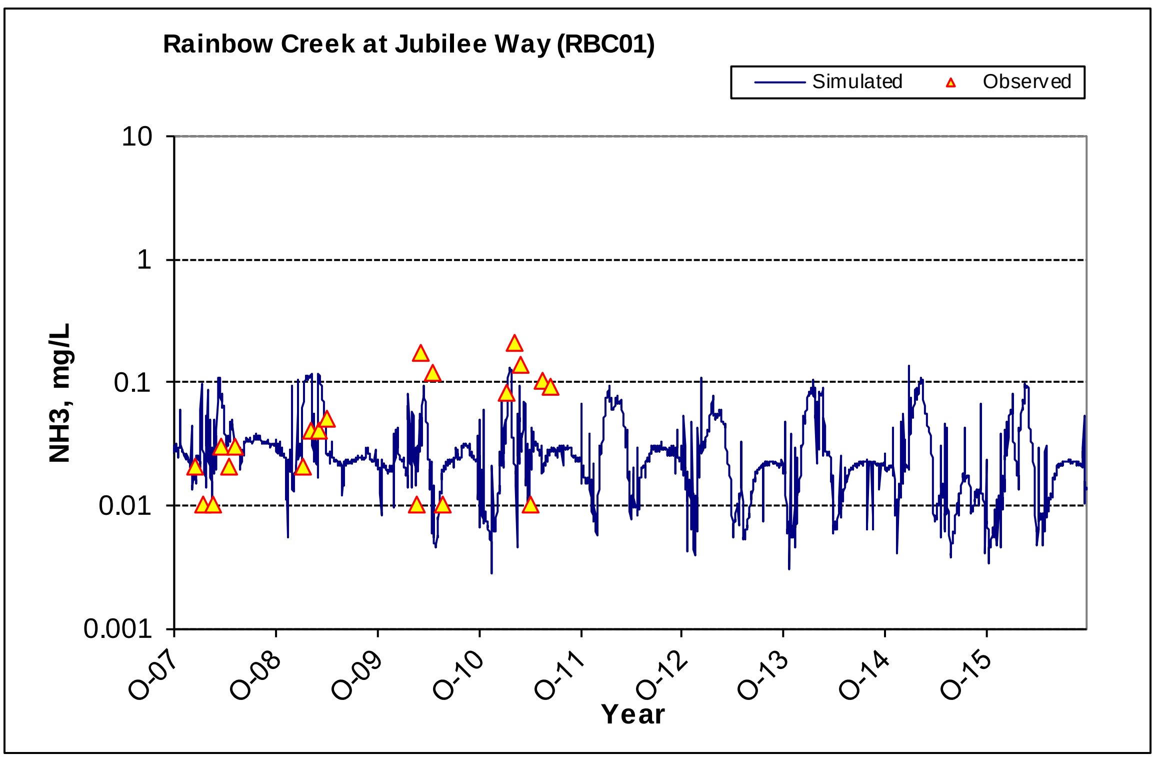


Figure 2-19. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Jubilee Way (RBC01)

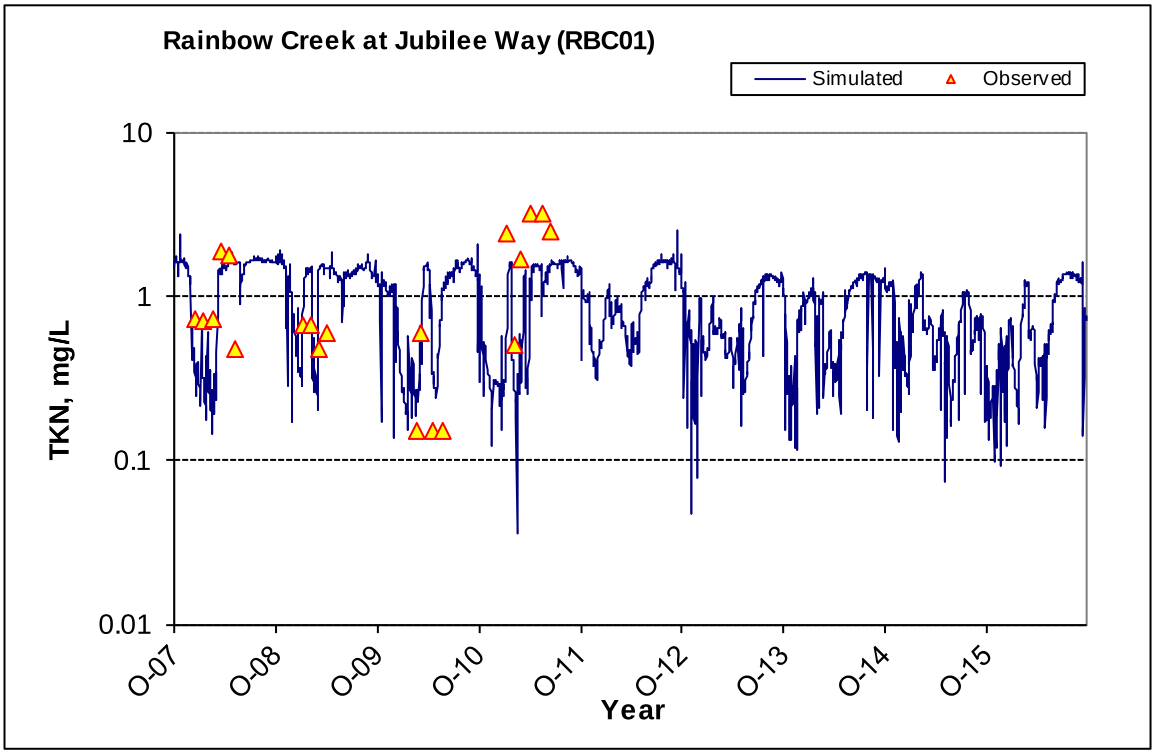


Figure 2-20. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Jubilee Way (RBC01)

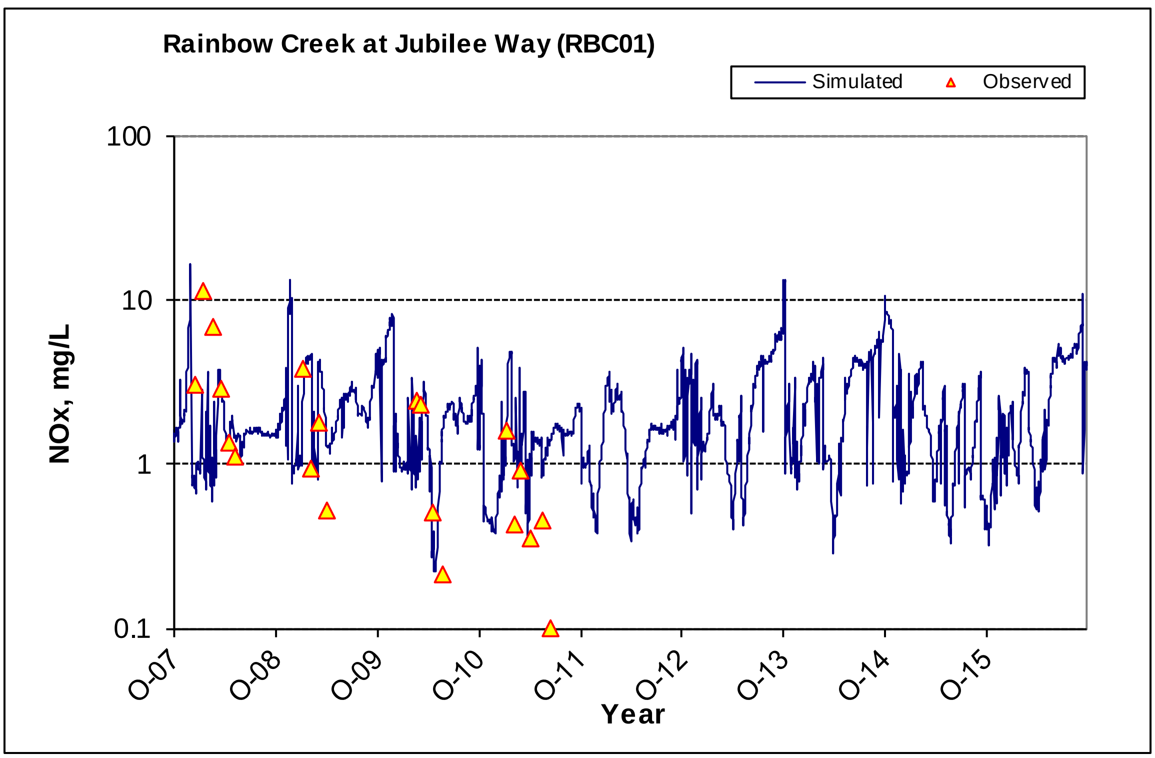


Figure 2-21. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Jubilee Way (RBC01)

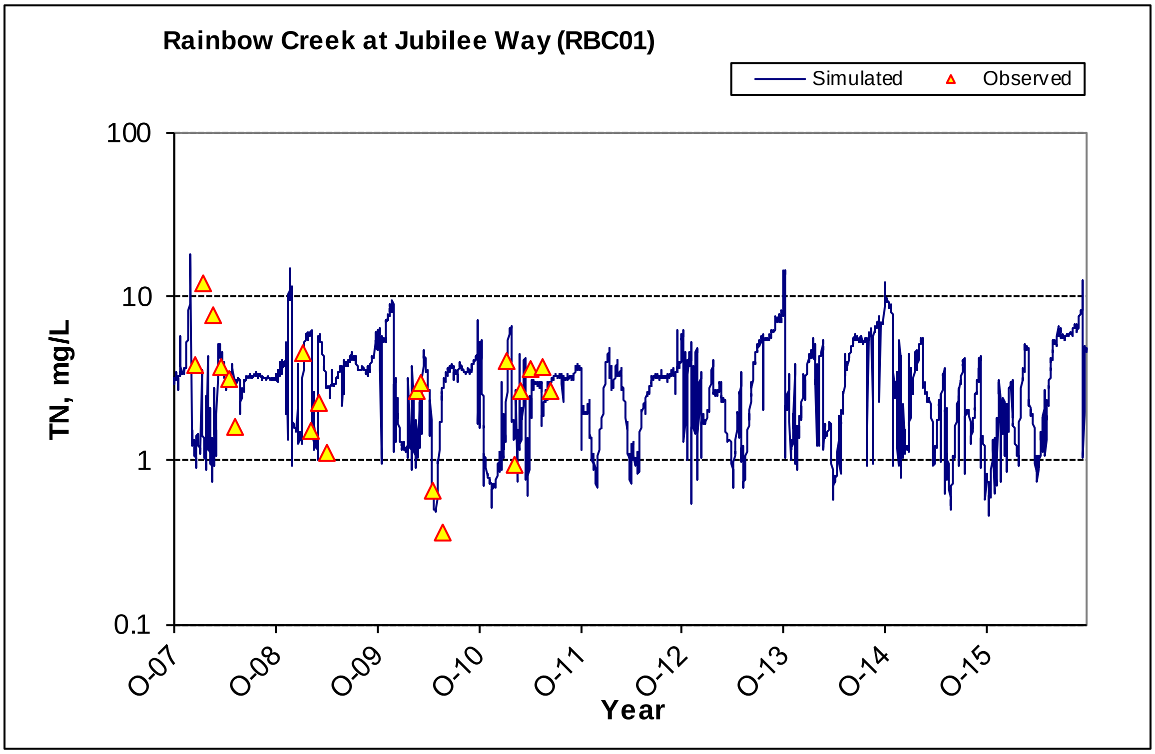


Figure 2-22. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Jubilee Way (RBC01)

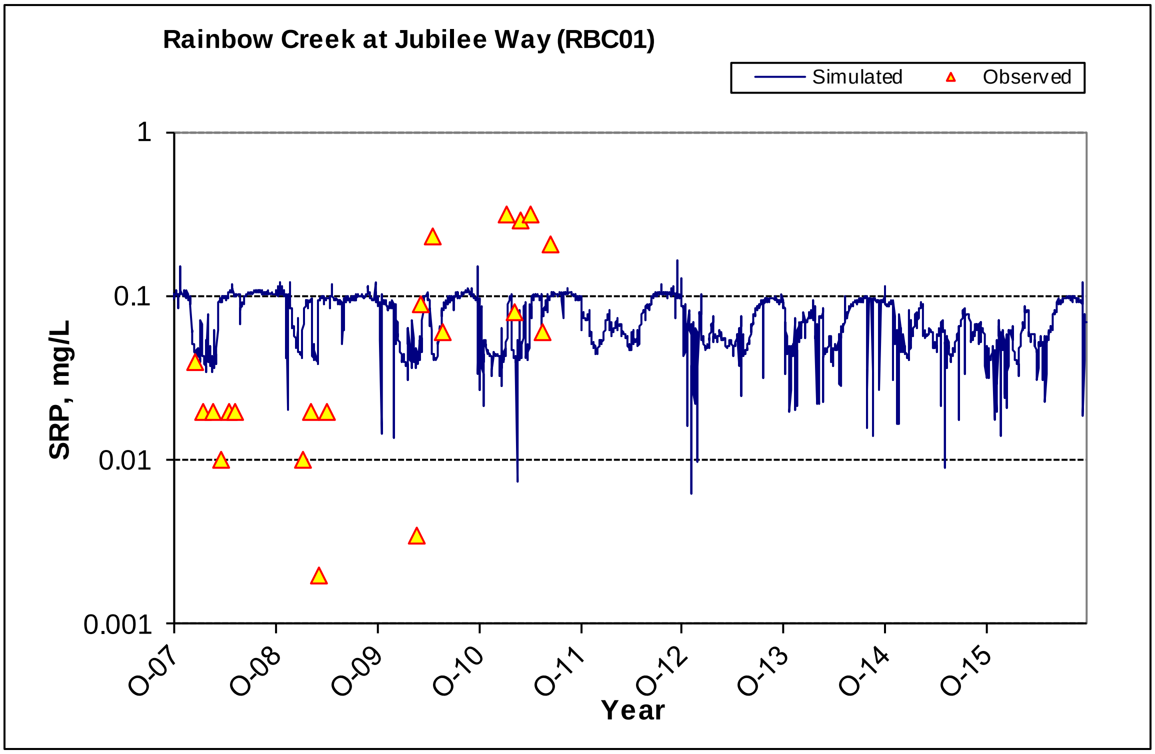


Figure 2-23. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Jubilee Way (RBC01)

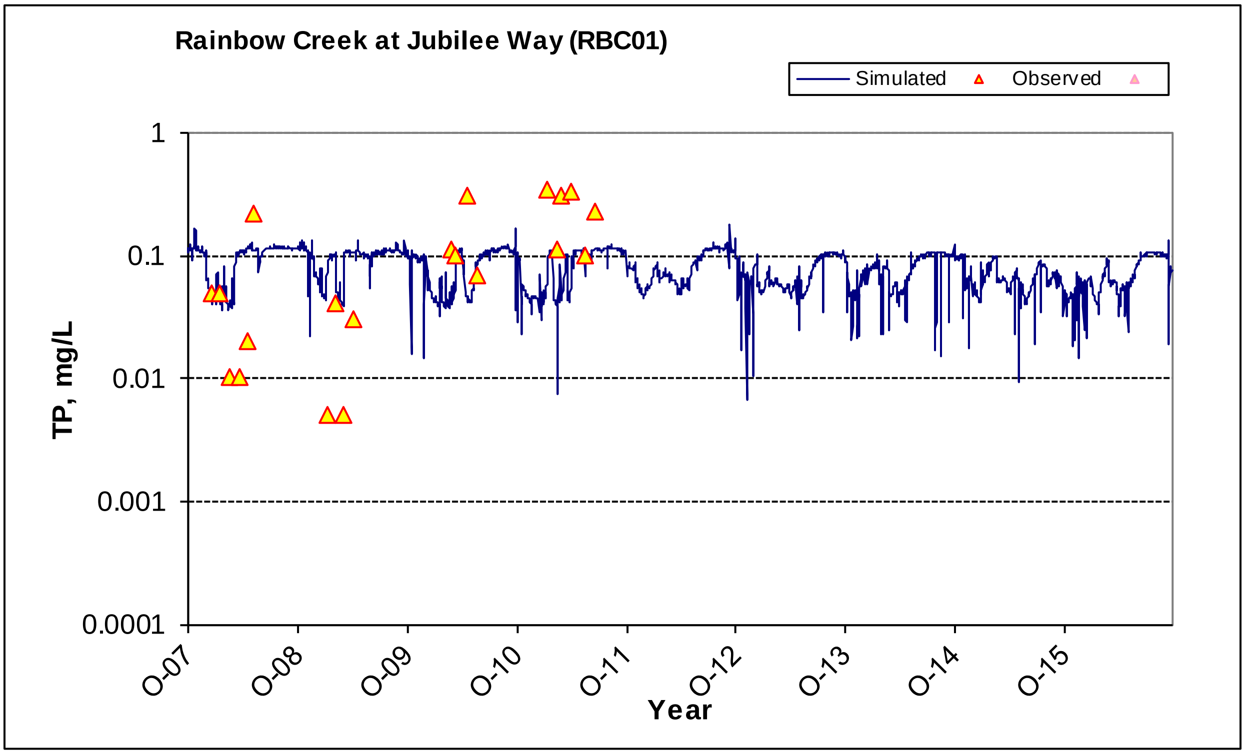


Figure 2-24. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Jubilee Way (RBC01)

1.1.2.2 Rainbow Creek at Huffstatler Street (RBC02)

The Huffstatler Street location is the second most upstream water quality sampling site for Rainbow Creek, but is in an area of intensive nursery development. Samples were retrieved more frequently during recent years. Time series plots of observed concentrations show temporal dynamics in nutrient concentrations at this location. Nitrite-N + nitrate-N concentrations spike in 2011 and remain elevated through 2016. This trend is possibly due to changes in fertilizer application, malfunctioning irrigation water recovery systems, or other practice changes by nurseries in the area.

Table 2-9. Water Quality Calibration Statistics at Rainbow Creek at Huffstatler Street (RBC02)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+NO_3 -N	TN	SRP	TP
Count	98	74	99	103	102	101	102
Concentration Average Error	-69.39%	17.68%	11.87%	-76.81%	-74.45%	3.79%	-8.90%
Concentration Median Error	-5.35%	44.36%	34.48%	-68.95%	-64.46%	10.88%	-4.29%
Load Average Error	-92.90%	-80.81%	-79.69%	-90.18%	-89.27%	-70.57%	-74.30%
Load Median Error	-1.03%	0.51%	0.53%	-56.19%	-51.44%	-7.66%	-8.07%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

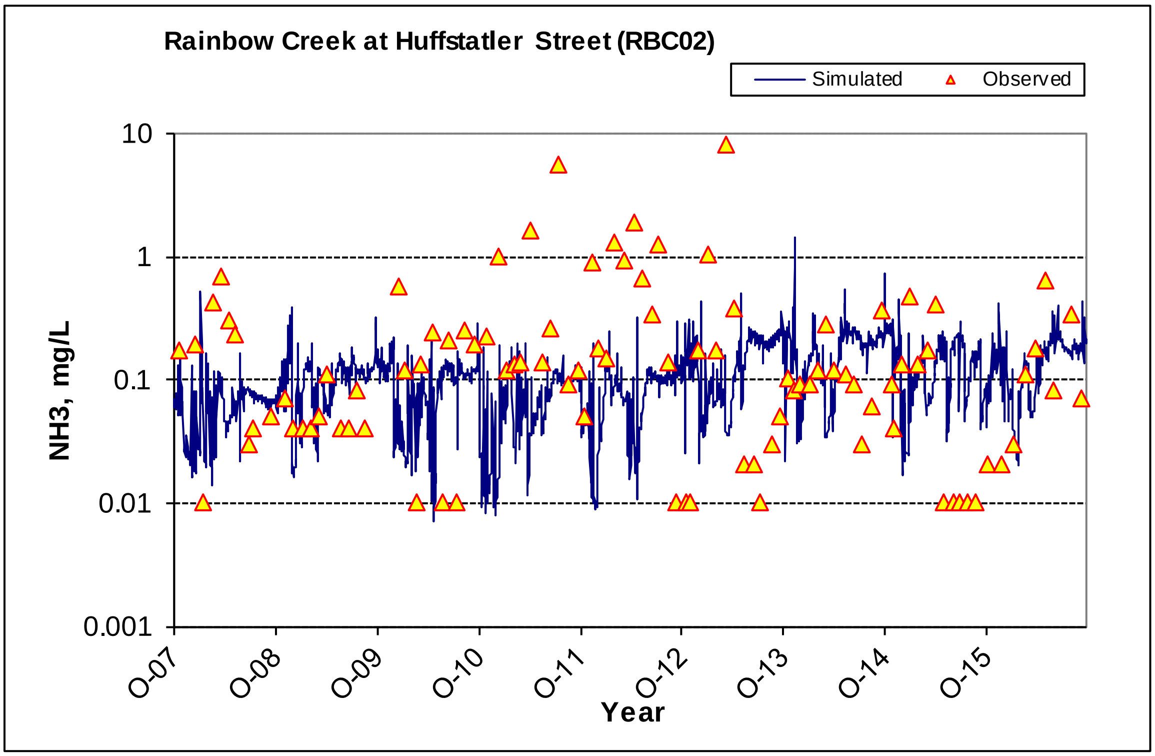


Figure 2-25. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

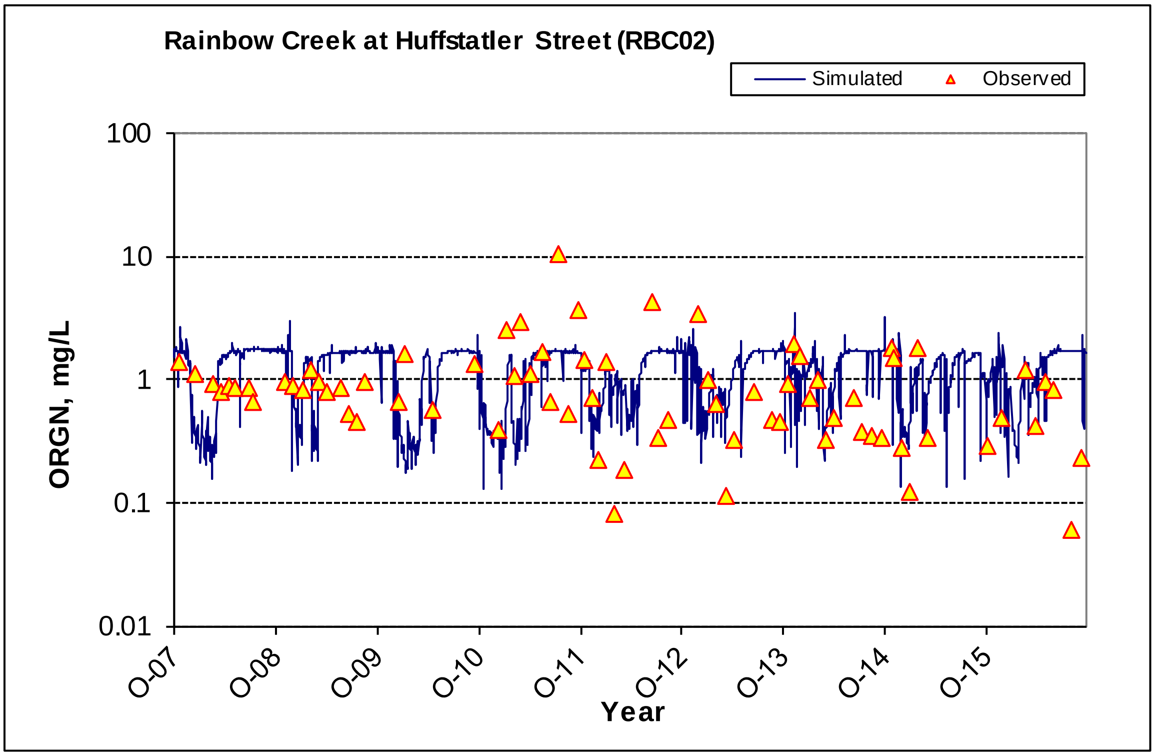


Figure 2-26. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

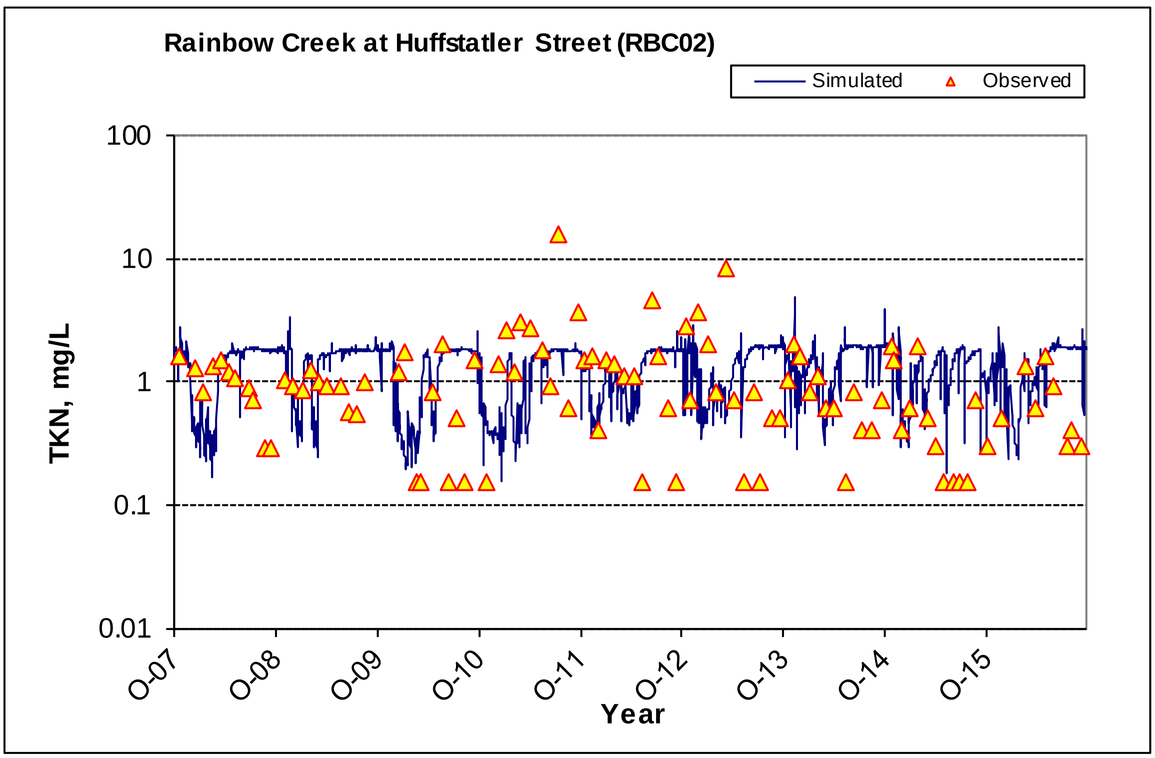


Figure 2-27. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

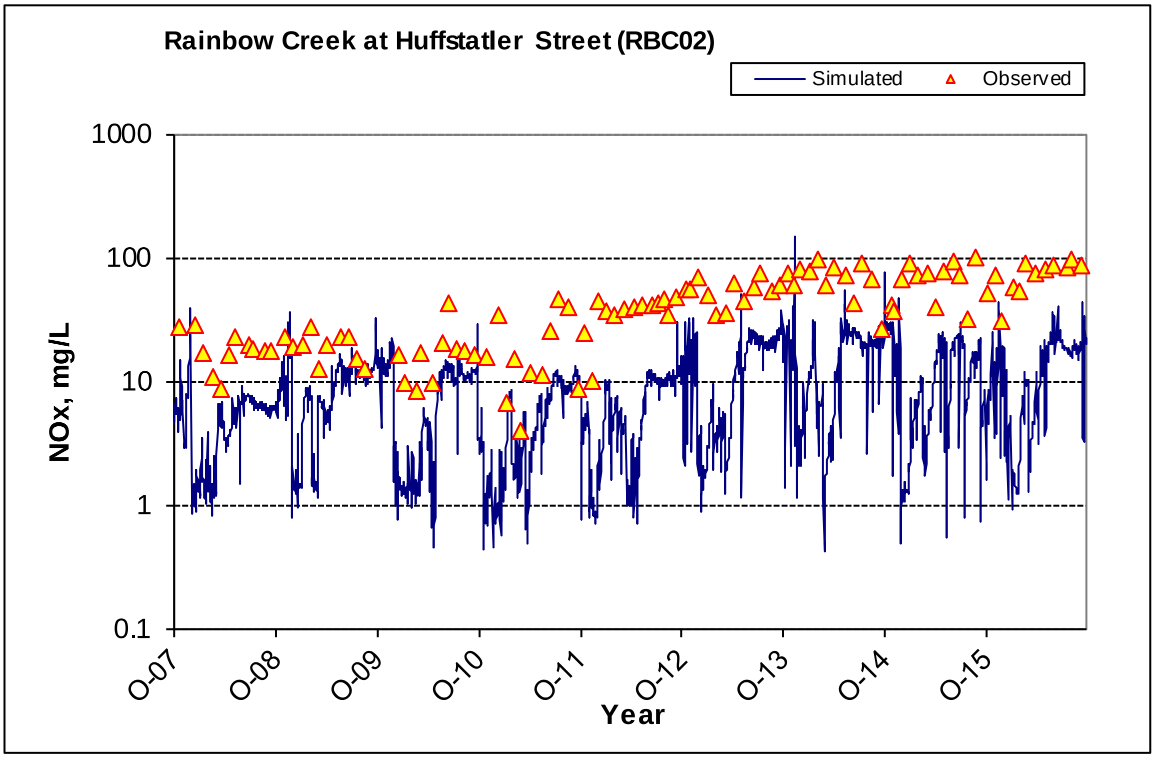


Figure 2-28. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

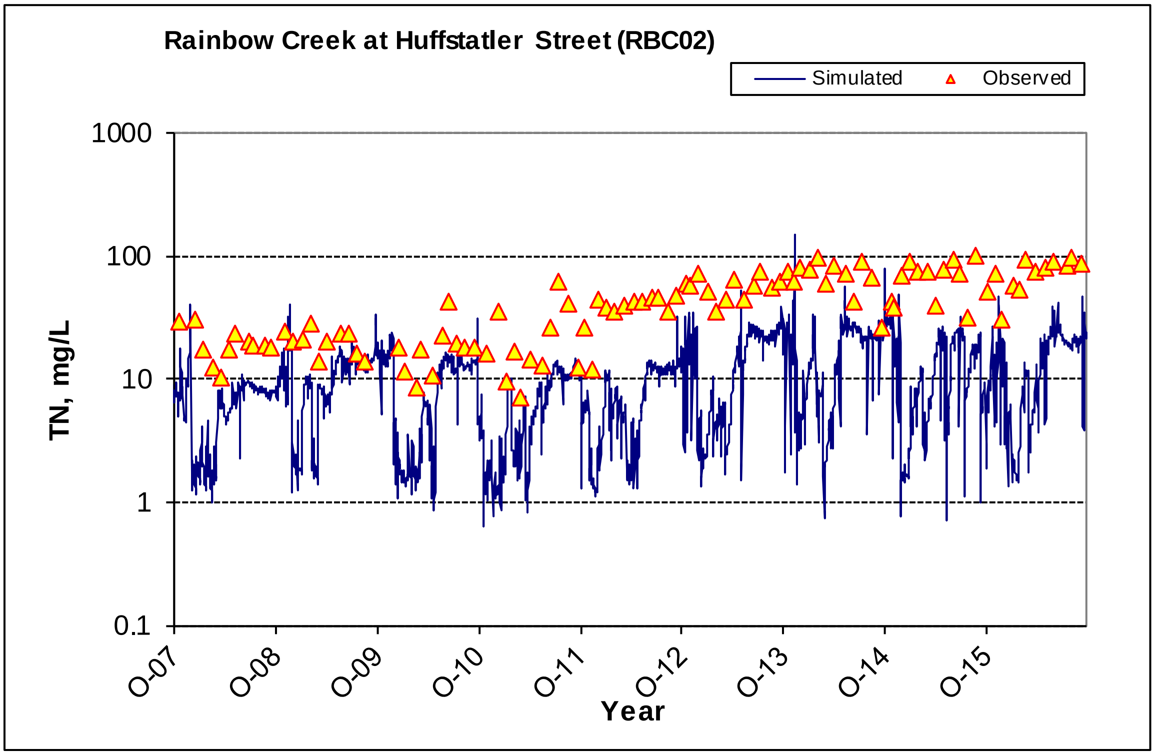


Figure 2-29. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

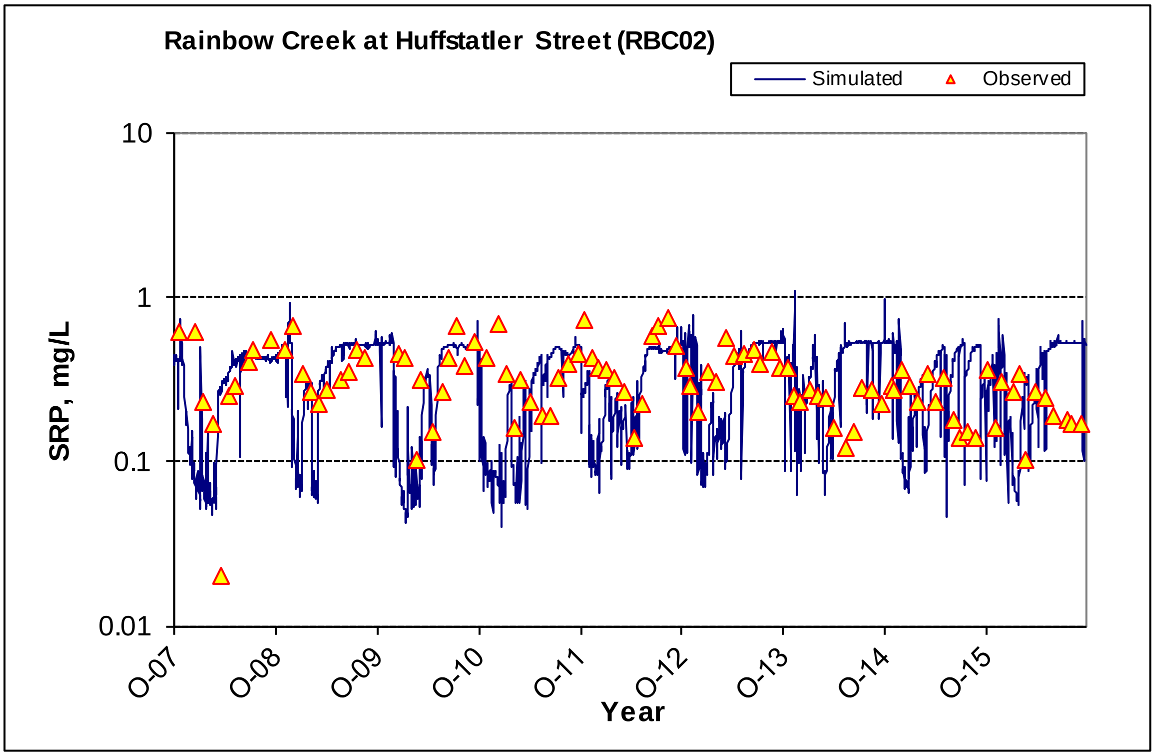


Figure 2-30. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

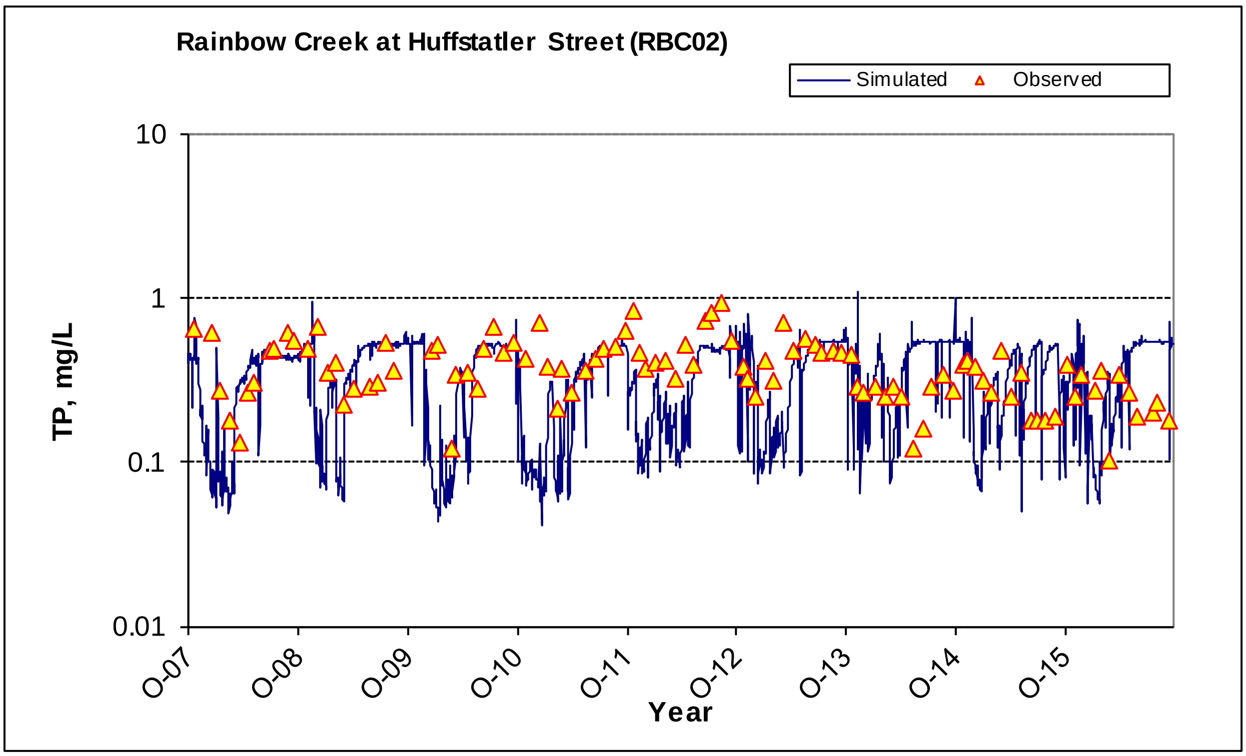


Figure 2-31. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

1.1.2.3 Rainbow Creek at Old Hwy 395 (RBC04)

The sampling location at Old Highway 395 is situated downstream of Huffstatler (RBC02). Similar to the Huffstatler site, observed nitrite-N + nitrate-N concentrations have been trending upward in recent years, consistent with the trend analysis in Appendix A to Weston (2017). Model fit for soluble reactive P is better for the recent period while simulated nitrite-N + nitrate-N concentrations match more closely to observed concentrations prior to 2011.

Table 2-10. Water Quality Calibration Statistics at Rainbow Creek at Old Hwy 395 (RBC04)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3 -N**	**TN**	**SRP**	**TP**
Count	99	76	99	106	105	104	105
Concentration Average Error	-58.02%	-21.84%	-23.30%	-66.37%	-63.98%	3.42%	-7.12%
Concentration Median Error	5.86%	23.95%	19.64%	-55.25%	-52.74%	12.96%	7.79%
Load Average Error	-89.72%	-80.40%	-81.96%	-90.46%	-89.67%	-72.45%	-75.19%
Load Median Error	-0.53%	0.40%	-0.70%	-38.60%	-36.97%	-10.92%	-11.75%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

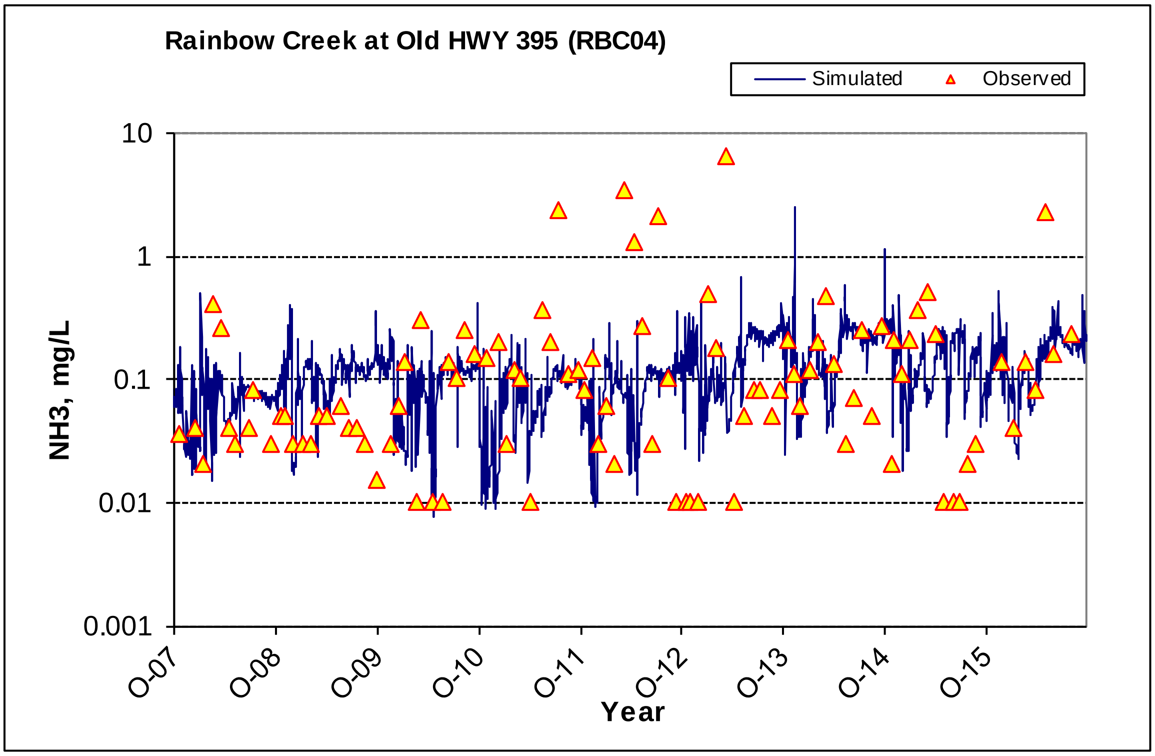


Figure 2-32. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

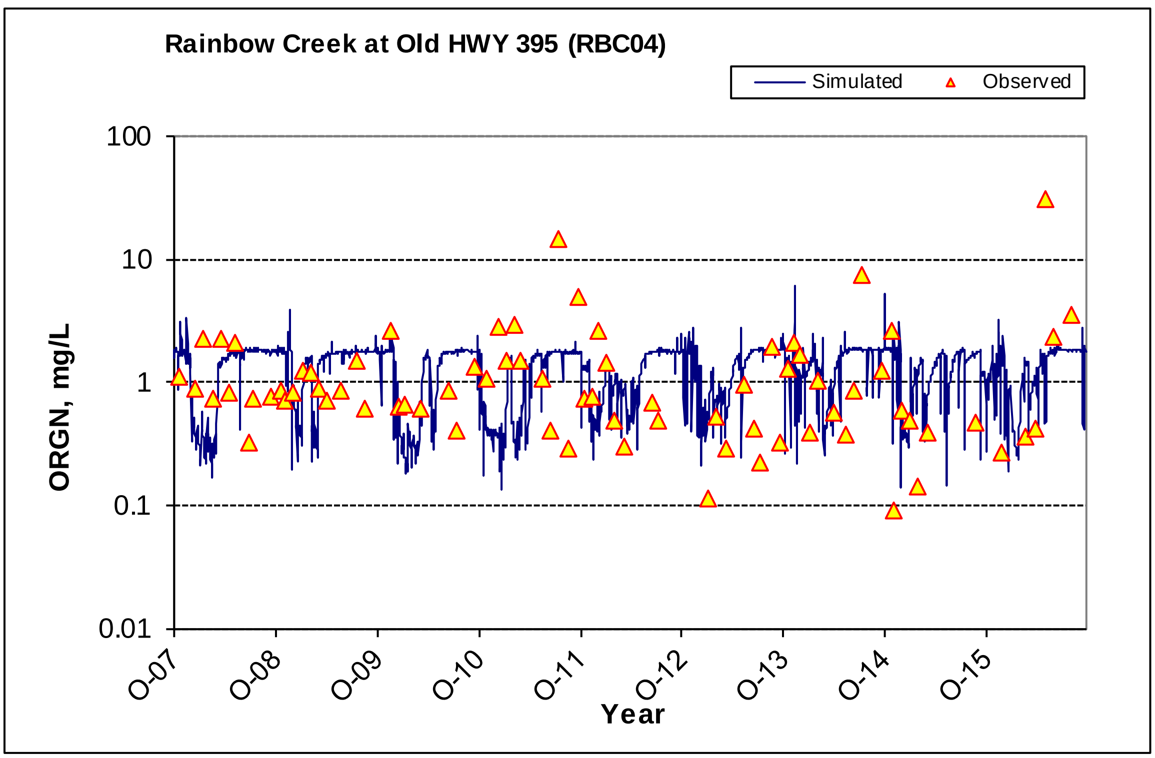


Figure 2-33. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

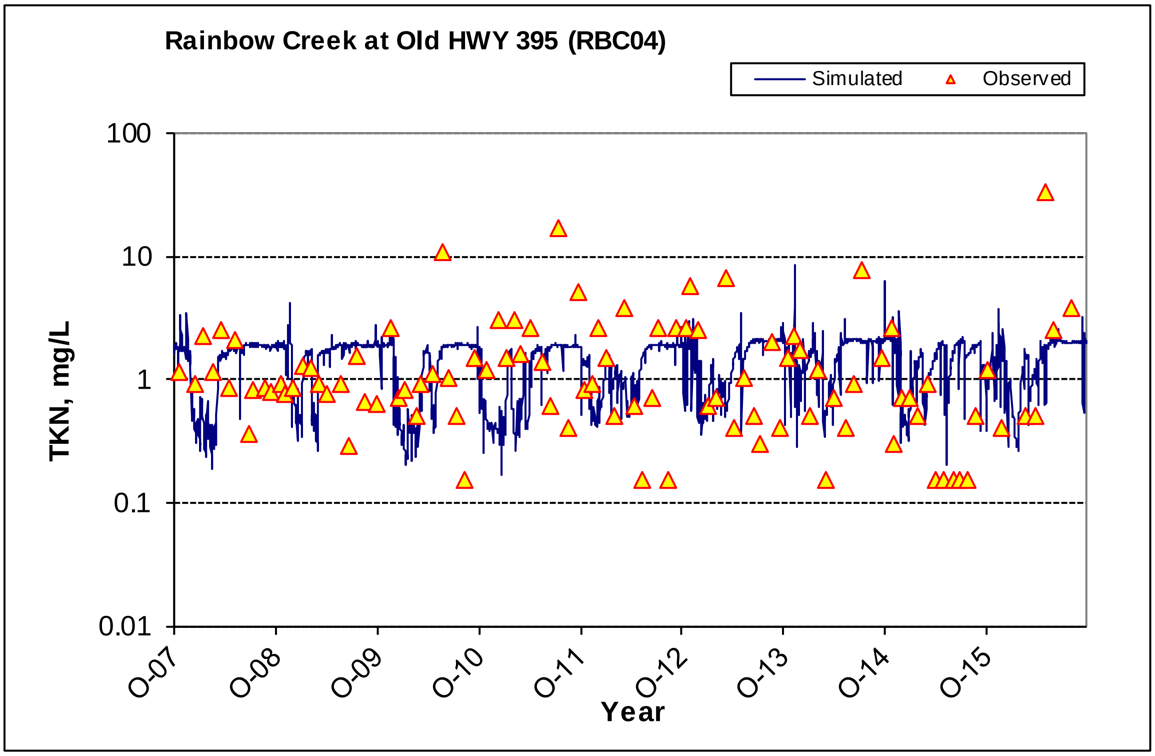


Figure 2-34. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

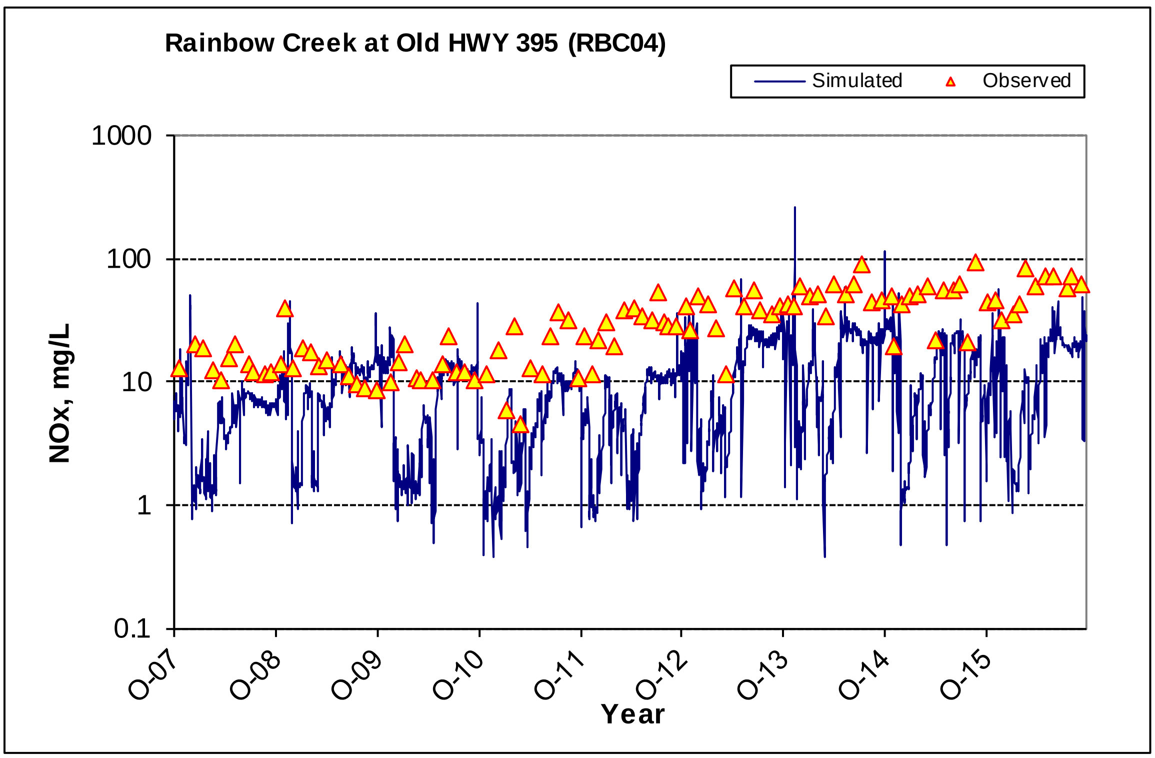


Figure 2-35. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

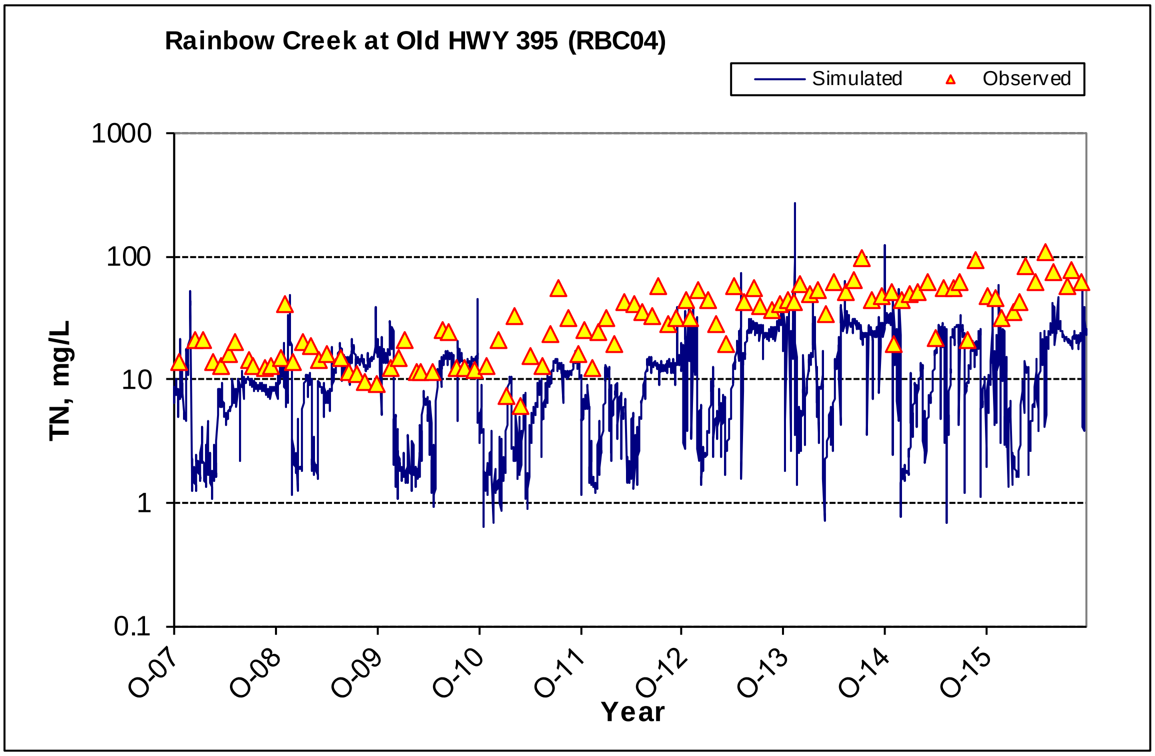


Figure 2-36. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

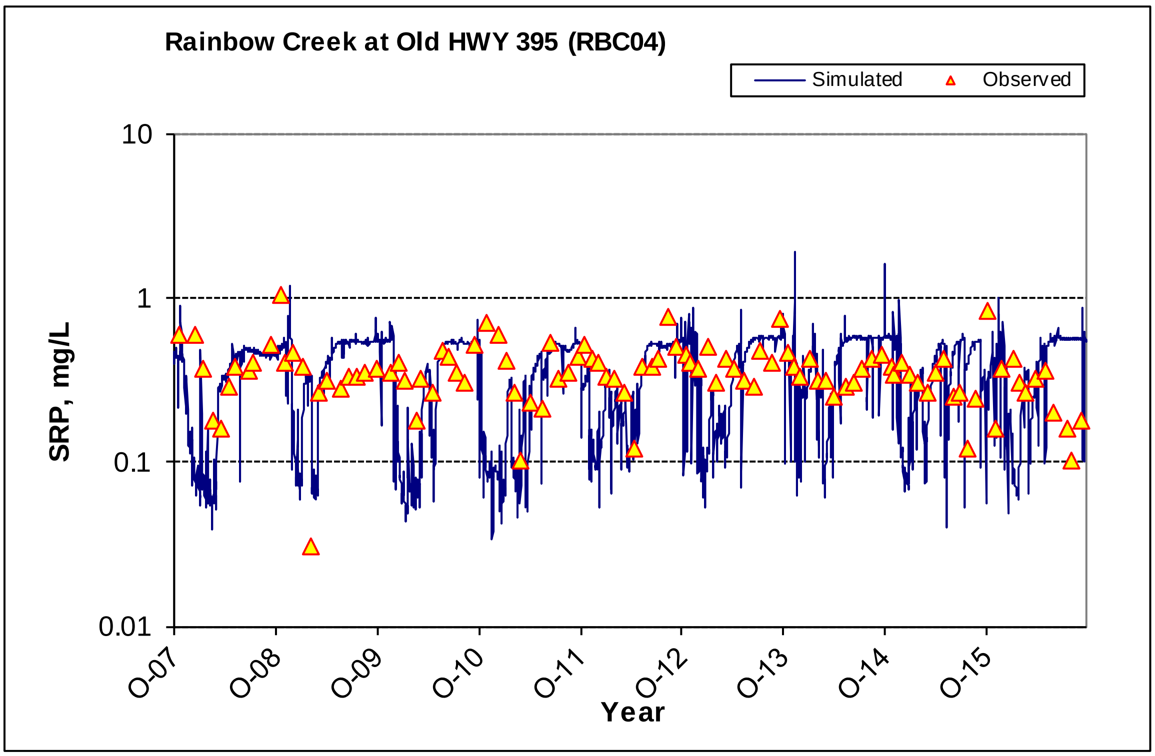


Figure 2-37. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

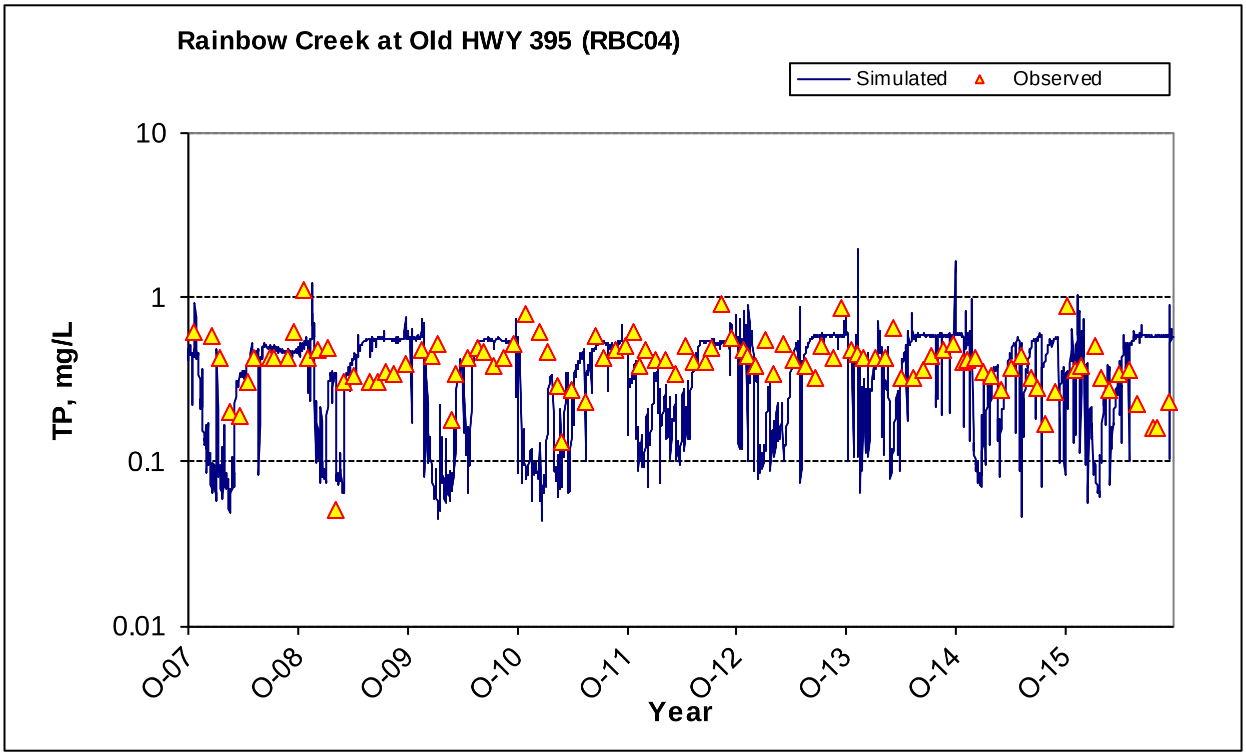


Figure 2-38. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

1.1.2.4 Rainbow Creek at MWD Road Crossing (RBC10)

Simulated ammonia-N + ammonium-N tend to be higher than observed concentrations under dry weather conditions at Rainbow Creek at MWD Road Crossing and may reflect model representation of onsite wastewater disposal systems. Simulated TKN concentrations are representative of instream TKN concentrations, especially in recent years. Instream soluble reactive P and TP concentrations are more diluted at MDW Road Crossing compared to upstream. The average soluble reactive P concentrations upstream at Huffstatler is 0.45 mg-P/L and at MDW Road Crossing the average concentration drops to 0.28 mg-P/L.

Table 2-11. Water Quality Calibration Statistics at Rainbow Creek at MWD Road Crossing (RBC10)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3 -N**	**TN**	**SRP**	**TP**
Count	82	64	84	86	86	85	86
Concentration Average Error	4.58%	35.44%	21.64%	-24.25%	-20.51%	34.64%	15.90%
Concentration Median Error	28.79%	72.02%	52.98%	-19.21%	-18.65%	42.98%	19.59%
Load Average Error	-36.94%	-19.79%	-41.32%	-72.19%	-69.14%	-29.61%	-35.91%
Load Median Error	9.13%	12.70%	9.75%	-7.12%	-6.55%	6.21%	3.60%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

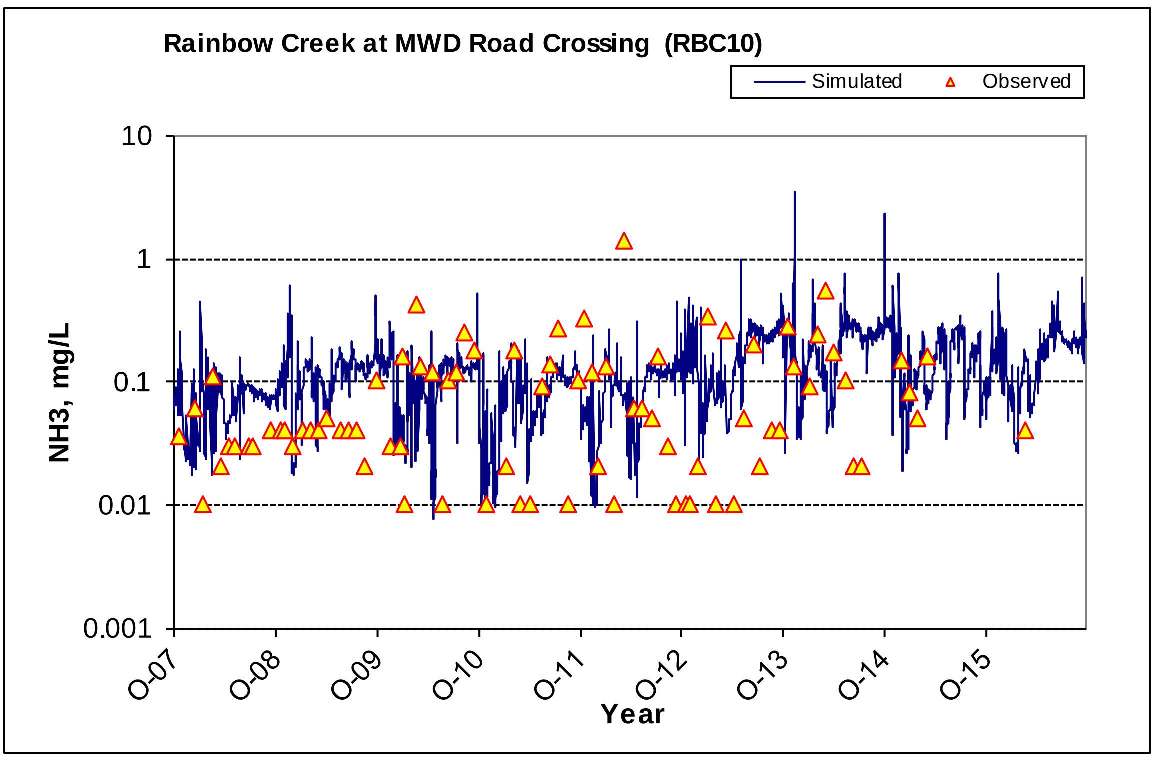


Figure 2-39. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

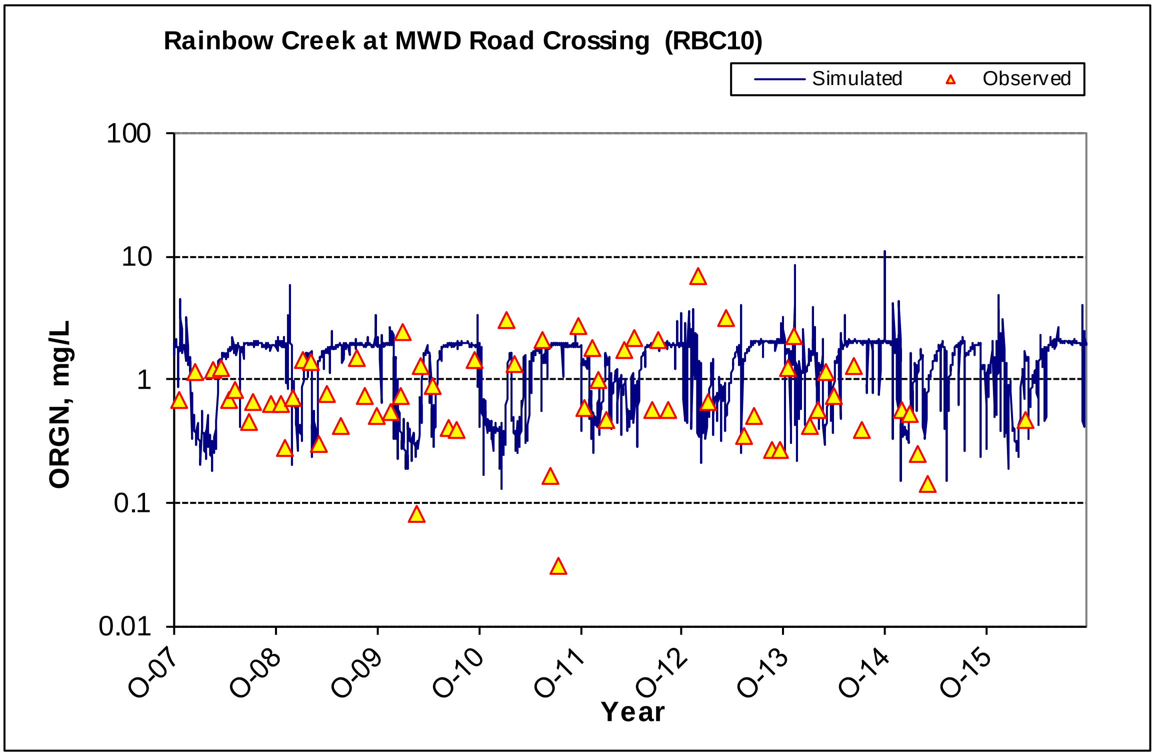


Figure 2-40. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

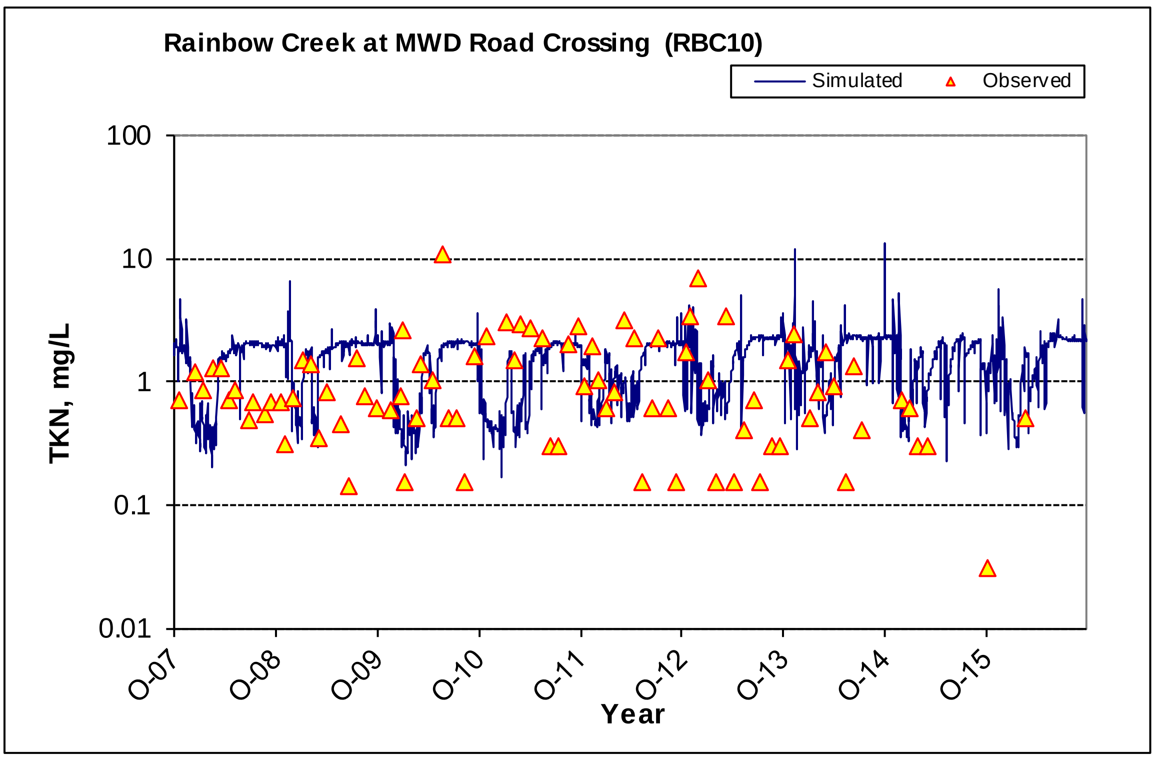


Figure 2-41. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

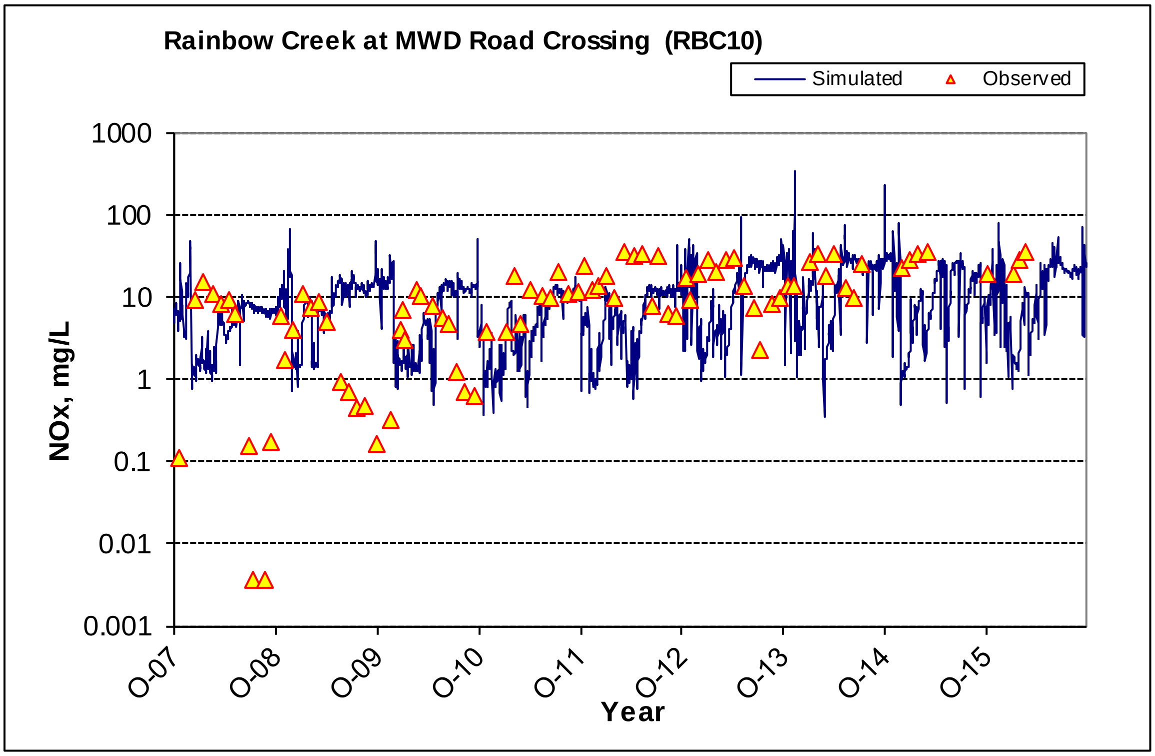


Figure 2-42. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

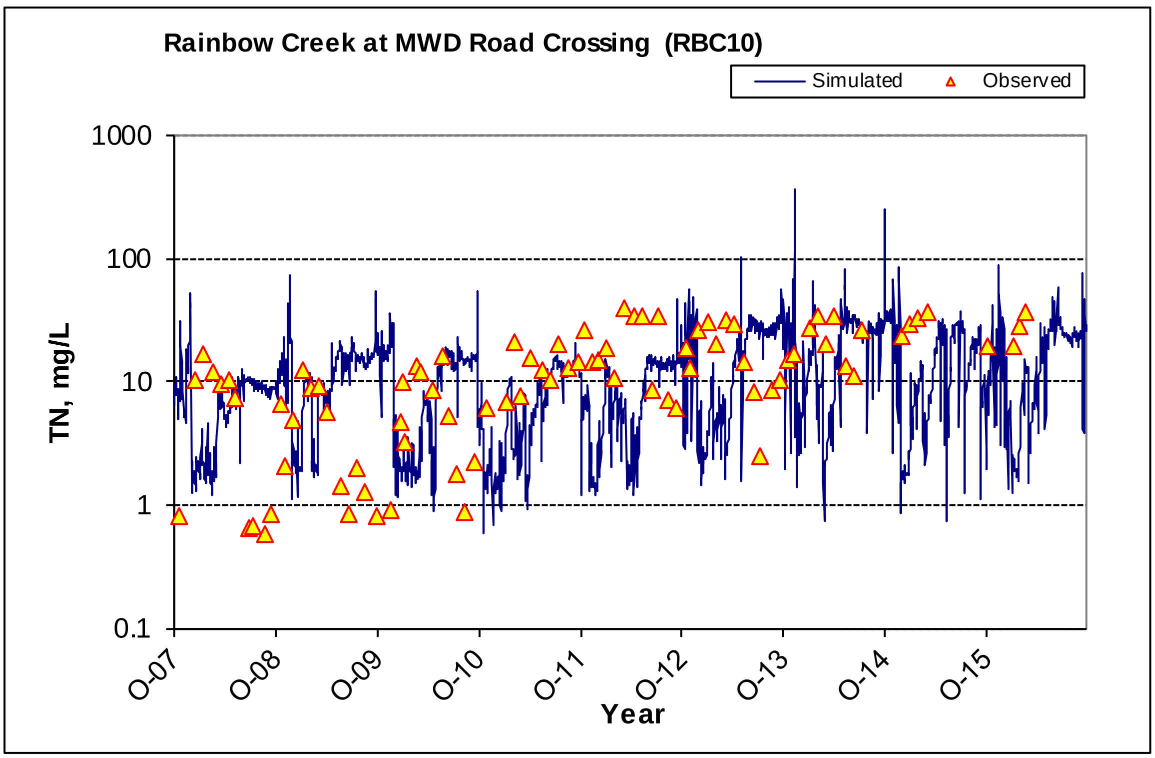


Figure 2-43. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

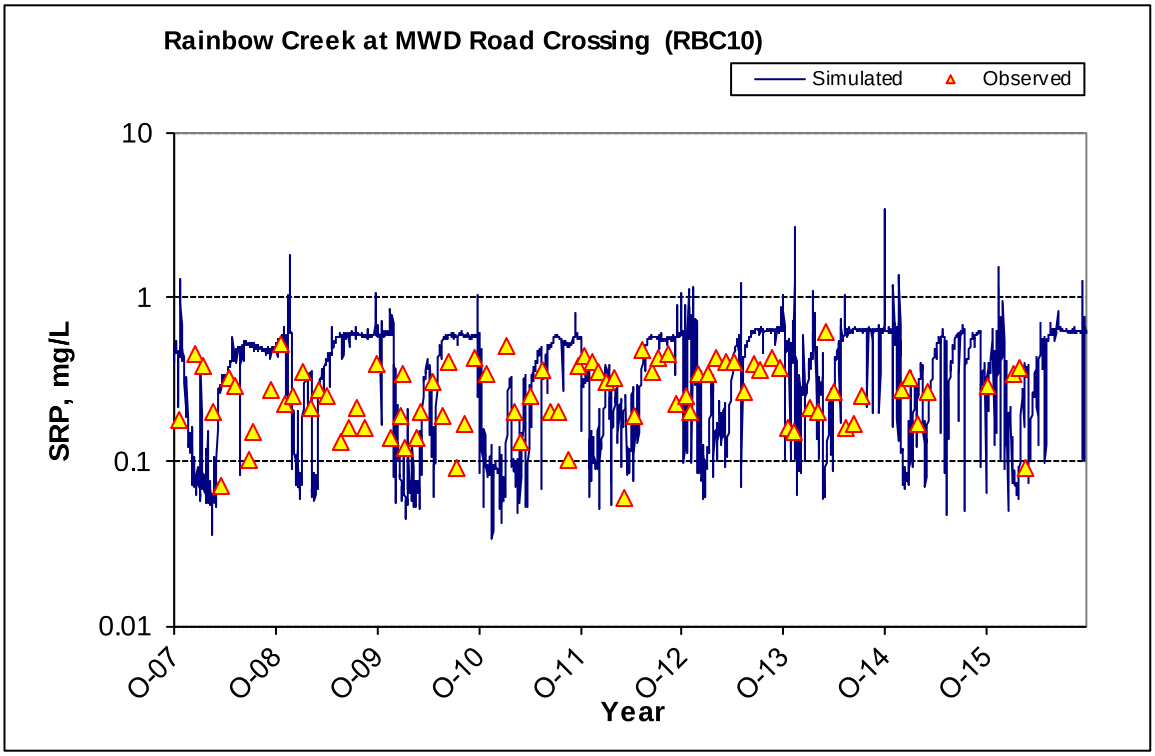


Figure 2-44. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

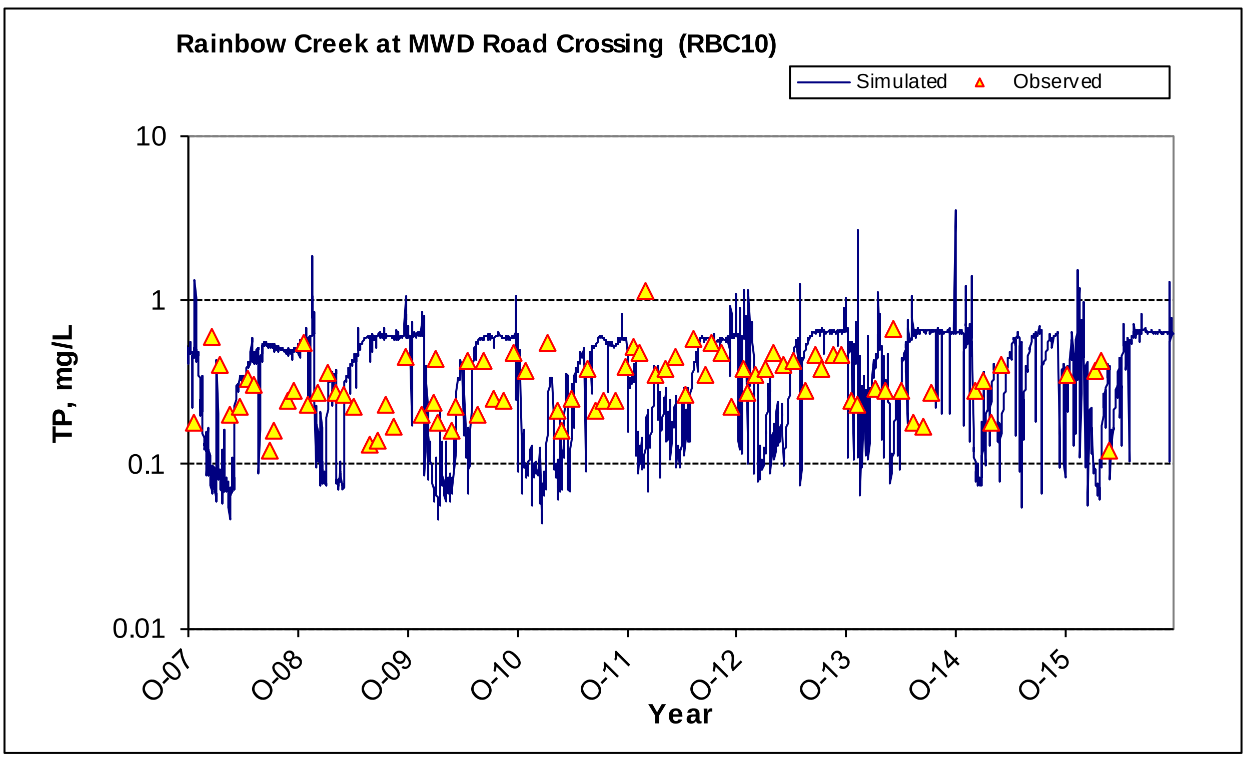


Figure 2-45. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

1.1.2.5 Rainbow Creek at Willow Glen Road (SMG05)

The Willow Glen Road sampling location is situated near the mouth of Rainbow Creek. Similar to upstream sites, temporal variations, which may be due to changes in analytical methods and/or changing nutrient management practices, are evident.

Table 2-12. Water Quality Calibration Statistics at Rainbow Creek at Willow Glen Road (SMG05)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3 -N**	**TN**	**SRP**	**TP**
Count	97	60	99	108	106	107	108
Concentration Average Error	-0.89%	13.89%	24.71%	-20.72%	-18.60%	86.91%	62.40%
Concentration Median Error	25.74%	54.41%	58.36%	-17.91%	-14.07%	88.59%	72.54%
Load Average Error	-71.28%	-68.71%	-58.35%	-69.77%	-68.53%	-34.23%	-44.69%
Load Median Error	6.17%	4.61%	8.77%	-1.93%	-1.15%	12.17%	7.85%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

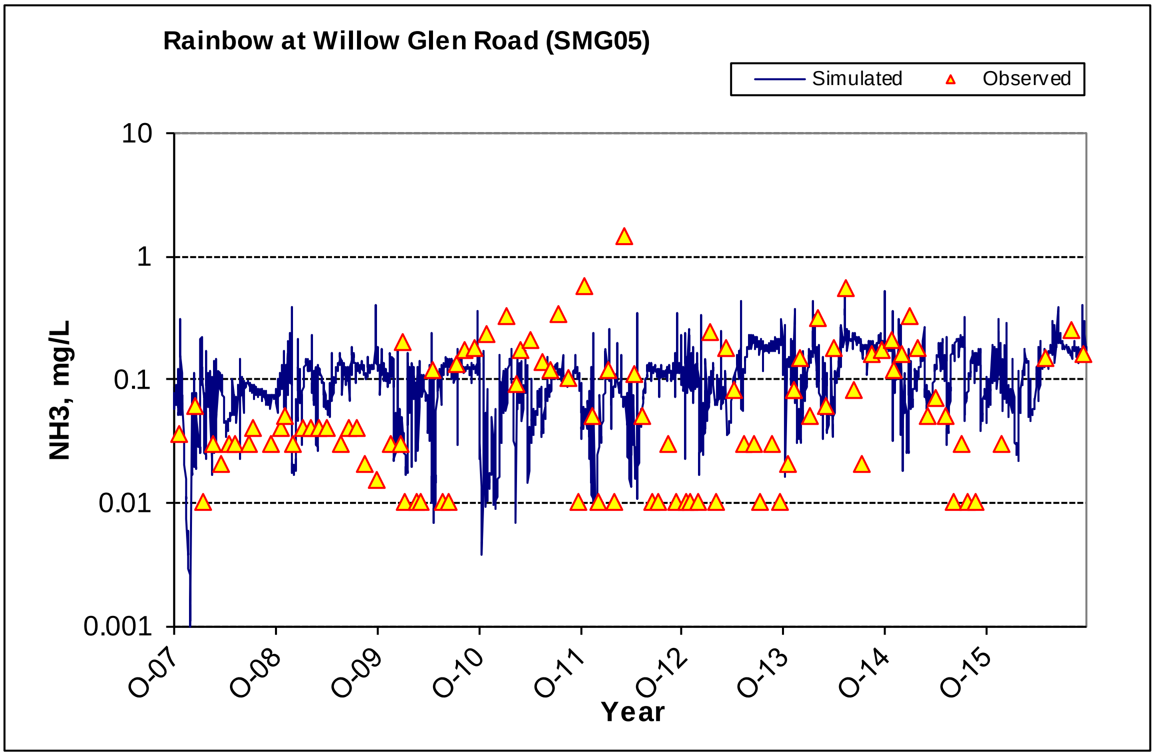


Figure 2-46. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow at Willow Glen Road (SMG05)

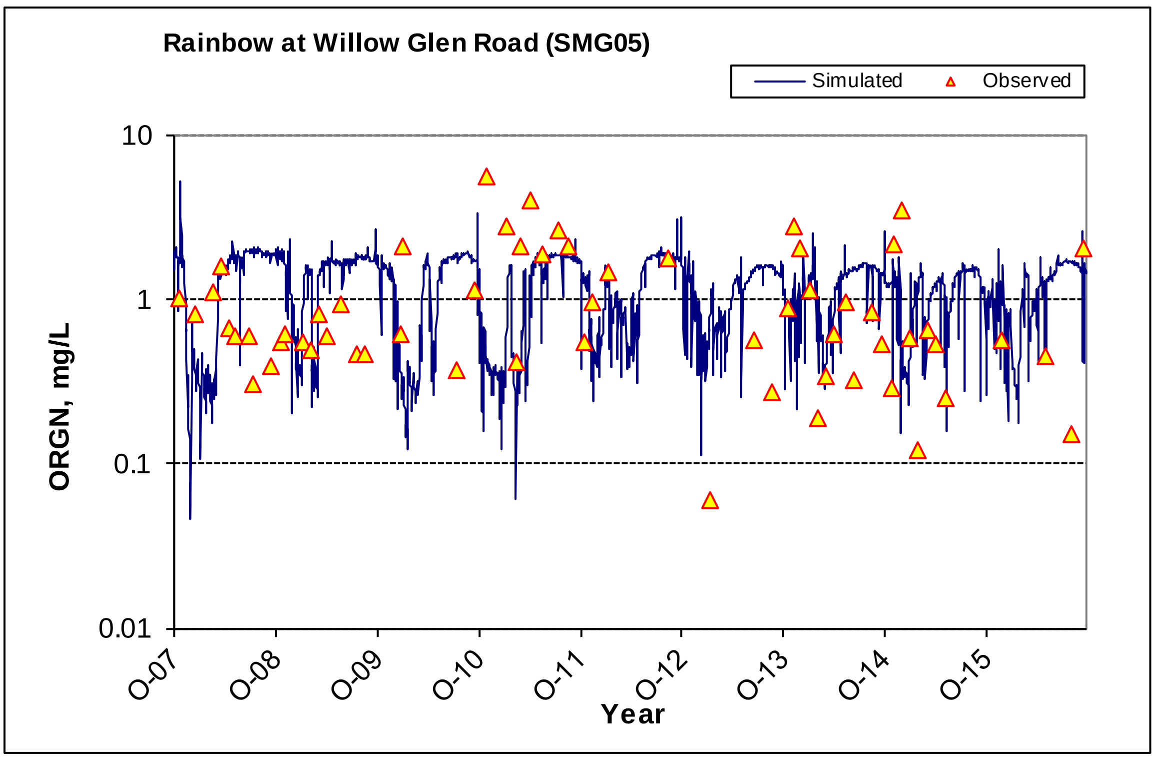


Figure 2-47. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow at Willow Glen Road (SMG05)

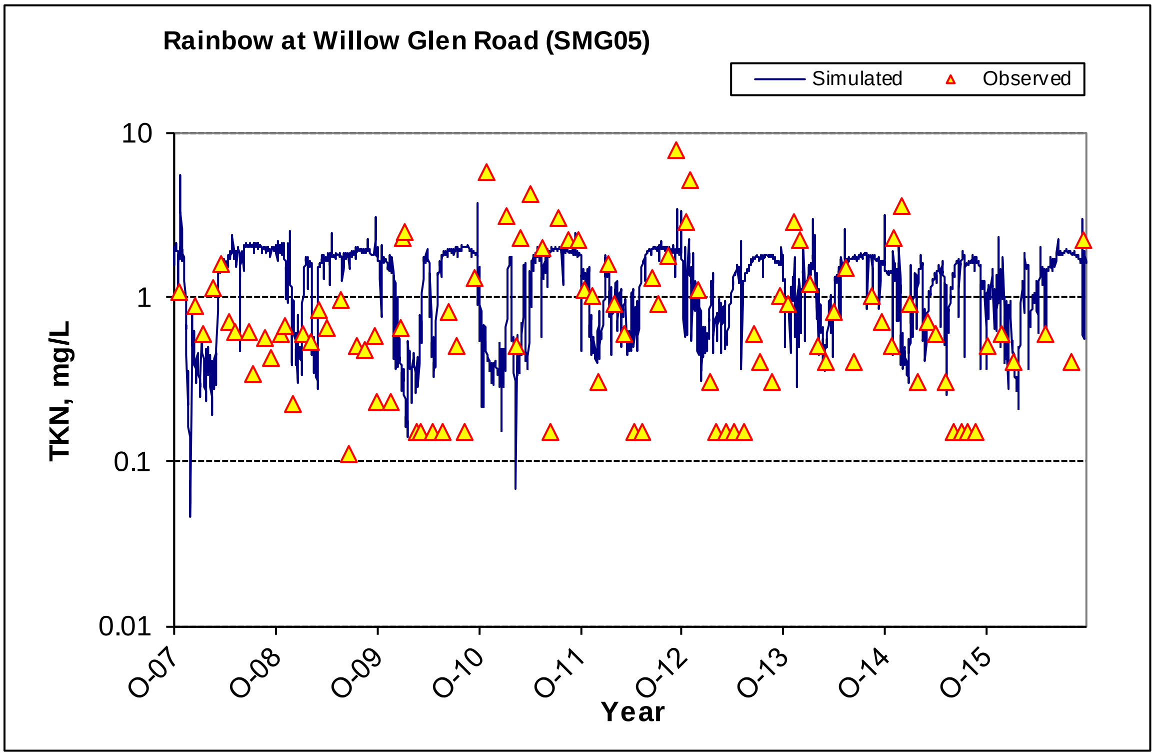


Figure 2-48. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow at Willow Glen Road (SMG05)

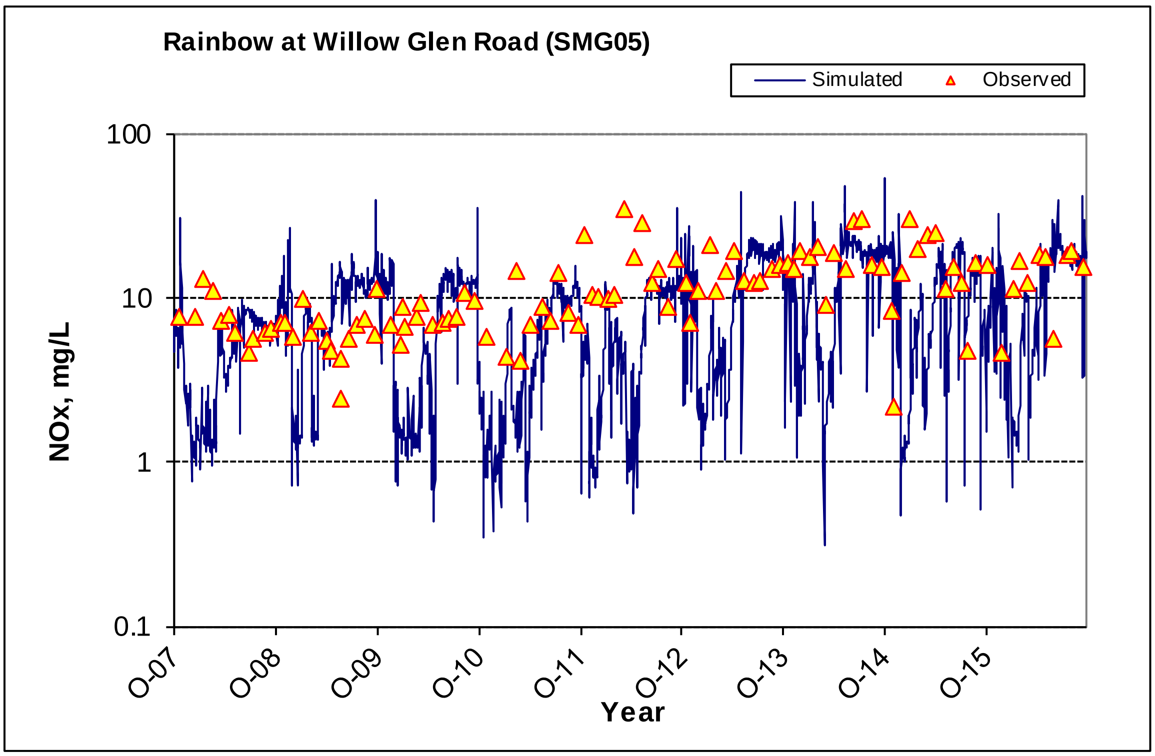


Figure 2-49. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow at Willow Glen Road (SMG05)

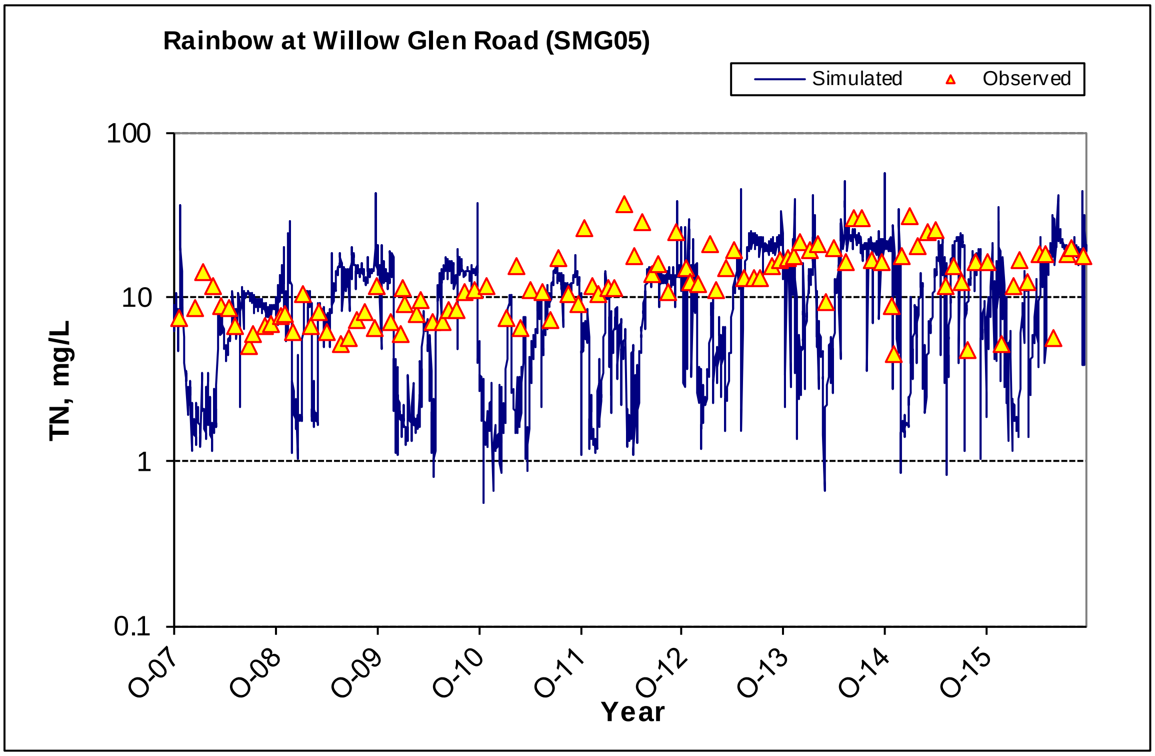


Figure 2-50. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow at Willow Glen Road (SMG05)

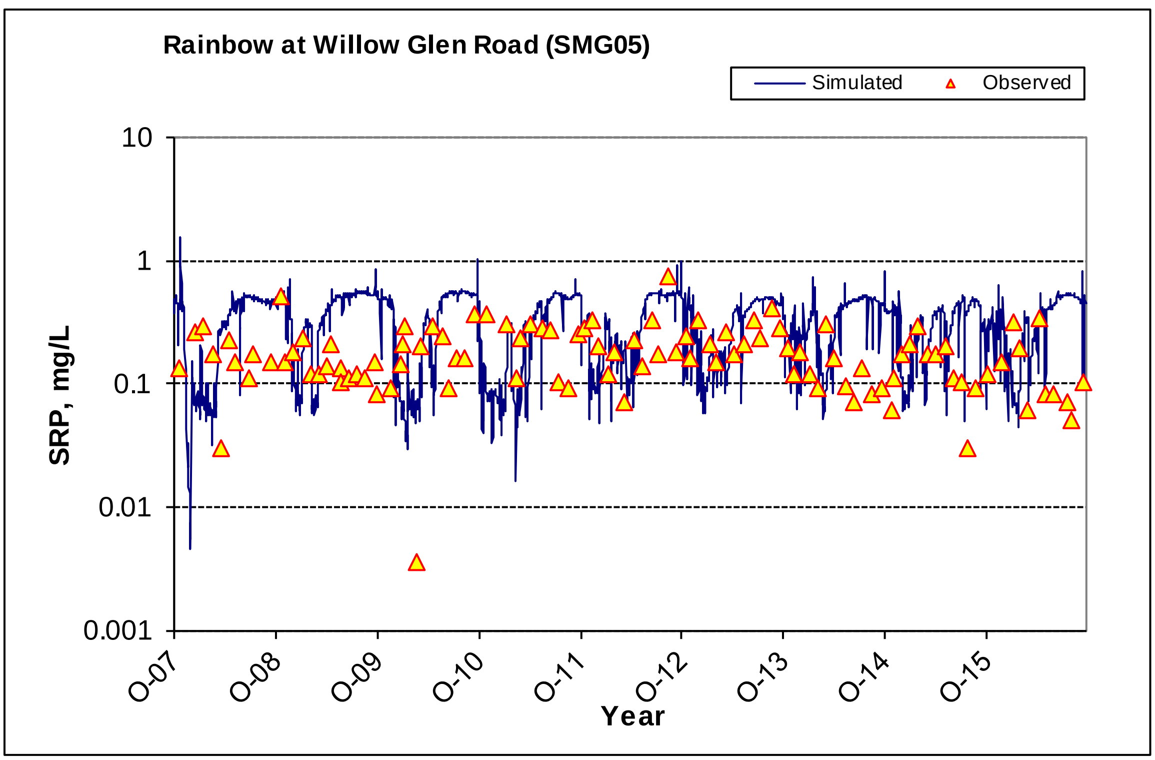


Figure 2-51. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow at Willow Glen Road (SMG05)

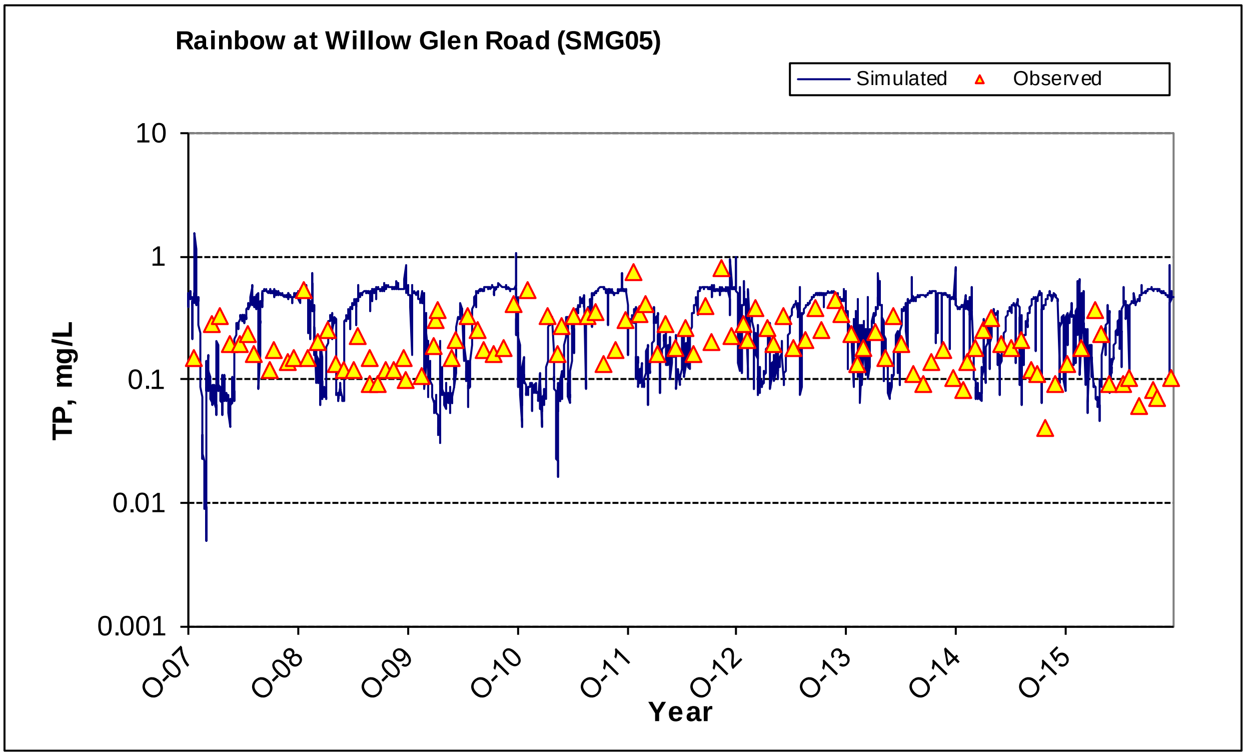


Figure 2-52. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow at Willow Glen Road (SMG05)

1.1.2.6 Rainbow Creek at Stage Coach Lane (SMG06, a.k.a. Fallbrook PUC Trail)

Frequent nitrite-N + nitrate-N samples were taken at Rainbow Creek at Stage Coach Lane and the model provides a good representation during the calibration period. Ammonia concentrations are suspect for the 2005-2009 period and reported data may be in error as they are higher than TKN. Simulated phosphorus concentrations are higher than observed concentrations although modeled loads are lower than estimates from the monitoring – although limited wet weather samples make conclusions about load unclear.

Table 2-13. Water Quality Calibration Statistics at Rainbow Creek at Stage Coach Lane (SMG06)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+NO_3 -N	TN	SRP	TP
Count	102	39	95	114	107	113	114
Concentration Average Error	-91.40%	9.74%	15.41%	-22.35%	-20.14%	124.89%	95.46%
Concentration Median Error	1.40%	13.18%	43.05%	-25.10%	-23.15%	146.84%	113.53%
Load Average Error	-97.58%	-72.03%	-57.35%	-83.15%	-81.14%	-50.08%	-55.33%
Load Median Error	-1.50%	-17.93%	-17.83%	-57.55%	-50.92%	-17.77%	-25.42%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

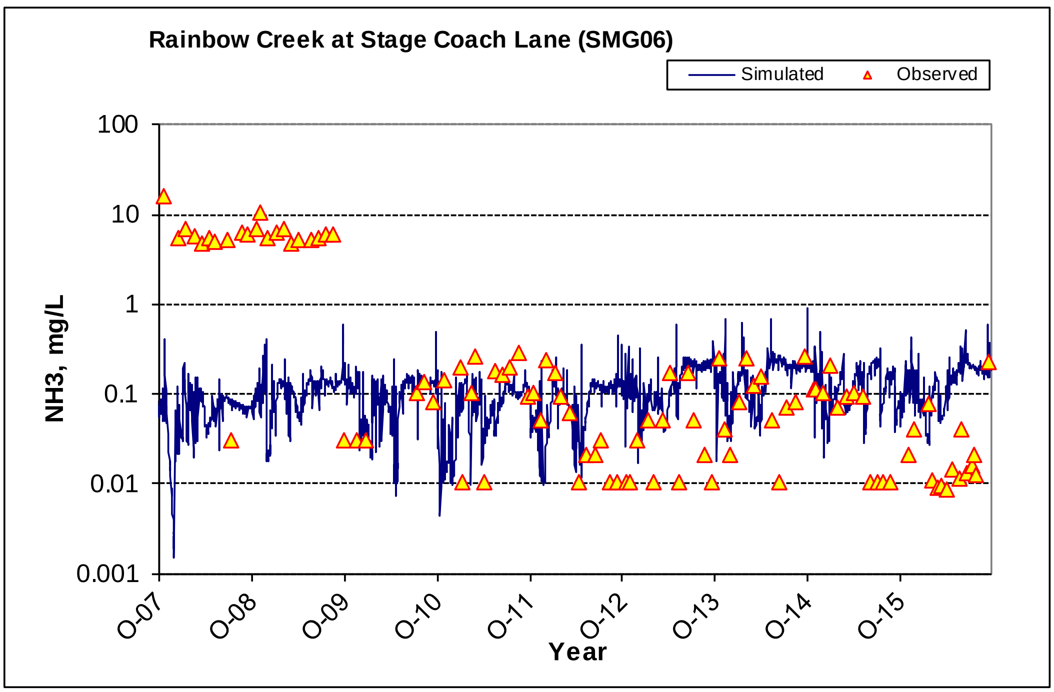


Figure 2-53. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

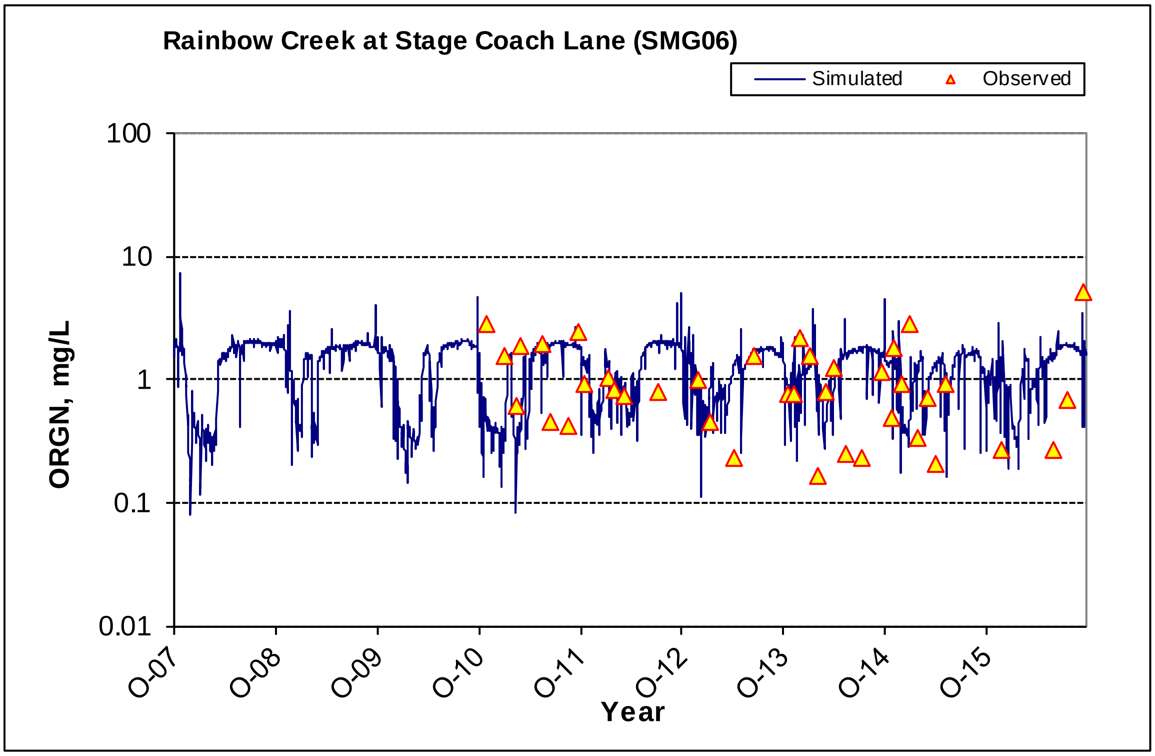


Figure 2-54. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

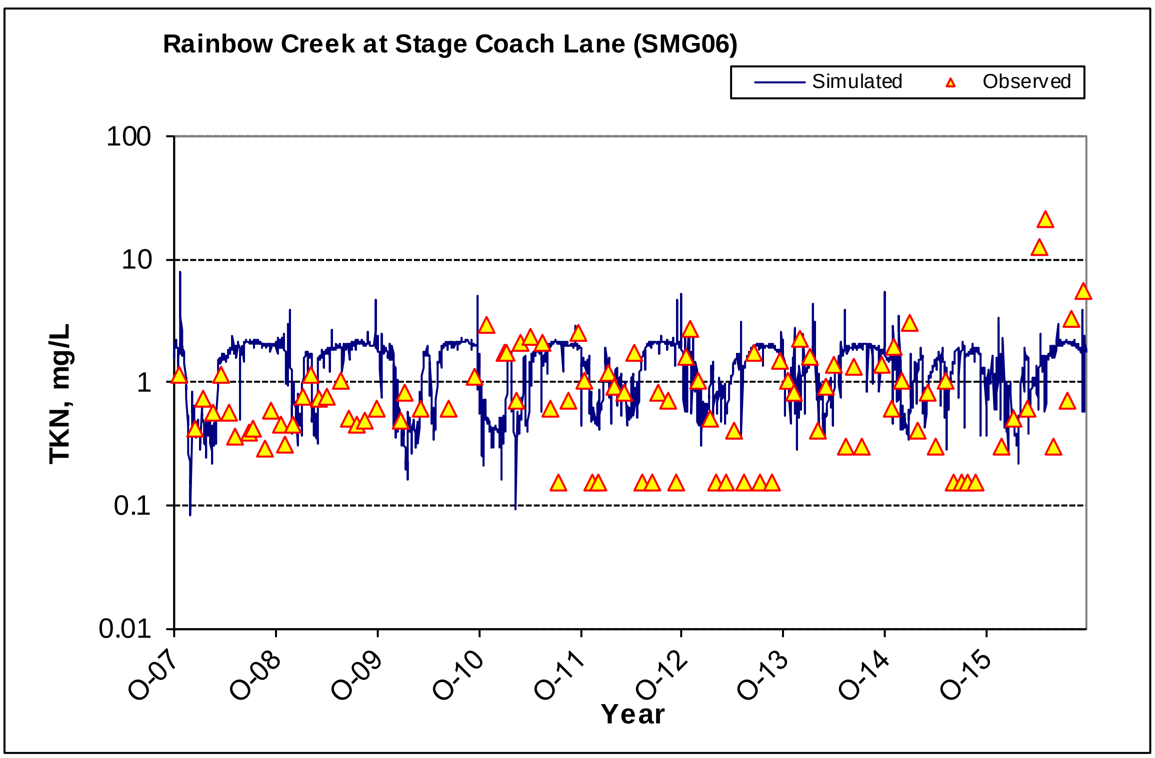


Figure 2-55. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

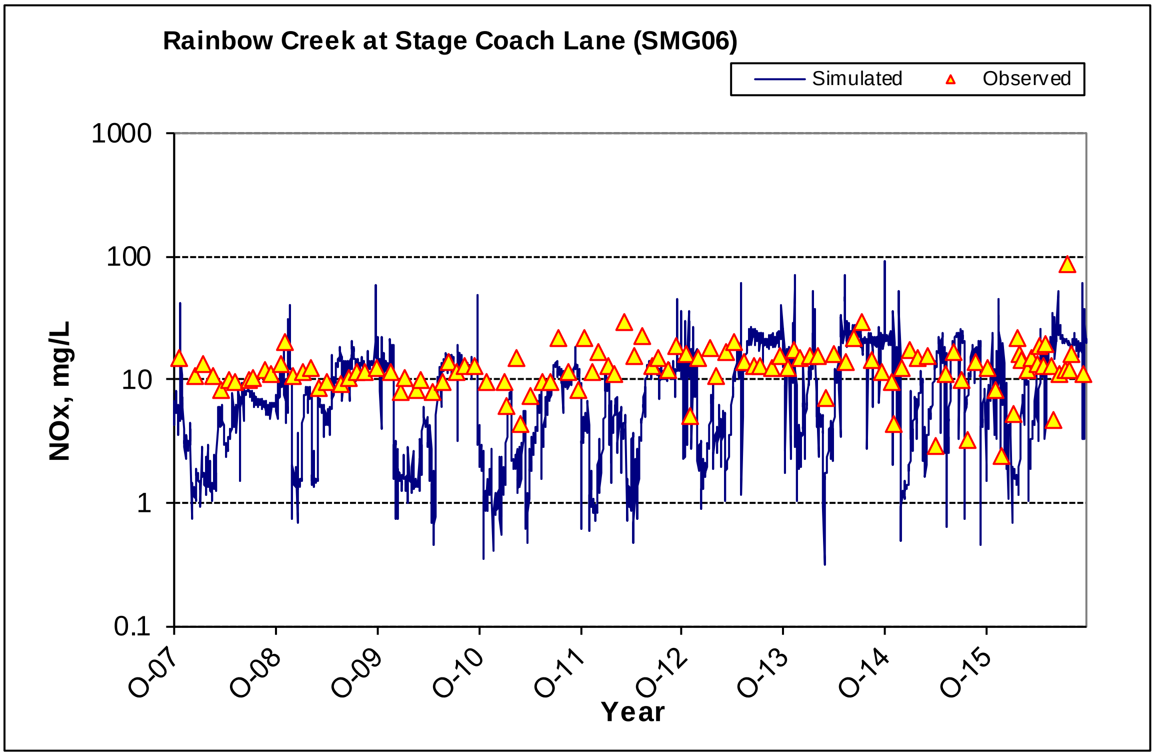


Figure 2-56. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

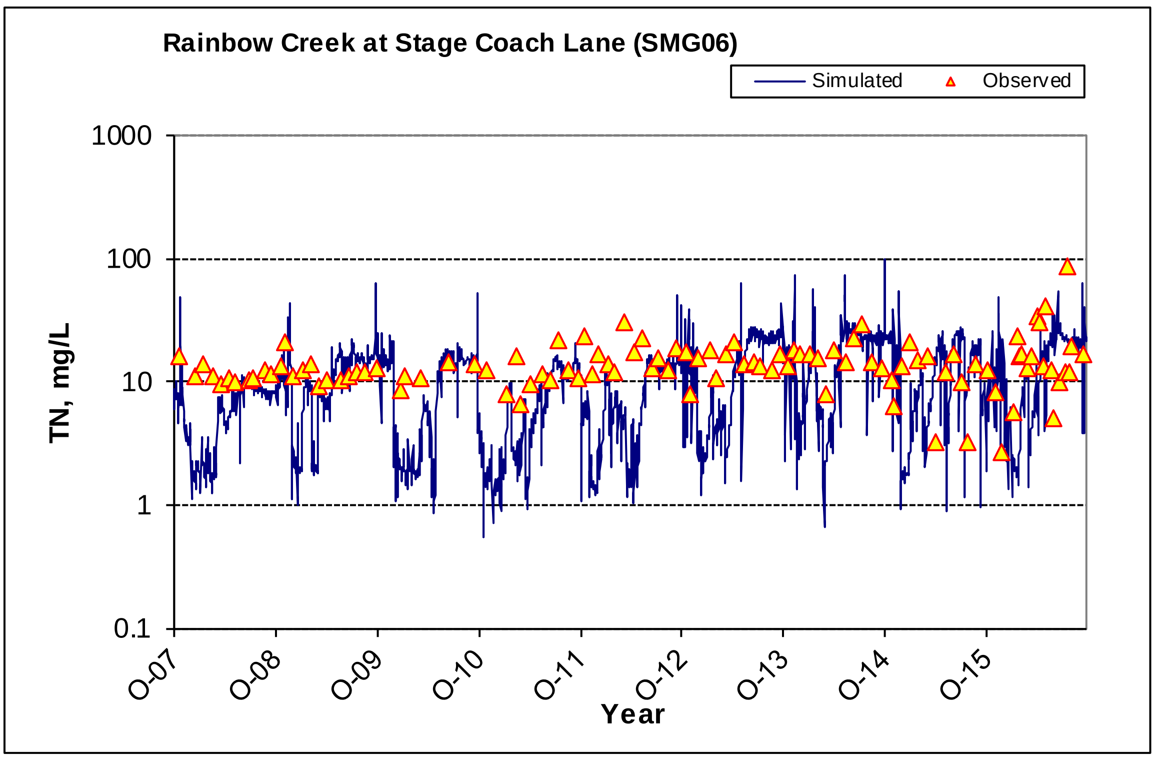


Figure 2-57. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

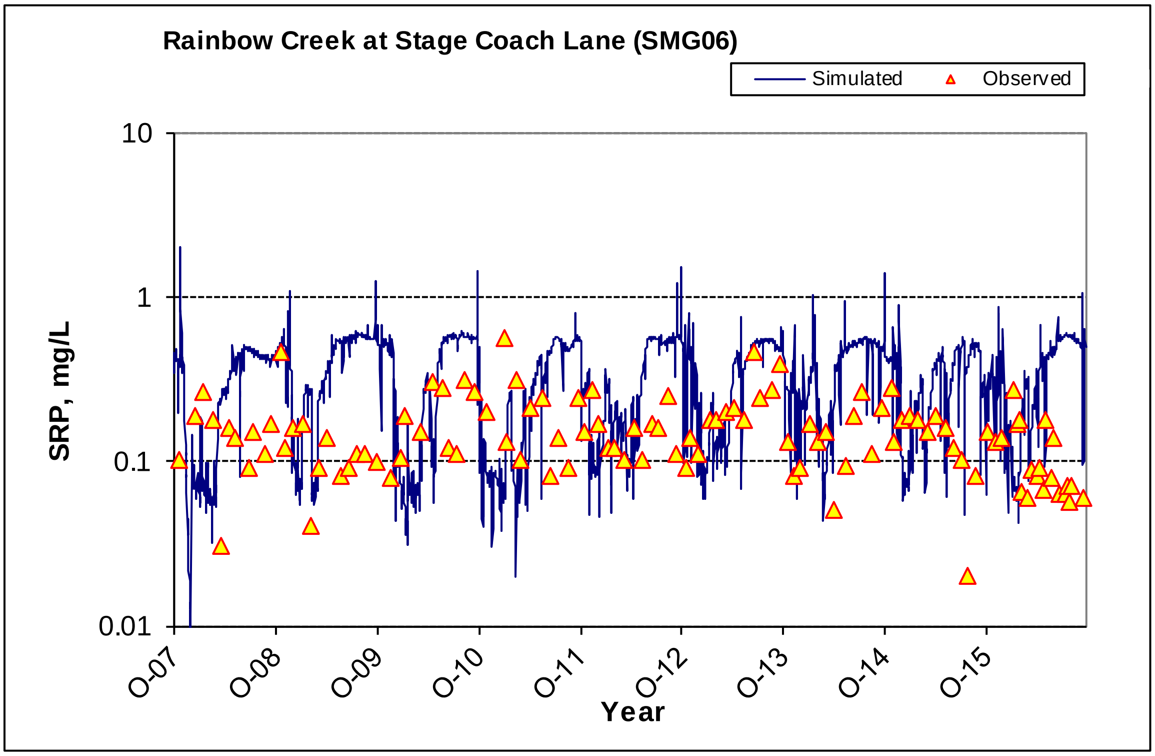


Figure 2-58. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

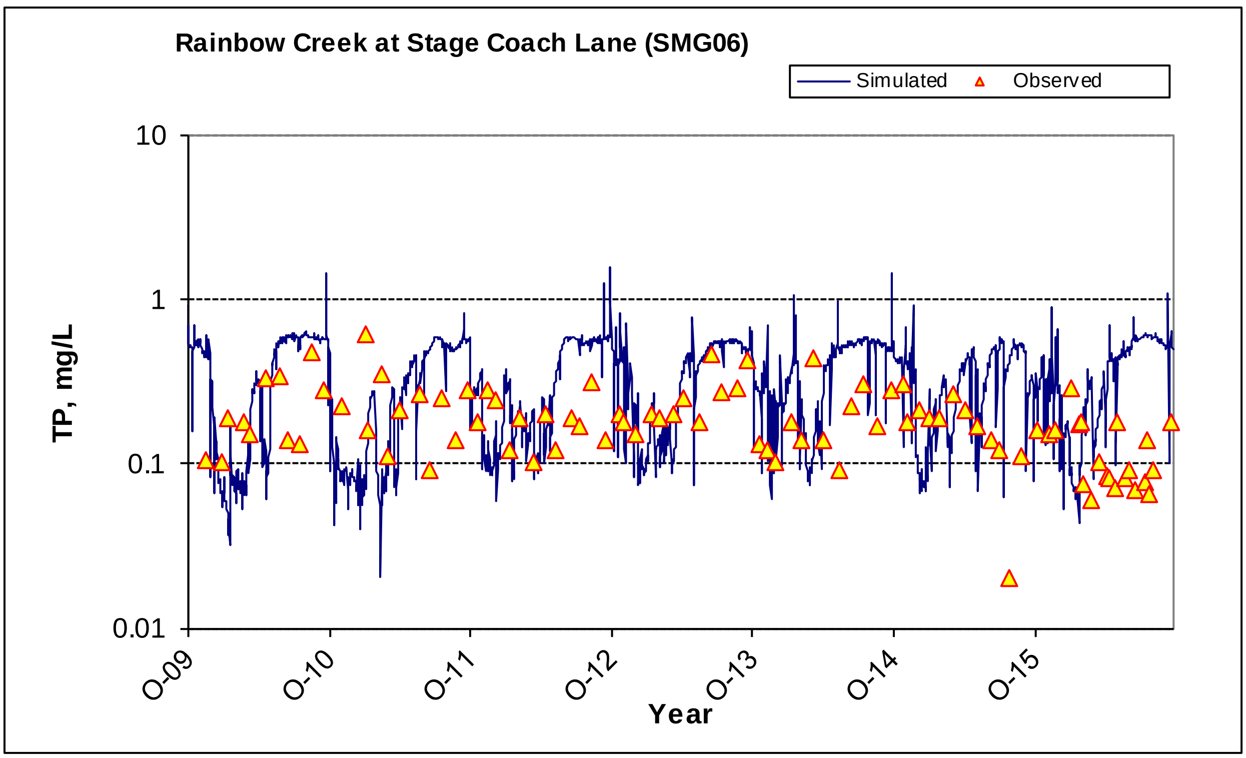


Figure 2-59. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

1.1.2.7 Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

There are limited water quality samples at Santa Margarita River near Fallbrook in recent years, so formal statistics are not presented. As evidenced by the time series plots, the model does a fair job of characterizing water quality conditions at this site.

Table 2-14. Water Quality Calibration Statistics at Santa Margarita River at FPUD Sump near Fallbrook (11044300)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3 -N**	**TN**	**SRP**	**TP**
Count	15	14	25	26	23	20	25

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

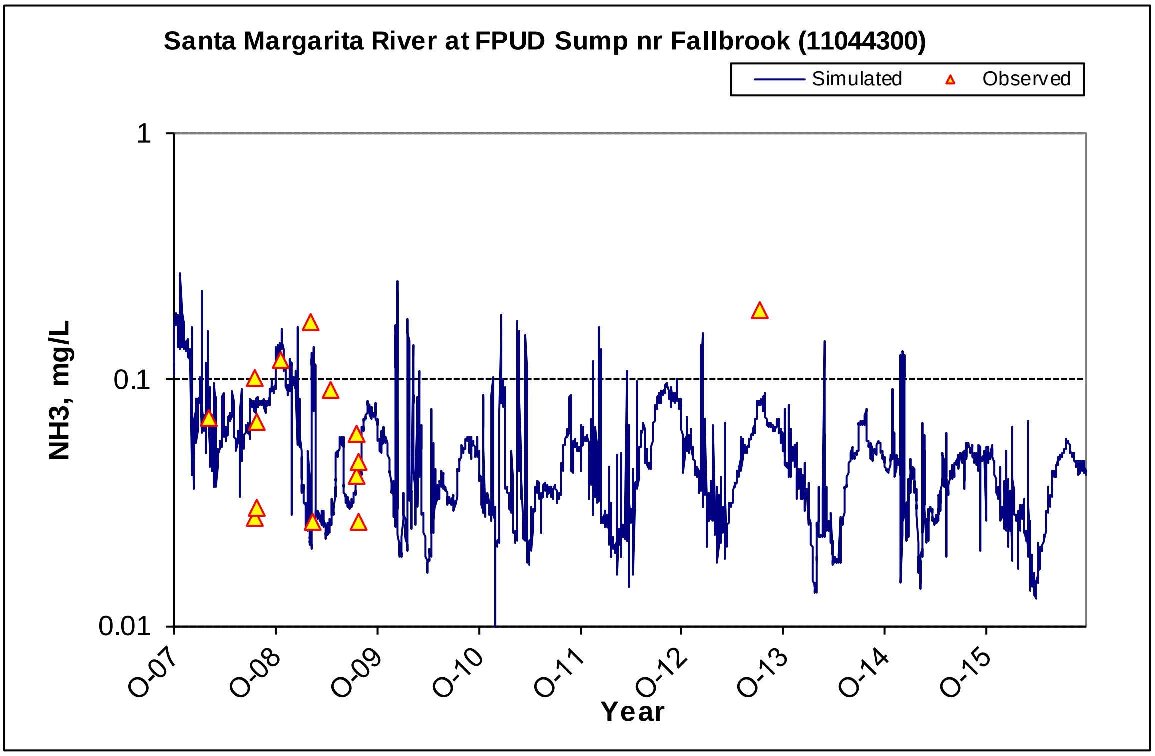


Figure 2-60. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

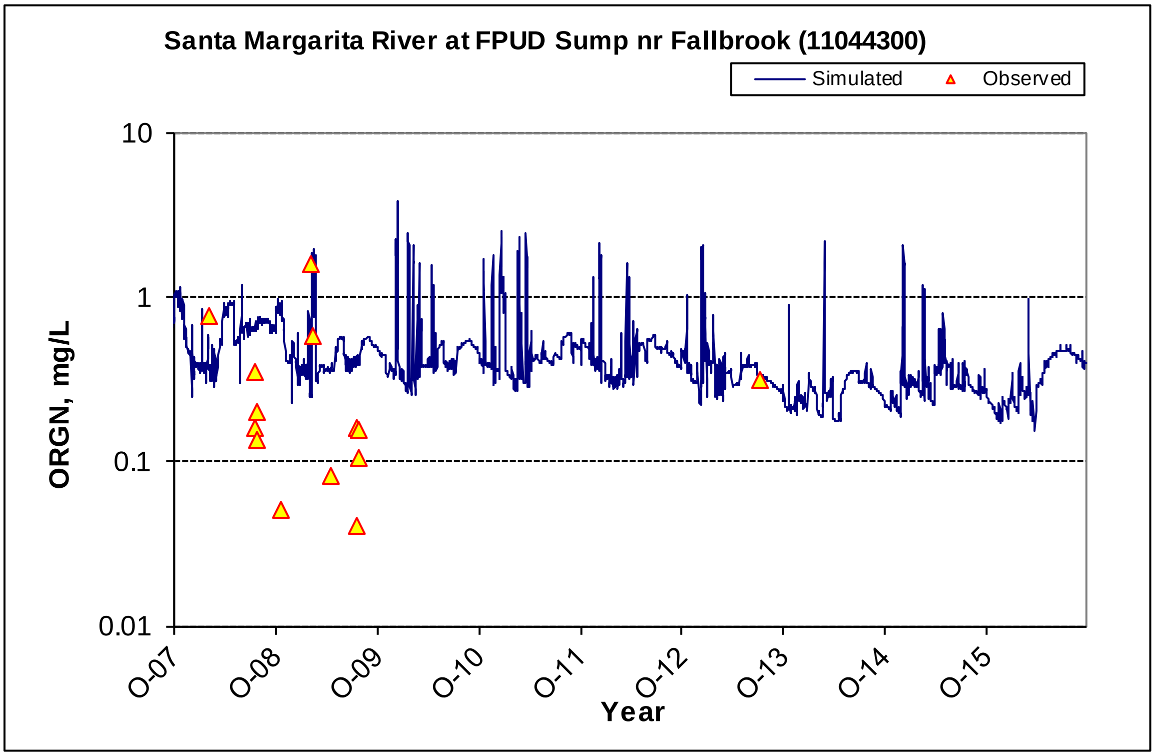


Figure 2-61. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

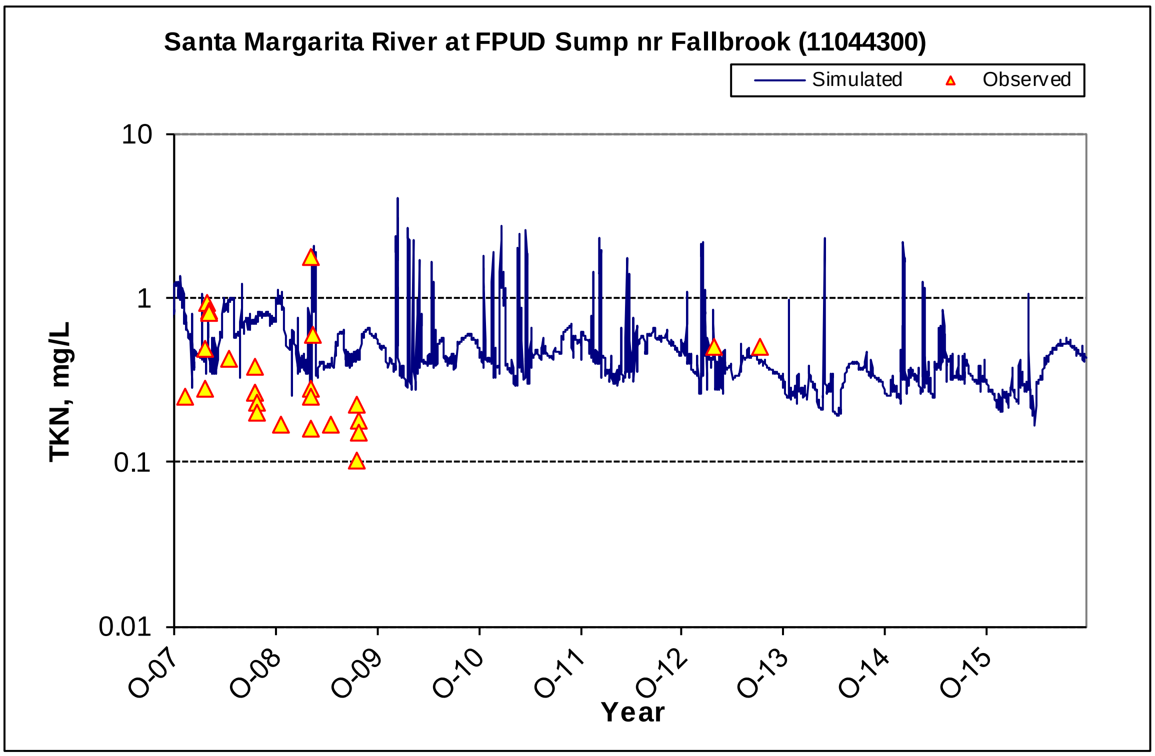


Figure 2-62. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

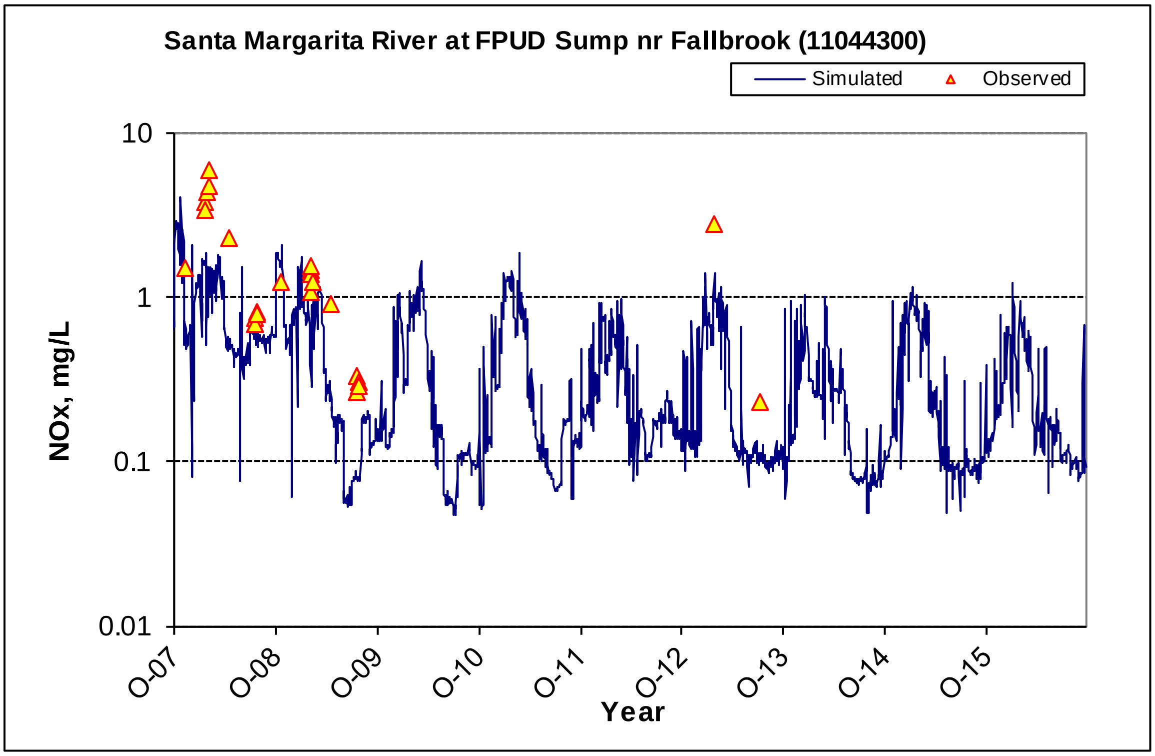


Figure 2-63. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

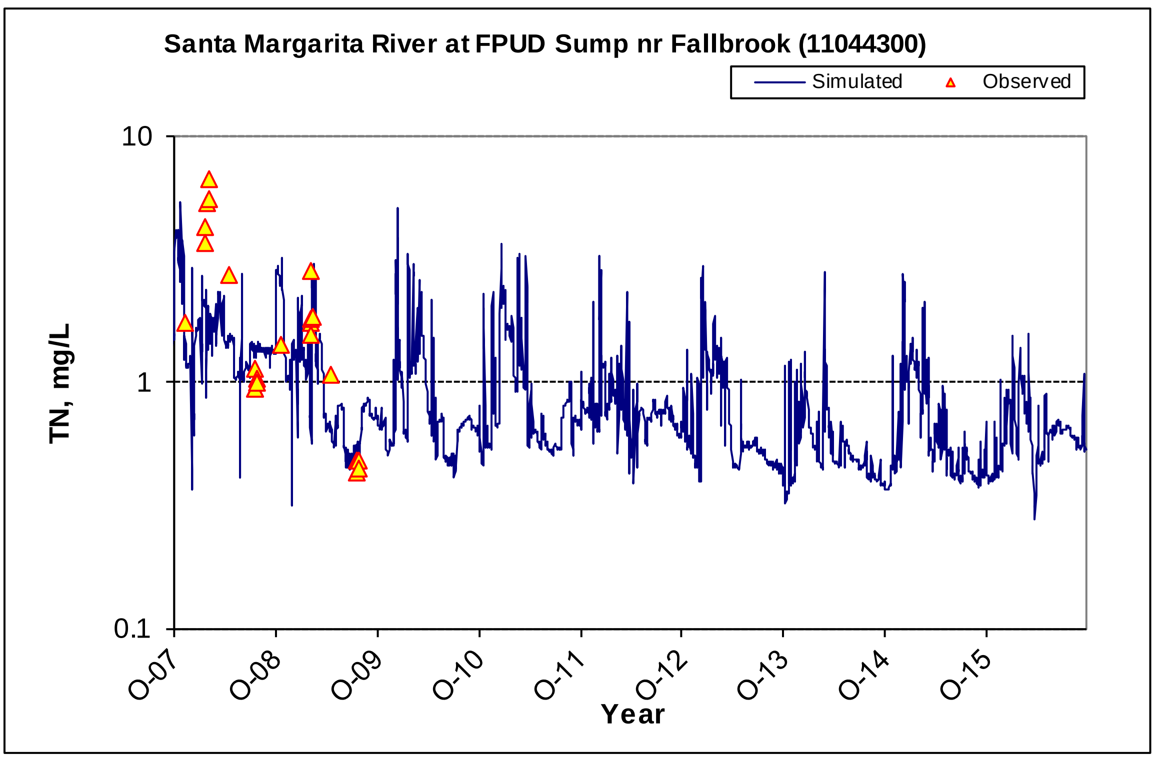


Figure 2-64. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

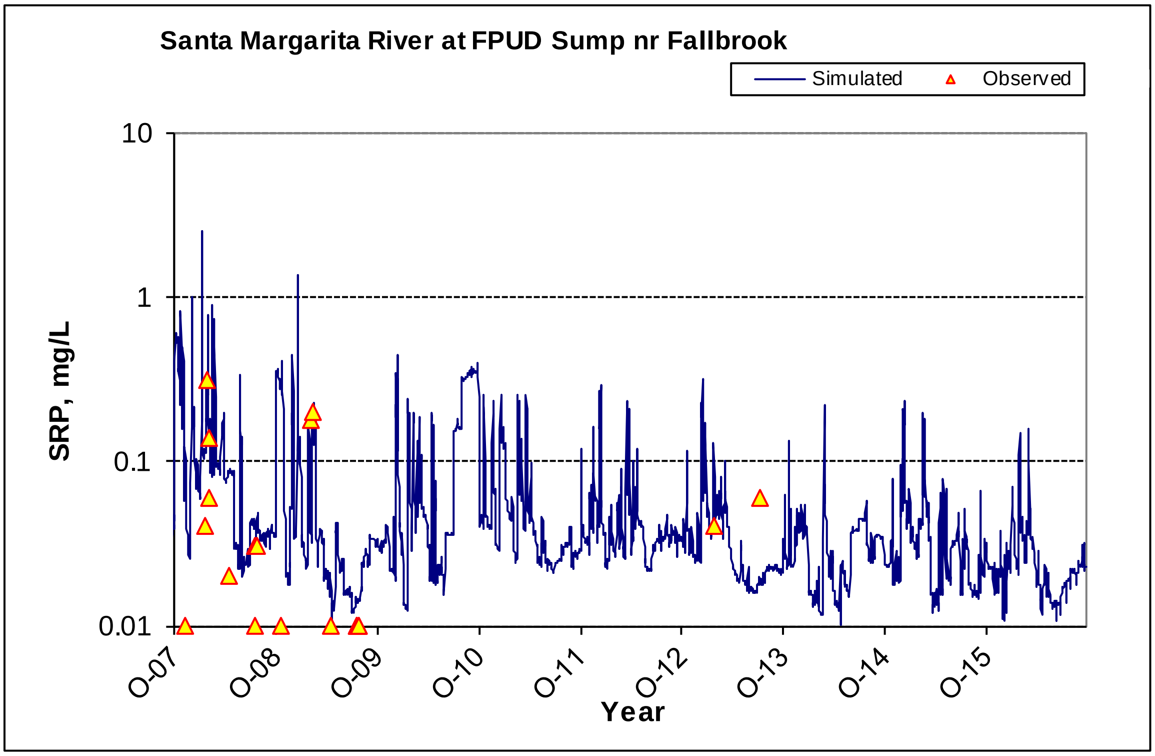


Figure 2-65. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

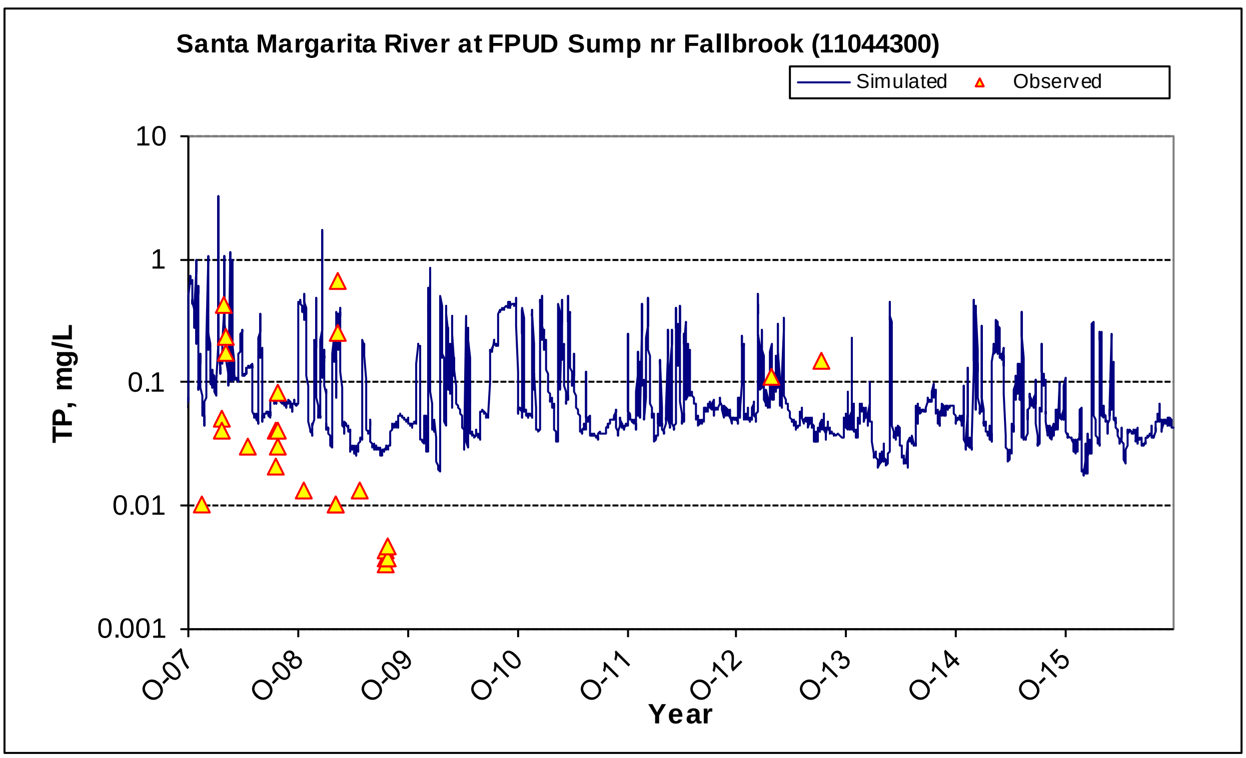


Figure 2-66. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

1.1.2.8 Sandia Creek at Sandia Creek Drive (11044350)

There are only limited sampling records at Sandia Creek. Model fit appears adequate.

Table 2-15. Water Quality Calibration Statistics at Sandia Creek at Sandia Creek Drive (11044350)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+NO_3 -N	TN	SRP	TP
Count	31	13	36	45	13	43	39
Concentration Average Error	-29.60%		-23.31%	-25.13%		55.06%	-13.61%
Concentration Median Error	-11.96%		54.30%	-16.58%		72.07%	16.64%
Load Average Error	-27.65%		27.73%	-48.61%		40.46%	-33.35%
Load Median Error	0.72%		23.72%	-8.73%		19.11%	1.99%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

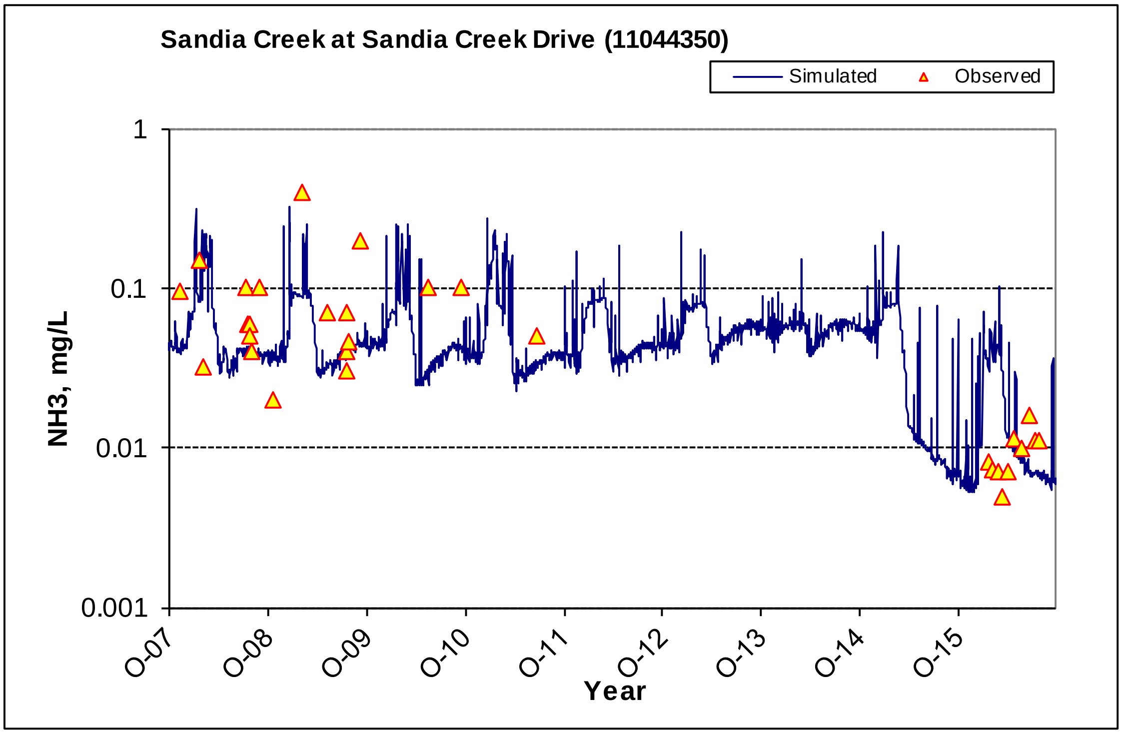


Figure 2-67. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

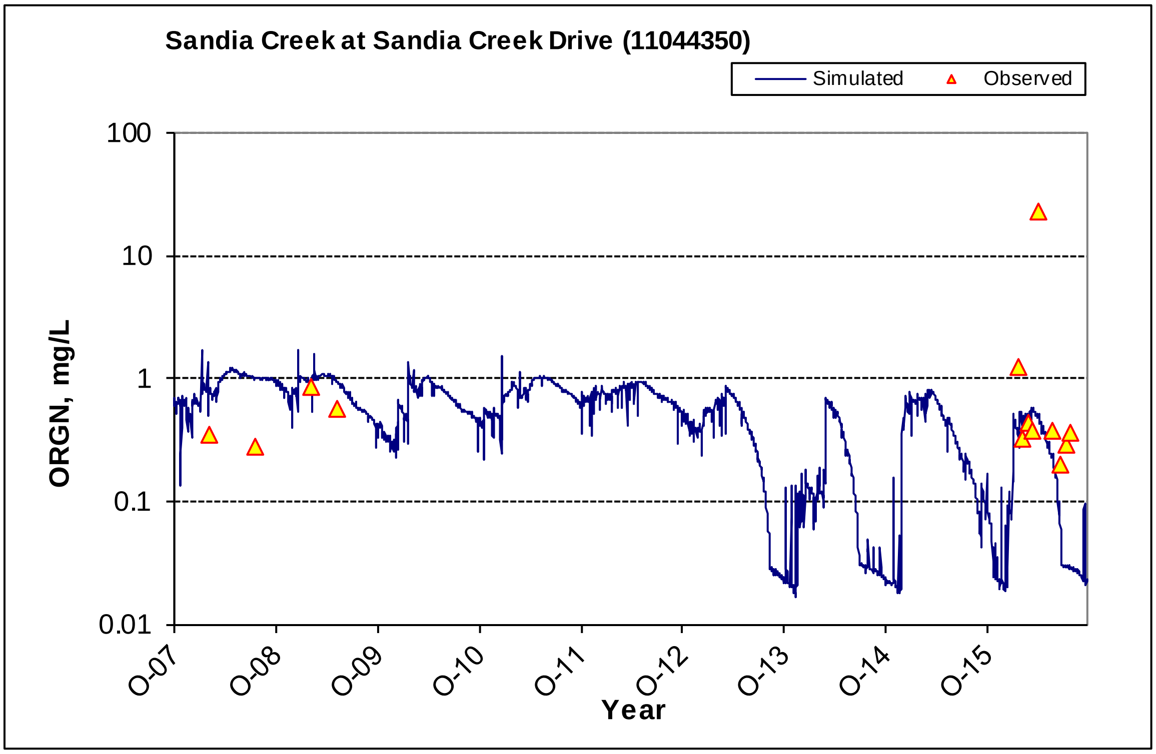


Figure 2-68. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

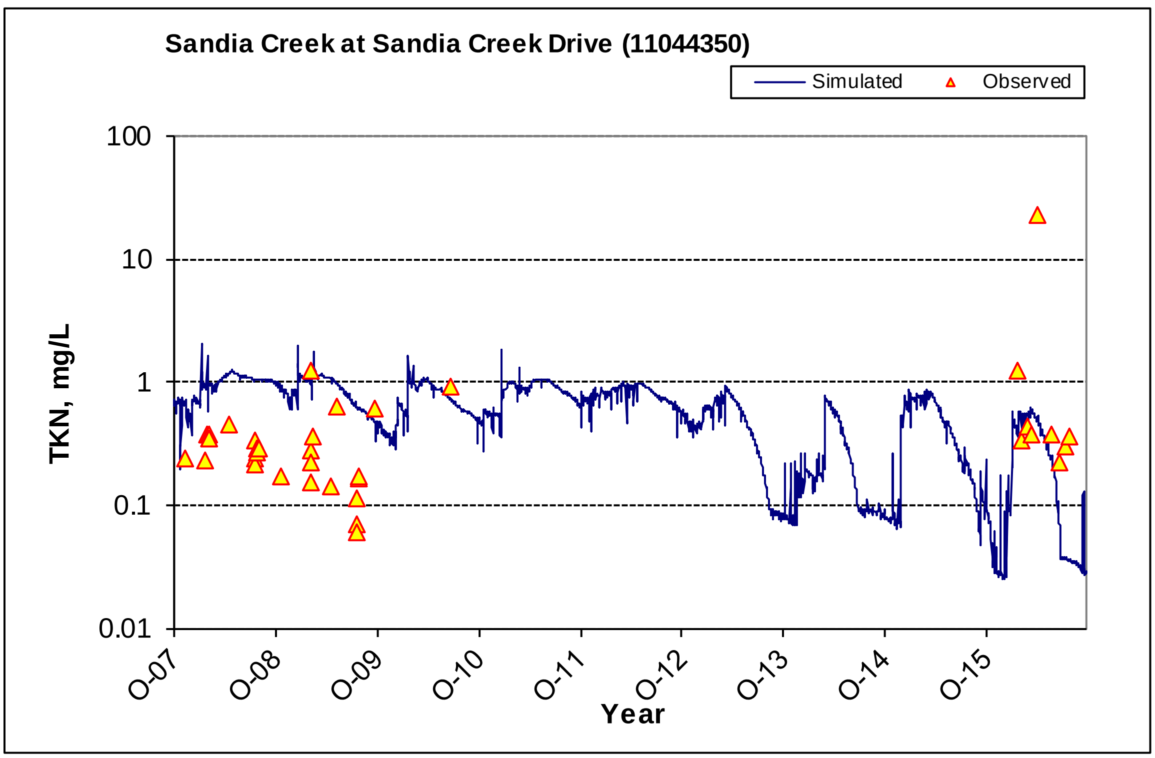


Figure 2-69. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

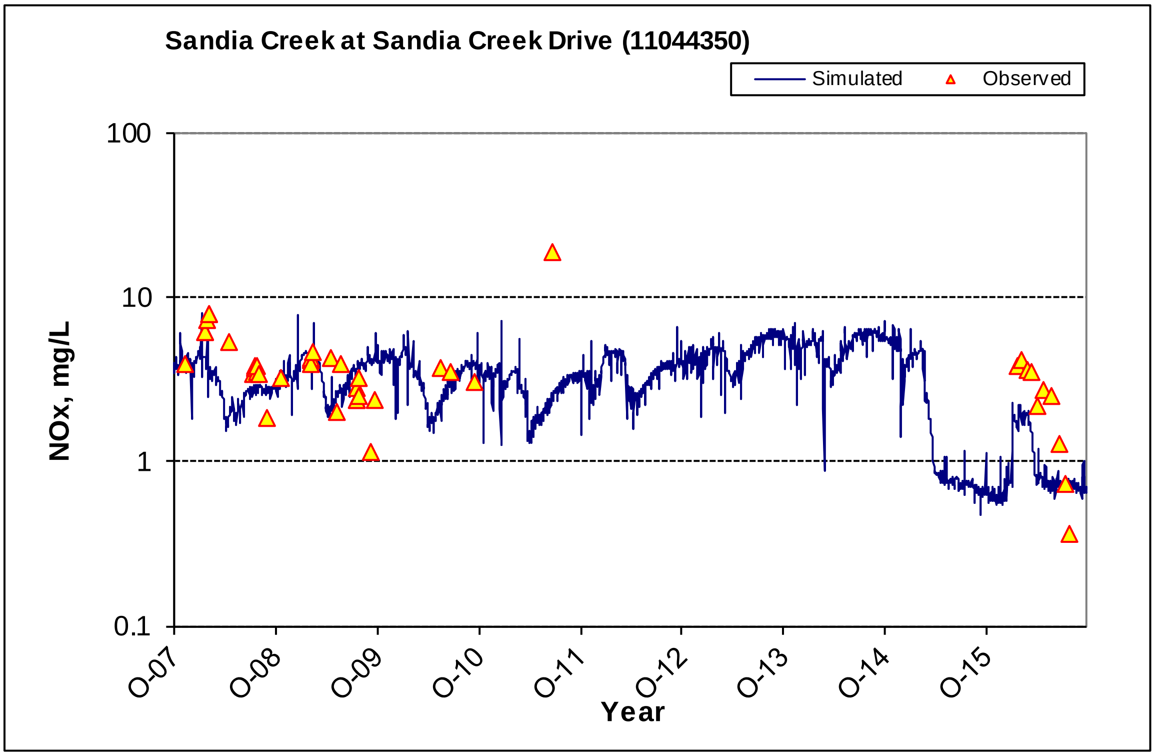


Figure 2-70. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

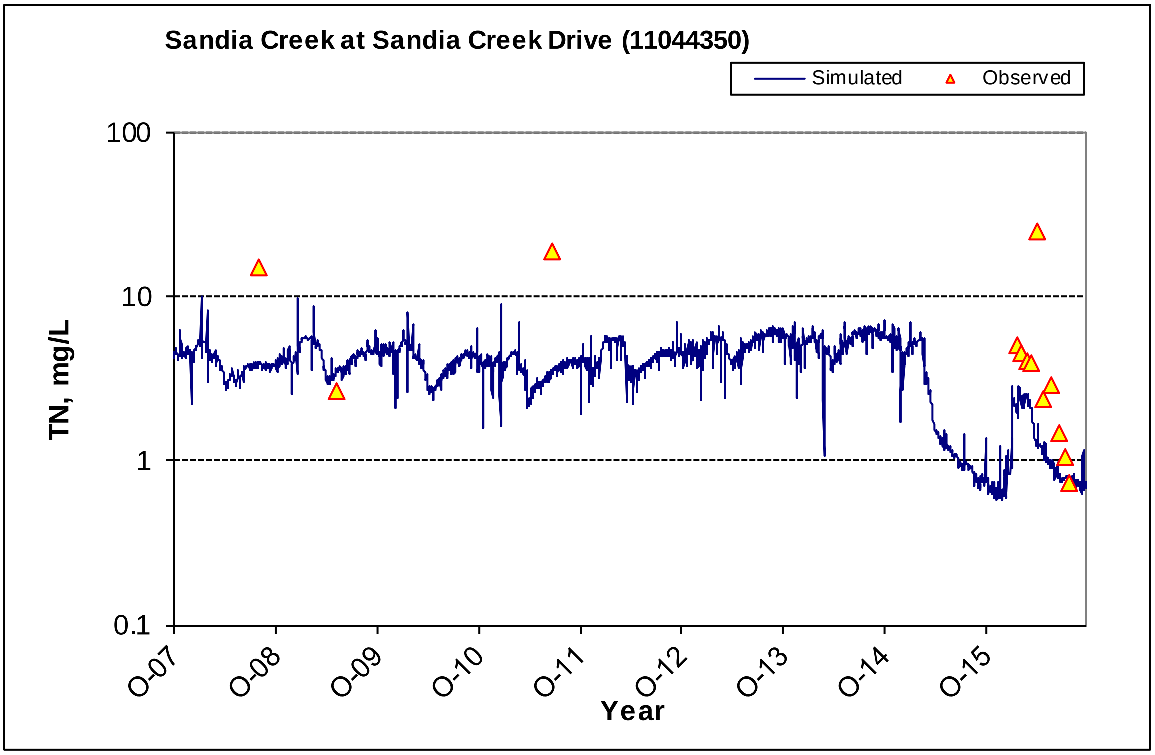


Figure 2-71. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

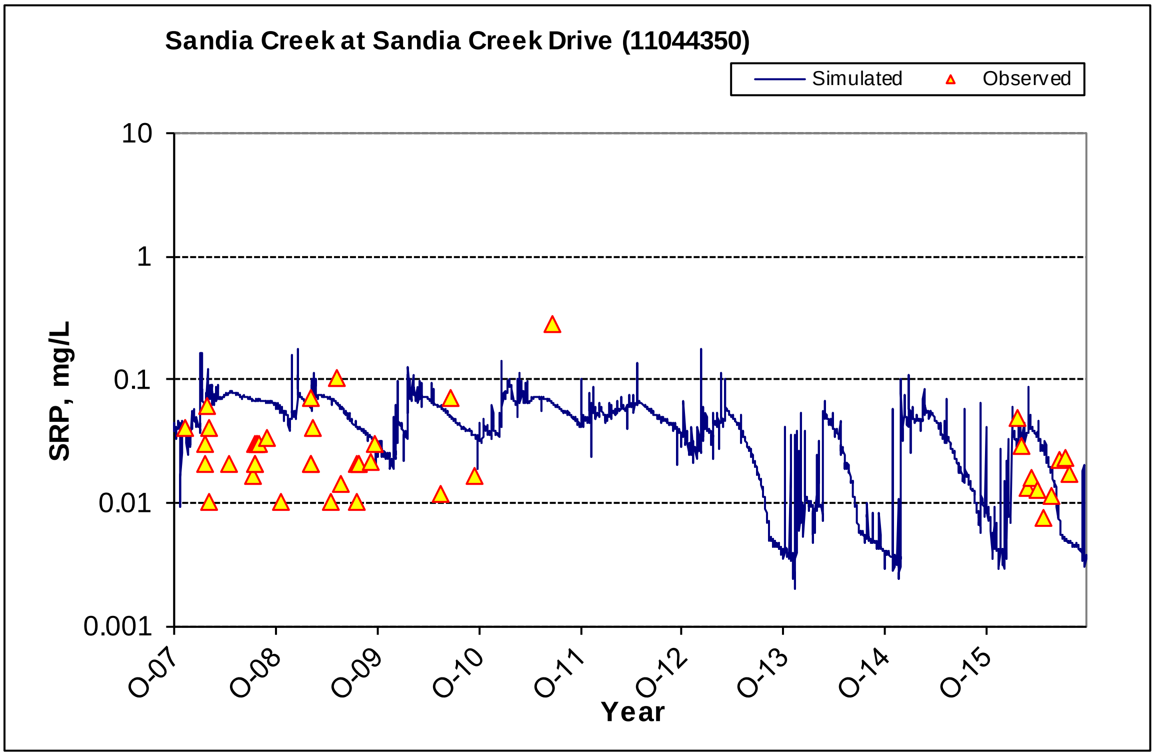


Figure 2-72. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

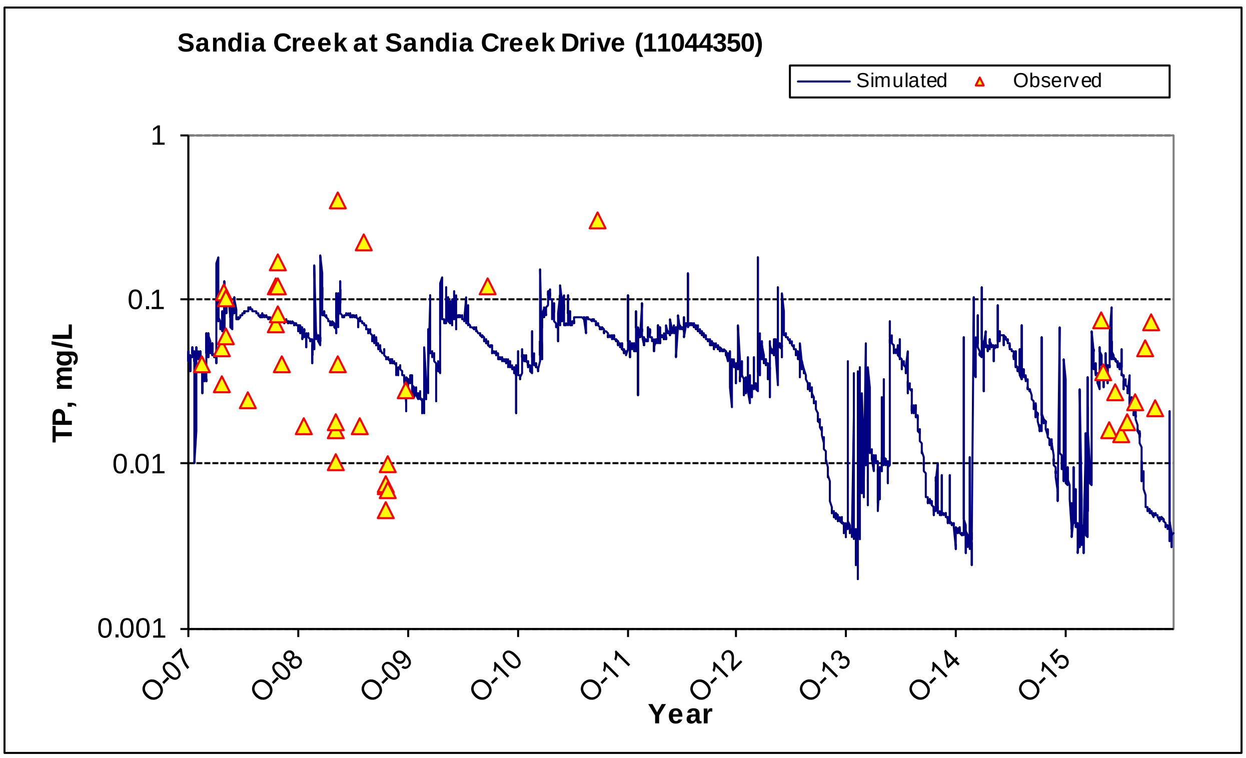


Figure 2-73. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

1.1.2.9 Santa Margarita River at Old Hospital (SCCWRP SMR5 and SMR6)

This area is immediately above the Camp Pendleton Diversion, and was only sampled in 2015-2016 by SCCWRP. This is a key location for the nutrient response modeling so full statistics are presented despite the small sample size.

Table 2-16. Water Quality Calibration Statistics for Santa Margarita River at Old Hospital (SMR5 and 6)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3 -N**	**TN**	**SRP**	**TP**
Count	21	21	21	21	21	21	21
Concentration Average Error	26.90%	-2.81%	-1.64%	32.86%	13.43%	-10.79%	3.91%
Concentration Median Error	28.14%	-3.22%	-1.91%	50.68%	11.55%	-23.80%	-0.99%
Load Average Error	20.02%	1.95%	2.69%	4.27%	3.59%	21.17%	34.96%
Load Median Error	29.46%	-2.52%	-1.49%	19.45%	7.12%	-23.82%	-0.76%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

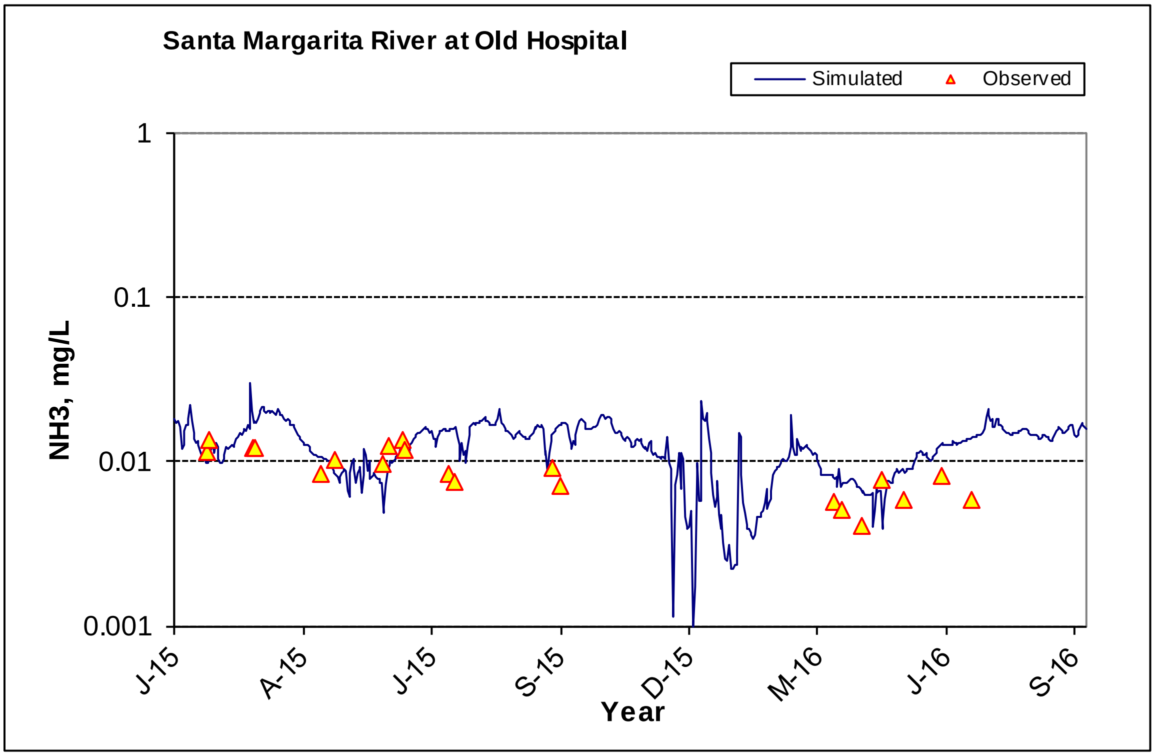


Figure 2-74. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Santa Margarita River at Ysidora (11046000)

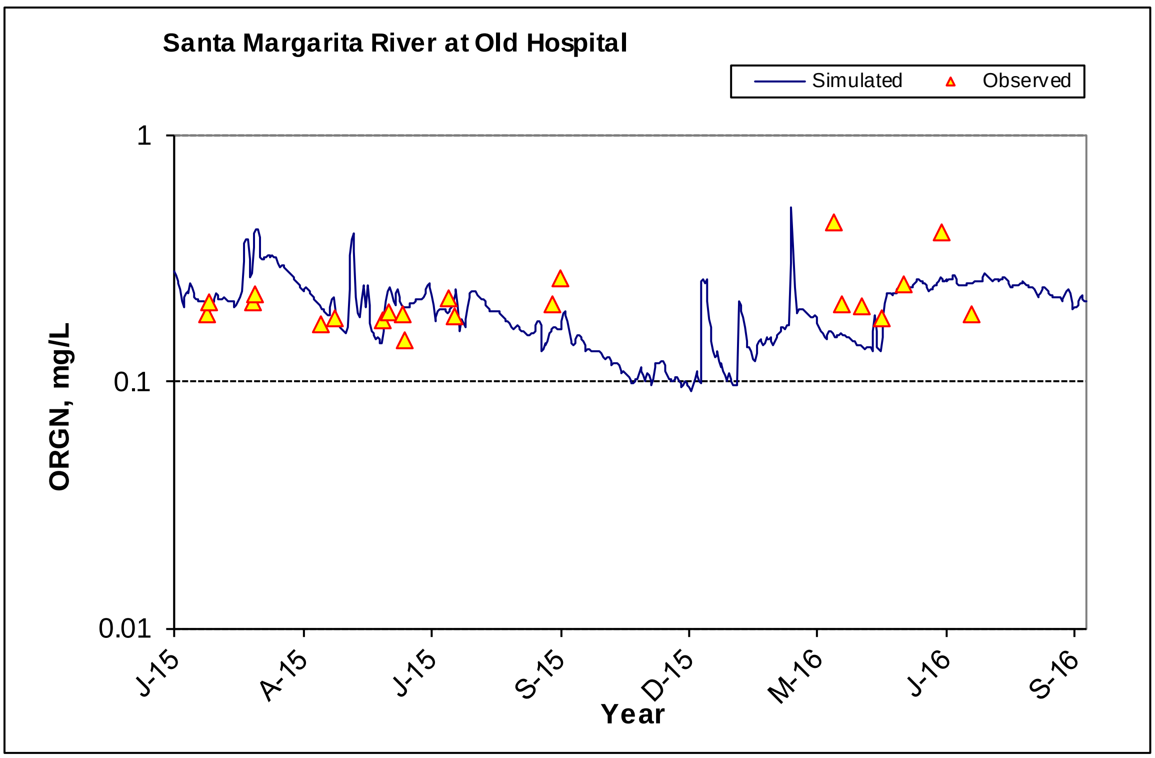


Figure 2-75. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Santa Margarita River at Ysidora (11046000)

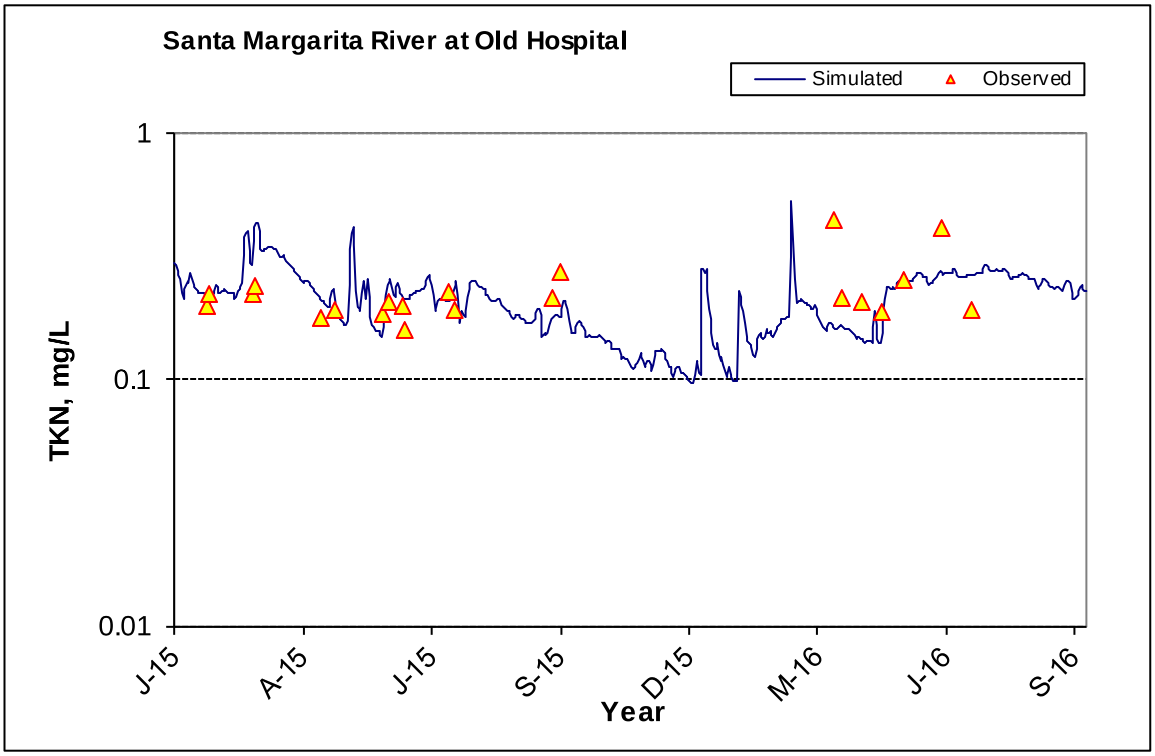


Figure 2-76. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Santa Margarita River at Ysidora (11046000)

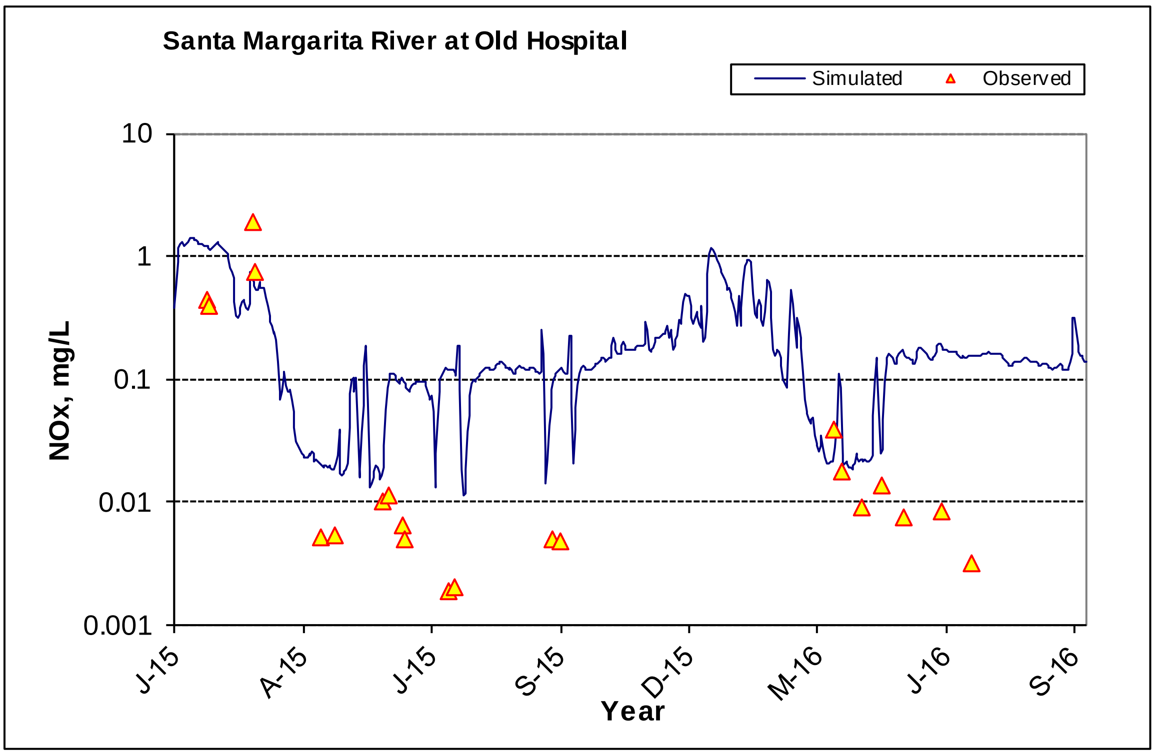


Figure 2-77. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Santa Margarita River at Old Hospital (SMR5 and SMR6)

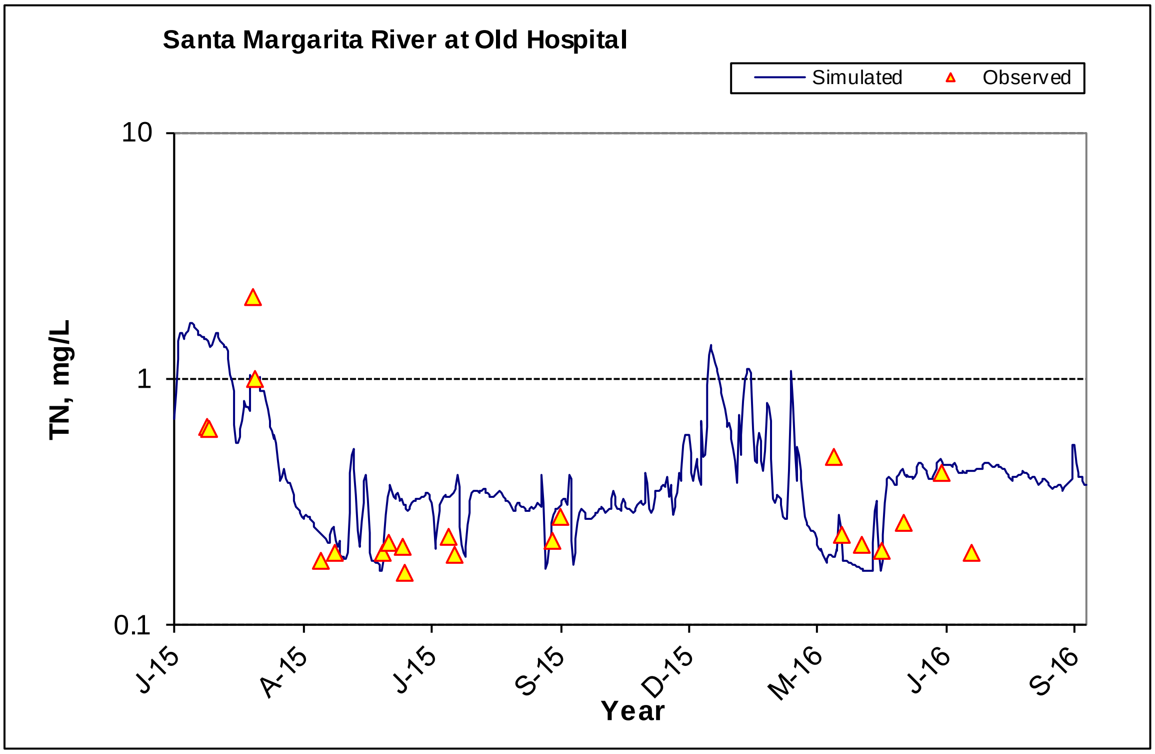


Figure 2-78. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Santa Margarita River at Old Hospital (SMR5 and SMR6)

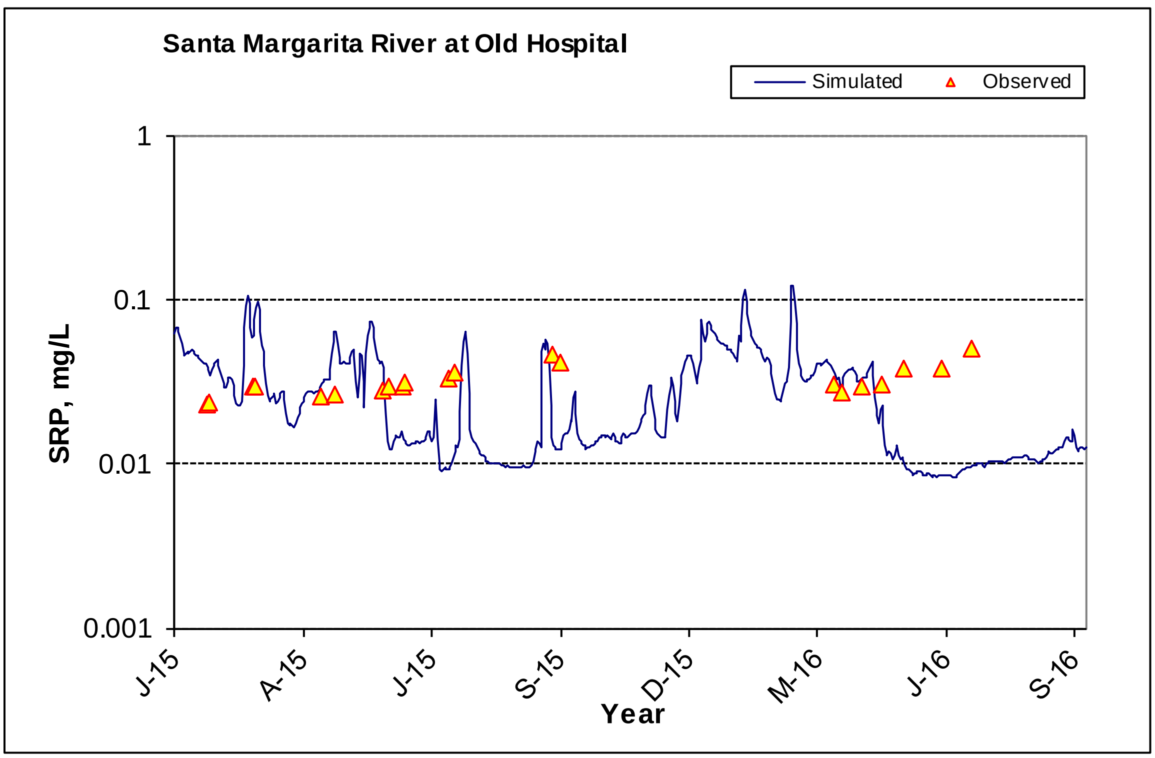


Figure 2-79. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Santa Margarita River at Old Hospital (SMR5 and SMR6)

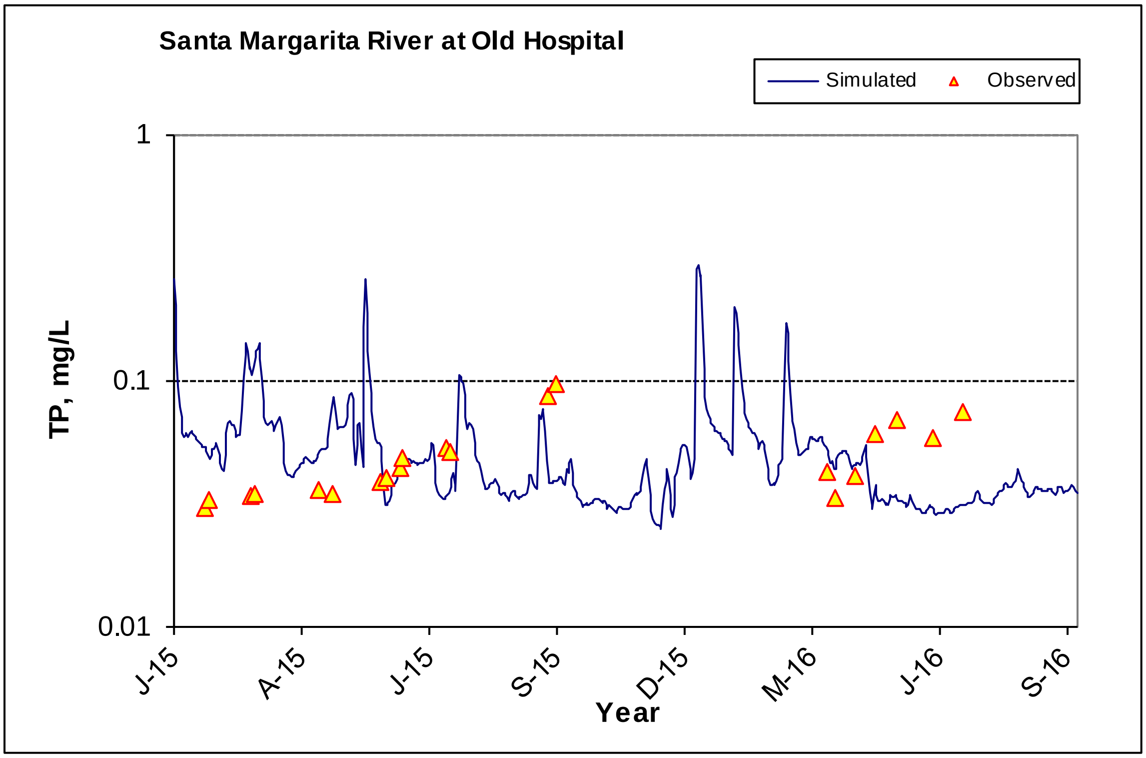


Figure 2-80. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Santa Margarita River at Old Hospital (SMR5 and SMR6)

TP and TN concentrations are generally low at this station (dry weather sampling only available) and average errors indicate a good fit. Note that while there is an average error of 13 percent for TN, this represents a discrepancy of only 0.055 mg/L. Similarly, the average error on TP is only 0.0019 mg/L. Simulated vs. observed scatterplots show that the model is doing a good job of capturing observed TN variability. In contrast, for TP the model is representing the mean of the dry weather observations, but not the sample-to-sample variability.

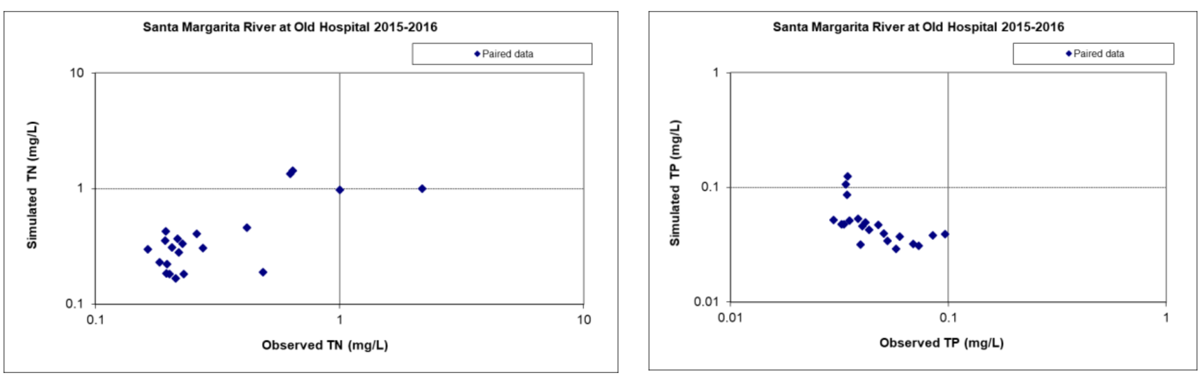


Figure 2-81. Scatterplots for Observed and Simulated TN and TP for Santa Margarita River at Old Hospital (SMR5 and SMR 6)

1.1.2.10 Santa Margarita River at Ysidora (11046000 and SCCWRP SMR2, SMR3, and SMR4)

The Santa Margarita River at Ysidora station is also of high interest for the lower river response modeling and full statistics are presented despite low sample counts, less than the desired minimum of 30. Flow is intermittent at this site and strongly affected by exchanges with the alluvial aquifer influenced by recharge on Camp Pendleton and pumping wells. The load average errors are skewed by a few outliers and small number of wet weather samples.

Table 2-17. Water Quality Calibration Statistics at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	**OrgN**	**TKN**	**NO_2+NO_3 -N**	**TN**	**SRP**	**TP**
Count	26	19	27	27	27	29	24
Concentration Average Error	21.98%	-11.23%	28.20%	64.31%	38.18%	-18.55%	21.34%
Concentration Median Error	39.34%	15.01%	22.77%	1.21%	20.54%	-7.50%	16.00%
Load Average Error	-43.52%	-23.33%	203.88%	56.72%	107.13%	60.58%	86.71%
Load Median Error	0.65%	-13.92%	-1.09%	0.00%	-1.10%	-5.56%	-2.34%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

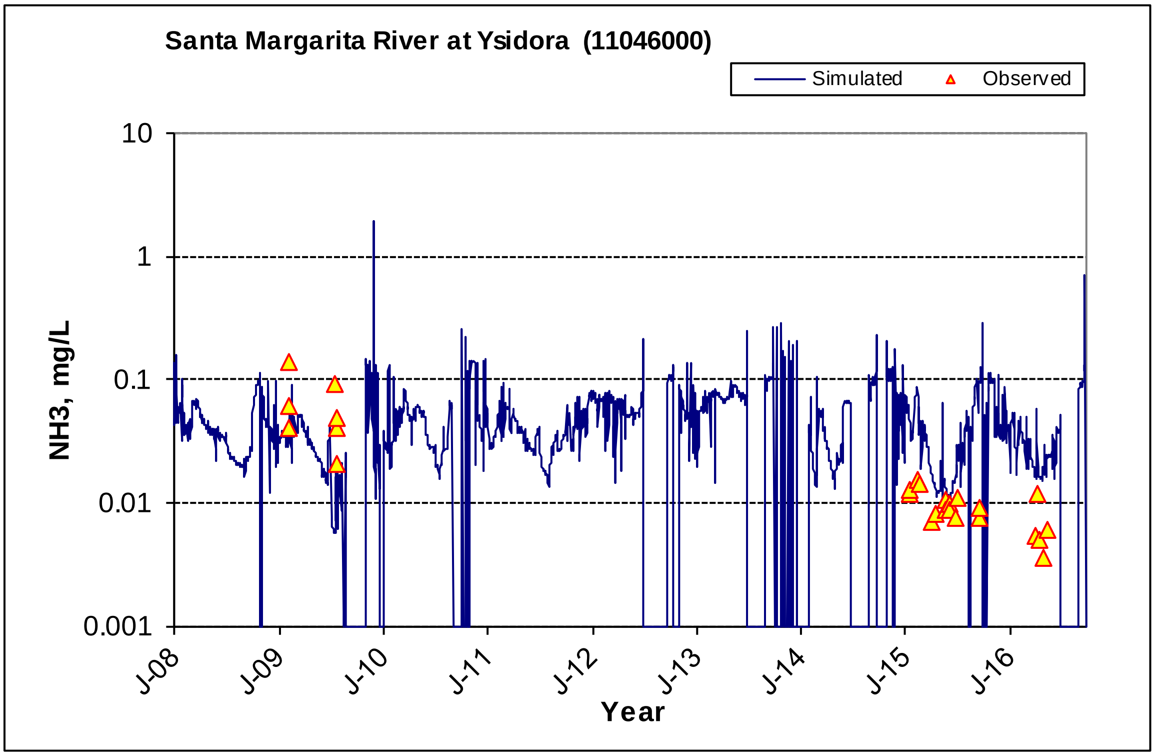


Figure 2-82. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

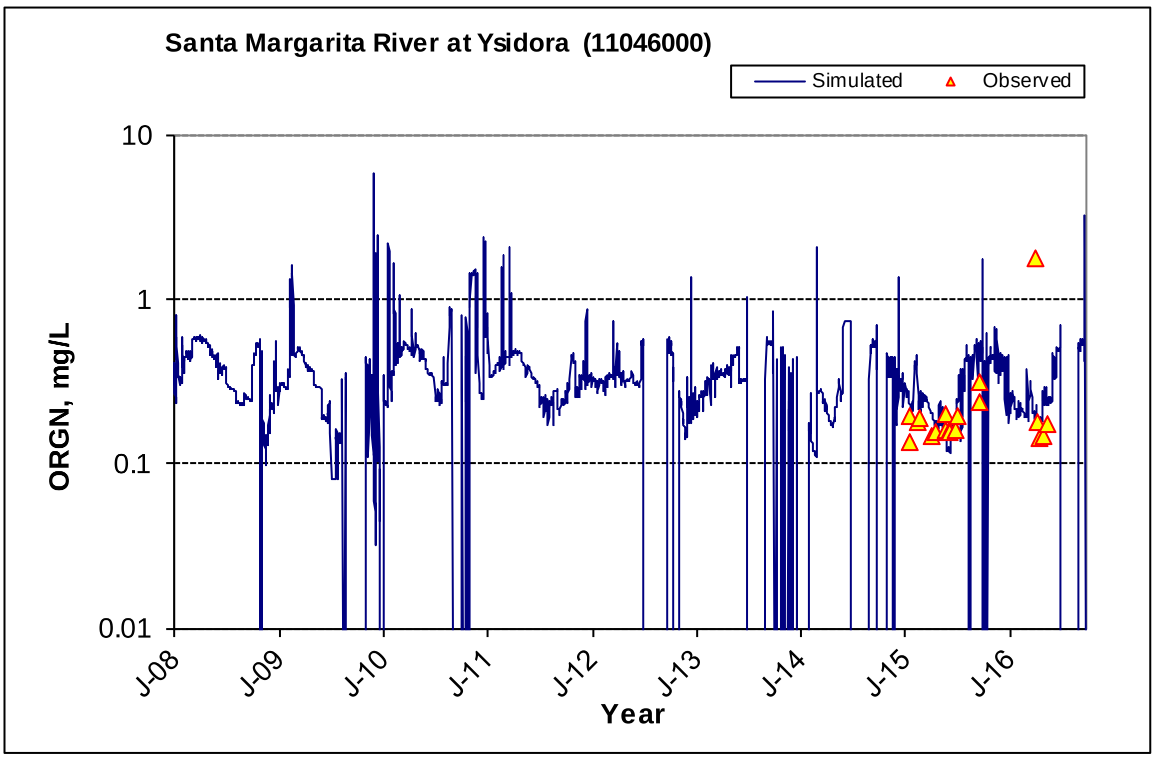


Figure 2-83. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

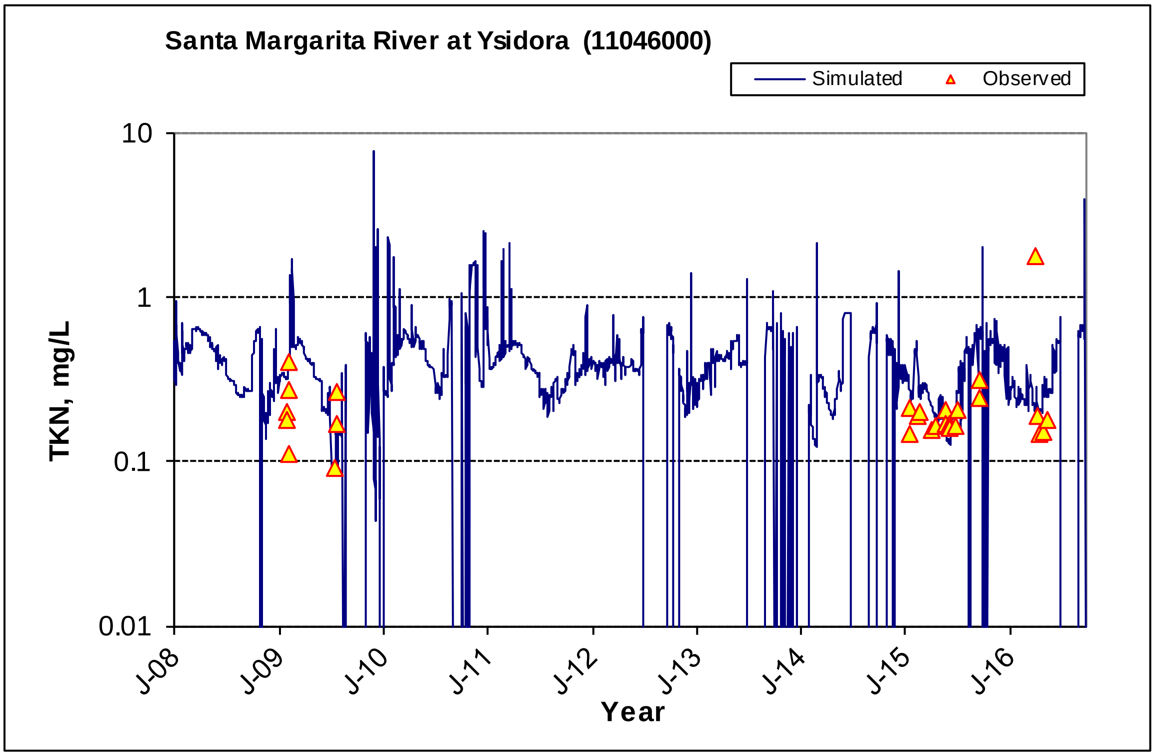


Figure 2-84. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

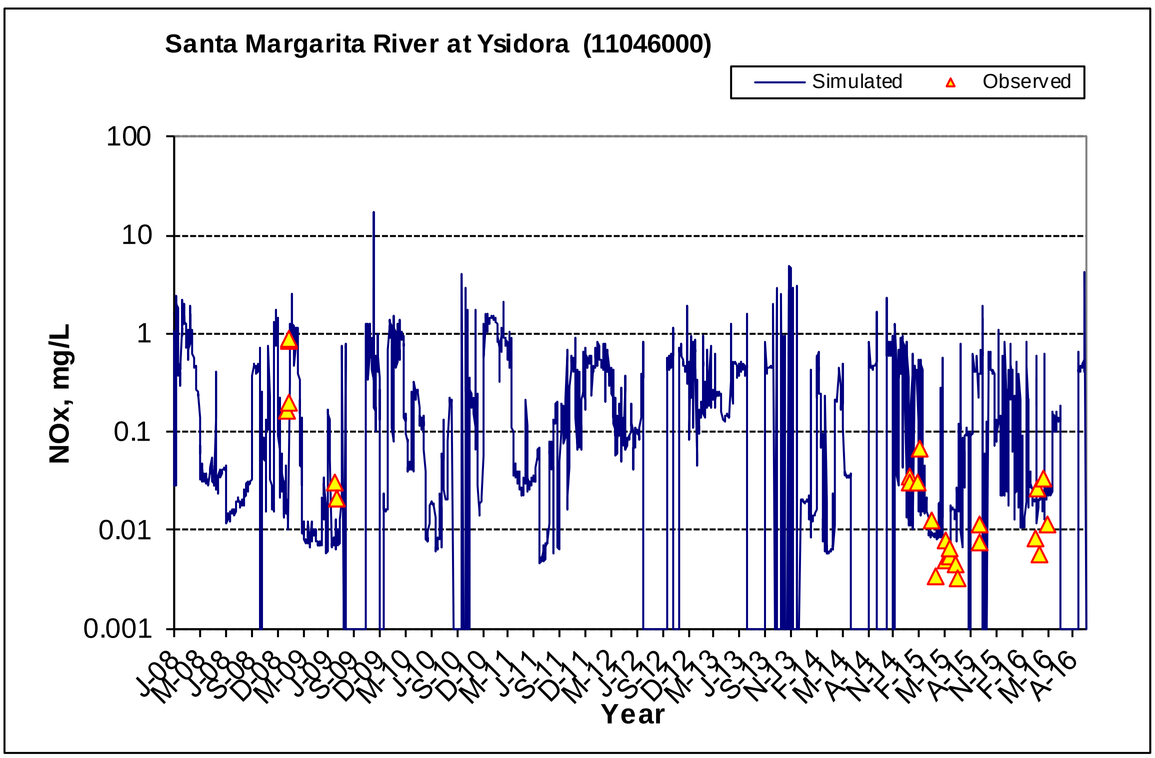


Figure 2-85. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

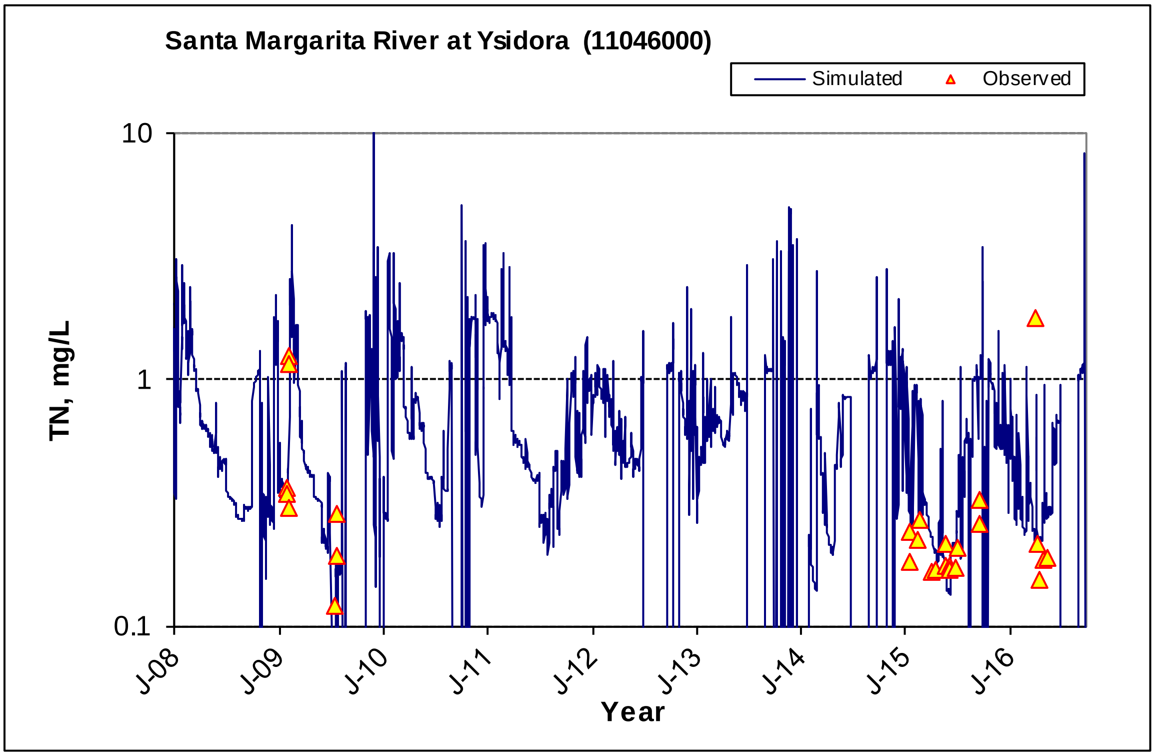


Figure 2-86. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

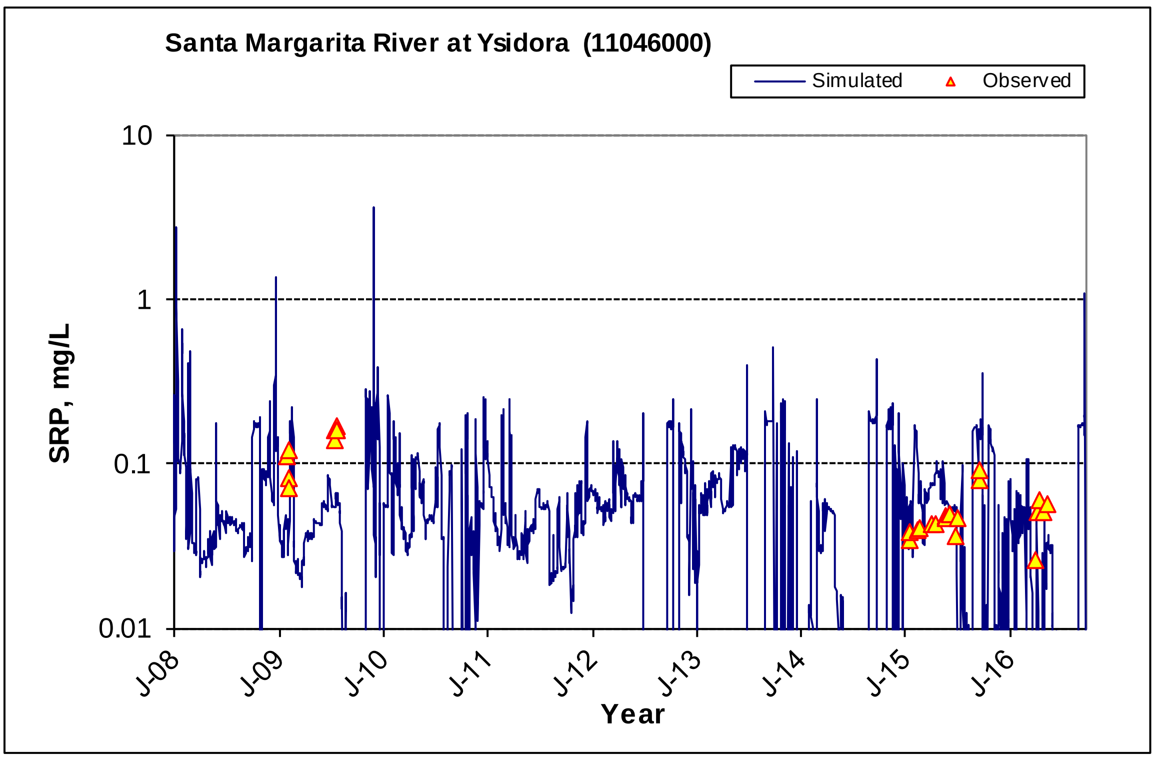


Figure 2-87. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

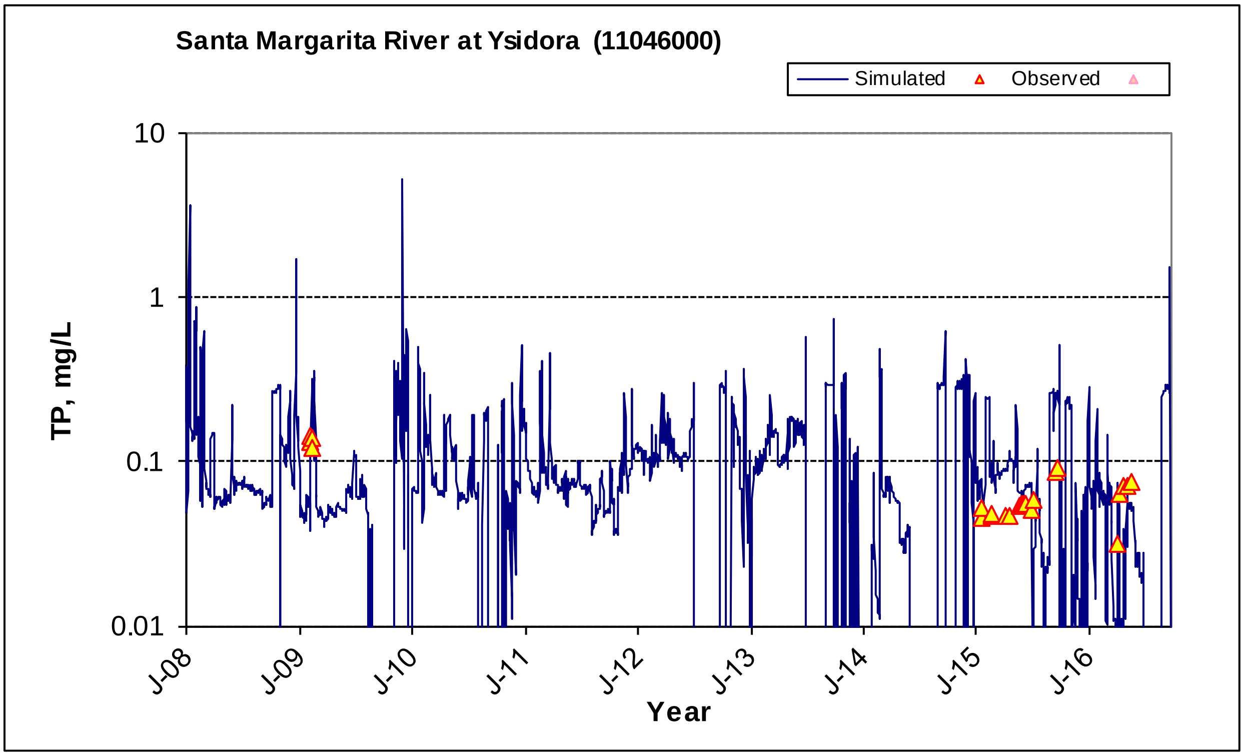


Figure 2-88. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Santa Margarita River at Ysidora (11046000 and SMR2-SMR4)

1.1.2.11 Santa Margarita River nr Macs Road (MLS-1)

Sample records are limited at MLS-1, the most downstream sampling site used for the model nutrient calibration. Unlike most upstream sampling locations, nutrient concentrations were often measured during wet weather conditions. Flow is intermittent at this location.

Table 2-18. Water Quality Calibration Statistics at Santa Margarita River near Macs Road (MLS-1)

Metric	Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+NO_3 -N	TN	SRP	TP
Count	13	7	18	20	15	0	22

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

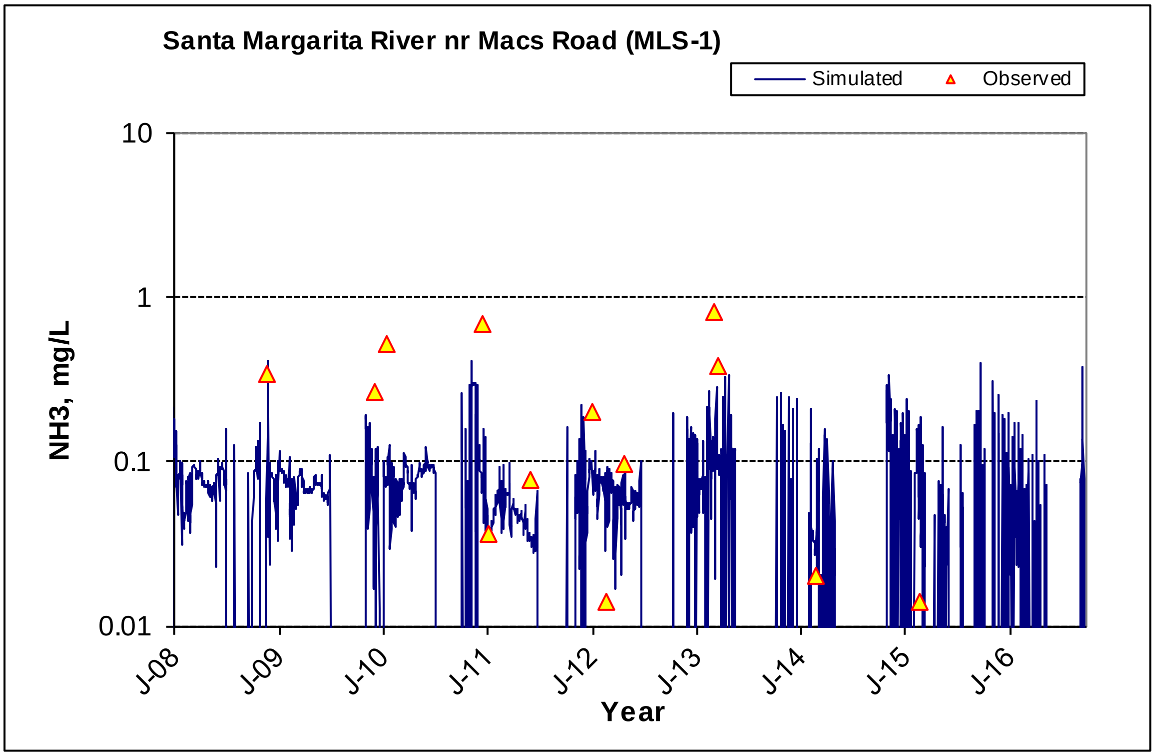


Figure 2-89. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Santa Margarita River nr Macs Road (MLS-1)

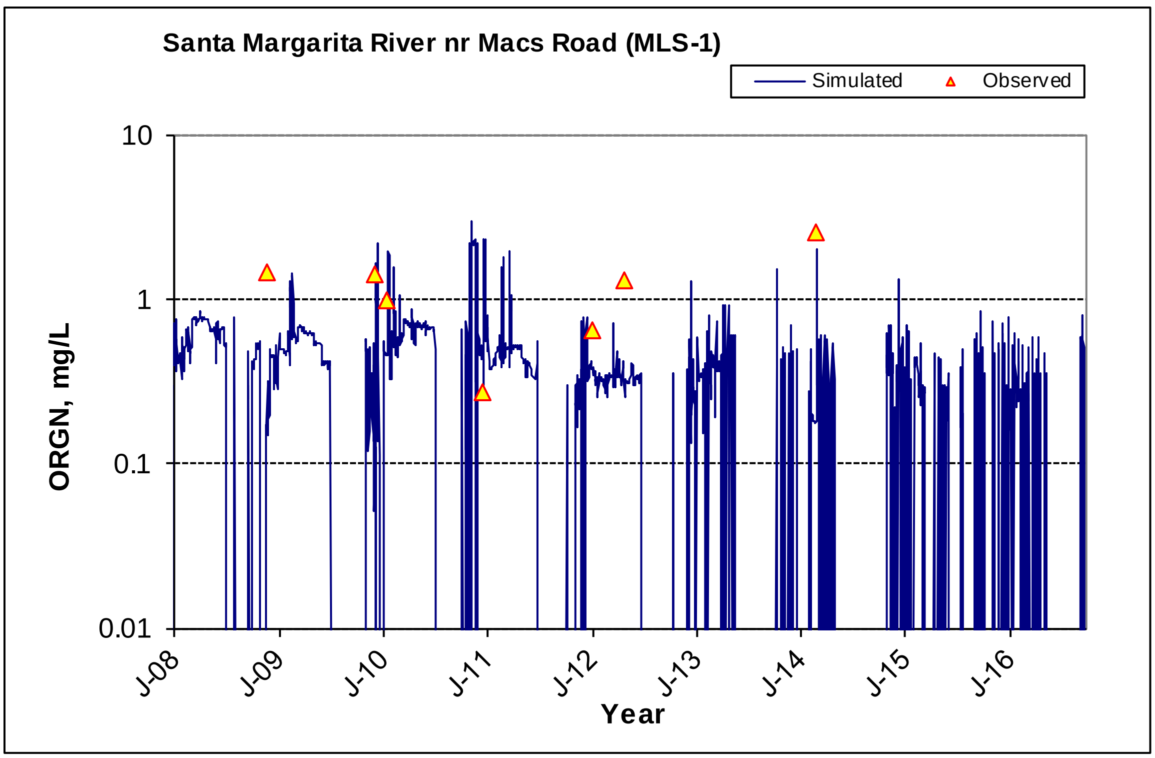


Figure 2-90. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Santa Margarita River nr Macs Road (MLS-1)

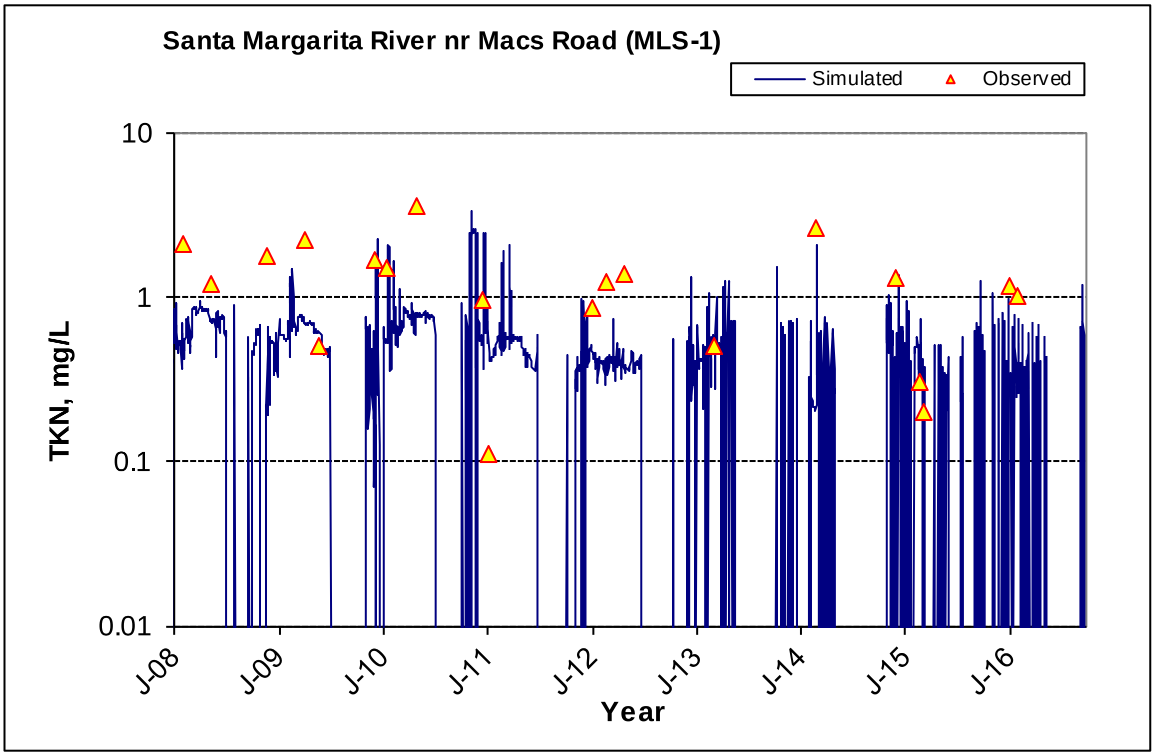


Figure 2-91. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Santa Margarita River nr Macs Road (MLS-1)

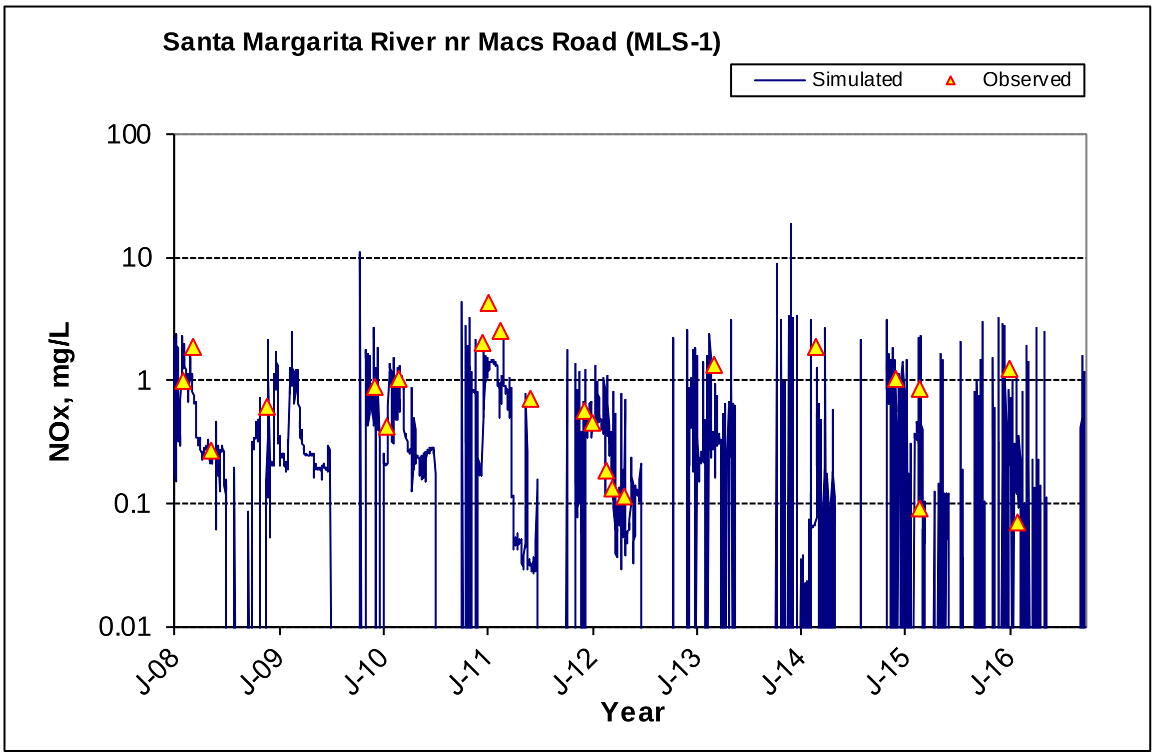


Figure 2-92. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Santa Margarita River nr Macs Road (MLS-1)

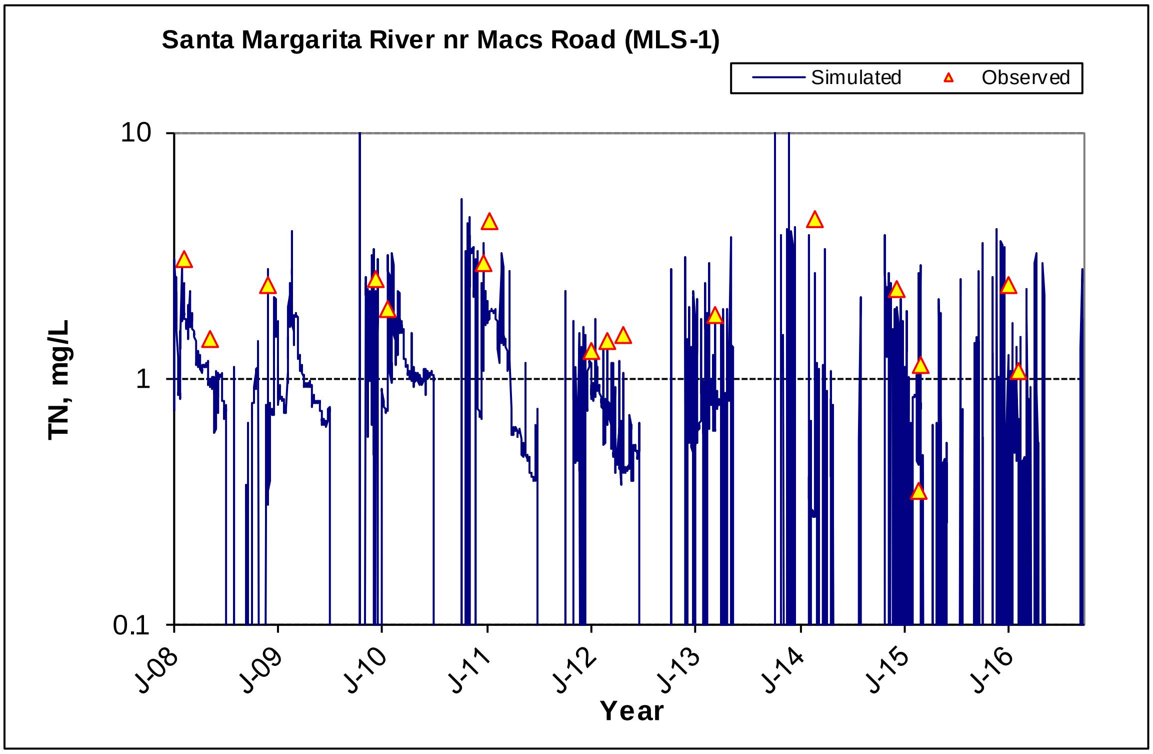


Figure 2-93. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Santa Margarita River nr Macs Road (MLS-1)

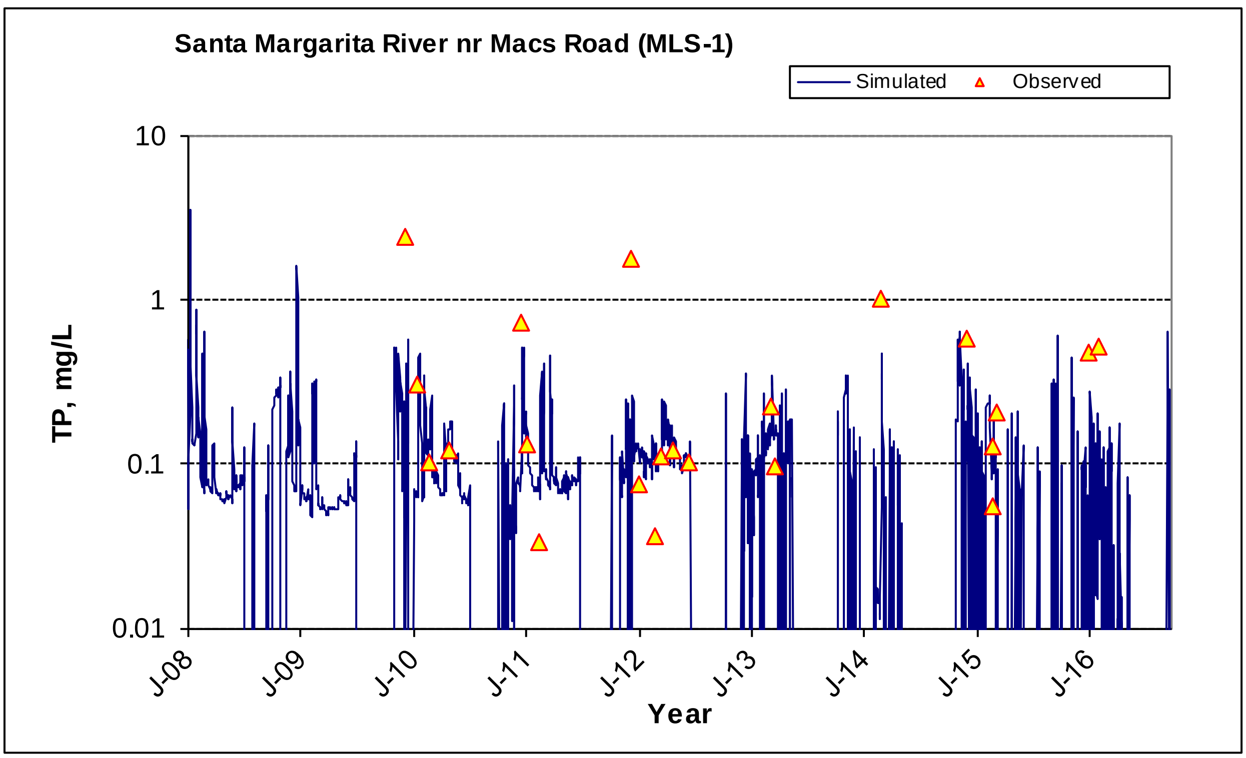


Figure 2-94. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Santa Margarita River nr Macs Road (MLS-1)

2.6 USE OF HSPF AS A NUTRIENT RESPONSE MODEL

One purpose of this work is to compare different model options for simulating nutrient responses in flowing streams. The primary purpose of the HSPF watershed model in this context is to provide boundary conditions to more detailed nutrient response models. However, HSPF itself can be used as a nutrient response model as it contains routines that address algal growth dynamics, dissolved oxygen, water temperature and pH. The model formulation does have limitations. Most notably, HSPF represents stream reaches as 1-dimensional, fully-mixed reactors, and the stream reaches in this model are several miles in length. Thus, HSPF is not expected to fully capture all the three-dimensional details and finer-scale variability of a stream, particularly for algal growth. The model simulates only a single, generic type of planktonic algae and a single, generic type of benthic algae, while temperature and DO resolution is limited by coarse-scale reach representation. Nonetheless, the HSPF model does provide a representation of receiving water nutrient response. Indeed, it needs to do a credible job of capturing the general characteristics of the nutrient-temperature-algae-DO relationships to provide an appropriate representation of the balance between different forms of nutrients for input into the other receiving water models.

2.6.1 Model Calibration for Temperature, DO, and Algae

2.6.1.1 HSPF Modules

The HSPF modules used to represent water temperature include PSTEMP (soil and ground water temperature) and HTRCH (heat exchange and water temperature within flowing reaches). Simulation of soil temperature is accomplished in HSPF by using three layers: surface, upper subsurface, and ground water. The surface layer is the portion of the land segment that determines the overland flow water temperature. The upper subsurface layer determines interflow temperature while the groundwater subsurface layer determines groundwater temperature. Surface and upper subsurface layer temperatures are estimated by applying a regression equation relative to measured air temperature. The groundwater temperatures are user-supplied to reflect average characteristics of the region.

PSTEMP provides estimates of temperature in water discharging to the stream via surface outflow, upper subsurface/interflow outflow, and groundwater outflow. Once the water is in the stream, the temperature is modified by energy exchanges that can increase or decrease the heat content of the water. Mechanisms that can increase the heat content of the water are absorption of solar radiation, absorption of long-wave radiation, and conduction-convection. Mechanisms that decrease the heat content are emission of long-wave radiation, conduction-convection, and evaporation. Heat exchanges between the water and stream bed are also simulated.

The DO balance in streams reflects a complex interaction of reaeration rate (a function of turbulence), the oxygen concentration of inflowing water, the saturation concentration of oxygen (which depends on temperature and salinity), consumption of oxygen by bacterial breakdown of carbonaceous and nitrogenous material in the water column (biochemical oxygen demand (BOD)) and at the water-sediment interface (sediment oxygen demand (SOD)), production of oxygen during photosynthesis by algae and macrophytes, and consumption of oxygen during nighttime algal/macrophyte respiration (Figure 2-95). The effects of plant photosynthesis/respiration and diel cycles of water temperature result in a situation where grab sample measures of DO are not very informative for model calibration. Further, the influence of algae/macrophytes on DO means that DO and algae must be calibrated simultaneously.

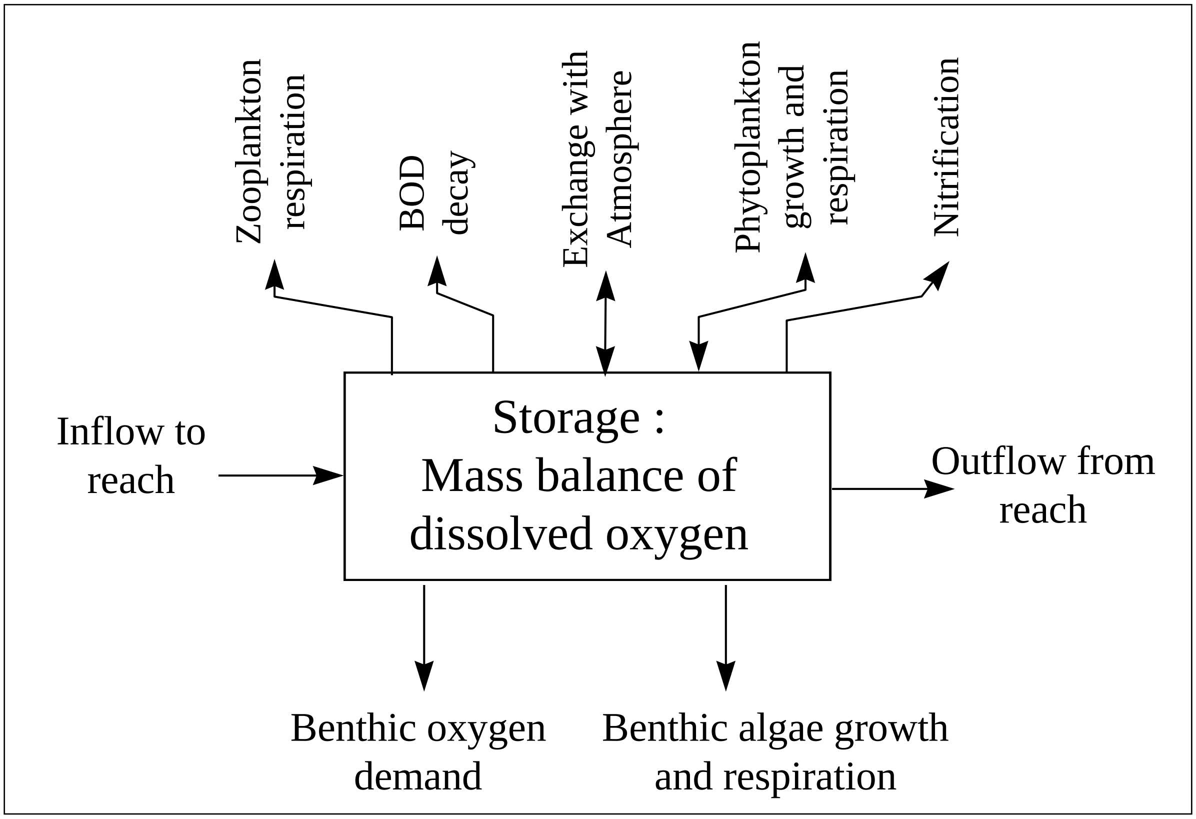


Figure 2-95. Process Diagram for Oxygen Mass Balance in HSPF

The following describes the representation of the aforementioned processes in the watershed model:

Reaeration: When oxygen concentrations are reduced below saturation, oxygen tends to move from the atmosphere to the water, a process known as reaeration. The rapidity of reaeration depends on how well the water is mixed and the turbulence present at the water surface. HSPF provides several options for simulating stream reaeration. For the Santa Margarita, there are no direct measurements of reaeration rate; however, we found that the Tsivoglou energy dissipation equation (HSPF option 1; Tsivoglou and Wallace, 1972) provides a reasonable fit to observed data.

Biochemical Oxygen Demand: HSPF simulates nitrogenous and carbonaceous components of biochemical oxygen demand separately, with the nitrogenous component being determined by concentrations of reduced inorganic nitrogen species (ammonium and nitrite). Carbonaceous biochemical oxygen demand (CBOD) loading from the watershed is simulated as the labile fraction of total organic carbon. As the decay of CBOD results in the conversion of labile organic matter to inorganic nutrients, the representation of CBOD is largely constrained by the nutrient calibration. For the Santa Margarita watershed, there are no permitted point sources, but CBOD is loaded as part of the storm washoff of plant material and detritus in the watershed. CBOD is also generated instream by the growth and senescence of algae.

The CBOD decay rate (k_d) is expected to be relatively low due both to the nature of organic carbon derived from upland sources. A k_d value of 0.003 per hour (0.072 per day) appears to provide reasonable results for DO. This is near the low end of the range of values reported nationally for streams without untreated waste input (USEPA, 1997).

Benthic Interactions. Organic sediment stored in the stream channel affect the oxygen balance. These may both release BOD into the stream and exert a sediment oxygen demand (SOD) at the sediment-water interface. No direct measurements of SOD are available, so this becomes a calibration adjustment factor. The results of this calibration are discussed in Section 2.6.1.3. Within the sandy or gravelly parts of the Santa Margarita channel there is likely substantial hyporheic flow within the bed medium. This process is not represented separately in HSPF, so any oxygen consumption that occurs during hyporheic flow is treated as part of the SOD.

Algal Dynamics: The activities of floating (planktonic) and attached (benthic) algae also affect the oxygen balance in streams. Within flowing streams like the Santa Margarita, it is the attached algae that typically dominate. Algae produce oxygen as a byproduct of photosynthesis during sunlight hours, but are net consumers of oxygen through respiration at night. Algae can also die off, contributing to the biochemical oxygen demand. Santa Margarita sampling does include measures of both benthic chlorophyll *a* and benthic ash-free dry mass, both of which were used to constrain and calibrate the model. Note that HSPF does not include explicit representation of either rooted plants or macroalgae that are attached but floating in the water column; these must be approximated through the water column regime.

HSPF also allows simulation of the carbonate system that determines pH, as well as providing for potential limitation of algal growth by the availability of inorganic carbon. The carbonate system controls the pH. The four important types of inorganic carbon in streams are CO_2, H_2CO_3, HCO_3^{-1}, and CO_3^{-2}, which in turn determine the hydrogen ion and hydroxyl ion concentrations, and thus the pH. (The pH is essentially determined by the ratio of CO_2 to total inorganic carbon.) User input is based on CO_2 plus alkalinity, defined as the amount of acid required to attain a pH value equal to that of a total inorganic carbon molar solution of H_2CO_3, and thus is a measure of the defined as the amount of acid required to attain a pH value equal to that of a total inorganic carbon molar solution of H_2CO_3 content of the water. The carbonate system is assumed to be conservative except for the CO_2 concentration, which may increase or decrease due to exchanges across the water-air interface, and algal growth and respiration. When algae are actively photosynthesizing, CO_2 is depleted, lowering the acid level, and increasing the pH. The opposite occurs during nighttime algal respiration. The Santa Margarita has relatively high alkalinity (around 200 mg/L in monitoring), indicating that the system is well-buffered and that changes in pH associated with algal growth and respiration will be muted.

2.6.1.2 Water Temperature

Boundary water temperatures below the confluence of Murrieta and Temecula Creek are monitored by USGS (station 11044000) and are specified directly to the model. Available records include monthly average minimum and maximum (1994-1999), daily minimum and maximum (1999-2007) and 15-minute time series (2007-on), which were used to assemble a consistent hourly time series. This provides a strong representation of the boundary condition. Temperatures in flowing water downstream are then modified by heat exchange processes with the air and sediment. We calibrated the model by adjusting the fraction of the water surface open to the sky and the bed heat transfer factor to ensure a reasonable match to observations from 2015-2016 reported by Sutula et al. (2016b) at the Old Hospital stations (SMR5 and SMR6), both of which fall within HSPF Reach 108. Note that preliminary data in Sutula et al. (2016b) have been updated and corrected. These revised results were provided directly by SCCWRP.

During 2015, sonde deployments were brief. The model does a reasonable job of reproducing observed temperatures at both SMR5 and SMR6 (Figure 2-96), although the simulated daily peaks produced by the model are higher than observations, perhaps due to model inability to represent topographic shading. Note that there are some clearly faulty water temperature measurements at SMR6 during May- June when a nearly constant temperature of 7 °C was reported, likely due to the probe being buried. Omitting those observations, the average error was 0.86 °C at SMR5 and 1.3 °C at SMR6; average absolute errors were 1.6 and 2.2 °C, respectively. These errors are within the expected range of ability of HSPF for stream temperature simulation (see Duda et al., 2012).

In 2016, temperature was monitored for longer periods of time, but the records at SMR5 and SMR6 diverge for unknown reasons, even though the two stations are only 600 feet apart. The model splits the difference between the two monitoring stations (Figure 2-97). The average error was -3.3 °C at SMR5 and +1.4 °C at SMR6; average absolute errors were 3.7 and 2.4 °C, respectively.

Additional monitoring took place near the Ysidora stream gage (SMR3 and SMR4). Unlike the Old Hospital reach, the river frequently goes dry at this location. This causes problems for HSPF, which turns off the temperature simulation at low flows and instead sets water temperature equal to air temperature to preserve model stability. Despite this, the simulation looks good in 2015 (Figure 2-98), with observations covering only a few days in 2016 (Figure 2-99).

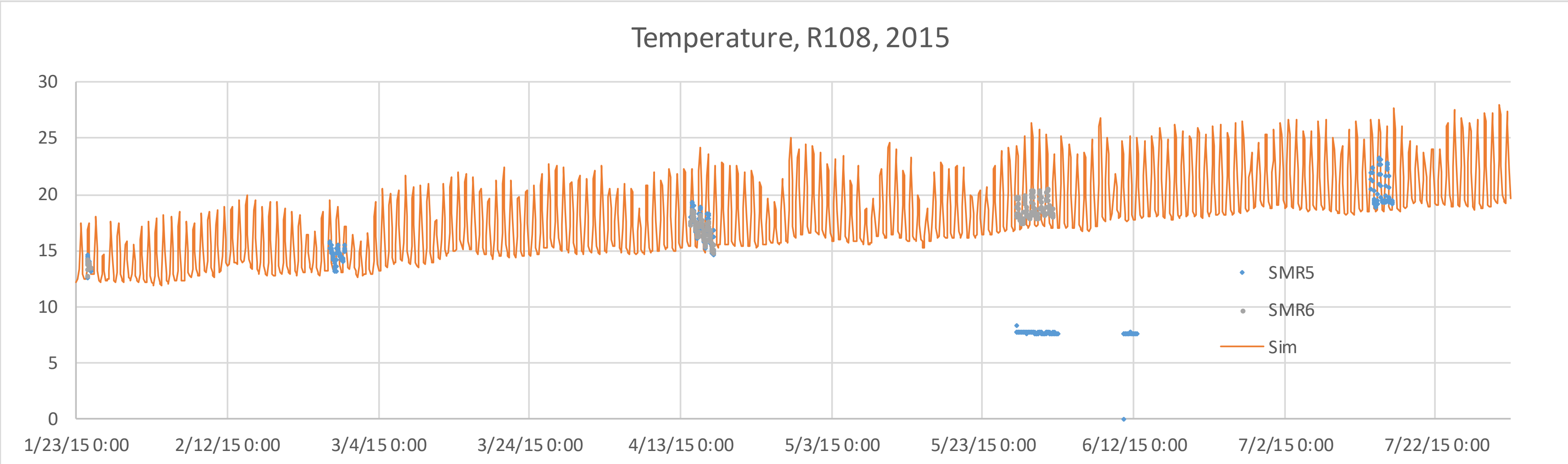


Figure 2-96. Simulated and Observed Water Temperature near Old Hospital, 2015

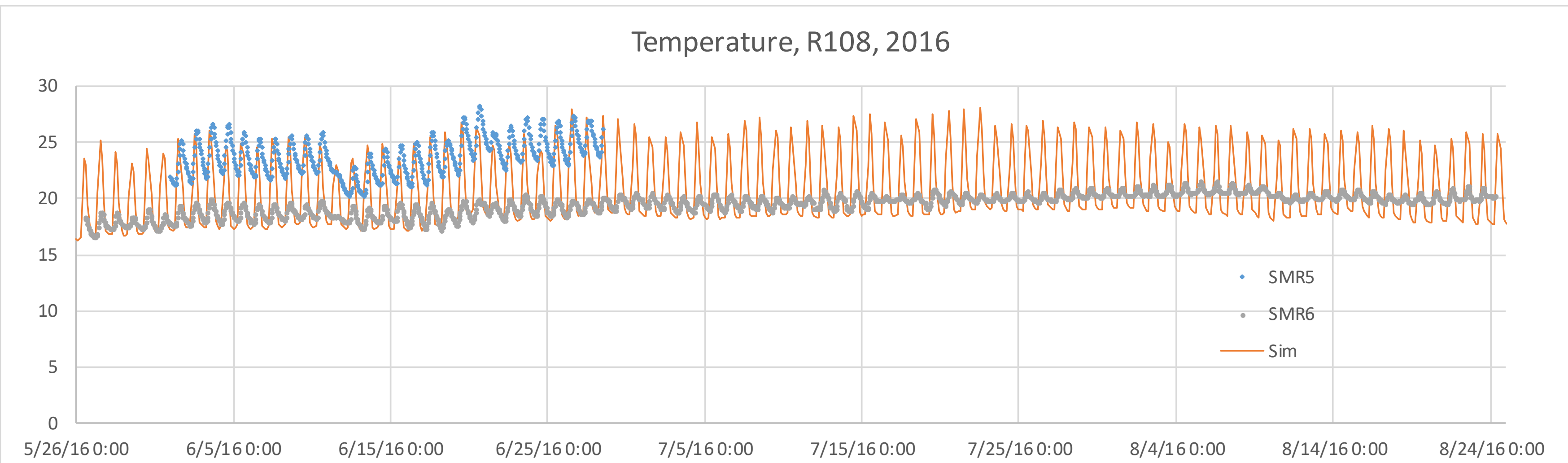


Figure 2-97. Simulated and Observed Water Temperature near Old Hospital, 2016

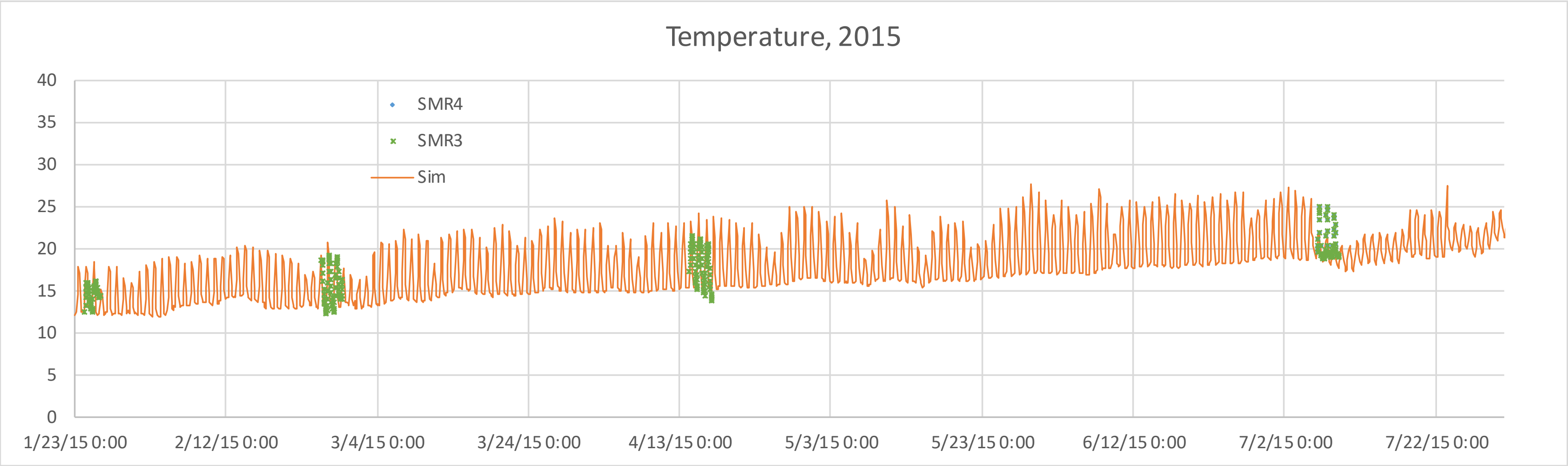


Figure 2-98. Simulated and Observed Water Temperature near Ysidora Gage, 2015

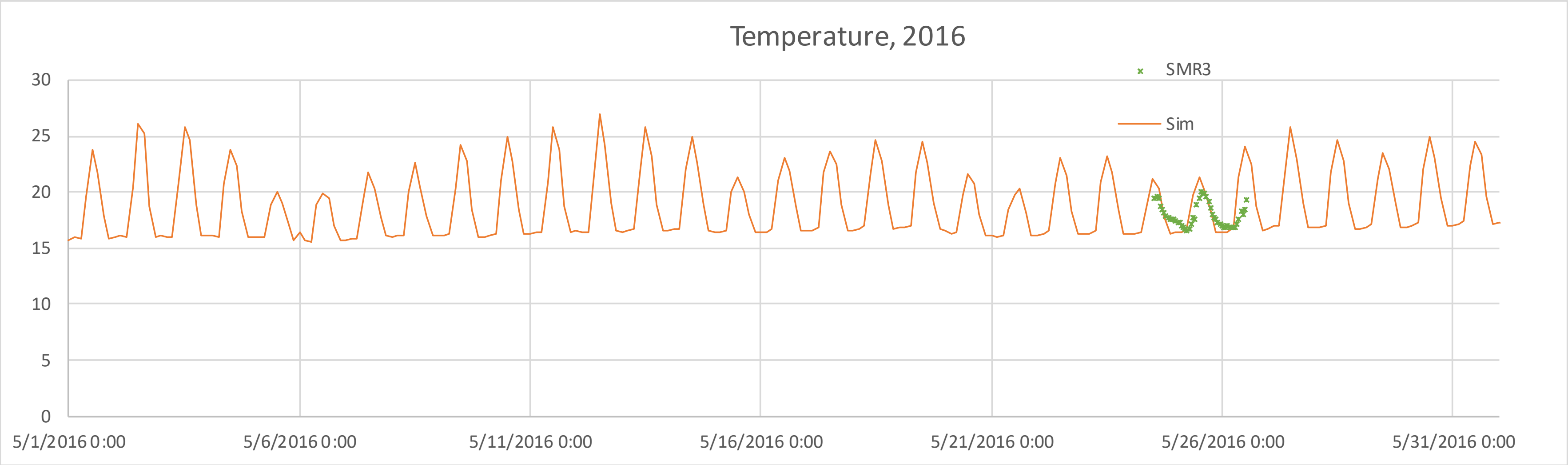


Figure 2-99. Simulated and Observed Water Temperature near Ysidora Gage, 2016

2.6.1.3 Dissolved Oxygen

The primary controls on the dissolved oxygen simulation are algal growth and respiration (which determine the diel variability) and sediment oxygen demand (which, in conjunction with any other constant sources of oxygen demand and in balance with reaeration, controls the magnitude of the daily average). Calibrated estimates of sediment oxygen demand (75 mg/m^2/hr at 20 °C for reach 108 near the Old Hospital and 50 mg/m^2/d for reach 105 above the Ysidora gage) are moderate and well within the range of measured values reported in USEPA (1997). Benthic algal densities are also moderate and consistent with measurements (see Section 2.6.1.4). Reaeration rate coefficients were left at Tsivoglou defaults, but are low due to low velocities (average 0.1 ft/s during 2015-2016). The net result is a depression of dissolved oxygen below saturation.

Continuous DO observations are available at the same stations as temperature, as described in Sutula et al. (2016b). Comparison of observed and HSPF-simulated DO is provided in Figure 2-100 through Figure 2-103. As with temperature, there are marked differences between results for SMR5 and SMR6 in 2016. Table 2-19 provides model fit statistics for observed dissolved oxygen, emphasizing the differences between SMR5 and SMR6 in 2016.

Table 2-19. Dissolved Oxygen Simulation Uncertainty Statistics

	SMR5 & SMR6, 2015 (R108)		SMR5 & SMR6, 2016 (R108)		SMR3 & SMR4, 2015 (R105)		SMR3 & SMR4, 2016 (R105)	
	SMR5	SMR6	SMR5	SMR6	SMR3	SMR4	SMR3	SMR4
Average Observed (mg/L)	7.30	9.64	7.59	2.96	7.47	6.41	6.25	ND
Average Error (mg/L)	-0.77	-0.96	-4.17	0.78	-1.51	-3.94	1.59	ND
Average Absolute Error (mg/L)	0.95	0.99	4.17	1.19	1.87	4.00	1.59	ND

While the average DO is largely determined by the interaction of SOD and reaeration, the diel swings in DO are driven by algal photosynthesis and respiration (with additional contributions from the daily temperature cycle, which affects the saturation concentration of DO in water as well as biochemical reaction rates and thus modifies the reaeration rate.) The diel DO range is thus potentially more directly relevant to analysis of eutrophication responses than the absolute DO concentration. Examination of the DO calibration figures suggests that HSPF is doing a reasonable job of reproducing the observed diel variability in most cases. Statistics are provided in Table 2-20. For the Old Hospital sites, HSPF does an excellent job reproducing the diel range, with both average and absolute errors less than 1 mg/L – except for the seemingly anomalous results for SMR5 in 2016. The fit does not appear to be quite as good near the Ysidora gage (SMR3 and SMR4). That could in part be due to HSPF's difficulties in simulating shallow, drying streams; however, note also that the sample size for complete days is quite small for these stations.

Table 2-20. Dissolved Oxygen Diel Range Simulation Uncertainty Statistics

	SMR5 & SMR6, 2015 (R108)		SMR5 & SMR6, 2016 (R108)		SMR3 & SMR4, 2015 (R105)		SMR3 & SMR4, 2016 (R105)	
	SMR5	SMR6	SMR5	SMR6	SMR3	SMR4	SMR3	SMR4
Number of complete days	22	29	10	41	15	4	3	0
Average Observed (mg/L)	1.82	1.05	2.90	0.83	2.51	4.07	1.11	ND
Average Error (mg/L)	-0.62	-0.10	-1.96	-0.40	-0.72	-2.89	0.88	ND
Average Absolute Error (mg/L)	0.86	0.85	1.96	0.56	1.67	2.89	0.88	ND

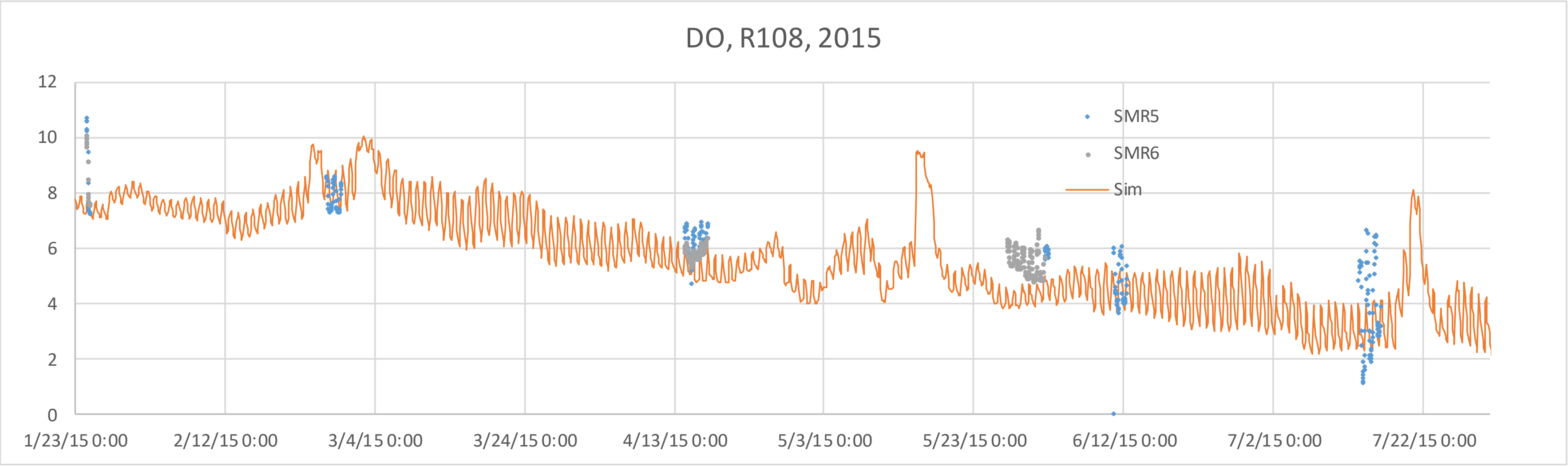


Figure 2-100. Simulated and Observed Dissolved Oxygen near Old Hospital, 2015

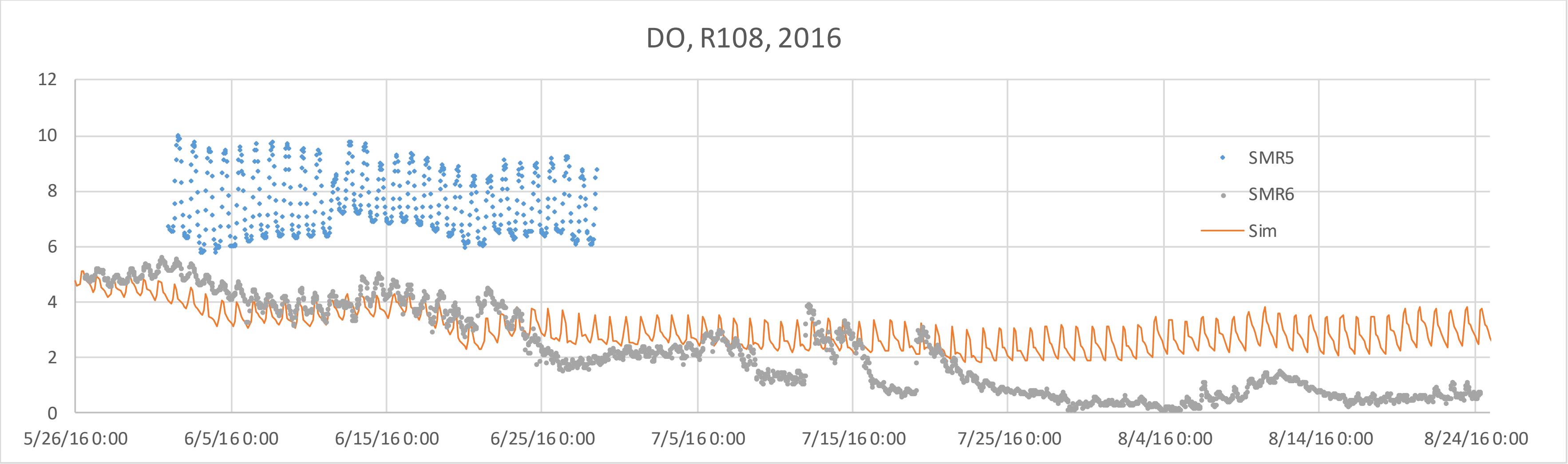


Figure 2-101. Simulated and Observed Dissolved Oxygen near Old Hospital, 2016

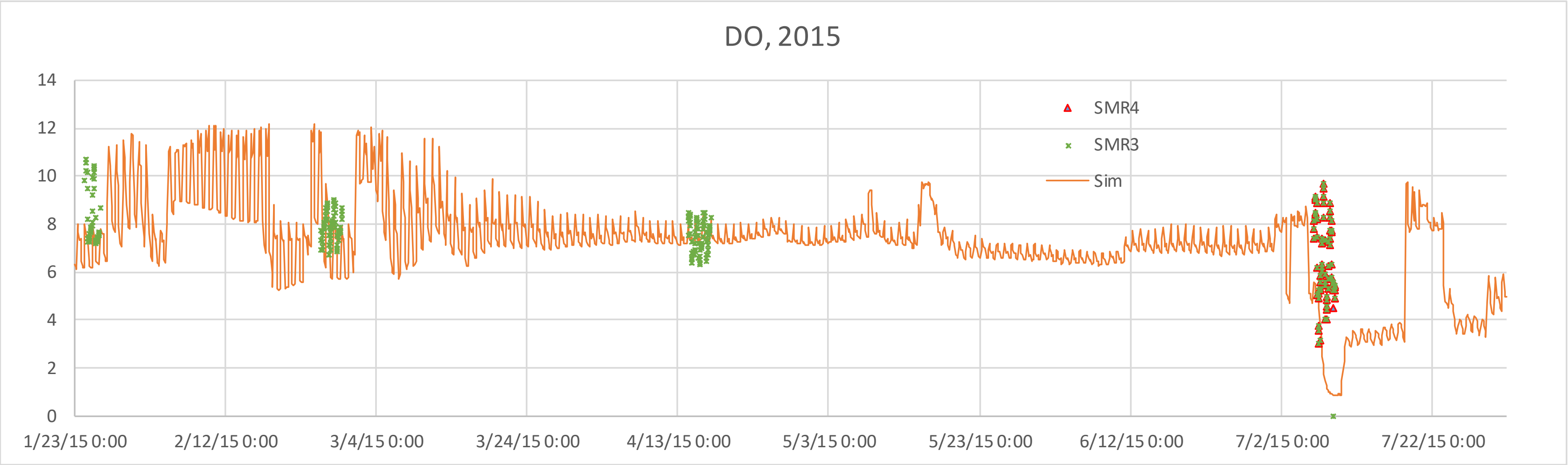


Figure 2-102. Simulated and Observed Dissolved Oxygen near Ysidora Gage, 2015

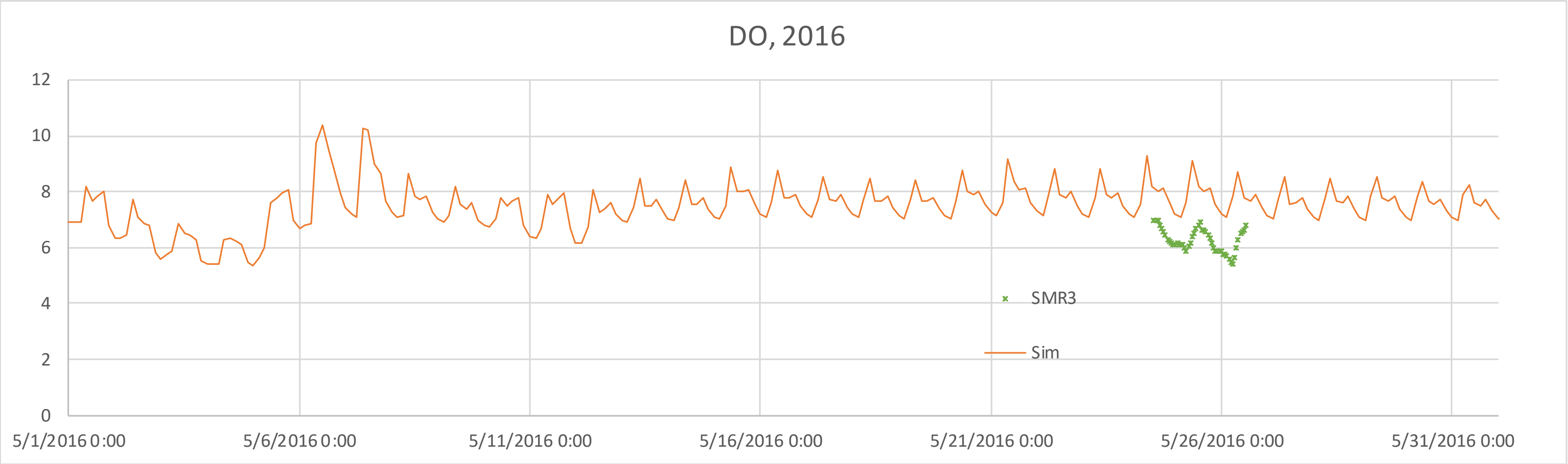


Figure 2-103. Simulated and Observed Dissolved Oxygen near Ysidora Gage, 2016

2.6.1.4 Algae

Both phytoplankton and benthic algae are simulated, although benthic algae (which also implicitly represent rooted macrophytes in the model) predominate. The benthic algae simulation uses option 1 in HSPF, in which a single generic species of benthic algae is represented and modeled using the same equations as are applied for phytoplankton with the exceptions that (1) advection does not occur unless there is sloughing, (2) light availability is modified to account for average depth, (3) growth and respiration rates may be adjusted relative to phytoplankton, and a maximum areal density above which sloughing occurs is specified. HSPF also contains an option to simulate multiple benthic algal species with different characteristics for riffle and runs; however, this option has not been widely tested or documented, and sufficient spatial data are not available to implement it in the Santa Margarita River.

A limited number of observations of benthic algal density (expressed both as benthic chlorophyll *a* and ash-free dry mass [AFDM]) are documented in Sutula et al. (2016b) and were provided by SCCWRP with some corrections. A reasonable fit of model predictions to observed densities is obtained, after correcting between model representation of reach average width and the measured width observed in the field, with a nominal density limit (prior to width corrections) of 20 g/m^2 as AFDM and benthic algal respiration rates reduced to half those of phytoplankton in Reach 108. This latter adjustment reflects the role of floating and emergent macrophytes, which may exchange gases directly with the atmosphere.

Simulated benthic chlorophyll *a* in Reach 108 near the Old Hospital (Figure 2-104) tends to decline over the winter and early spring, then increases during the summer. A different pattern is seen in simulations for Reach 105 (near Ysidora gage), where concentrations are low over the summer. This is likely an artifact of HSPF shutting off certain kinetic processes when water depth is low.

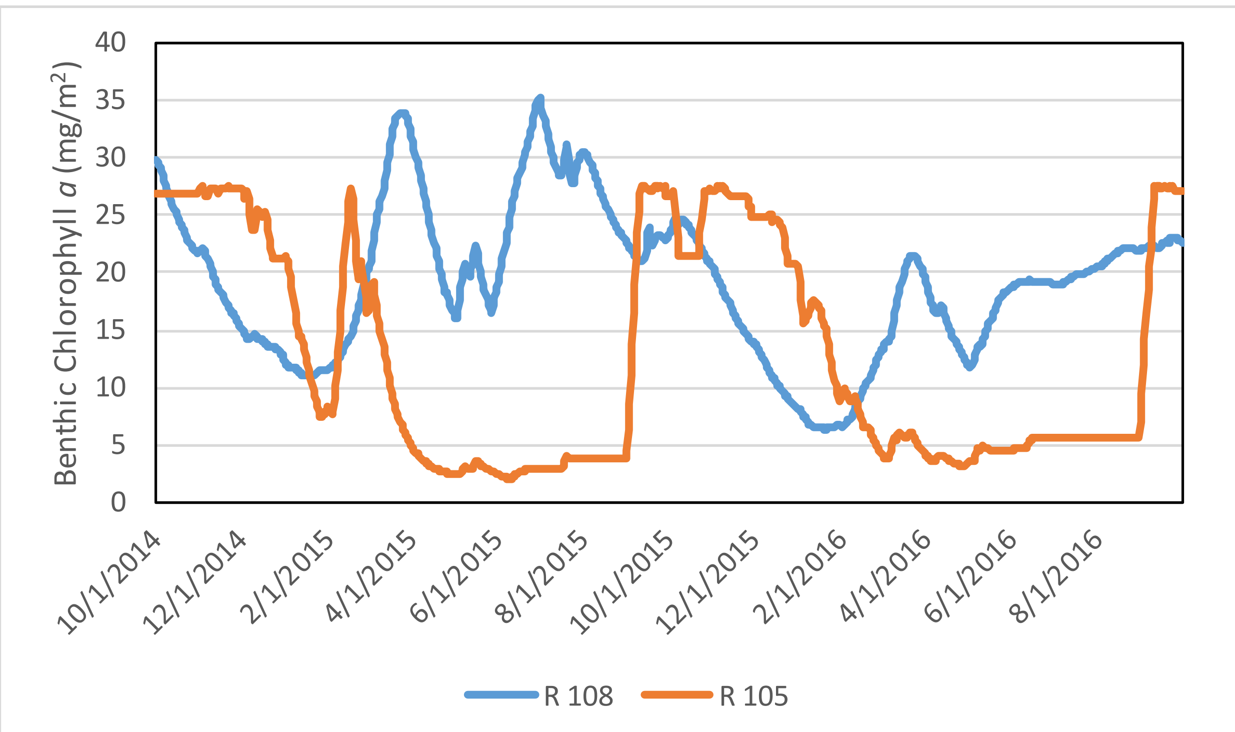


Figure 2-104. Simulated Benthic Chlorophyll *a*

SCWRRP collected benthic observations along several transects per station on each sampling date. As we expect significant spatial heterogeneity, these observations were averaged for each date. The model provides an approximation, albeit rough, of the observed seasonal pattern at the Old Hospital (Figure 2-105). This is not the case near Ysidora, where the summer concentrations are under-estimated due to the low flow conditions.

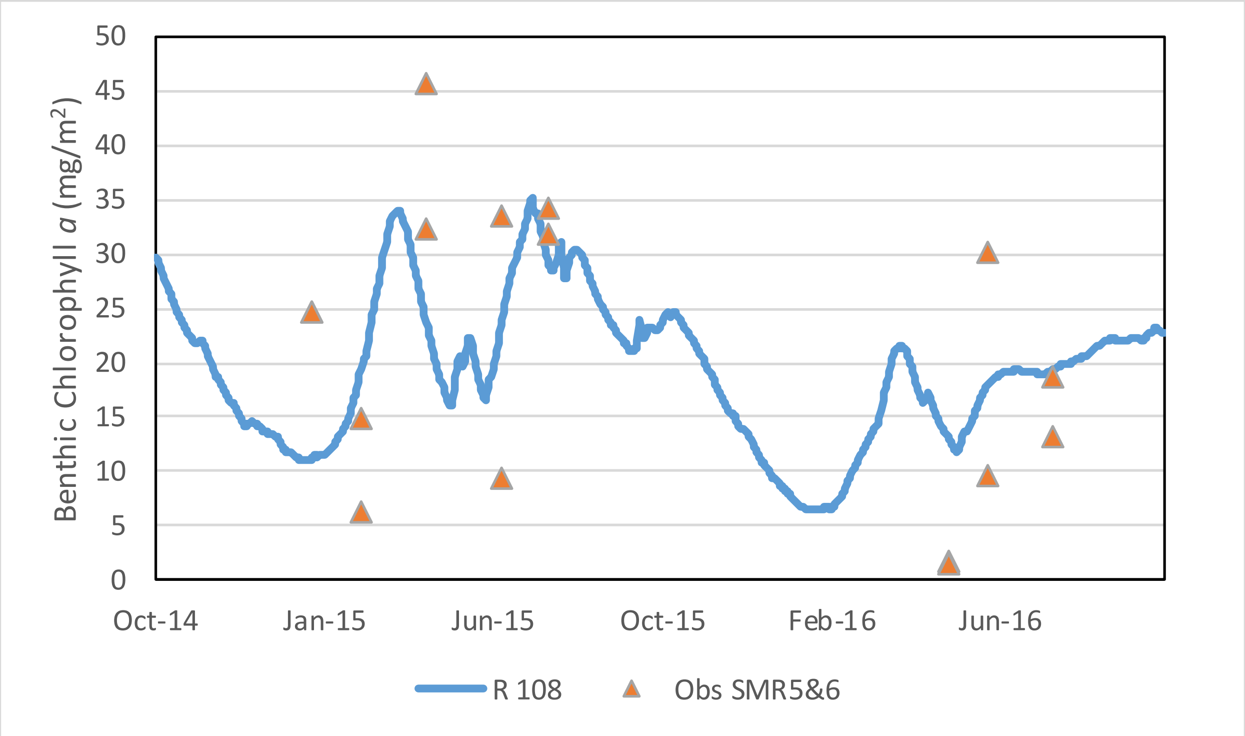


Figure 2-105. Simulated and Observed Benthic Chlorophyll *a* near Old Hospital

Comparison of the HSPF model predictions to observations shows that the model approximates observed benthic chlorophyll *a* at the Old Hospital Stations (SMR5 and SMR6), while under-predicting benthic chlorophyll *a* at the Ysidora stations (SMR3 and SMR 4). On the other hand, AFDM is under-estimated at all stations. This appears to be due to the presence of substantial detrital biomass that is not associated with living phytoplankton.

Table 2-21. Simulated and Observed Benthic Chlorophyll *a* and AFDM

Station	Days Observed	Observed Chlorophyll *a* (mg/m^2)	Simulated Chlorophyll *a* (mg/m^2)	Obs AFDM (g/m^2)	Simulated AFDM (g/m^2)
SMR5	8	25.15	19.75	51.79	23.16
SMR6	8	16.38	19.75	82.48	23.16
SMR3	7	21.51	6.58	22.18	7.72
SMR4	7	35.81	6.58	20.77	7.18

HSPF reports the limiting factors for algal growth on an hourly basis. Analysis of the limiting factors (Figure 2-106) shows for the Old Hospital reach that light is the most common limiting factor (i.e., night time), following by inorganic P and inorganic N. In many cases, the P and N limitations occur during different parts of the same day as algal uptake depletes available stores. For the Ysidora reach, low water levels are most limiting on HSPF simulation of algal growth more than a third of the time. (This represents situations where HSPF turns off the algal growth routines, even though some water may be present.)

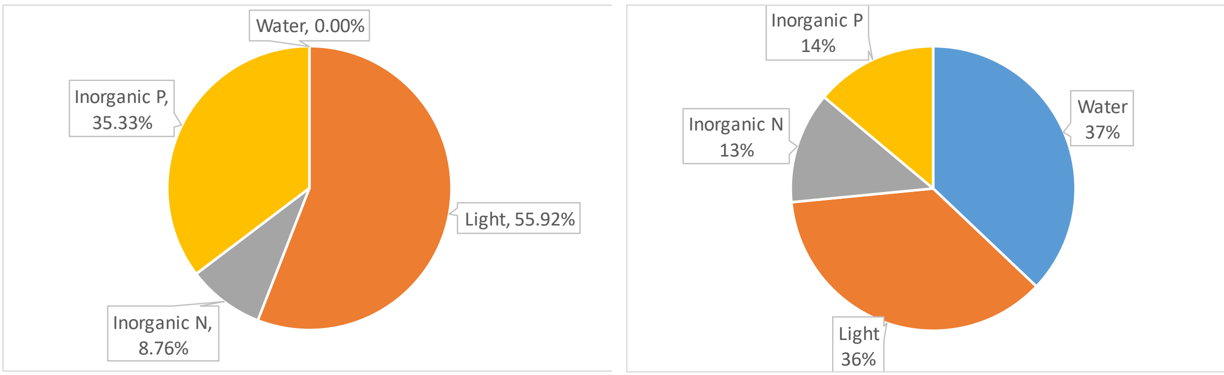


Figure 2-106. Limiting Factors on Benthic Algal Growth, Old Hospital (left) and Ysidora (right), Water Years 2015-2016

2.6.2 HSPF Sensitivity Analysis

The calibrated HSPF model provides a platform with which to test the eutrophication responses to changes in model inputs. Such tests can first be interpreted as measures of sensitivity, indicating the relative importance of a given input to model responses. The tests also represent scoping scenarios, showing what change in response is likely to occur in response to a specific change in inputs, such as nutrient loads.

Sensitivity analyses may be conducted in a univariate (change one factor at a time) or multivariate mode. Results can be reported in terms of summary measures of the response variable in its native unit of measurement (e.g., mg/L of DO); however, for comparing across different inputs in univariate sensitivity analyses it is more useful to examine the response in terms of unitless leverage coefficients. A leverage coefficient is the fractional change in the response divided by the fractional change in the input, calculated as follows:

$$C_r = \frac{\Delta R}{\Delta S}$$

$$\Delta R = \frac{R_i - R_o}{R_o}$$

$$\Delta S = \frac{S_i - S_o}{S_o}$$

where C_r is the leverage coefficient, ΔR is the relative change in the response variable calculated based on R_i, the resulting value of the response variable due to the altered input variable, and R_o the initial value of the response variable. ΔS is the relative change in the input variable calculated based on S_i, the changed value of the input and S_o the initial value of the input. For example, a leverage coefficient of 0.8 can be interpreted as stating that a 10% change in the input variable would result in an 8% change in the response. Responses need not be linear; however, we find that univariate responses do tend to be approximately linear across moderate ranges of change in inputs. Multivariate sensitivity analyses are most clearly represented as a response surface, such as a contour plot.

In the remainder of this section we first examine univariate leverage coefficients for factors affecting summer average (May – September) DO, diel DO range, and benthic algal density. The focus is on the summer because this is when the lowest DO concentrations and highest benthic algal densities are observed. In addition, the winter period coincides with periodic high flow events that can scour out benthic algae, a phenomenon that is not represented in detail in the HSPF model.

Scenarios for nutrient reductions can be complex to construct because of the many different nutrient pathways in HSPF. One challenge is the representation of organic nutrients. HSPF considers both refractory and labile forms of organic N and organic P. The labile organic forms can decay to reconstitute inorganic nutrients that are available for algal growth; however, they are represented in HSPF as a fraction of organic matter for which reactions are proportional to the decay of carbonaceous BOD (CBOD), with inorganic nutrients created per the stoichiometry of organic matter. Refractory organic nutrients do not decay, but are also loading from the land surface as part of generalized organic matter. This entanglement makes it very difficult to perform a true univariate analysis on both the inorganic and organic fractions of TN and TP. For most of the sensitivity analyses we focus on at-source reductions of inorganic N and P – including loads from the land surface and loads present at the upstream boundary of the model at the confluence of Murrieta and Temecula creeks. This means that labile organic nutrients (which can reconstitute inorganic forms) are not reduced in the univariate scenarios. In addition, we do not reduce instream sediment concentrations of ortho-phosphate and ammonium (which are subject to scour) or the small simulated releases of ortho-phosphate and CBOD from reach sediment back to the water column. Finally, while inorganic nutrient loads in groundwater from the uplands are reduced in these scenarios, N and P additions from resurfacing ground water in the alluvial aquifer on Camp Pendleton are not reduced on the theory that the large stores in the alluvial aquifer would result in a situation in which concentrations change only gradually over time. (This only affects reaches downstream of the Camp Pendleton diversion and is not relevant to concentrations at the Old Hospital).

The at-source reductions of inorganic nutrients result in a smaller reduction in instream inorganic nutrient concentrations in the lower river, due to the decay or organic material within the river. As an alternate approach for the analysis of sensitivity to nutrients we instead reduce the inorganic nutrient loads that are transferred into Reach 108 (the HSPF model segment adjacent to the Old Hospital) from upstream by inserting a multiplicative factor into the Mass-Link block.

2.6.2.1 Leverage Coefficients for Summer Average DO

Leverage coefficients (as defined above) for DO concentration near the Old Hospital (HSPF Reach 108) for 2015-2016 water years are shown via a tornado diagram in Figure 2-107. Inputs were adjusted by ±20% for this analysis. The nutrient coefficients are based on at-source reductions in organic nutrient loads. Non-nutrient factors are based on direct application. SOD, shade, and reaeration coefficient are modified for all model reaches, while upstream DO analysis is based on modifying the DO concentration as it enters reach 108 to separate this factor from the impacts of other inputs that may also alter upstream DO. Results of this analysis show that the average DO concentration in Reach 108 is most sensitive to SOD, followed by upstream DO, reaeration, and shade (which influences both algal growth and water temperature). Sensitivity to nutrient concentrations is relatively small, suggesting that nutrient reductions alone would not be effective at raising the average DO concentration in this reach. High sensitivity to SOD and low sensitivity to nutrients is also seen in the Ysidora reach (Figure 2-108); however, results for this reach are difficult to interpret due to the difficulties experienced by HSPF in simulating low flows. It is perhaps for that reason that a high sensitivity to flow is seen in the Ysidora reach. This reach is affected by seepage from the alluvial aquifers, for which nutrient concentrations have not been reduced.

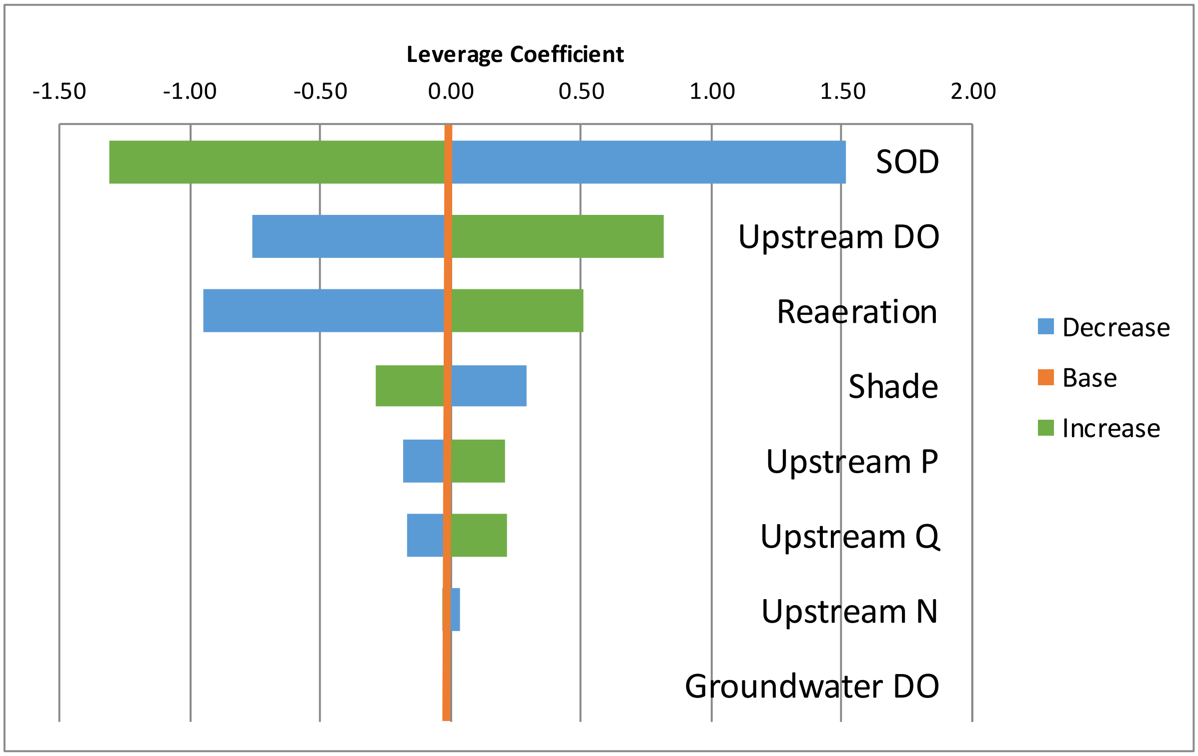


Figure 2-107. Univariate Leverage Coefficients for Summer Average DO, Old Hospital Reach

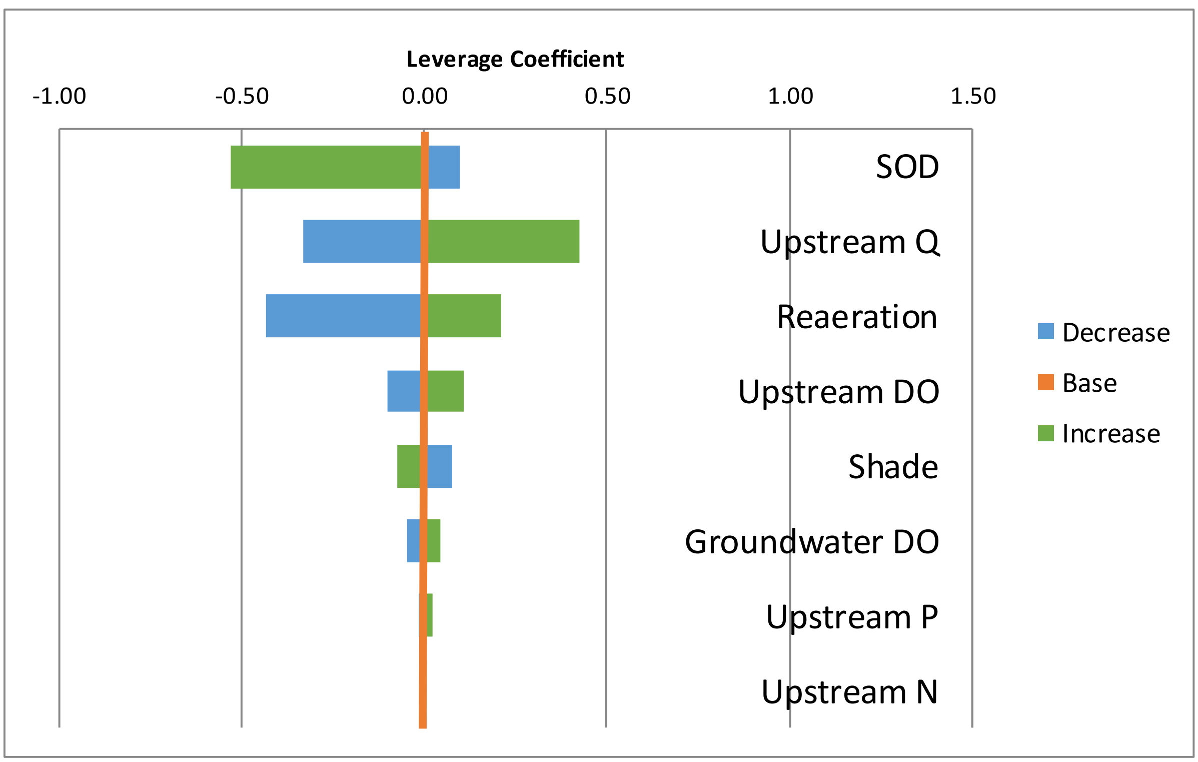


Figure 2-108. Univariate Leverage Coefficients for Summer Average DO, Ysidora Reach

2.6.2.2 Leverage Coefficients for Summer Diel DO Range

As noted above, the diel DO range may be a more useful response indicator for evaluating nutrients in the Santa Margarita River. The diel range at the Old Hospital is highly sensitive to flow and upstream phosphorus loading (Figure 2-109). SOD and reaeration play only a smaller role in controlling the diel range, but phosphorus is important in promoting algal growth. Increased N causes a reduction in diel range at the Old Hospital. Univariate leverage coefficients are not readily interpretable for summer conditions in the Ysidora reach because of HSPF's difficulties with simulation of responses at low flows, but show low sensitivity to nutrients. It is, however, of interest to note that evaluating the diel range over the whole year (thus washing out the influence of the low flow period) results in significant leverage coefficients for nitrogen at Ysidora (0.40 and -0.33 for positive and negative adjustments of upstream N).

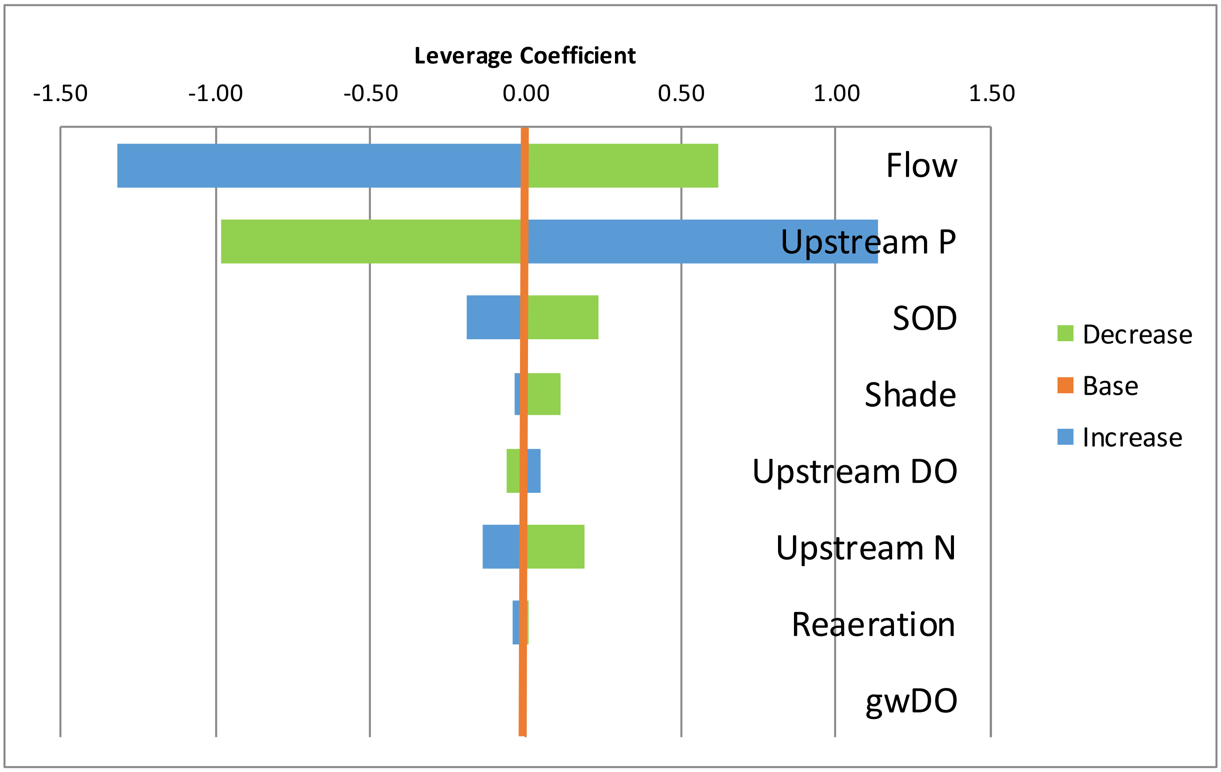


Figure 2-109. Univariate Leverage Coefficients for Summer DO Diel Range, Old Hospital Reach

2.6.2.3 Leverage Coefficients for Benthic Algal Density

In HSPF, the relationship between benthic algae density as chlorophyll *a* and as AFDM is fixed by the stoichiometry assumptions for biomass, so leverage coefficients are the same for either measure. Interestingly, the summer average densities are much less sensitive to changes in nutrients than the summer median densities when nutrient loads are changed on a constant fraction basis. This indicates that increasing nutrients is decreasing the periods of nutrient limitation (when densities tend to be lower), but having less of an effect on the peak concentrations that contribute disproportionately to the average (see Figure 2-104 in Section 2.6.1.4 above). As the central tendency of algal density over time is likely more significant for biotic effects, we report the median basis. As with the diel DO range, which is closely related to algal density, non-nutrient factors other than flow are of minor significance for benthic algal density. The leverage coefficients are shown in Table 2-22. The extreme leverage for increased flow at Ysidora reflects additional periods in which HSPF simulation of algal growth is activated in the model.

Table 2-22. Univariate Leverage Coefficients for Median Benthic Algal Density, Water Years 2015-2016

	Old Hospital (Reach 108)		Ysidora (Reach 105)	
	Plus	Minus	Plus	Minus
Upstream N	-0.03	0.05	0.10	-0.07
Upstream P	0.75	-0.68	0.02	0.03
Shade	-0.04	0.03	0.01	-0.01
Aquifer N	NA	NA	0.13	-0.15
Aquifer P	NA	NA	0.00	0.00
Flow	-0.94	0.69	16.55	-0.20

2.6.2.4 Nutrient Response Curves for Diel DO Range and Benthic Chlorophyll *a*

We ran multiple single-factor experiments to examine the shape of the diel DO range response curve to inorganic N and P load reductions. Presentation of the results is complicated by the internal processes that regenerate inorganic nutrients, so the response is shown in several ways. First, we present the predicted May – September average diel DO range plotted against nominal concentrations in Reach 108. This plots the results against the TN or TP concentration that would result from reductions applied to the nutrients entering Reach 108. Results are shown only for the Old Hospital area (Reach 108) due to the difficulties in simulating diel DO range in the intermittent reach at Ysidora (Reach 105). For simplicity, these plots also assume that there is no diel variability when nutrient concentration is zero, which is not quite correct due to temperature effects. Viewed in this way, the TP response curve is nearly, but not quite linear. The TN response curve is more muted until substantial reductions are achieved.

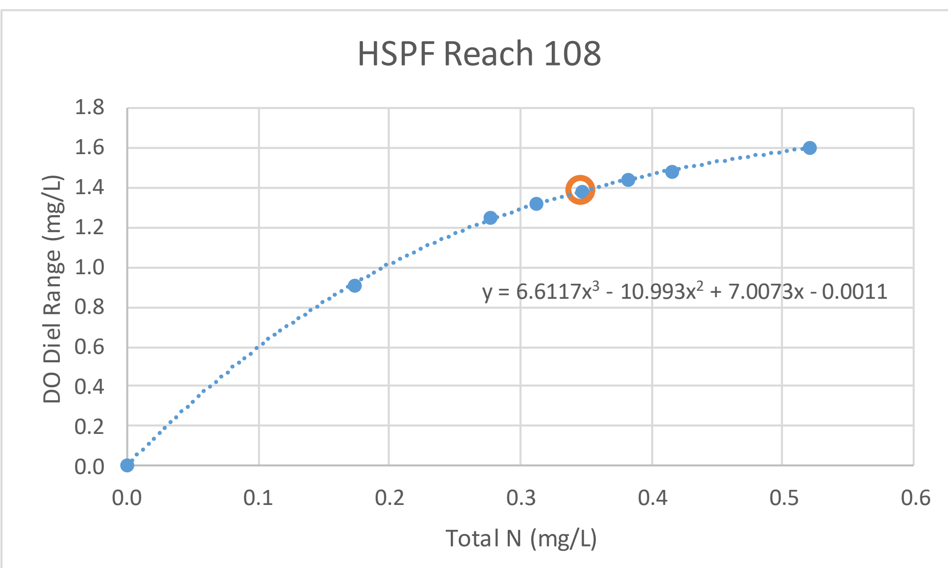


Figure 2-110. Summer Average Diel DO Response Curve for TN near Old Hospital

Note: X axis shows the concentration obtained by reducing the loads entering Reach 108 by a specified fraction. The orange circle shows the WY 2015-2016 summer average concentration.

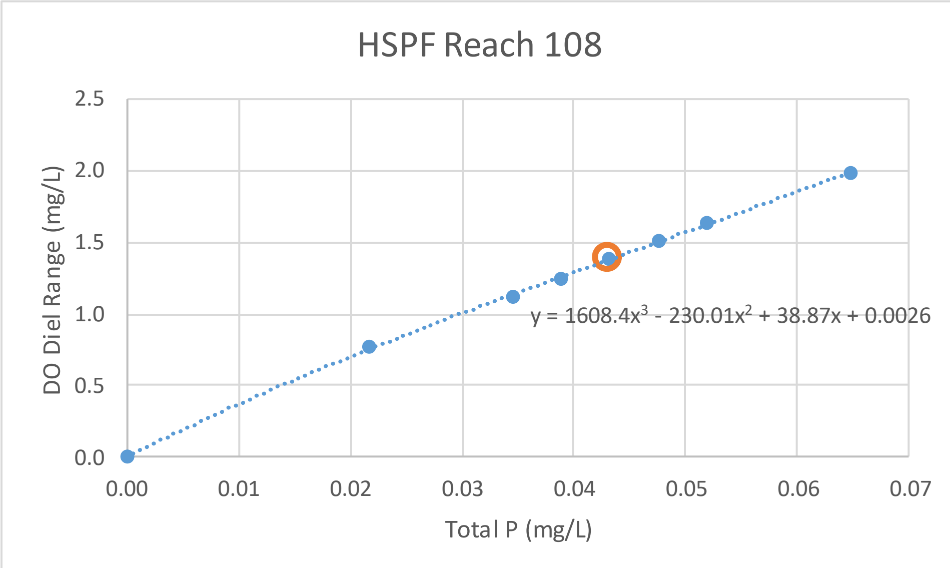


Figure 2-111. Summer Average Diel DO Response Curve for TP near Old Hospital

Note: X axis shows the concentration obtained by reducing the loads entering Reach 108 by a specified fraction. The orange circle shows the WY 2015-2016 summer average concentration.

Figure 2-112 and Figure 2-113, in contrast, look at the responses to various levels of reduction in inorganic nutrient source loads. Nutrient regeneration occurs instream due to the decomposition of organic matter (CBOD); thus, concentrations in Reach 108 do not reach zero even when there is a 100% reduction in source loads. Note that the increasing TN results in a decrease in the diel range in the vicinity of existing concentrations, consistent with the negative leverage coefficient seen in Figure 2-109.

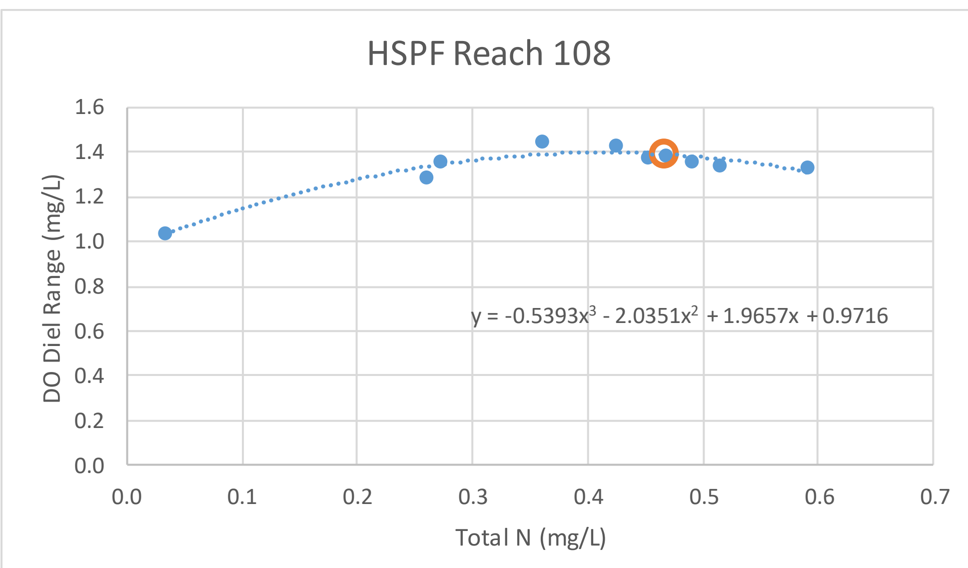


Figure 2-112. Summer Average Diel DO Response Curve for TN near Old Hospital (Version 2)

Note: X axis shows the actual simulated concentration predicted after reducing source loads. The existing concentration is shown by the orange circle.

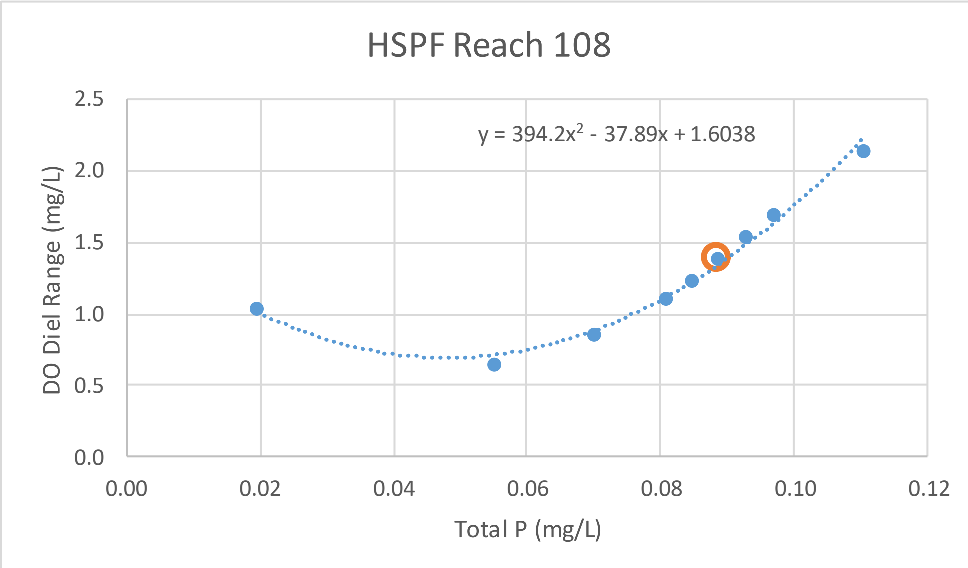


Figure 2-113. Summer Average Diel DO Response Curve for TP near Old Hospital (Version 2)

Note: X axis shows the actual simulated concentration predicted after reducing source loads. The existing concentration is shown by the orange circle.

Response curves for benthic chlorophyll *a* are very similar in shape to those for DO diel range.

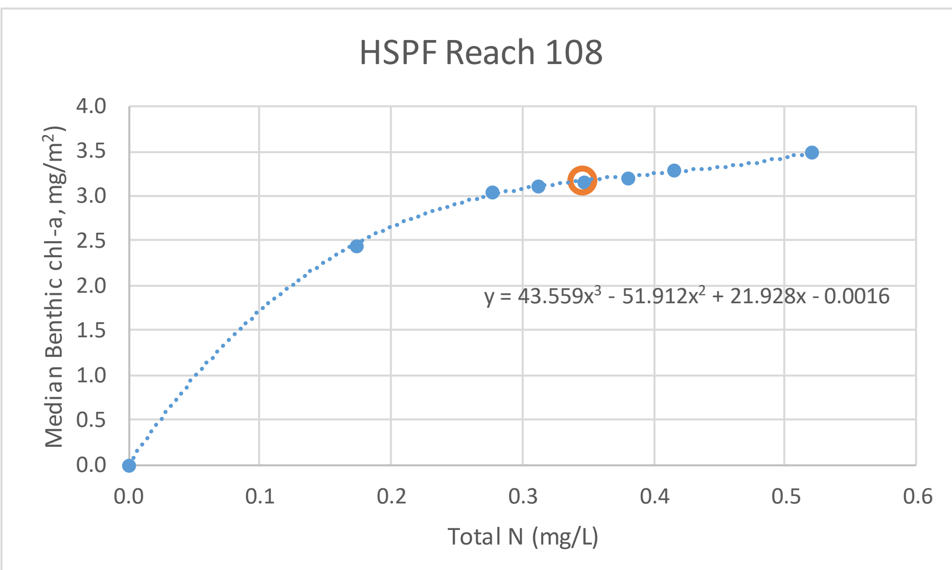


Figure 2-114. Summer Median Benthic Chlorophyll *a* Response Curve for TN near Old Hospital

Note: X axis shows the concentration obtained by reducing the loads entering Reach 108 by a specified fraction. The orange circle shows the WY 2015-2016 summer average concentration.

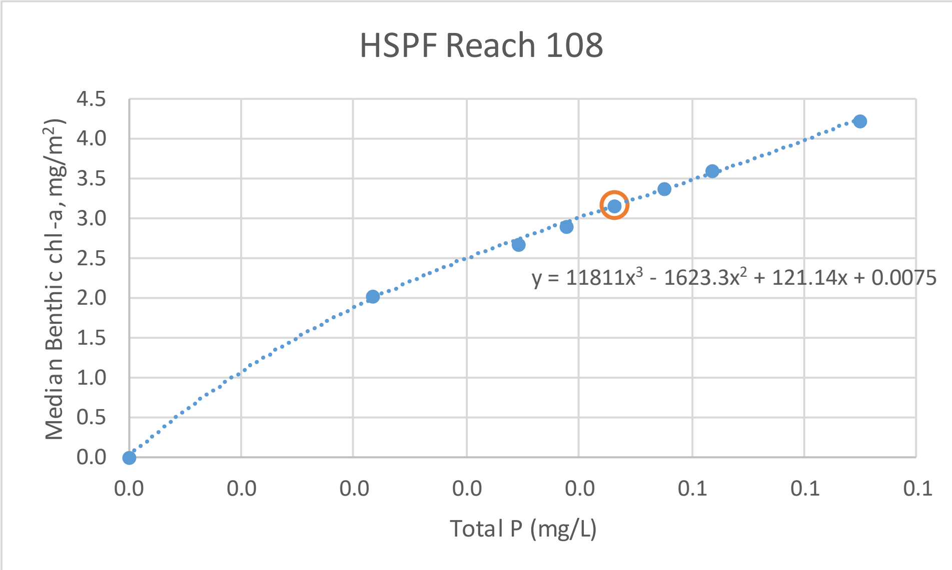


Figure 2-115. Summer Median Benthic Chlorophyll *a* Response Curve for TN near Old Hospital

Note: X axis shows the concentration obtained by reducing the loads entering Reach 108 by a specified fraction. The orange circle shows the WY 2015-2016 summer average concentration.

2.6.2.5 Multivariate Sensitivity Analysis for Nutrients

Finally, we assessed interactions among nutrients by generating response surfaces at multiple levels of N and P reductions, again shown in two ways. Figure 2-116 addresses of nutrient loads entering Reach 108, while Figure 2-117 shows the result of reducing inorganic source loads.

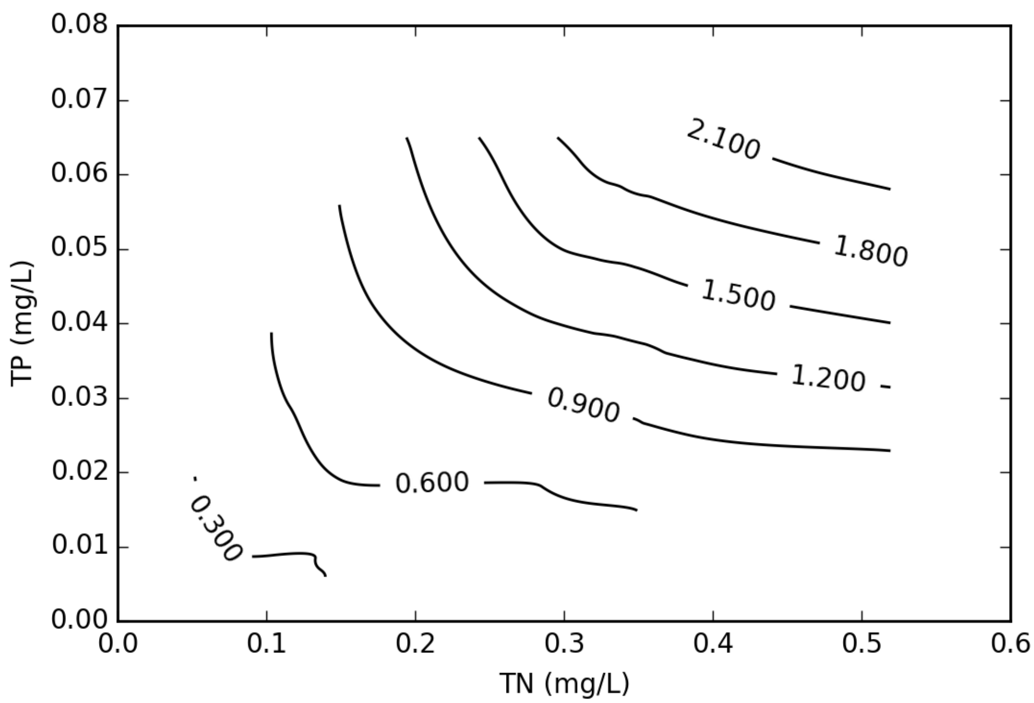


Figure 2-116. Response Surface for Average Summer Diel DO Range, Reduction of Loads Entering R108

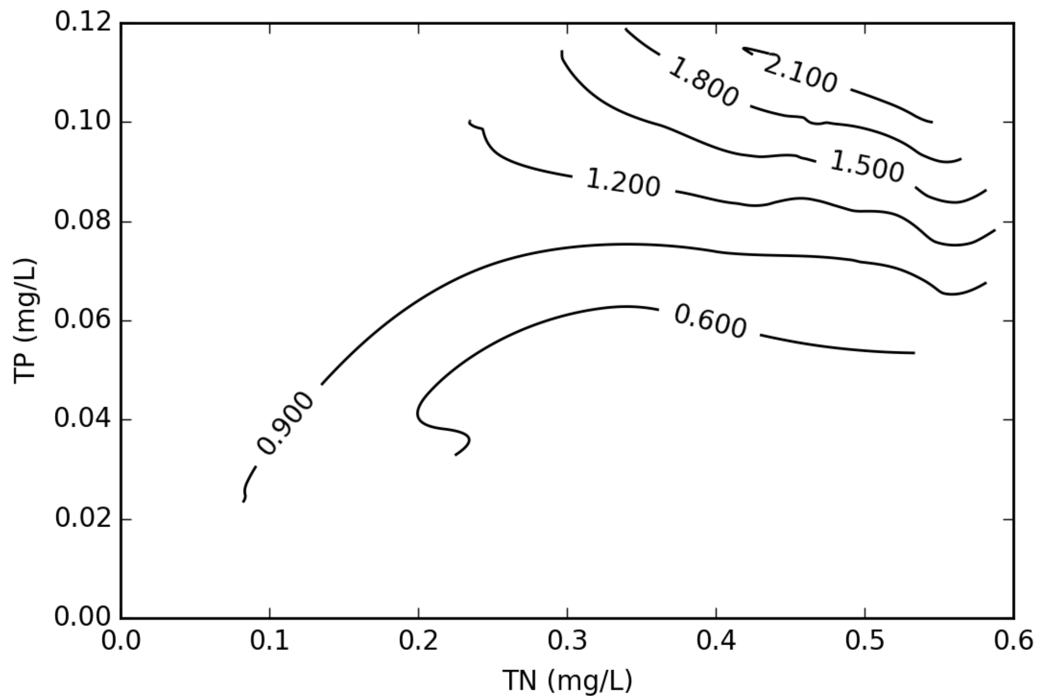


Figure 2-117. Response Surface for Average Annual Summer Diel DO Range, Reduction of Inorganic Nutrient Source Loads

2.7 HSPF SUMMARY

The Santa Margarita watershed is a complex, managed system that includes discharges, diversions, and significant interaction between surface and groundwater. Pre-existing models included the HSPF watershed loading model (Tetra Tech, 2013, 2014, 2017) and the USMC Camp Pendleton/Stetson Engineers MODFLOW groundwater model. As described in this report, the HSPF model was updated to improve model calibration and simulation of the Rainbow Creek watershed to support development of the SMR Water Quality Improvement Plan (WQIP), while the MODFLOW calibration has also been refined and the application extended to simulate the exchange of both nitrogen and phosphorus between surface and groundwater in the area around Camp Pendleton.

The current iteration of the HSPF model focuses on the watershed downstream of the confluence of Murrieta and Temecula Creeks (represented as a boundary condition). The focus of the current work is on the Lower Main stem, defined as the Santa Margarita from the confluence with De Luz Creek to the estuary and constituting HSPF subbasins 108 through 101 (plus 201). The MODFLOW model covers the three alluvial groundwater basins on Camp Pendleton, corresponding to HSPF model subbasins 106 through 103.

In the current work, we enhanced the watershed loading model with the primary goal of improving the representation of dry weather ambient nutrient concentrations throughout the river network, as well as the simulation of additional constituents necessary to support additional receiving water models. An important part of this effort provided an improved linkage between the HSPF and MODFLOW models, which is key to representing conditions downstream of the Camp Pendleton diversion. The HSPF model was enhanced to simulate water temperature, DO, floating and attached algae, the carbon cycle, alkalinity, and pH in both the Upper and Lower River. This provides two functions. First, the representation of these constituents is necessary to provide boundary conditions to more detailed receiving water models. Second, HSPF itself can potentially serve the role of a receiving water model, although it is limited by a one-dimensional representation of river reaches at a rather coarse spatial scale. This provides a useful point of comparison to the more detailed receiving water models discussed below.

The watershed loading model was calibrated through water year 2016 under the current phase as the groundwater model currently ends in September 2016 and the discrete and continuous water quality and biological data collected by SCCWRP in the Lower River is within this time frame. Model performance in simulating flow and nutrients is generally good, although affected by uncertainty in the specification of the upstream boundary condition and in the time series of exchanges with the alluvial aquifer (which MODFLOW simulates only on a monthly basis). HSPF is thus a suitable tool for supporting additional receiving water models, as described in the following sections.

HSPF can also itself be used as a receiving water model for addressing measures relevant to the evaluation of biostimulatory conditions as it provides hourly predictions of DO, benthic algal density, and pH. Limitations for using the Santa Margarita River HSPF model as a nutrient response model include its relatively coarse spatial scale (as currently implemented) and one-dimensional representation of stream reaches. HSPF performance for simulating water temperature, DO, and benthic algal density appears adequate, but the model does not resolve fine-scale spatial differences between nearby monitoring stations within the same HSPF reach (e.g., SMR5 and SMR6). The HSPF model also encounters difficulties in simulating extreme low flow conditions (e.g., near the Ysidora gage) as the model code shuts off many kinetic processes, including those controlling algal growth and DO, to preserve stability as flow depth declines toward zero.

Sensitivity analyses conducted with the HSPF model show that the DO concentration near the Old Hospital are most responsive to sediment oxygen demand (SOD) and the DO concentration in flow entering the lower river. Daily average DO exhibited relatively low sensitivity to algal dynamics associated with changes in N and/or P loads and concentrations. SOD is the oxygen demand exerted on the water column by decomposition of organic matter in and on stream sediment. An implication of this finding is that allochthonous (external) sources of organic matter and their biological oxygen demand are driving the mean trend in DO, not live algal biomass produced on site by local ambient TN and TP. The sensitivity analysis also suggests that DO conditions in the lower river are to a large extent controlled by processes in the upper river.

In contrast to the magnitude of DO concentration, the diel range of DO is largely determined by the cycle of algal photosynthesis and respiration. In the HSPF simulations, both diel DO range and benthic algal density are sensitive to local nutrient concentrations – suggesting that nutrient reduction could have a strong effect on the diel variability in DO, but less effect on the daily mean. Calculated leverage coefficients provide a convenient summary of the relationship between nutrients, diel DO, and benthic algal density that could be used to design scenarios to achieve specific management goals.

3.0 WASP NUTRIENT RESPONSE MODEL

3.1 LOWER SANTA MARGARITA RIVER WASP MODEL

The Water Quality Analysis Simulation Program (WASP) is a dynamic, mechanistic receiving water model developed by USEPA (http://epawasp.twool.com/). WASP simulates continuous hydraulics and water quality in full mixed and connected box segments. WASP's compartment modeling approach can be adapted to represent advective and diffusive transport of constituents in linear streams (1-D), stratified lakes (2-D), or complex estuary systems (3-D). Segmentation design in WASP is more flexible than it is in HSPF, which simulates 1-D free-flowing or lake segments in addition to its robust representation of upland processes. Because WASP is strictly a receiving water model segments can be of finer spatial resolution than in HSPF; however, adequate information must be available to characterize channel properties for each of the segments. Another advantage of WASP over HSPF is the variable time step. HSPF applies a user-defined continuous time step. The lower Santa Margarita River HSPF model simulates multiple decades so a 1-hour time step is appropriate, and a finer time step would drastically increase model run time. WASP computes a variable time step throughout the simulation period that is based on residence time in the segments, and this ensures stability and accuracy in the simulation. For the lower Santa Margarita River WASP model the average time step is approximately 2-minutes.

Two modules have been developed for WASP. These are EUTRO, which simulates conventional pollutants (e.g. nitrogen and phosphorus) and nutrient response variables (e.g., dissolved oxygen and free-floating or attached algae), and TOXI, recently updated to simulate organic toxin fate and transport.

The lower Santa Margarita River WASP model is an application of the WASP EUTRO module. A schematic of the state variables and feedbacks in the WASP EUTRO model are shown in Figure 3-1. It is useful to apply WASP in conjunction with HSPF because of WASP's macroalgae and sediment diagenesis subroutines. The WASP sediment diagenesis subroutine can be used to predict, rather than describe, the sediment oxygen demand due to local algal activity. WASP can also simulate multiple forms of benthic, submersed or floating algae and macrophytes. The state variables represented in the lower Santa Margarita River WASP model include:

- Solids
- Water temperature
- Ammonia
- Nitrite + nitrate
- Organic nitrogen
- Dissolved inorganic phosphorus
- Organic phosphorus
- Carbonaceous biochemical oxygen demand (ultimate)
- Phytoplankton
- Benthic algae
- Detrital matter

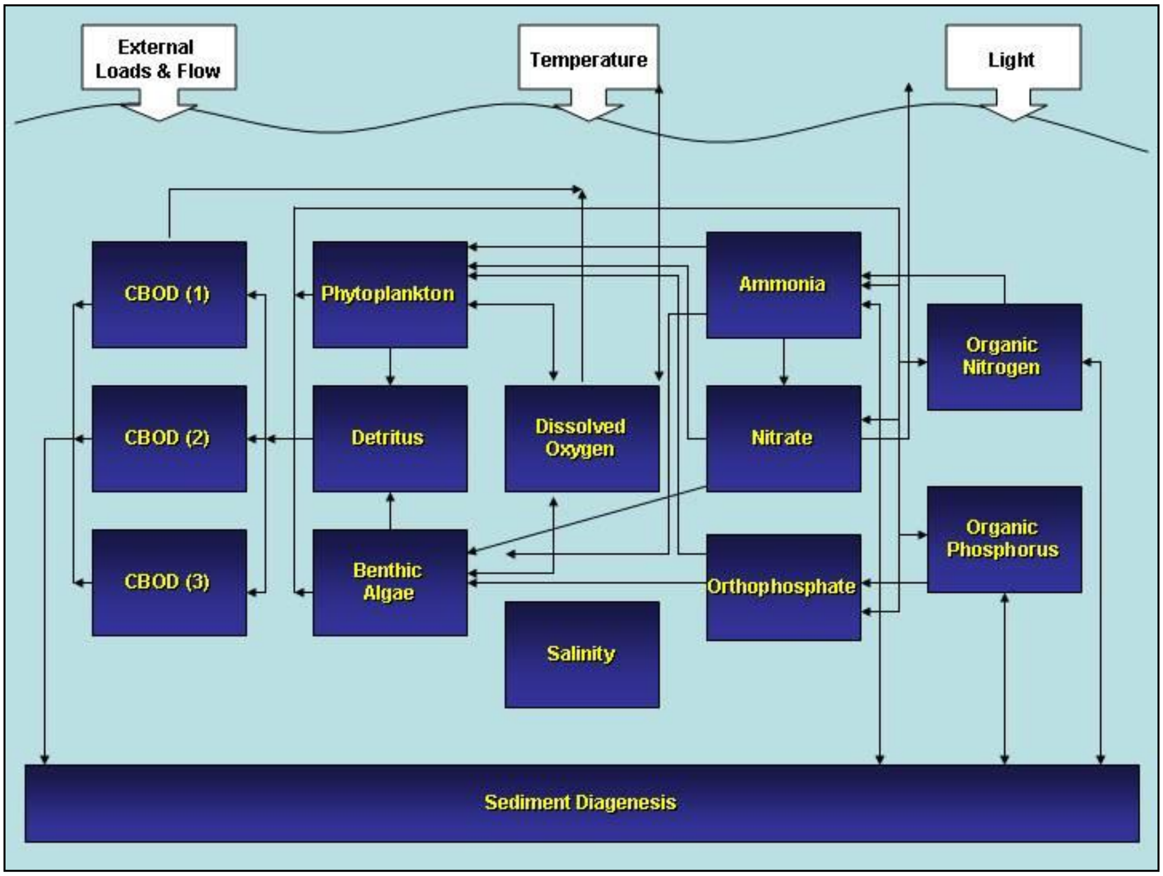


Figure 3-1. Schematic of the WASP Eutrophication (EUTRO) Module

Source: Knightes, C. 2005. Introduction to WASP7 Eutrophication Module [PowerPoint slides]. Retrieved from http://epawasp.twool.com/

3.2 MODEL EXTENT AND SIMULATION PERIOD

The spatial extent of the lower Santa Margarita River WASP model includes the mainstem from its confluence with De Luz Creek to the area near the Old Hospital above the Camp Pendleton water diversion (Figure 3-2). This portion of the river is represented as subbasin 108 in the HSPF model and aligns with two SCCWRP sampling sites, SMR6 and SMR5. This section of the river exhibits perennial flow. Continuous simulation of the river downstream of the Old Hospital would be unstable in WASP because flow diverted to Lake O'Neill and groundwater pumping of the alluvial aquiver result in intermittent flows. As shown in Figure 3-2, a steady-state QUAL2kw model was developed to address critical conditions for the Santa Margarita River downstream of the Old Hospital using kinetics similar to those currently implemented in WASP.

The WASP model consists of five segments in series. The location and extent of the WASP segments are shown in alternating colors of green and purple in Figure 3-3, ranging from segment 1 at the upstream boundary to segment 5 at the downstream boundary.

A framework diagram for the Santa Margarita River WASP model is presented in Figure 3-4. Meteorological time series derived from gridded data sources are input to WASP stream segments. As discussed in Section 3.4, these include solar radiation, air temperature, wind speed, cloud cover and dew point temperature. Shading due to the combined effects of surrounding topography and riparian cover is also an input to model segments. Flow and constituent concentrations at the upstream boundary (WASP segment 1) were derived from HSPF model output (Section 3.5).

The WASP model simulates conditions in the river for Water Year (WY) 2012 – WY 2016. Observed hydraulic and water quality data were collected at SMR5 and SMR6 during WY 2015 and WY 2016 so the WASP model calibration focused on these two years.

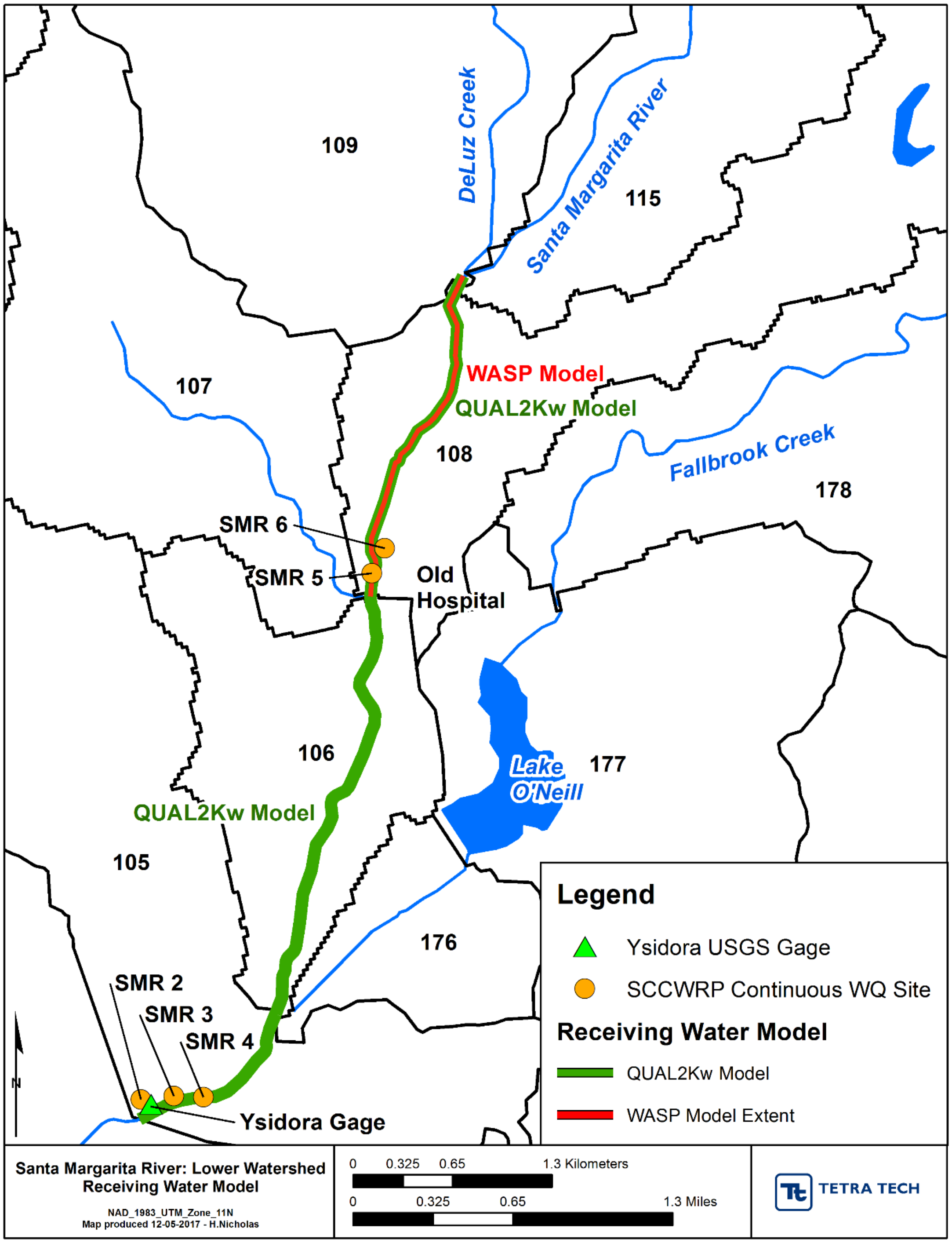


Figure 3-2. Receiving Water Model Domains

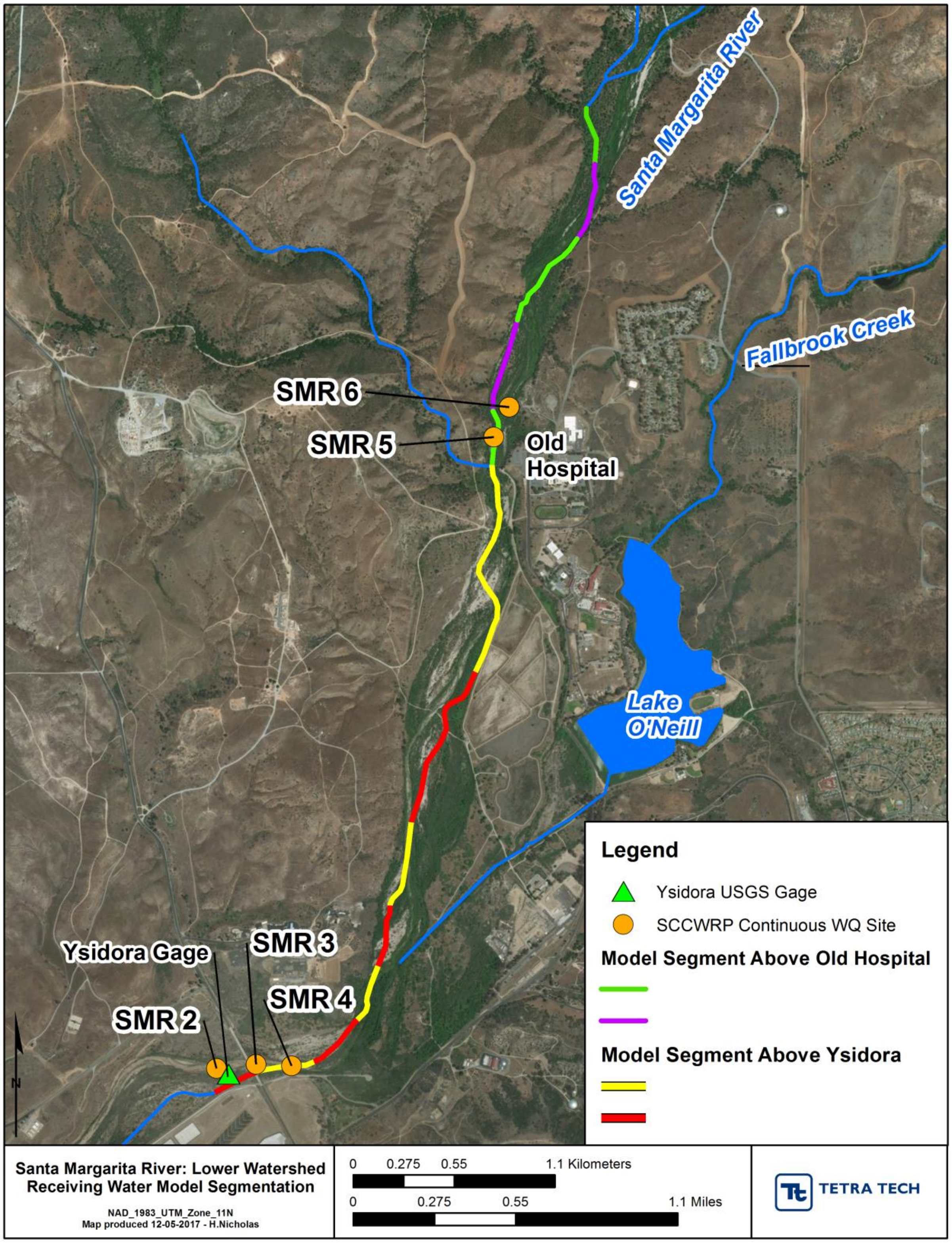


Figure 3-3. Segmentation in the WASP and QUAL2Kw Receiving Water Models

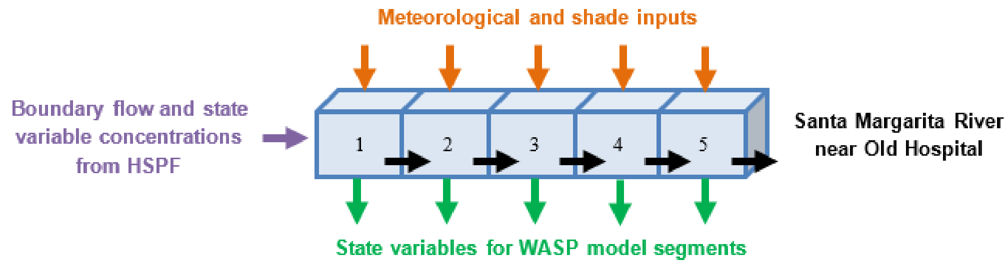


Figure 3-4. WASP Model Framework

3.3 REACH HYDRAULICS

WASP includes several options for representing segment hydraulics (USEPA, 2009). The kinematic wave flow routing option represents wave propagation through the stream system and the resulting channel top width, cross-sectional average depth, and velocity for each segment. The kinematic wave flow routing method is appropriate for linear, free-flowing streams with limited channel hydraulic data, so it was selected for representing segment hydraulics in the Santa Margarita River WASP model. Hydrogeometric parameters were defined for each model segment following the methods discussed in the WASP7 Stream Transport – Model Theory and User's Guide (USEPA 2009). Flow power functions are used to solve for velocity, average cross-section depth, and top width. Exponents for the depth and velocity power functions are specified and the width exponent is computed during the simulation based on the rule that the sum of the three exponents equals 1.0. For example, velocity, depth, and width exponent values of 0.2, 0.3 and 0.5 are representative of a shallow channel (USEPA, 2009)

Information from cross sections represented in a HEC-RAS model of the lower Santa Margarita River were used to derive initial hydrogeometric parameters for the WASP segments (WEST Consultants, 2000). This representation is nearly 20 years old and it is expected that substantial modification of local channel dimensions may have occurred since that time; however, the WEST measurements are assumed to be at a minimum representative of typical hydraulic geometry of these reaches. Hydraulics simulated by WASP are uniform along the length of each segment. Channel width, and other geometric characteristics, vary quite a bit along the lower Santa Margarita River. Figure 3-5 shows an aerial view of the river near SMR6. Approximately 15 meters downstream of the SMR6 sampling site the river narrows to 12 m, and not much further downstream the river widens to 26 m. Fine resolution channel data was not available for parameterizing and calibrating the WASP model. Observed velocity, width, and depth data were available at two sites, SMR6 and SMR5, and these provided information about site-specific channel hydraulics in the lower Santa Margarita River. These sites align with WASP segment 4 and segment 5. Calibrated hydraulic parameters in the WASP model are provided in ***Table 3-1***.

WASP computes a variable time step throughout the simulation period that is based on residence time in the segments, and this ensures stability and accuracy in the simulation. Maximum and minimum allowable time steps were set as 0.042 days (~60 minutes) and 0.0001 days (8.6 seconds), respectively. The mean time step simulated by the lower Santa Margarita River WASP model is approximately 2 minutes.

Figure 3-5. Aerial View of the Santa Margarita River near SMR6

Table 3-1. Reach Segments in the Santa Margarita WASP Model

WASP Model Segment	Initial Volume (m^3)	Length (m)	Manning's n Roughness Coefficient	HEC-RAS Cross-Section Number	Depth Exponent	Velocity Exponent
1	1,450	316	0.045	61803.02	0.139	0.097
2	3,186	429	0.045	61043.39	0.158	0.111
3	12,028	569	0.045	58918.76	0.130	0.091
4	6,310	517	0.070	56780.57	0.139	0.195
5	1,611	304	0.030	55579.35	0.140	0.196

3.4 METEOROLOGICAL FORCING AND SHADING

Biological and chemical reactions in the stream segments are temperature- and light-dependent. Heat exchanged at the air-water interface, due to solar radiation, evaporative heat loss and sensible heat conduction, is computed using meteorological inputs. Hourly time series for solar radiation, wind speed, air temperature, cloud cover and dew point temperature derived from NLDAS gridded weather data were used in the HSPF model (Tetra Tech, 2017), and these time series were converted to WASP compatible units and applied to the WASP model (Table 3-2). The net exchange of water from precipitation to and evaporation from the stream was also included as an input time series to WASP. Meteorological input time series were assumed identical for all WASP model segments.

Light is required for growth and production of photosynthetic free-floating and attached algae. Incoming solar radiation is input as an hourly time series in the WASP model. However, only a portion of incoming light reaches the water surface, and then particulate matter and phytoplankton attenuate light in the water column. Light is filtered in the atmosphere by clouds in the sky. Riparian vegetation and sloped land surrounding the stream also block light. WASP accounts for effects of both cloud cover and shading on solar radiation. Percent cloud cover is input as an hourly model time series (Table 3-2). The fraction of the stream that is shaded due to the combined effects of topography and riparian vegetation is also a model input. A review of aerial imagery, LiDAR and ground-level photography indicated that most of the width of the lower Santa Margarita River immediately upstream of the Old Hospital has only limited shading. Therefore, canopy shading was assumed to be 10% for all reach segments in the WASP model.

Table 3-2. Units for Meteorological Time Series in WASP

Meteorological Time Series	WASP Model Units
Solar radiation	W/m^2
Air temperature	ºC
Wind speed	m/s
Dew point temperature	ºC
Cloud cover	Fraction
Net exchange due to precipitation and evaporation	m^3/s

3.5 BOUNDARY CONDITIONS

The upstream extent of the lower Santa Margarita River WASP model is situated below the confluence of the mainstem and De Luz Creek. Hourly flow and water quality constituent concentrations simulated by the HSPF model were applied as boundary conditions for the WASP model (and thus encompass all uncertainties present in the HSPF simulation). Two HSPF model reaches (R109 and R115) are routed to R108, the HSPF reach that is represented in more detail in the WASP model. Flows from the two upstream reaches were combined to form the inflow time series. Flow-weighted concentration time series were also developed for the following WASP state variables: water temperature, ammonia, nitrite + nitrate, organic nitrogen, dissolved inorganic phosphorus, organic phosphorus, sediment, dissolved oxygen, ultimate carbonaceous biochemical oxygen demand, and detrital matter (as nitrogen and phosphorus). HSPF does not distinguish between detrital and non-detrital components for organic nitrogen and phosphorus. Organic nitrogen and phosphorus were initially split into equal detrital and non-detrital components for WASP, and then were adjusted to be 60% detrital matter and 40% non-detrital matter during the nutrient calibration.

3.6 WASP MODEL PARAMETERIZATION

Both the HSPF model and WASP model theory and guidance manuals (http://epawasp.twool.com/docs/) informed the initial parameterization of the lower Santa Margarita River WASP model. As discussed in Section 3.7, water quality observations were used to refine the representation of state variables simulated by the WASP model. Key parameters governing inorganic and organic nutrient kinetics, CBOD, water temperature, dissolved oxygen and benthic algae are provided in Table 3-3, and results from the calibration are provided in the following section.

Table 3-3. Key Parameters in the Calibrated WASP Model

Parameter	Value
Inorganic nutrient kinetics	
Nitrification rate constant (at 20 ºC, day^{-1})	1.2
Nitrification temperature coefficient	1.07
Half saturation constant for nitrification oxygen limit (mg/L)	1.0
Denitrification rate constant (at 20 ºC, day^{-1})	1.92
Denitrification temperature coefficient	1.07
Half saturation constant for denitrification oxygen limit (mg/L)	1.0
Organic nutrient kinetics	
Detritus dissolution rate (day^{-1})	0.3
Dissolved organic nitrogen mineralization rate constant (at 20 ºC, day^{-1})	0.3
Dissolved organic phosphorus mineralization rate constant (at 20 ºC, day^{-1})	0.3
Temperature coefficient for detritus dissolution	1.04
Dissolved organic nitrogen mineralization temperature coefficient	1.08

Parameter	Value
Dissolved organic phosphorus mineralization temperature coefficient	1.08
Settling velocity of detritus (m/day)	5
Carbonaceous Biochemical Oxygen Demand	
CBOD decay rate constant (at 20 ºC, day^{-1})	0.072
CBOD decay rate temperature coefficient	1.047
CBOD half saturation oxygen limit (mg/L)	0.2
Water temperature	
Heat exchange option (0 = full heat balance, 1 = equilibrium temperature)	0
Coefficient of bottom heat exchange (W/m^2/ºC)	70
Sediment temperature (ºC)	16
Dissolved oxygen	
Reaeration option (0 = Covar, 1 = O'Connor, 2 = Owens, 3 = Churchill, 4 = Tsivoglou	4
Reaeration from wind and hydraulics (0 = no, 1 = yes)	1
Oxygen to carbon stoichiometric ratio	2.667
Reaeration temperature correction (theta)	1.024
Tsivoglou escape coefficient	0.05
Sediment oxygen demand (g/m^2/day)	2.5
SOD temperature correction (theta)	1.07
Macroalgae	
Macroalgae option (1 = floating, 2 = surface, 3 = submersed, 4 = benthic)	4
Macroalgae P:C ratio (mgP/mgC)	0.015
Macroalgae chlorophyll-a ratio (mgChl-a/mgC)	0.003
Growth model (0 = zero order, 1 = first order)	0
Growth rate (day^{-1})	7

Parameter	Value
Coefficient for macroalgae growth	1.07
Macro algal respiration rate constant (day^{-1})	0.048
Temperature coefficient for macro algal respiration	1.07
Internal nutrient excretion rate constant for macro algae (day^{-1})	0.04
Temperature coefficient for macro algal nutrient excretion	1.07
Macro algae death rate constant (1/day)	0.06
Temperature coefficient for macro algal death	1.07
Macro algal half saturation uptake constant for extracellular nitrogen (mg N/L)	0.03
Macro algal half saturation uptake constant for extracellular phosphorus (mg P/L)	0.01
Macro algal light constant for growth (Langleys/day)	100
Macro algae ammonia preference (mg N/L)	0.01
Minimum cell quota of internal nitrogen for macro algal growth (mgN/gDW)	7.2
Minimum cell quota of internal phosphorus for macro algal growth (mgP/gDW)	1
Maximum nitrogen uptake rate for macro algae (mgN/gDW-day)	300
Maximum phosphorus uptake rate for macro algae (mgP/gDW-day)	50
Half saturation uptake constant for macro algal intracellular nitrogen (mgN/gDW)	9
Half saturation uptake constant for macro algal intracellular phosphorus (mgP/gD	1.3
Macroalgae D:C ratio (mg D/mg C)	2.5
Macroalgae N:C ratio (mg N/mg C)	0.147
Macroalgae O2:C production (mg O2/mg C)	1.31
Fraction of bottom segment covered by benthic algae	0.7

3.7 WASP MODEL PERFORMANCE

Water quality has been monitored at several locations in the lower Santa Margarita River watershed. As shown in Figure 2-10 and described in Table 2-5, nutrient grab samples and continuous physico-chemistry data were collected at two sites within the WASP model domain. These include SMR5 and SMR6. Available data at these sites were limited (collected during brief periods in WY 2015 – WY 2016) and inadequate to split into separate calibration and validation periods. Therefore, all monitoring records were used to inform the WASP model calibration, and these are shown on plots depicting model results in the following subsections.

3.7.1 Hydraulics

As discussed in Section 3.3, the lower Santa Margarita River WASP model utilized the kinematic wave method to compute dynamic channel hydraulics. Hydrogeometric parameters were initially defined based on cross-section information obtained from an older HEC-RAS model that was focused on high flow conditions (WEST Consultants, 2000). Channel data collected by SCCWRP at SMR5 and SMR6 were used to refine the hydraulic simulation. Observed channel top width, average depth, and velocity at SMR6 and SMR5 are provided in Table 3-4. Model results are also listed in Table 3-4, and time series plots of width and velocity are shown in Figure 3-6 - Figure 3-9.

As shown in Figure 3-5, the Santa Margarita River naturally widens and narrows repetitively along its length (even within a short distance). Variations in channel geometry occur at a much finer spatial resolution than is represented in WASP, which simulates uniform geometry along the length of each segment. WASP provides a reasonable representation of hydraulics in the lower Santa Margarita River based on the limited available data for calibration and considering the spatial discrepancies in channel geometry.

Table 3-4. Simulated and Observed Channel Top Width, Average Depth, and Velocity for SMR5 and SMR6

Hydraulic Property	Range and Mean at SMR5 (n = 5), WASP Segment 5			Range and Mean at SMR6 (n = 8), WASP Segment 4		
	Simulated	Observed	Average Error	Simulated	Observed	Average Error
Width (m)	10.4 – 22.2 (16.8)	4.8 – 17.0 (10.1)	6.7	8.8 – 18.8 (13.4)	6.0 – 14.4 (10.7)	2.7
Depth (m)	0.09 – 0.10 (0.09)	0.10 – 0.21 (0.15)	-0.05	0.2 -0.23 (0.22)	0.14 – 0.56 (0.37)	-0.15
Velocity (m/s)	0.14 – 0.17 (0.16)	0.07 – 0.22 (0.13)	0.02	0.07 – 0.08 (0.07)	0.01 – 0.10 (0.04)	0.04

Note: Simulated range and mean calculated for monitored periods.

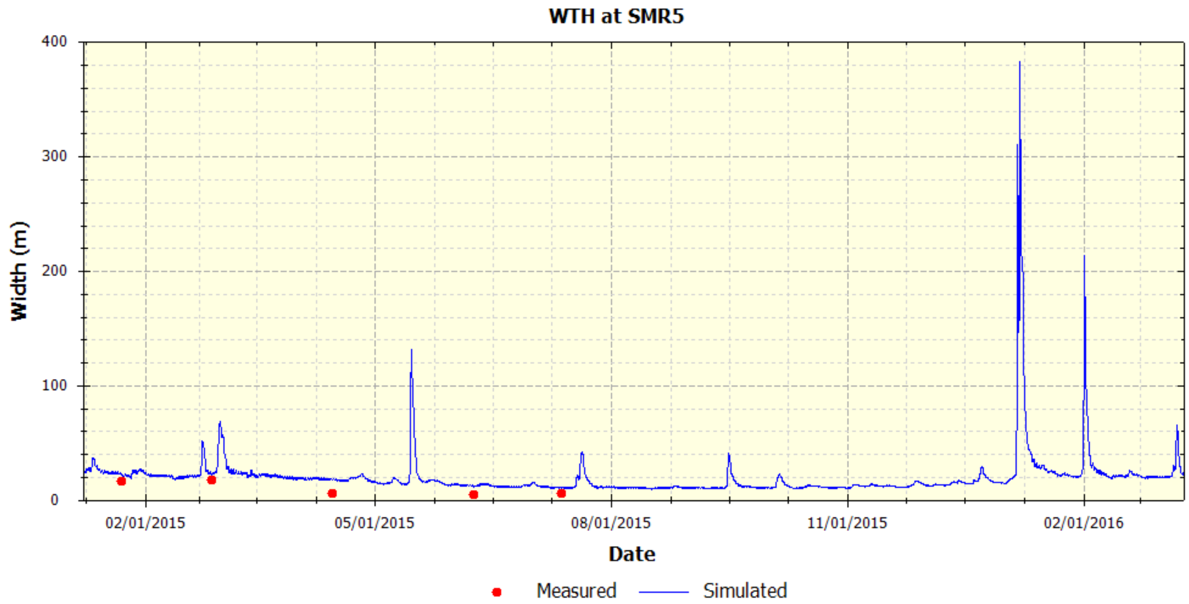


Figure 3-6. Simulated and Observed Channel Width at SMR5

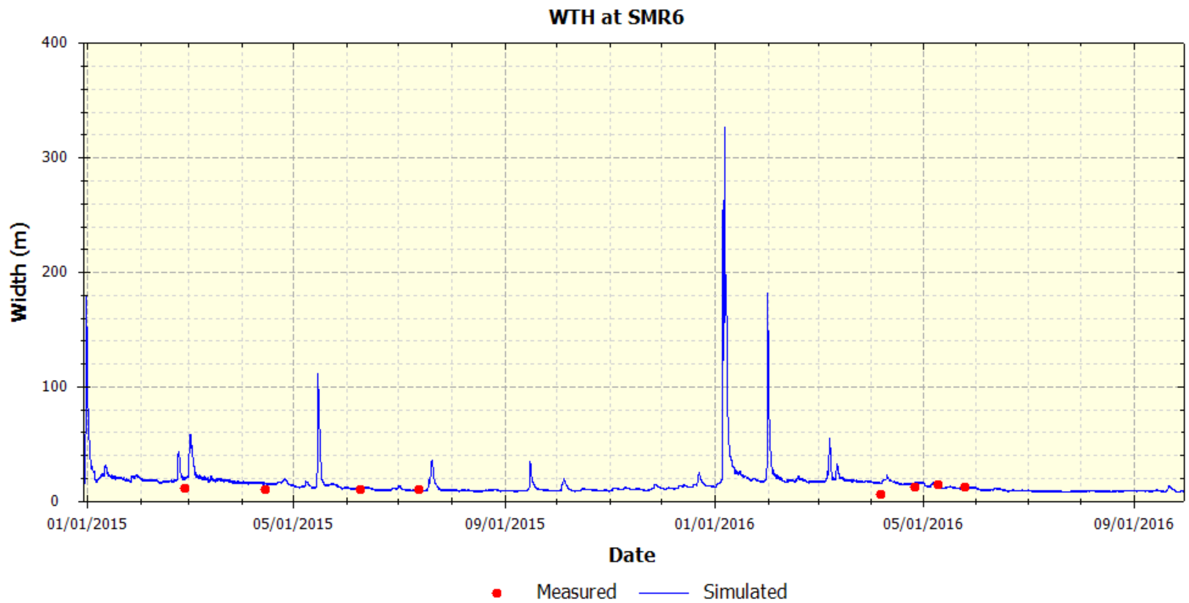


Figure 3-7. Simulated and Observed Channel Width at SMR6

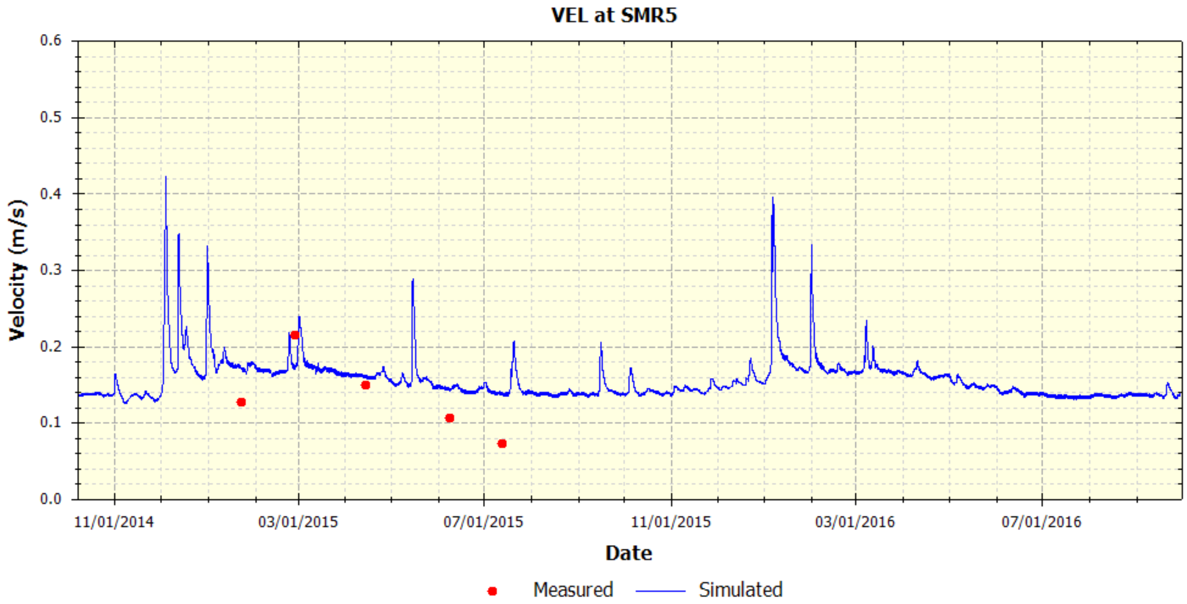


Figure 3-8. Simulated and Observed Velocity at SMR5

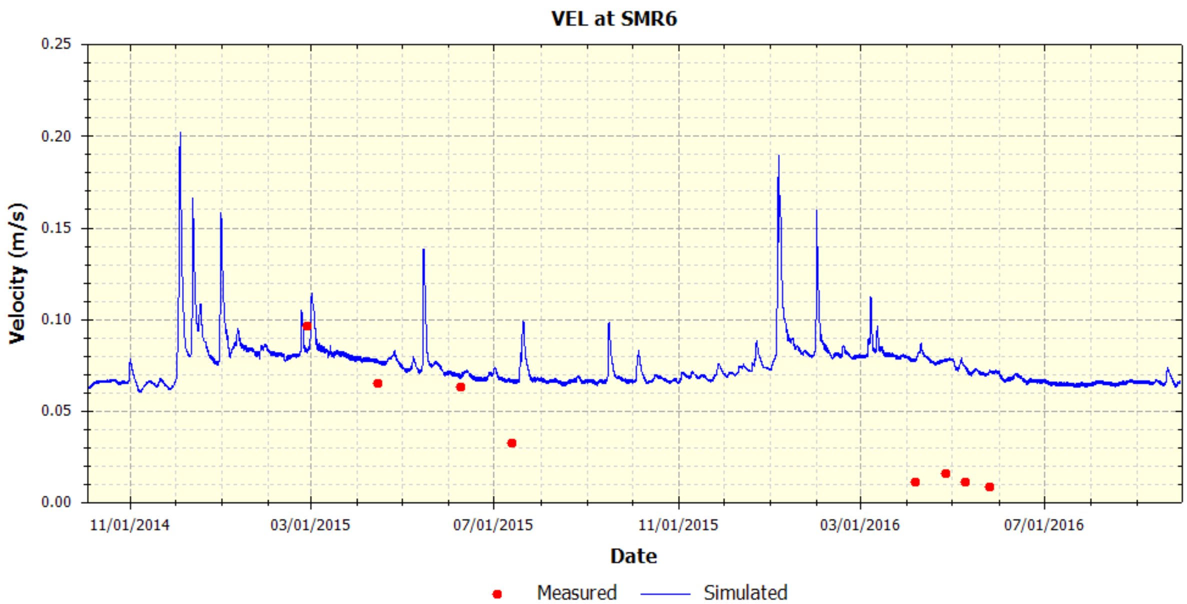


Figure 3-9. Simulated and Observed Velocity at SMR6

3.7.2 Water Temperature

Results from the water temperature calibration are shown in Figure 3-10 - Figure 3-13. A full heat balance is applied in the WASP model to determine water temperature in each of the segments. This approach accounts for heat exchanged at the air-water interface and at the water-sediment interface. In addition, water temperature in the segments is influenced by water temperature at the upstream boundary. Simulated water temperatures are like sonde data collected at SMR5 and SMR6 in 2015. Observed water temperature at SMR5 in late May to early June 2015, however, was recorded at a nearly-steady 7ºC; this is probably due to malfunctioning sonde equipment and data from this period was not considered representative of water temperature at this site. In 2016, reported water temperature diverged at the two neighboring sites; SMR5 was recorded as being much warmer than SMR6. This could be due to a temporary change in the microclimate (since it was not evident in the 2015 data). Water temperature at SMR6 in June 2016 resembles that of June 2015, which is not the case for SMR5, potentially due to altered riparian shading, switched sonde equipment, changes in the depth or exact location of monitoring. The WASP model provides a middle-ground representation of water temperature at both sites across the full period of record.

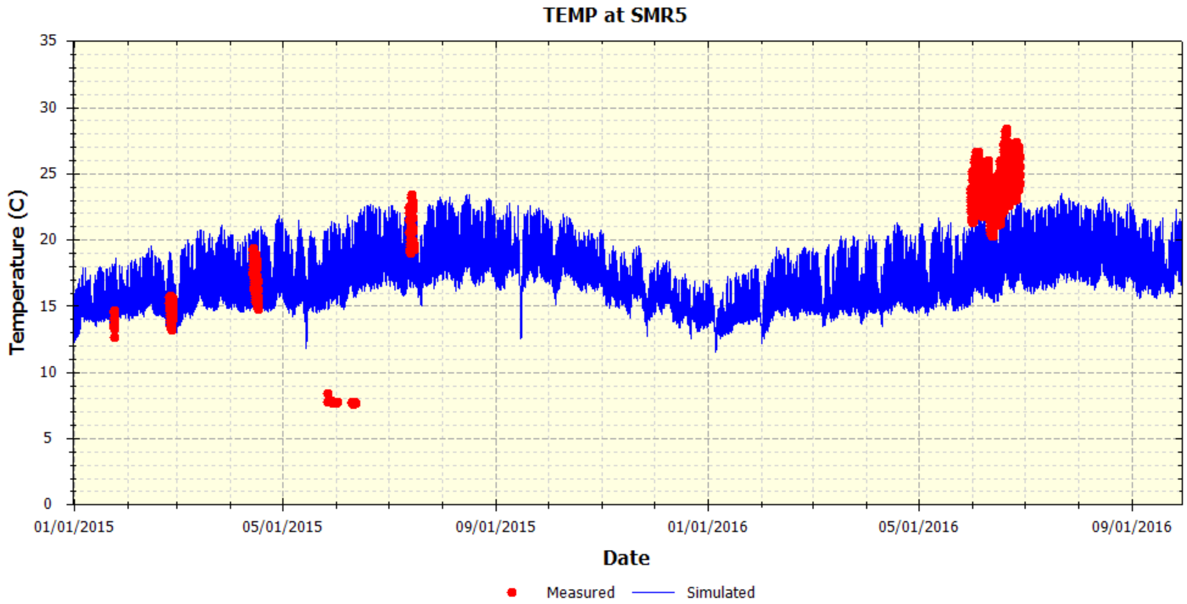


Figure 3-10. Simulated and Observed Water Temperature at SMR5

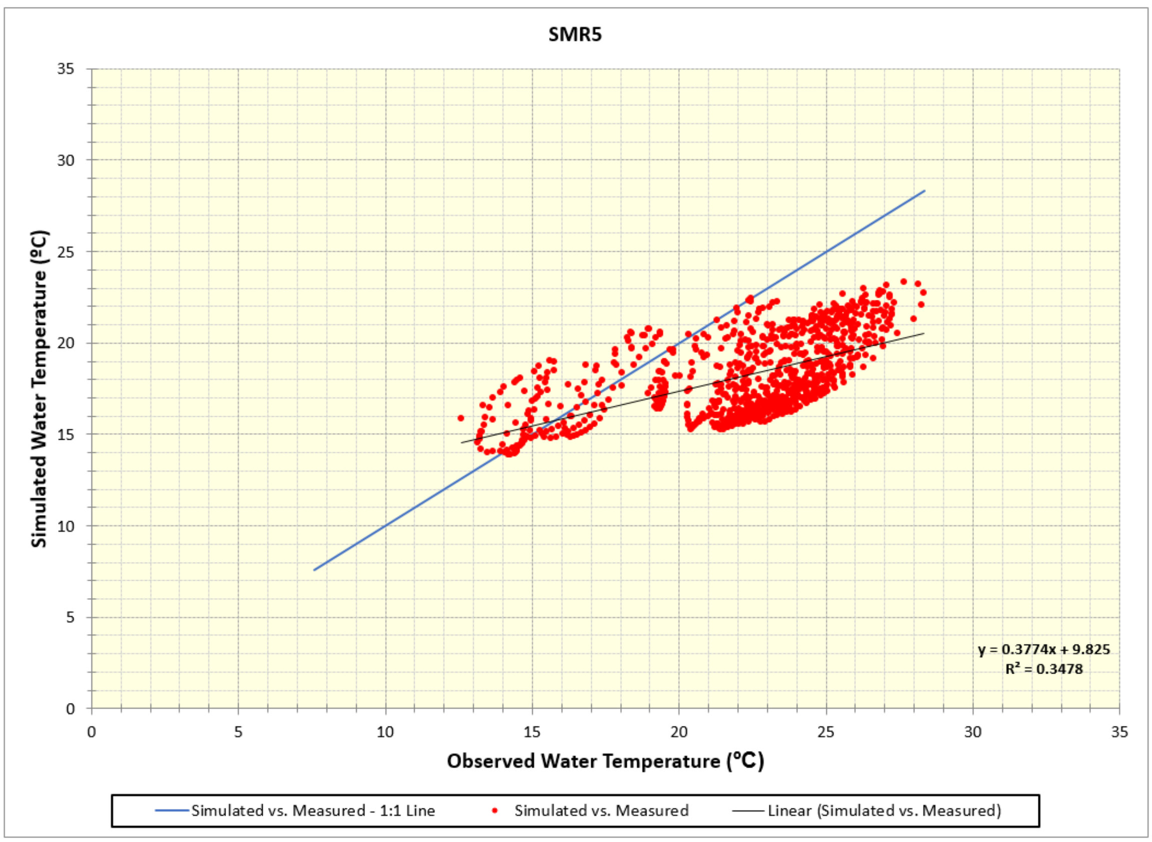


Figure 3-11. Scatter Plot of Observed vs Simulated Water Temperature at SMR5

Note: Observed water temperature data from late May to early June 2015 were removed because the sonde equipment appeared to have malfunctioned resulting in a steady 7ºC reading.

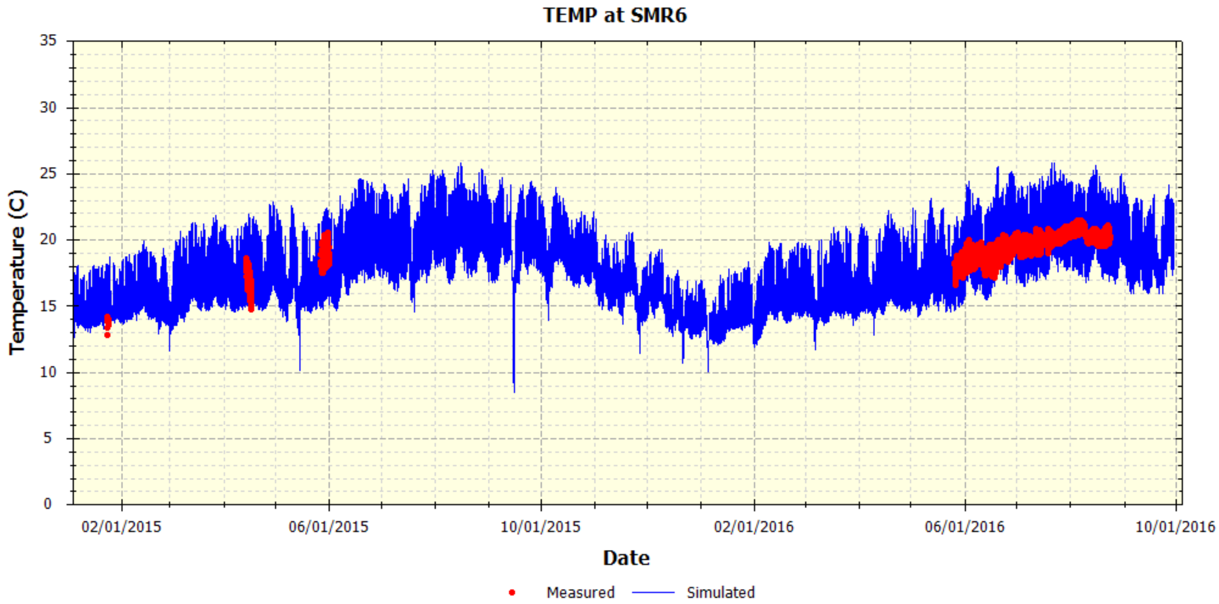


Figure 3-12. Simulated and Observed Water Temperature at SMR6

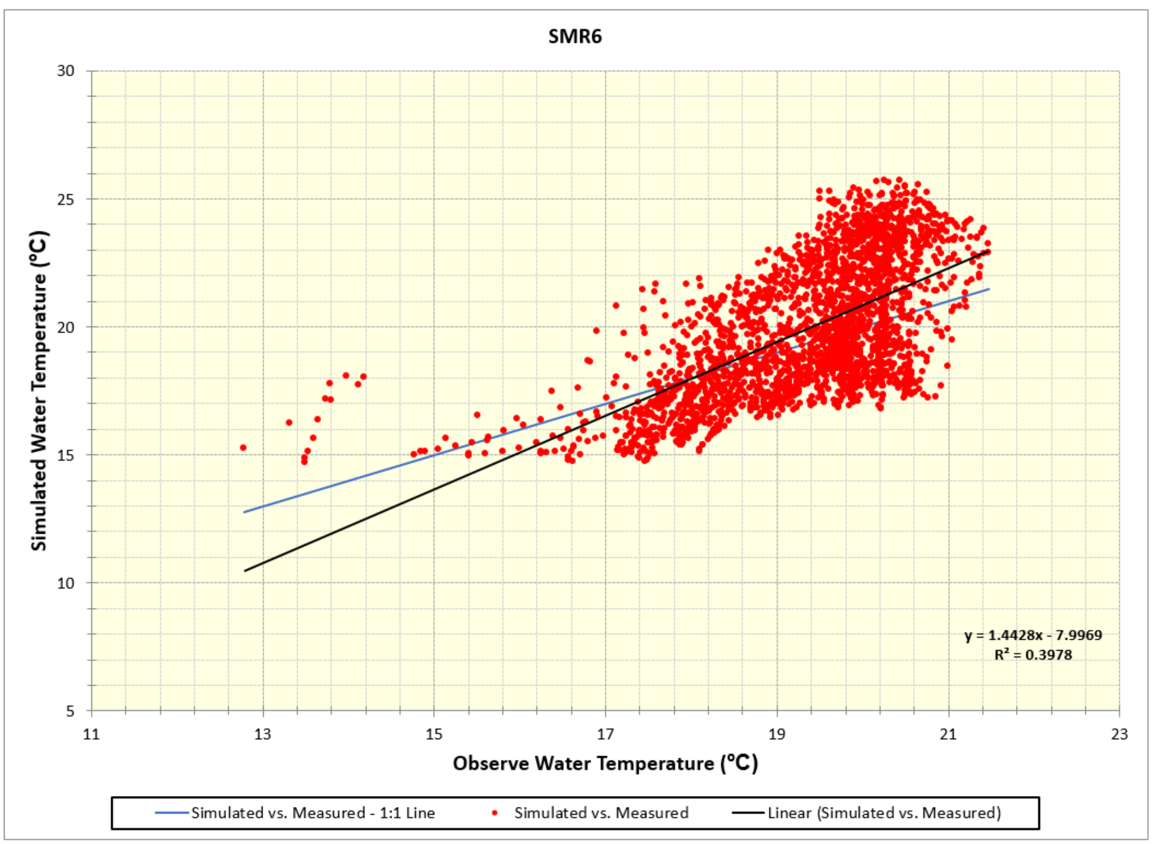


Figure 3-13. Scatter Plot of Observed vs Simulated Water Temperature at SMR6

3.7.3 Nutrients

WASP simulates physical, biological, and chemical processes that impact nutrient transport, transformation, and uptake by algae. Therefore, an iterative approach was used to calibrate nutrients, algae, and dissolved oxygen in tandem. Results from the water quality calibration are discussed in this subsection and the following subsections.

The model provides a reasonable representation of nutrients in the lower river, as shown by the summary statistics (Table 3-5), and time series and distribution plots for TN and TP (Figure 3-14 - Figure 3-17). Monitoring records indicate that the probability of TN being below 0.3 mg/L is approximately 50% at both sites. Model cumulative distribution function curves show a similar pattern for concentrations of this magnitude. However, the model does underestimate a relatively high TN concentration that was reported in the late winter of 2015. The model also underestimates higher observed TP concentrations at SMR5 (>0.07 mg/L) but achieves a good fit at SMR6 where the highest reported TP concentration is about 0.07 mg/L.

Table 3-5. Summary Statistics for TN and TP

Constituent	SMR5 (WASP Segment 5)			SMR6 (WASP Segment 4)		
	Simulated Mean	Observed Mean	Average Error	Simulated Mean	Observed Mean	Average Error
TN (mg/L)	0.48	0.42	0.06	0.46	0.40	0.06
TP (mg/L)	0.05	0.06	-0.01	0.05	0.04	0.01

Note: Simulated mean calculated for monitored periods.

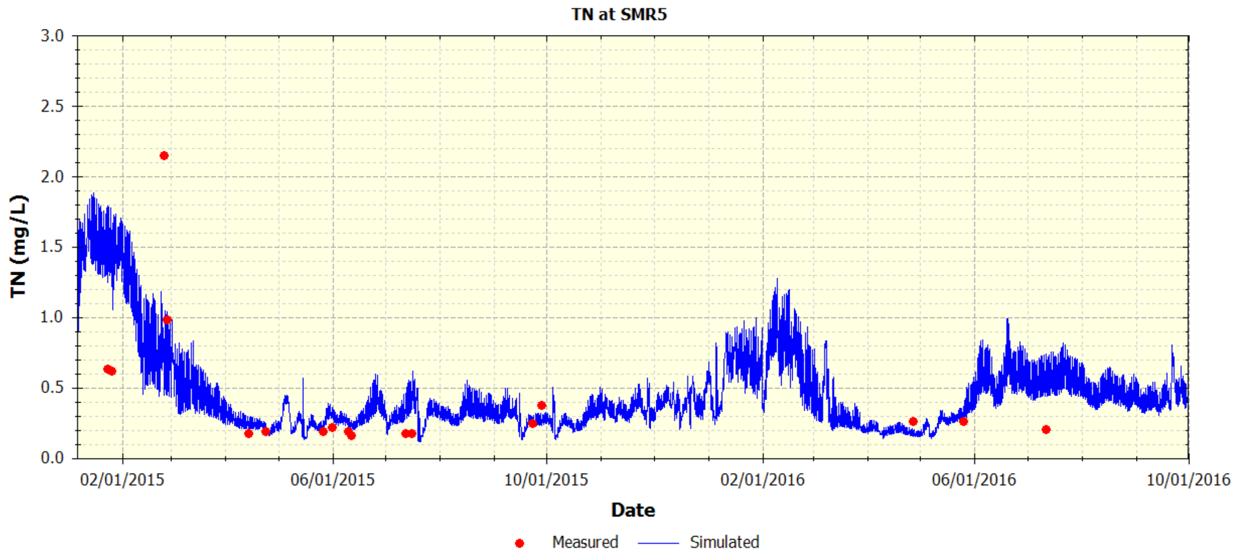


Figure 3-14. Simulated and Observed Total Nitrogen Concentration at SMR5

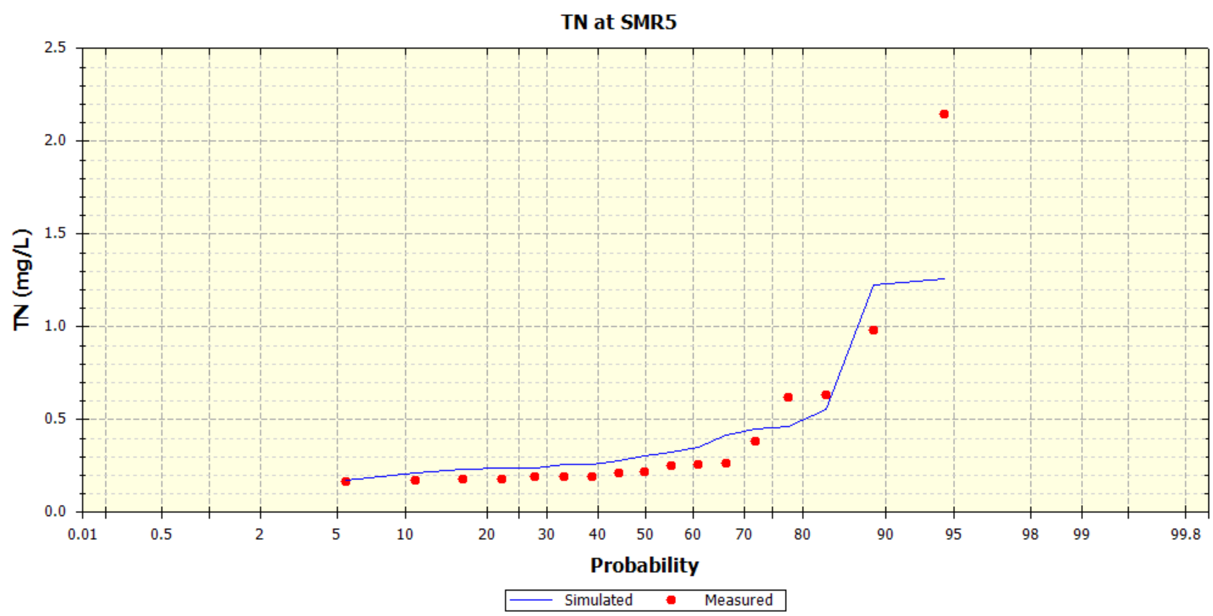


Figure 3-15. Distribution of Total Nitrogen Concentrations at SMR5

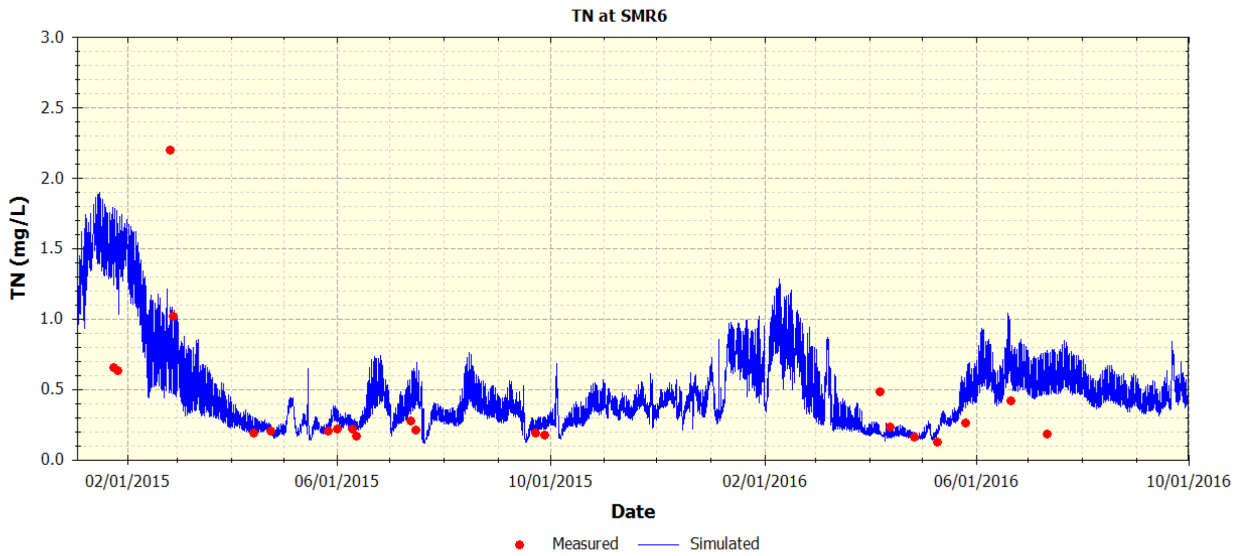


Figure 3-16. Simulated and Observed Total Nitrogen Concentration at SMR6

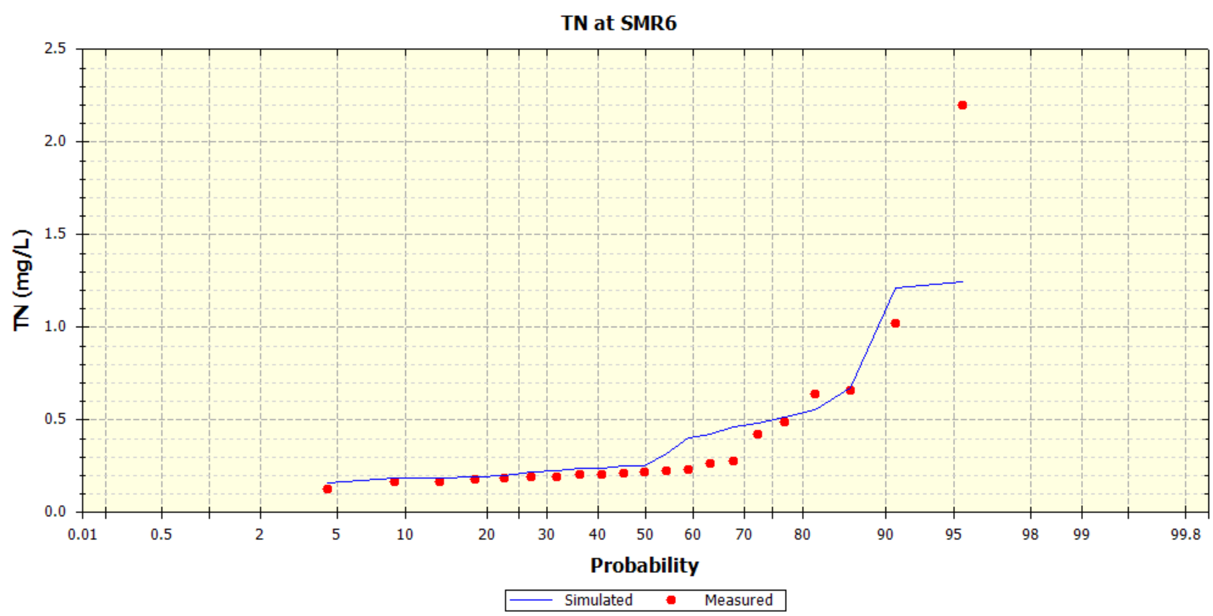


Figure 3-17. Distribution of Total Nitrogen Concentrations at SMR6

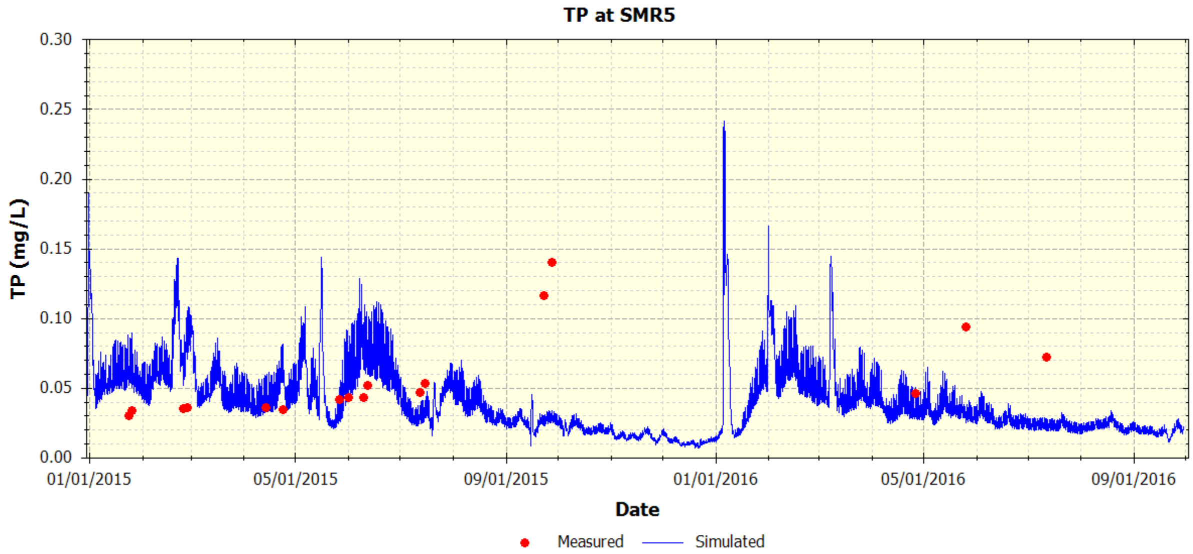


Figure 3-18. Simulated and Observed Total Phosphorus Concentration at SMR5

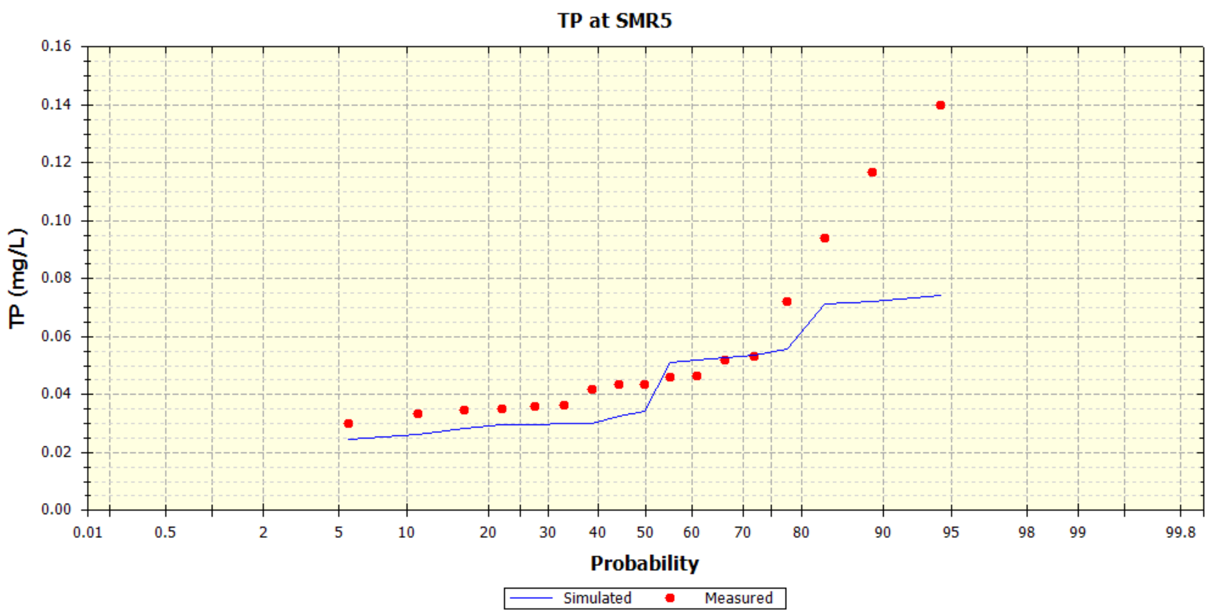


Figure 3-19. Distribution of Total Phosphorus Concentrations at SMR5

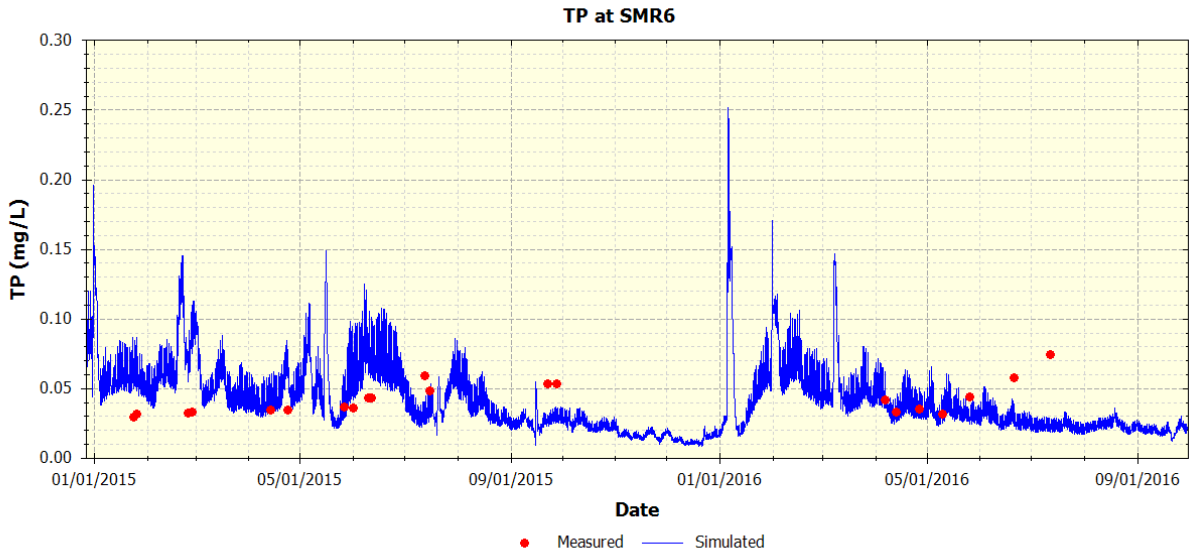


Figure 3-20. Simulated and Observed Total Phosphorus Concentration at SMR6

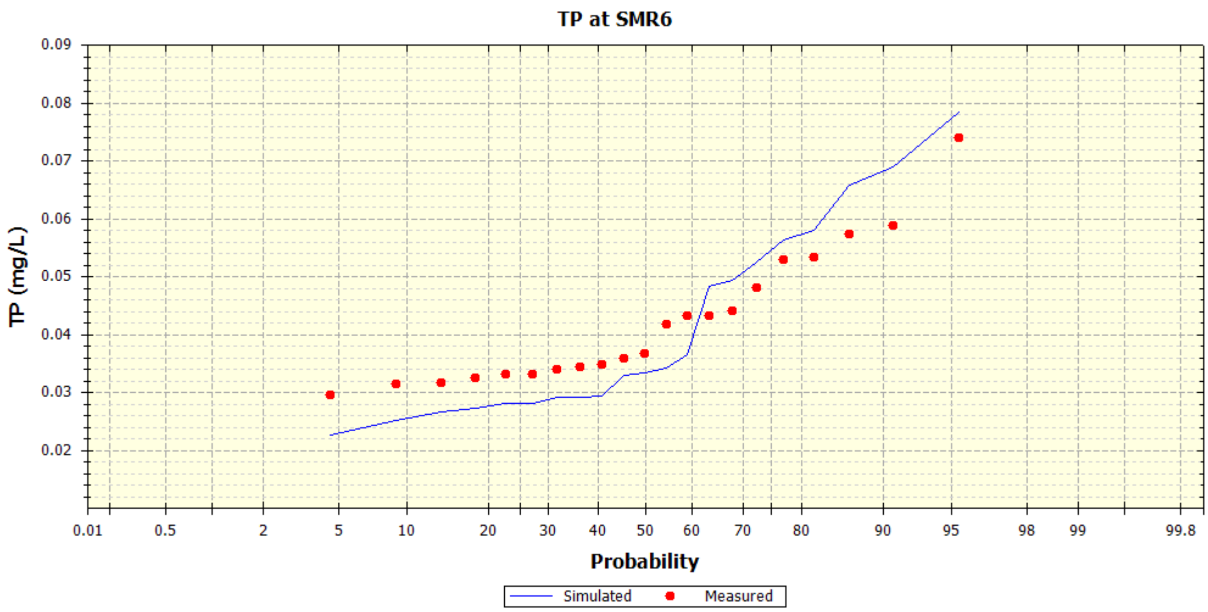


Figure 3-21. Distribution of Total Phosphorus Concentrations at SMR6

3.7.4 Model Performance: Ash Free Dry Mass and Benthic Algae

WASP simulates benthic algae as Ash Free Dry Mass (AFDM) and then applies a conversion to estimate benthic chlorophyll *a*. However, this estimate of AFDM is not directly comparable to observed AFDM, which, in addition to algae, accounts for other organic matter (e.g., detritus, bacteria, fungi) collected in the sample. AFDM simulated by WASP does not include non-algal components of AFDM. Considering this, simulated AFDM should be lower than observed AFDM, and this is the case for the lower Santa Margarita River WASP model. Simulated and observed AFDM are presented in Figure 3-22 - Figure 3-23.

A more direct comparison for actively photosynthesizing benthic algae is chlorophyll *a*. Benthic chlorophyll *a* was measured in 2016 at SMR5 and SMR6, as was benthic P, C, and N. These samples were used to define benthic algal stoichiometry in the WASP model, and these were also used to translate simulated benthic AFDM to benthic chlorophyll *a*. Chlorophyll *a* sample records indicate that there is significant spatial variation of algal density within the stream. The minimum, mean, and maximum observed chlorophyll *a* density are shown for sampling days at SMR5 in Table 3-6. On April 15, 2015 samples at the SMR5 site ranged from as low as 8.6 mg/m^2 to as high as 68.2 mg/m^2. Model predicted benthic chlorophyll *a* tends to be in the range of observations, as shown in Figure 3-24 and Figure 3-25.

Table 3-6. Summary of Chlorophyll *a* Samples at SMR5

Sample Date	Observed Chlorophyll-a (mg/m^2)		
	Minimum	Mean	Maximum
1/23/2015	22.6	24.6	26.3
2/27/2015	10.6	14.9	19.5
4/15/2015	8.6	45.8	68.2
6/9/2015	12.6	33.6	60.8
7/13/2015	18.3	31.8	39.7
4/27/2016	0.9	1.6	2.4
5/26/2016	22.1	30.2	39.2
7/12/2016	11.5	18.7	27.3

Table 3-7. Summary Statistics for Benthic Algae Chlorophyll *a*

Constituent	SMR5 (WASP Segment 5)			SMR6 (WASP Segment 4)		
	Simulated Mean	Observed Range and Mean	Average Error	Simulated Mean	Observed Range and Mean	Average Error
Chlorophyll *a* (mg/m^2)	29.6	0.9 – 68.2 (25.2)	4.5	31.1	0.9 – 59.3 (16.4)	14.7

Note: Simulated mean calculated for monitored periods.

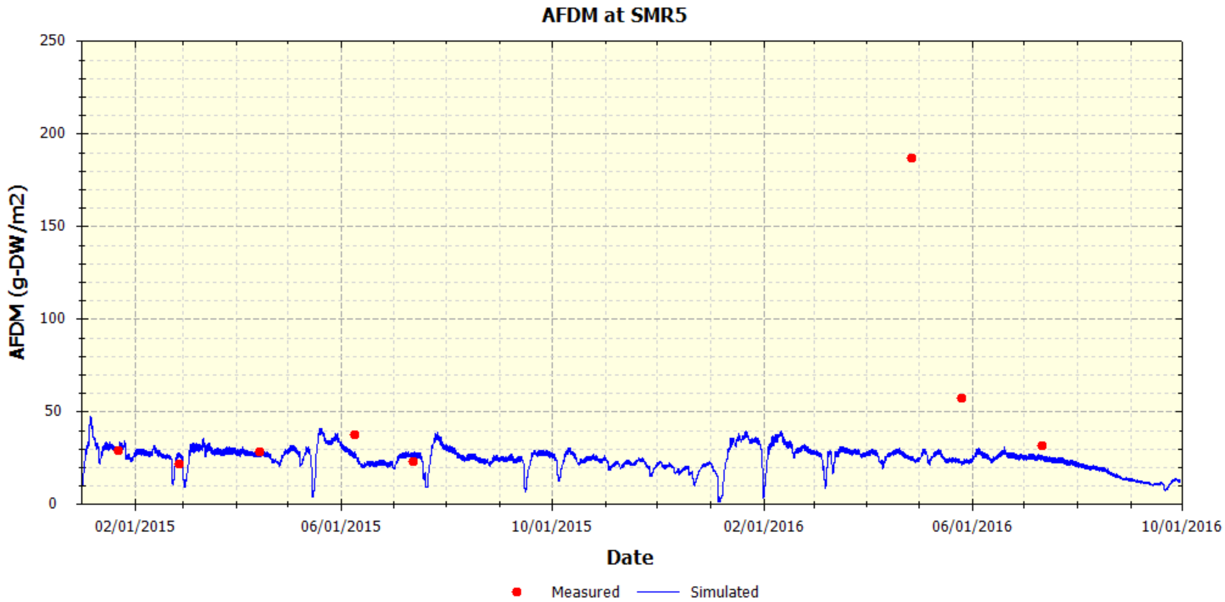


Figure 3-22. Simulated and Observed AFDM at SMR5

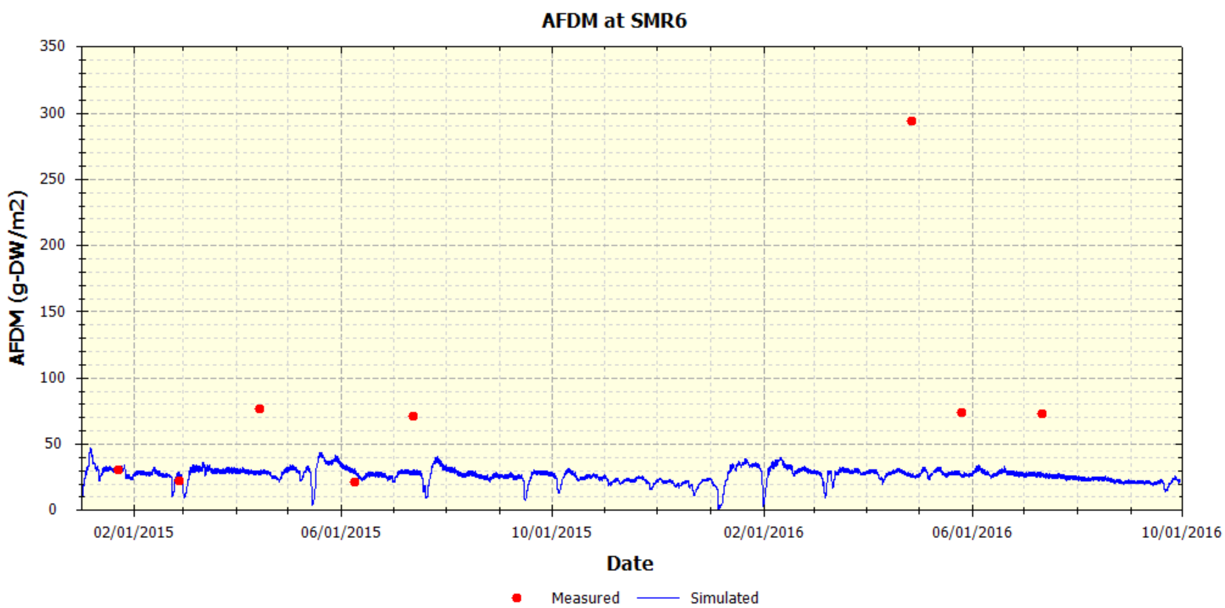


Figure 3-23. Simulated and Observed AFDM at SMR6

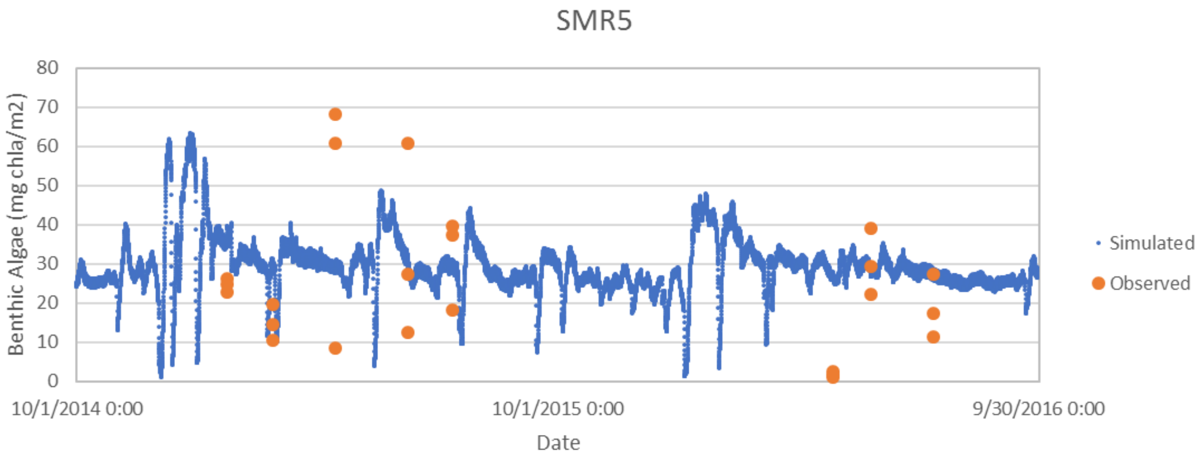


Figure 3-24. Simulated and Observed Benthic Algae Chlorophyll *a* at SMR5

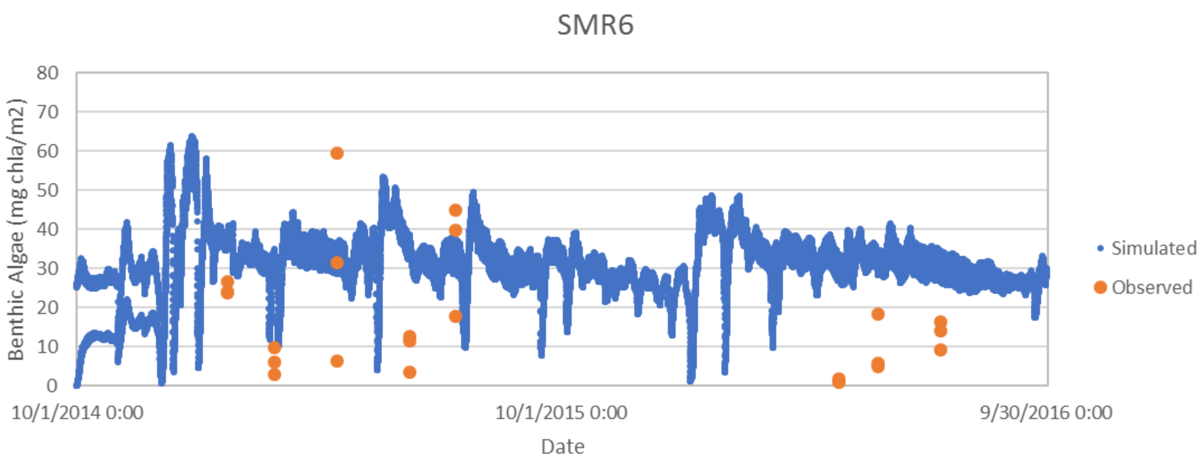


Figure 3-25. Simulated and Observed Benthic Algae Chlorophyll *a* at SMR6

3.7.5 Model Performance: Dissolved Oxygen

Dissolved oxygen (DO) simulated by the WASP model resembles observed DO at SMR5 and SMR6 in 2015 (Table 3-8; Figure 3-26 and Figure 3-27). However, DO concentrations diverge at the two monitoring sites in 2016; at SMR5 concentrations were reported as ranging from about 6 mg/L to 10 mg/L whereas at SMR6 concentrations were below 6 mg/L and approaching 0 mg/L in early August 2016. The discrepancy between DO at the two sites may be due to unknown local conditions or possibly due to malfunctioning equipment (e.g., buried probe). The WASP model is unable to account for the unknown factors that result in very different DO concentrations at the two sites in 2016. Rather, WASP predicts DO concentrations that are representative of 2015 monitoring and the model splits the difference between SMR5 and SMR6 in 2016.

Simulated DO diel range was also assessed (Table 3-8), and the range simulated by the WASP model is more comparable to SMR5 than it is for SMR6.

Table 3-8. Summary Statistics for Mean Dissolved Oxygen Concentration and Diel Variability

Constituent	SMR5 (WASP Segment 5)			SMR6 (WASP Segment 4)		
	Simulated	Observed	Average Error	Simulated	Observed	Average Error
Mean DO (mg/L)	5.1	6.8	-1.6	5.7	2.6	3.1
DO Diel Range (mg/L)	2.51	2.43	0.08	2.47	0.73	1.75

Note: Simulated mean calculated for monitored periods.

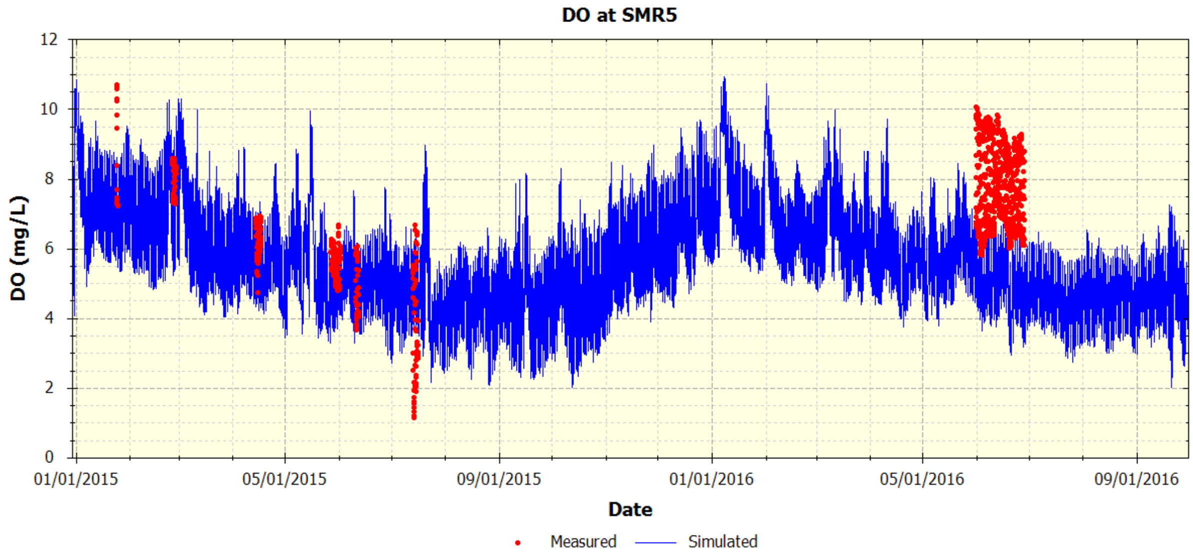


Figure 3-26. Simulated and Observed Dissolved Oxygen at SMR5

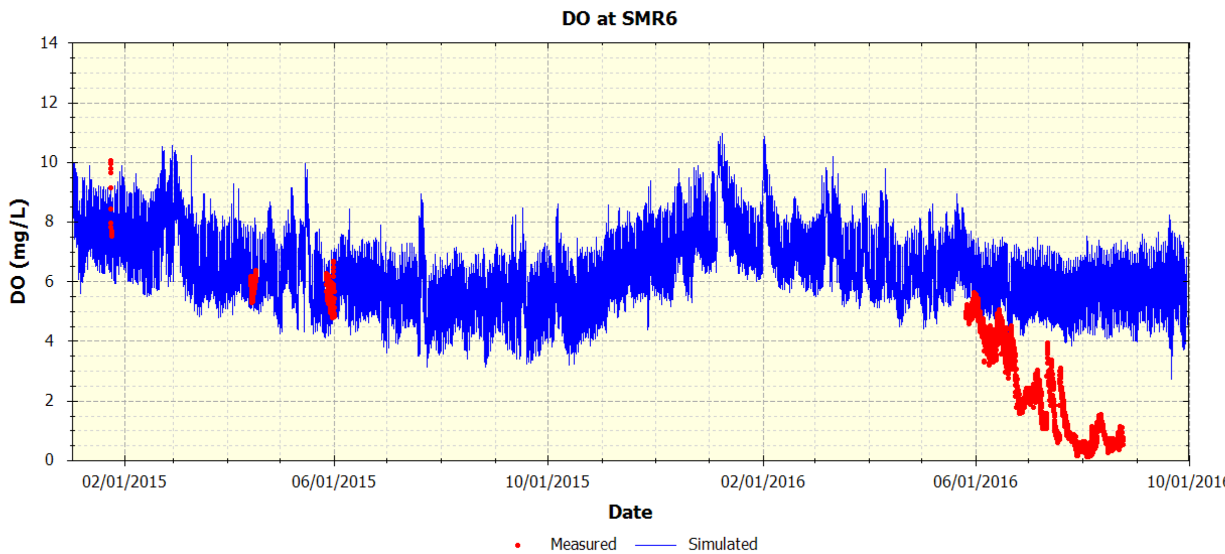


Figure 3-27. Simulated and Observed Dissolved Oxygen at SMR6

3.8 WASP MODEL SENSITIVITY

Several tests were completed to examine DO and benthic algae sensitivity to various stressors. These are listed and described in ***Table 3-9***.

Table 3-9. Description of WASP Model Sensitivity Tests

Sensitivity Test	Description
Boundary DO	Hourly DO concentrations associated with upstream boundary flow scaled by +/- 20%
Boundary flow	Hourly upstream boundary flow scaled by +/- 20%
Boundary N	Hourly N constituent concentrations associated with upstream boundary flow scaled by +/- 20%
Boundary P	Hourly P constituent concentrations associated with upstream boundary flow scaled by +/- 20%
Boundary N and P	Hourly N and P constituent concentrations associated with upstream boundary flow scaled by +/- 20%
SOD	Sediment oxygen demand rate scaled by +/- 20%
Reaeration	Tsivoglou Neal escape coefficient scaled by +/- 20%
Shade	Fraction of stream channel shaded scaled by +/- 20%

Univariate leverage coefficients were computed to evaluate response variable sensitivity for each scenario (Section 2.6.2 describes how these coefficients were calculated). Leverage coefficients for daily mean DO, DO diel variability and benthic algae chlorophyll-a are presented in tornado diagrams (Figure 3-28 - Figure 3-30).

Daily mean DO was most sensitive to the upstream DO boundary condition. An increase of 1 mg/L in DO at the upstream boundary resulted in an increase that was greater than 1 mg/L in the WASP model. Mean DO was inversely sensitive to SOD; an increase in SOD resulted in an almost equal magnitude decrease in DO. An increase in shade or boundary flow cooled water temperatures, which raised mean DO in the stream segments. Improved reaeration was also shown to raise mean DO. Impacts due to changes in boundary N and/or P were, however, respectively minor.

Impacts of stressors on DO diel variability was also assessed because large swings in DO can be detrimental to fish and other aquatic species. Stream segments were shallower and warmer when boundary flow was reduced, increasing DO diel variability significantly. Lower reaeration, SOD, or DO in upstream waters produced larger swings in DO. Conversely, a simulation of lower N and P was shown to be most effective at reducing DO diel variability. Isolated reductions of either N or P were less effective but still narrowed the diel range.

Simulations revealed that lower concentrations of N and P in boundary waters slowed benthic algae growth and resulted in lower benthic chlorophyll *a*. Reductions of either N or P also limited benthic chlorophyll *a*, but less severely compared to when concentrations of both nutrients were lower. Algae were also inhibited by lower flow; stream segments were shallower for this scenario and water temperatures were warmer, which altered nutrient cycling (e.g., more rapid nitrification), availability (e.g., lower ammonia concentrations), and algal uptake. Benthic algae were less responsive to other stressors that were tested, including shade, SOD, reaeration, and boundary DO concentration.

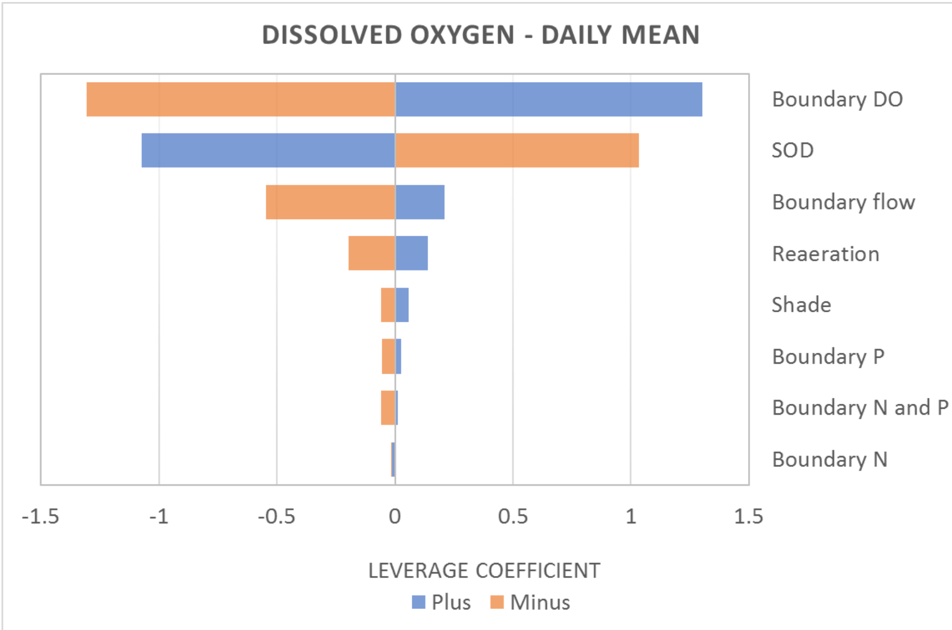


Figure 3-28. WASP Model Sensitivity Tornado Diagram: Leverage Coefficients for Daily Mean Dissolved Oxygen Concentrations

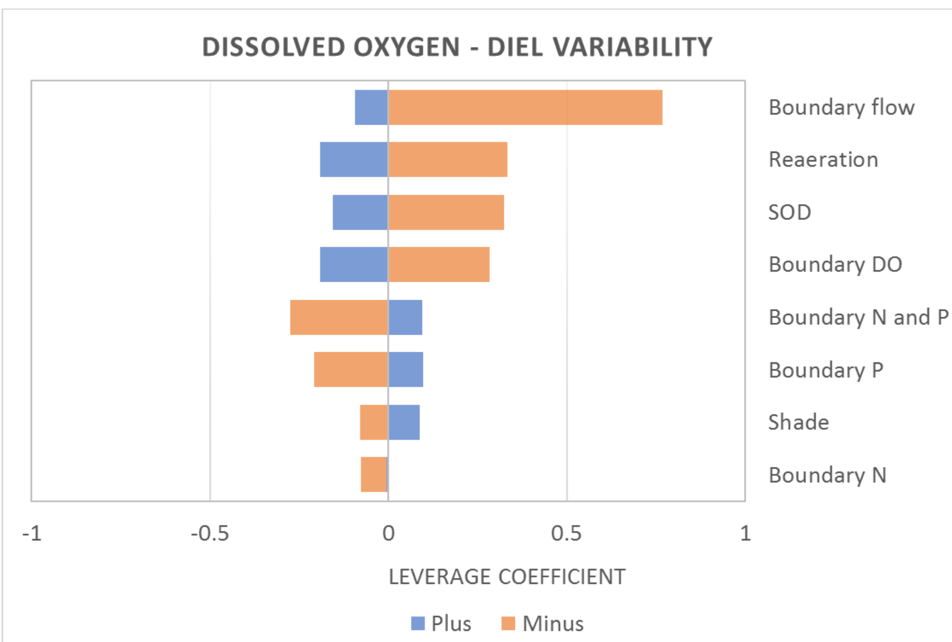


Figure 3-29. WASP Model Sensitivity Tornado Diagram: Leverage Coefficients for Dissolved Oxygen Diel Variability

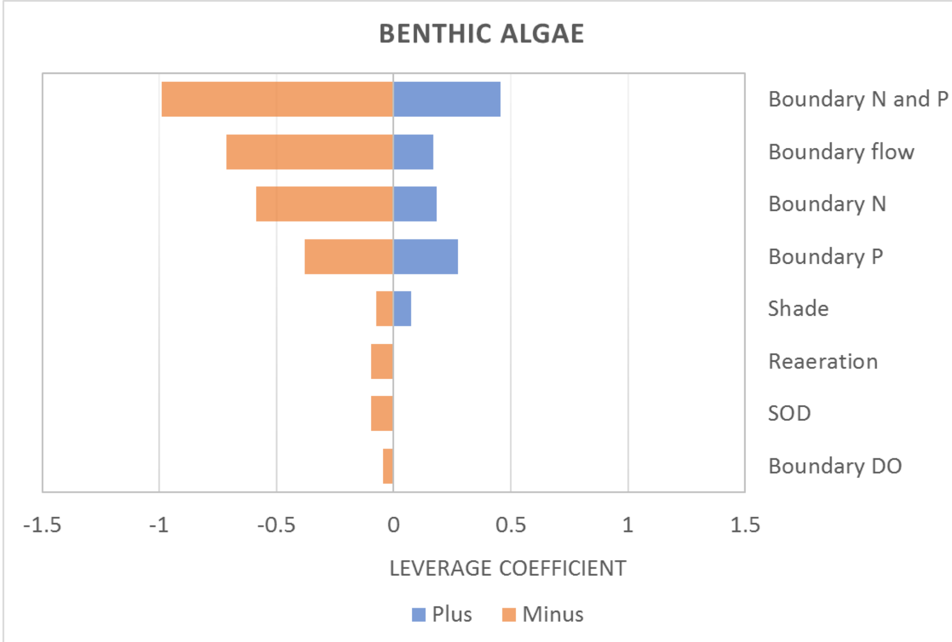


Figure 3-30. WASP Model Sensitivity Tornado Diagram: Leverage Coefficients for Benthic Algae as Chlorophyll-a

3.9 NUTRIENT RESPONSE CURVES

Several scenarios were simulated with the WASP model to assess the impacts of boundary TN and TP on benthic algae and DO diel variability. Steady-state concentrations of TN (0.1, 0.3, 0.7, and 1.0 mg/L) were paired with the hourly TP concentration boundary time series that was derived from HSPF output. Response curves for benthic algae and dissolved oxygen diel variability during May – September are shown for TN in Figure 3-31 and **Figure 3-32** (plot a). Response curves were also developed for steady-state TP concentration scenarios (0.01, 0.03, 0.07, and 0.1 mg/L; plot b), and for combined TN and TP scenarios (where TP = 0.1 * TN; plot c).

Lower simulated TN and/or TP concentrations limited benthic algae growth and narrowed the DO diel range. DO diel variability is largely driven by respiration and photosynthesis of benthic algae, so DO and benthic algae response curves exhibit similar trends for the nutrient scenarios. The lowest simulated TN (0.1 mg/L) or TP (0.01 mg/L) scenarios predicted algae concentrations of 3.78 and 2.78 mg/m^2 and DO diel ranges of 1.88 and 1.87 mg/L.

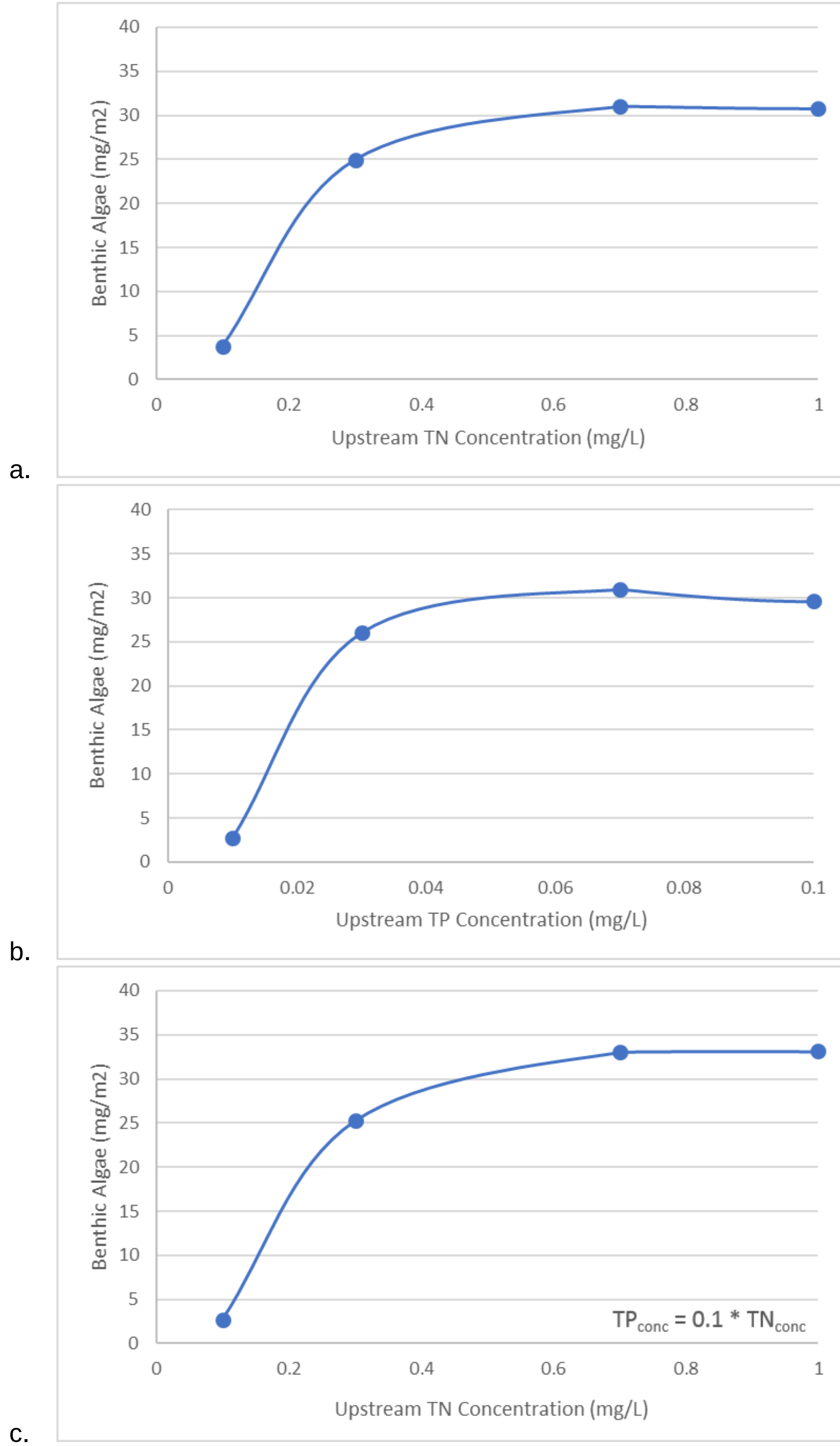


Figure 3-31. Benthic Algae Response Curves for Steady-State Boundary Flow Concentrations of a) TN, b) TP and c) TN and TP (May-September)

Note: For (a) the hourly TP concentration time series derived from the HSPF model was paired with steady-state concentrations of TN and for (b), the hourly TN concentration time series derived from the HSPF model was paired with steady-state concentrations of TP. Steady-state concentrations of TN and TP were paired for( ),. where TP = 0.1 * TN.

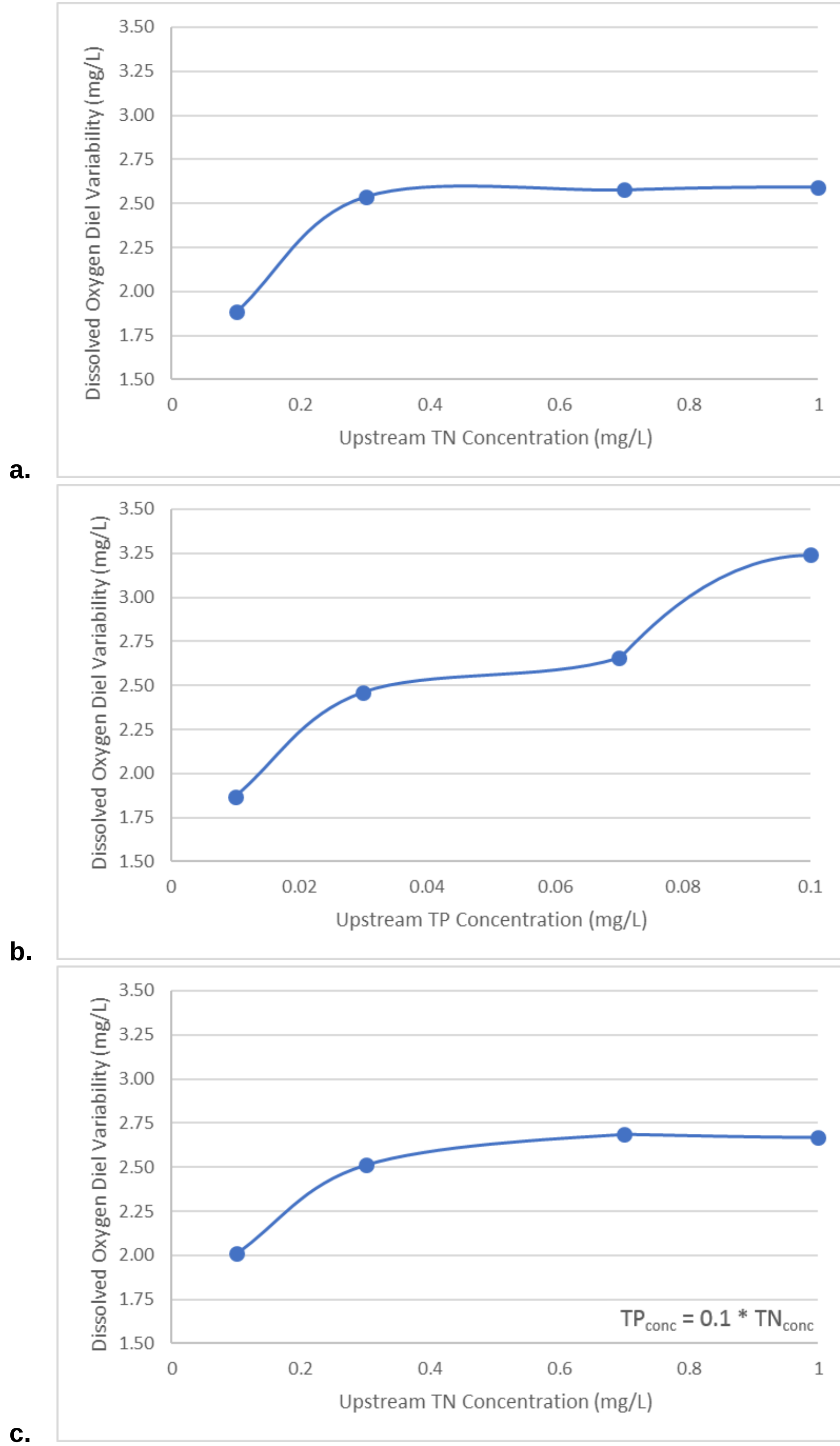


Figure 3-32. Dissolved Oxygen Diel Range Response Curves for Steady-State Boundary Flow Concentrations of a) TN, b) TP and c) TN and TP (May-September)

Note: For (a), the hourly TP concentration time series derived from the HSPF model was paired with steady-state concentrations of TN and for (b), the hourly TN concentration time series derived from the HSPF model was paired with steady-state concentrations of TP. Steady-state concentrations of TN and TP were paired for (c), where TP = 0.1 * TN.

3.10 WASP SUMMARY

A WASP model (EUTRO module) was developed as part of the lower Santa Margarita River modeling framework. Continuous simulations by WASP are stable where perennial flow and a reasonable depth is maintained. Flow in the mainstem from the De Luz Creek confluence to near the Old Hospital upstream of the Camp Pendleton diversion is perennial, so the WASP model represents this portion of the channel. Flow is intermittent in the lower Santa Margarita River downstream of the diversion. This portion of the lower river was not included in the WASP extent but was studied with critical period QUAL2kw models, as discussed in the following section.

It is advantageous to utilize WASP in combination with HSPF. HSPF is a comprehensive watershed model and it provides useful information for characterizing WASP boundary conditions. WASP simulates the river at a finer spatial and temporal resolution than HSPF. Monitoring sites are co-located in HSPF reaches whereas in WASP a separate segment was defined for each monitoring site. WASP is also a beneficial tool because of the sediment diagenesis subroutine that can be used to predict, rather than describe, the sediment oxygen demand due to local algal activity. This is particularly important in the lower Santa Margarita River where mean DO is largely driven by SOD. WASP is also capable of simulating multiple forms of benthic, submersed or floating algae and macrophytes. This may be an important feature if the WASP model is extended to represent the upper river where egregious blooms have been observed.

The WASP model provides a reasonable representation of water temperature, nutrients, dissolved oxygen, and benthic algae in the lower Santa Margarita River. The model does a better job of representing 2015 conditions than it does 2016 conditions. This is because observed water temperature and dissolved oxygen at SMR5 and SMR6 diverged for unknown reasons in 2016, likely due to changes at the microclimate scale or malfunctioning equipment. WASP more closely matches observations at SMR5 for benthic algae, mean DO, DO diel variability.

DO and benthic algae response to various stressors were examined with WASP. Daily mean DO was found to be most sensitive to the upstream DO boundary condition and SOD (40% attributed to local algal activity and 60% attributed to unknown, non-local sources). Cooler water temperatures, due to either increased flow or shade, raised mean DO. WASP sensitivity analyses indicate that benthic algae are most sensitive to changes in nutrient concentrations. Lower nutrient concentrations limit benthic algae and narrow the DO diel range. Response curves were developed from various N and P concentration scenarios. These can be used to translate lower nutrient concentration targets to benthic algae chlorophyll *a* and DO diel variability.

4.0 QUAL2KW NUTRIENT RESPONSE MODEL

4.1 DEVELOPMENT OF LOWER SANTA MARGARITA QUAL2KW MODEL

The modeling framework of QUAL2K was originally developed at Tufts University as a one-dimensional river water quality model capable of simulating steady-state hydraulics, and diel heat budget and water quality kinetics (Chapra et al., 2012). The Washington State Department of Ecology updated the original model to QUAL2Kw which is capable of simulating dynamic hydraulics with continuous simulation of variable boundary conditions (Pelletier and Chapra, 2006). QUAL2Kw is a one-dimensional model that simulates the diel heat budget, diel water quality, phytoplankton, bottom algae, pH, and the full dissolved oxygen balance. The model also allows for the incorporation of hyporheic flow through the riverbed, and several other dynamic and complex simulation options. The kinetic representation of hydraulics and water quality are like those in the current version of the Water Quality Analysis Simulation Program (WASP), which were adapted from the QUAL2Kw code. In general, HSPF and WASP models are preferred for long-term continuous simulations, and the QUAL2Kw model is most appropriate when exploring short-term critical simulation periods.

4.1.1 Model Extent

Two QUAL2Kw models were developed to align with subbasins constructed for the HSPF model. The QUAL2Kw model “Above Old Hospital” extends from the confluence of De Luz Creek and SMR down to the Lake O’Neil diversion from SMR at the old hospital (encompassing HSPF subbasin 108), and the second model, “Above Ysidora”, extends from immediately downstream of the diversion to downstream of the USGS Ysidora flow gage (USGS gage 11046000, Santa Margarita River at Ysidora, California) at the northeast corner of the Camp Pendleton airport (encompassing HSPF subbasins 106 and 105). The Above Old Hospital model extent matches the extent of an ongoing modeling exercise using the WASP model. The two QUAL2Kw model extents are shown above in Figure 3-2.

Note that there are no point sources present along either model extent during the simulation periods. Diffuse inflow and loss to groundwater during the simulation periods was extremely low based on HSPF model results. These inputs and losses were excluded from the model as they were on the order of < 1 cfs and were deemed negligible to the simulation based on expert opinion. Diffuse flows do not play a large role in local hydraulics during the critically low-flow dry summer periods.

4.1.2 Simulation Date Selection

The QUAL2Kw models were developed to simulate critical conditions along the lower SMR during which monitoring data was available. Critical conditions typically include low flows, high thermal inputs (high air temperature), low DO, and high algal biomass. Using observed data collected by SCCWRP (Figure 2-10), the criteria for selecting model simulation periods were:

1. Flow must be present at the USGS gage at Ysidora
2. Continuous DO concentrations must be monitored at the downstream end of the model extent to use for calibration and performance assessment, and
3. Simulation dates of particular interest are those during spring or summer when air temperatures are high, promoting rapid algal growth.

SCCWRP conducted detailed eutrophication monitoring of the lower SMR from January 2015 – August 2016 which narrowed the focus of the simulation periods and provided access to grab sample measurements of various nutrients, algal conditions, temperature, DO concentrations, and physical parameters such as width, depth, velocity, and flow measurements on sampling dates (Sutula et al., 2016b). Based on the selection criteria, three simulation periods were identified for each QUAL2Kw model extent (Table 4-1).

Table 4-1. SMR QUAL2Kw Simulation Periods

Model Extent	Reference Name	Simulation Dates	Simulation Days	Downstream Gage
Above Old Hospital	May 2015	May 27 – June 1, 2015	6	SMR6
	July 2015	July 13 – 16, 2015	4	SMR5
	August 2016	August 1 – 7, 2016	7	SMR6
Above Ysidora	April 2015	April 14 – 17, 2015	4	SMR3
	May 2015	May 27 – 31, 2015	5	SMR2
	May 2016	May 24 – 26, 2016	3	SMR2

Model setup included time zone specification (Pacific Standard Time), simulation mode selection as “continuous”, and specifying the presence of daylight savings time. Downstream gage data used for calibration was always based on the last day of the simulation for which there was observed a full 24-hour cycle of data.

4.1.3 Reach Segmentation

Reach segmentation was based on available cross-section hydraulic data. HEC-RAS cross-sections were developed previously for the Santa Margarita River Hydrology, Hydraulics, and Sedimentation Study (WEST Consultants, 2000). These cross-sections, although two decades old, were aggregated to represent typical hydraulic conditions and flow dynamics averaged across reaches of approximately a half-mile long. Eight cross-sections were present along the Above Old Hospital extent, which were used to subdivide the QUAL2Kw model into five reaches. 32 cross-sections were present along the Above Ysidora extent and used to subdivide the model into eight reaches, four within each HSPF subbasin, respectively (Table 4-2). Reach specifications such as length and elevations were identified using NHDPlusV2 flowlines, and a 3-meter DEM generated using Interferometric Synthetic Aperture Radar (IfSAR) (NOAA, 2004).

Table 4-2. SMR QUAL2Kw Reach Segmentation

Model Extent	HSPF Sub	Reach	Reach Length (km)	Upstream Elevation (m)	Downstream Elevation (m)	HEC-RAS Cross-Section Identification Numbers
Above Old Hospital	***108***	***1***	0.50	40.80	40.10	61803.02
		2	0.43	40.10	38.54	61043.39
		3	0.57	38.54	36.61	58918.76
		4	0.52	36.61	35.70	57470.75, 56780.57
		5	0.30	35.70	34.55	56240.52, 55587.35, 55583.35
Above Ysidora	106	1	1.21	33.47	29.82	54830, 53980, 53130, 52130
		2	0.93	29.82	27.87	51305, 51105, 50105, 49580
		3	0.48	27.87	25.15	48145, 47846, 47528, 47124
		4	0.34	25.15	24.11	46840, 46496, 46179, 45818
	105	5	0.33	24.11	23.58	45548, 45281, 45057, 44848
		6	0.33	23.58	22.76	44644, 44405, 44084, 43667
		7	0.32	22.76	22.35	43408, 43194, 42715, 42471
		8	0.25	22.35	21.62	42425, 42314, 41958, 41674

4.1.4 Reach Hydraulics

Reach hydraulics and kinetics in QUAL2Kw are a function of channel slope and rating curve inputs (Table 4-3). Channel slopes were tabulated as the difference in upstream and downstream elevation for a given reach, divided by the reach length. Slopes are quite shallow along this portion of the SMR given the low elevation along the channel bed and the proximity to the coast.

Rating curve inputs were developed and initialized based on the HEC-RAS cross-sectional data, although manual adjustments were made to ensure the simulation adequately produced observed channel width, depth, and velocity in 2015-2016 sampling (Table 4-3). Simulated velocity (U, in m/s) and depth (H, in m) are calculated as power functions of streamflow (Q, in cms), where a/A and b/B are the coefficient and exponent, respectively (Leopold and Maddock, 1953):

$$U = a \cdot Q^b$$
$$H = A \cdot Q^B$$

Generally, HEC-RAS models are constructed to simulate streamflow hydraulic conditions during high flow events and are not finely detailed for extreme low flows. For this reason, the HEC-RAS hydraulic geometry reflect flow conditions ranging from 12 – 73,935 cfs. Flows during the QUAL2Kw simulation periods as measured at the Ysidora USGS gage were on the order of 3 – 7 cfs. Because the observed flows were out of range of the HEC-RAS geometry, many reaches were parameterized based on fitting to observed data (width, depth, velocity) if the inputs developed by HEC-RAS produced unreasonable results. Where HEC-RAS geometry could be used directly, inputs were developed by plotting power function trendlines for flow and velocity, and flow and depth relationships respectively. Where HEC-RAS geometry could not be used directly, exponents were set to 0.43 and 0.45 respectively based on QUAL2Kw manual suggestion, and the coefficients were parameterized by calibrating the model to observed conditions.

Table 4-3. SMR QUAL2Kw Reach Hydraulic Inputs

Model Extent	Reach	Slope (m/m)	Velocity Rating Curve		Depth Rating Curve	
			Coefficient (a)	Exponent (b)	Coefficient (A)	Exponent (B)
Above Old Hospital	Headwater	0.00223	0.0500	0.4300	0.9760	0.4500
	1	0.00223	0.0500	0.4300	0.9760	0.4500
	2	0.00362	0.0500	0.4300	0.9760	0.4500
	3	0.00340	0.0500	0.4300	0.9760	0.4500
	4	0.00176	0.0500	0.4300	0.7455	0.4500
	5	0.00377	0.0500	0.4300	1.4130	0.4500
Above Ysidora	Headwater	0.00300	0.1960	0.3443	0.4486	0.4500
	1	0.00300	0.2103	0.3527	0.4239	0.4500
	2	0.00210	0.1420	0.3351	0.6087	0.4500
	3	0.00570	0.2362	0.1993	0.2486	0.3946
	4	0.00300	0.3071	0.1649	0.2343	0.4257
	5	0.00160	0.3073	0.1790	0.2241	0.4340
	6	0.00250	0.2892	0.2028	0.2667	0.4104
	7	0.00130	0.2740	0.2499	0.2475	0.4079
	8	0.00290	0.2928	0.2347	0.2665	0.3739

4.1.5 Meteorological Forcing and Shading

Meteorological forcing inputs developed for the HSPF model were derived from national gridded datasets NLDAS and PRISM. These datasets adequately capture trends across grid-cells (4 km by 4 km for PRISM, 12 km by 12 km for NLDAS); however, point measurements within a cell may vary dramatically from the overall grid average. For this reason, weather inputs for the QUAL2Kw model were developed using a nearby meteorological gage located at the Camp Pendleton Marine Corps Air Station (station ID KNFG via WeatherUnderground.com). This station is located about one mile south from the USGS Ysidora gage, very close to the model extents. When comparing the gridded datasets to the local meteorological data, it was found that the observed range of air temperature was far greater from the local station, and it appeared to be more reasonable about the observed water temperatures in the lower SMR area. From local station KNFG, hourly data inputs for air temperature and dew point temperature were used directly as model input for the simulation dates. Average daily wind speeds measured at 10-m height were converted to 7-m height for model input, and applied to all hours of the day from which each measurement was tabulated. Anecdotal information on cloud cover (sky clarity) was used to develop an average daily percent cloud coverage for each simulation date. Solar radiation was tabulated by the QUAL2Kw model internally based on latitude, Julian day, and sky clarity.

An analysis of aerial imagery, LiDAR, and ground-level photography suggest that the lower SMR is not well-shaded from topography or riparian vegetation. Parameterization for hourly fraction of total solar radiation blocked by topography and vegetation was estimated as 25% for all hours and all reaches for the model Above Old Hospital, and 20% for the model Above Ysidora. These shade values provided the most reasonable approximation of water temperature, and may in some ways capture the instream shading provided by submerged aquatic vegetation which are not explicitly simulated.

Table 4-4. SMR QUAL2Kw Simulation Periods

Model Extent	Reference Name	Average Air Temperature (°C)	Average Dew Point Temperature (°C)	Average Wind Speed (m/s)	Cloud Cover (%)	Shade (%)
Above Old Hospital	May 2015	17.9	13.1	1.3	75	25
	July 2015	21.0	14.7	1.7	44	25
	August 2016	22.6	18.0	2.2	68	25
Above Ysidora	April 2015	17.7	13.0*	1.5	0	20
	May 2015	17.8	13.0	1.3	75	20
	May 2016	24.5	20.2	4.1	58	20

*Dew point temperature data during this period appeared unusual, so values from Above Ysidora May 2015 were applied

4.1.6 Boundary Conditions

Boundary conditions are identified for the two QUAL2Kw models as the headwater inputs. Tributaries and diffuse groundwater inflows and outflows play a negligible role in the flow balance of the stream during these isolated simulation dates of critically low flow and warm conditions. Headwater model inputs include flow and water chemistry parameterization, which are based on a combination of HSPF model output and SCWRRP observations where available.

For the model Above Old Hospital, model inputs for QUAL2Kw were developed using hourly flow and water quality concentrations simulated by the watershed loading model for HSPF model reaches R109 and R115 which are both routed to R108, the reach that is represented in the QUAL2Kw model Above Old Hospital (they are thus subject to all the uncertainty present in the HSPF model at this point). Flows from the two upstream reaches were combined to form the inflow time series. Flow-weighted concentration time series were also developed for the following QUAL2Kw state variables: water temperature, conductivity, inorganic solids, dissolved oxygen, ultimate carbonaceous biological oxygen demand, organic nitrogen, ammonia, inorganic nitrogen, organic phosphorus, inorganic phosphorus, phytoplankton, detritus, alkalinity, and pH.

For the model Above Ysidora, model inputs for QUAL2Kw were developed using hourly flow and water quality concentrations simulated by HSPF model reaches R107 (a small tributary that is mostly dry during these simulation periods), and R308 which is the reach immediately upstream, representative of the existing water in SMR immediately downstream of the Camp Pendleton water diversion. Boundary conditions for the following parameters were based on SCWRRP grab samples and continuous data observed from SMR5 or SMR6 (depending on the simulation period) at the upstream end of the model extent: headwater nutrient species, hourly temperature, conductivity, DO, and pH.

4.1.7 Initial Conditions

Reach initial conditions vary by model and are based on observations instream during the simulation period. For example, the average water temperature and DO concentrations observed downstream on the final simulation date of the April 2015 Above Ysidora simulation period were 20.6 °C and 6.8 mg/l, so those were input as the initial conditions for all reaches for that simulation. Below are the summarized initial conditions for each simulation (Table 4-5). Initial conditions for plant biomass, intracellular nitrogen and intracellular phosphorus were determined by running the model as steady state for an extended period to establish the levels of plant life the system can support based on all other driving factors. The steady state results related to benthic plants were used as initial conditions so the simulation period would start under the conditions that plant life is already growing and respiring in the system.

Table 4-5. SMR QUAL2Kw Initial Conditions for All Reaches by Simulation

Parameter	Model Above Ysidora			Model Above Old Hospital		
	April 2015	May 2015	May 2016	May 2015	July 2015	August 2016
Water Temperature (°C)	20.6	19.8	17.9	19.0	20.4	20.7
Dissolved Oxygen (mg/l)	6.8	4.8	6.3	5.4	4.1	0.5
Bottom Plant Biomass (gD/m^2)	25	22	20	20	30	20
Bottom Plants Intracellular Nitrogen (mgN/gD)	20	21	26	50	60	40
Bottom Plants Intracellular Phosphorus (mgP/gD)	10.0	4.0	7.7	4.0	3.0	3.5

4.1.8 Model Parameterization

The QUAL2Kw model requires further parameterization which largely remain unchanged between model runs as they represent governing functions and equations for the system. For example, the sediment thermal properties defined for one model were maintained for all models. Several of these governing equation and parameters are shown below, and the full suite of model parameterization is included in Appendix 4.A.

- Sediment oxygen demand (SOD) Coverage: 100%
- Sediment Thermal Properties
  - Sediment Thermal Conductivity: 2.5 W/m/°C
  - Sediment Thermal Diffusivity: 0.0079 cm^2/s
- Hyporheic Transient Storage Properties
  - Hyporheic Zone Thickness: 60 cm
  - Hyporheic Flow Fraction: 0.25
  - Hyporheic Sediment Porosity: 40%
- Sky opening for longwave radiation: 100%
- Fraction of width receiving longwave radiation from vegetation and banks: 0%

Model inputs for bottom algae coverage were initialized as 50% for all reaches in all simulation periods. This parameter controls the amount of streambed which may be colonized by bottom algae, which drives the amount of diel swing in DO in large part due to the amount of photosynthesis and respiration occurring instream. Bottom algae coverage was used as a key calibration parameter for DO based on the observed diel swing during any given simulation. Another key parameter for DO calibration is the prescribed SOD. SOD occurring instream due to local sediment diagenesis and biotic processes is simulated within the model; however, simulation results suggest that a large amount of the SOD impacting DO levels in the system is due to detrital input from upstream (e.g., dead algae sloughing off and depositing in the model extent to decay). This detrital form of SOD is applied in addition to locally occurring SOD, and was initialized as 1.8 $g/m^2/d$ for all reaches in all simulation periods, although it was used as a calibration parameter based on observed mean DO concentrations for each model.

Once all model inputs were set up and parameterized with initial conditions, simulation performance was assessed and calibrated based largely on observed data DO data.

4.2 QUAL2KW MODEL PERFORMANCE

Grab-sample and continuous water quality data monitored at several locations in the lower SMR were used to evaluate model performance in regards to simulated hydraulics (flow, velocity, depth, and width), water temperature, nutrients, algae, and DO.

4.2.1 Hydraulics

Headwater flow was parameterized based on HSPF model output. Hydraulic geometry observed at the time of grab sampling (flow, velocity, depth, and width) were used to examine model performance of flow parameters for each simulation (Table 4-6 and Table 4-7). In general, the simulated hydraulics are a good match for observed data around the simulation periods, due in large part to the use of HEC-RAS cross-sectional data in development of rating curve inputs.

Table 4-6. Observed and QUAL2Kw Simulated Hydraulics Along the Model Extent Above Old Hospital

Parameter	May 2015 Above Old Hospital		July 2015 Above Old Hospital		August 2016 Above Old Hospital	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Flow (cms)	0.11 - 0.17	0.16	0.05 - 0.06	0.12	0.06 - 0.17	0.11
Velocity (m/s)	0.06 - 0.11	0.02 - 0.02	0.03 - 0.07	0.02 - 0.02	0.01 - 0.02	0.02 - 0.02
Depth (m)	0.14 - 0.22	0.32 - 0.61	0.12 - 0.16	0.28 - 0.54	0.42 - 0.56	0.28 - 0.53
Width (m)	4.8 - 10.2	11.3 - 21.5	6.0 - 9.7	10.9 - 20.7	6.0 - 14.4	10.9 - 20.7

Table 4-7. Observed and QUAL2Kw Simulated Hydraulics Along the Model Extent Above Ysidora

Parameter	April 2015 Above Ysidora		May 2015 Above Ysidora		May 2016 Above Ysidora	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Flow (cms)	0.16 - 0.25	0.15	0.26 - 0.31	0.09	0.08 - 0.14	0.15
Velocity (m/s)	0.06 - 0.23	0.07 - 0.22	no data	0.06 - 0.20	0.01 - 0.31	0.08 - 0.22
Depth (m)	0.08 - 0.22	0.10 - 0.26	no data	0.08 - 0.20	0.11 - 0.42	0.10 - 0.26

Parameter	April 2015 Above Ysidora		May 2015 Above Ysidora		May 2016 Above Ysidora	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Width (m)	6.0 – 10.0	6.1 - 7.8	no data	4.9 - 6.9	4.0 – 12.0	6.1 - 7.9

4.2.2 Water Temperature

Results from the water temperature model simulations relative to observed data are shown in Figure 4-1. A full heat balance is simulated in QUAL2Kw to determine water temperature in each of the segments. This approach accounts for heat exchanged at the air-water interface and at the water-sediment interface, and some of the key drivers are channel shape, solar radiation, air temperature, cloud cover, and stream shading. In addition, water temperature in the segments is impacted by water temperature at the upstream boundary (headwaters). Simulated water temperatures are like sonde data, and, in general, water temperature averages and diel swings are adequately simulated. The water temperature diel cycle is dampened significantly at the SMR6 site during the 2016 sampling period (Above Old Hospital), which is not observed at nearby site SMR5 during similar sampling periods. The cause of this discrepancy between SMR5 and SMR6 during 2016 is unknown.

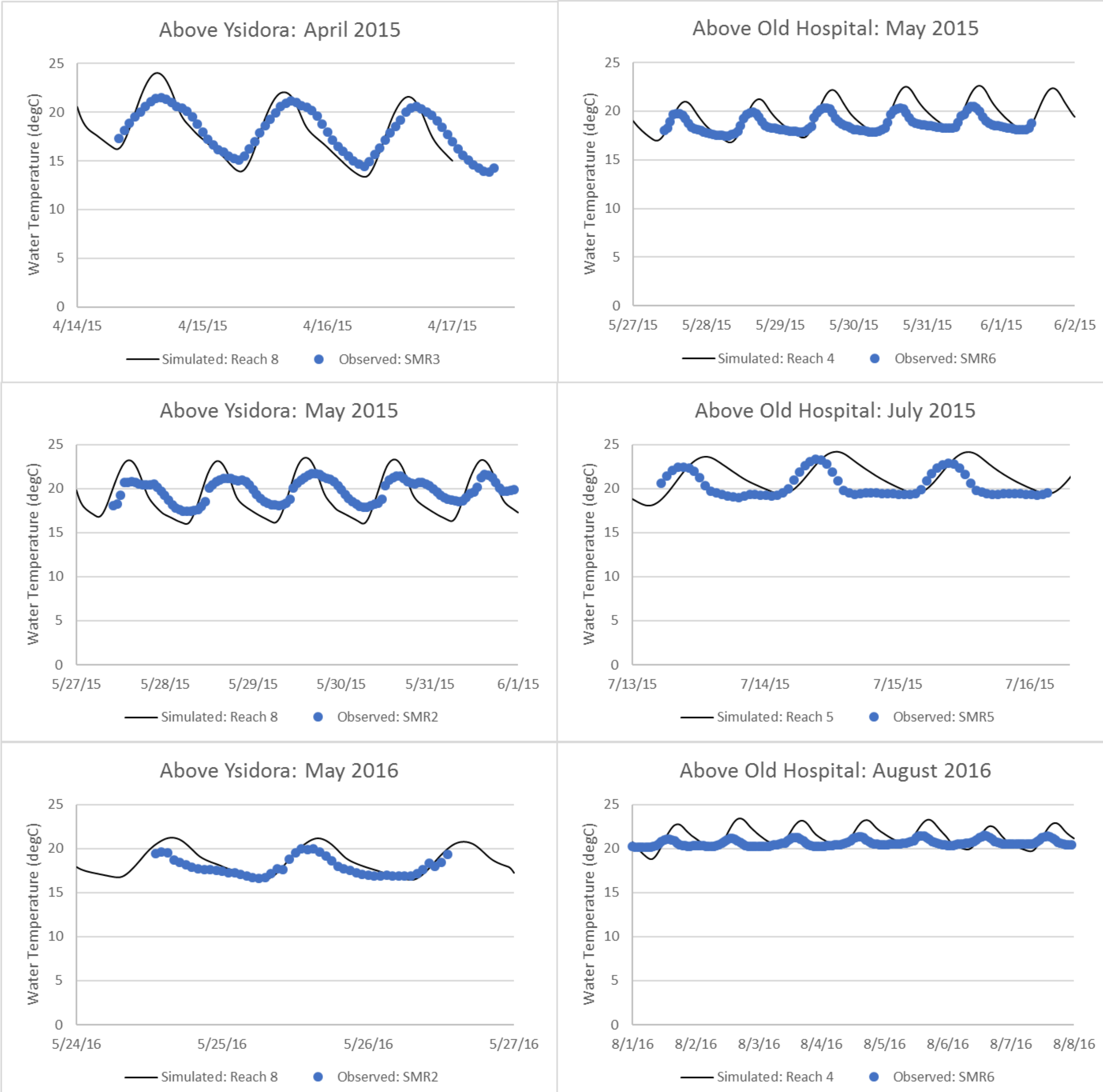


Figure 4-1. Lower SMR QUAL2Kw Simulated Water Temperature for All Modeling Periods Above Ysidora and Above Old Hospital Compared to Observed Data at the Downstream End of Each Extent

4.2.3 Nutrients

Observed nutrient concentrations are relatively low in the system during the modeling application periods, and so are simulated nutrient concentration results. Grab samples of nutrient concentrations collected within several days of the modeling period were used as reference for model performance evaluation (***Table 4-8*** and ***Table 4-9***). Observed TN and TP concentrations during simulation periods Above Old Hospital were observed to be less than 0.4 and 0.1 mg/l respectively, and average simulation results at the downstream end of the model extent were less than 0.5 and 0.1 mg/l respectively. Observed TN and TP concentrations Above Ysidora were observed to be less than 0.3 and 0.1 mg/l respectively, and average results at the downstream end of the model extent were less than 0.2 and 0.1 mg/l respectively.

Simulated nutrient concentrations for nitrogen were generally higher than observations, and for phosphorus were generally lower than observations, although all within a reasonable range.

Table 4-8. Observed Range and Simulated Mean Nutrient Concentrations Above Old Hospital

Parameter	May 2015 Above Old Hospital		July 2015 Above Old Hospital		August 2016 Above Old Hospital	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
TN (mg/l)	0.15 - 0.39	0.24	0.18 - 0.23	0.47	0.18 - 0.21	0.34
TP (mg/l)	0.04 - 0.06	0.01	0.03 - 0.04	0.01	0.07 - 0.08	0.03

Table 4-9. Observed Range and Simulated Mean Nutrient Concentrations Above Ysidora

Parameter	April 2015 Above Ysidora		May 2015 Above Ysidora		May 2016 Above Ysidora	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
TN (mg/l)	0.16 - 0.20	0.10	0.16 - 0.21	0.10	0.15 - 0.21	0.12
TP (mg/l)	0.04 - 0.05	0.01	0.05 - 0.09	0.01	0.07 - 0.08	0.03

4.2.4 Algae

QUAL2Kw simulates benthic algae as both ash free dry mass (AFDM) and benthic chlorophyll *a* based on a linear stoichiometric relationship. In comparing simulated to observed algal data, results are presented for benthic chlorophyll *a*, as AFDM may also include various other sources of organic matter which are not living algae (e.g., detritus, bacteria, fungi) collected in the sample. Benthic chlorophyll *a* observations from grab samples around each simulation period were used to assess model performance. Simulated algal densities are highly sensitive to initial conditions since the QUAL2Kw model is run for a short period of time and is parameterized based on the level of algae that the system can support under current nutrient conditions. In general, the model does a good job at predicting benthic chlorophyll *a* densities at the downstream due to the initial model parameterization (***Table 4-10*** and ***Table 4-11***).

Table 4-10. Observed Range and Simulated Mean Benthic Chlorophyll *a* Above Old Hospital

Parameter	May 2015 Above Old Hospital		July 2015 Above Old Hospital		August 2016 Above Old Hospital	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Benthic chlorophyll *a* (mg/m^2)	no data	24.3	17.8 - 44.9	30.2	9.1 - 27.3	19.5

Table 4-11. Observed Range and Simulated Mean Benthic Chlorophyll *a* Above Ysidora

Parameter	April 2015 Above Ysidora		May 2015 Above Ysidora		May 2016 Above Ysidora	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Benthic chlorophyll *a* (mg/m^2)	5.2 - 109.9	26.0	no data	26.0	3.5 - 24.5	23.5

4.2.5 Dissolved Oxygen

The DO simulation in the QUAL2Kw model does a reasonable job in predicting observed continuous DO data from SCCWRP sonde sites at the downstream end of each model extent by simulation period. The two model parameters adjusted during calibration for each simulation period were bottom algae coverage which controls the amount of algae respiring in the system and therefore the diel DO swing, and prescribed SOD which controls the amount of decaying organic matter along the streambed due to upstream sources and therefore the average DO in the water column. These calibrated parameters are described by model extent and simulation period in ***Table 4-12***.

As mentioned in the water temperature performance section, there is reason to believe based on water temperature results that the August 2016 SMR6 probe may have been buried such that the very low DO concentrations observed may reflect conditions in the streambed rather than the water column.

Table 4-12*. *QUAL2Kw Calibrated Model Parameterization for All Reaches in Both Model Extents

Parameter	Model Above Ysidora			Model Above Old Hospital		
	April 2015	May 2015	May 2016	May 2015	July 2015	August 2016
SOD (g/m^2/d)	2.5	5.5	4.5	3.0	3.5	5.0
Bottom Algae Coverage (%)	60%	80%	50%	50%	100%	10%

All paired hourly observed and simulation DO concentrations were plotted together to see the general trend of model performance, which looks reasonably good without significant biases in a single direction (Figure 4-2). The continuous DO data comparison for each simulation period and model extent is summarized in Figure 4-3. Variable ranges in DO swing and mean throughout the year may be due to changes in flora, nutrient fluxes through the reach, inflows of detrital materials, and seasonal changes due to variable temperature and kinetics. The QUAL2Kw simulations perform well in predicting DO concentration means and ranges between each simulation period and model extent, although causes for the specific parameterization related to bottom algae coverage and prescribed detrital SOD are not known as the simulation periods are short and non-continuous.

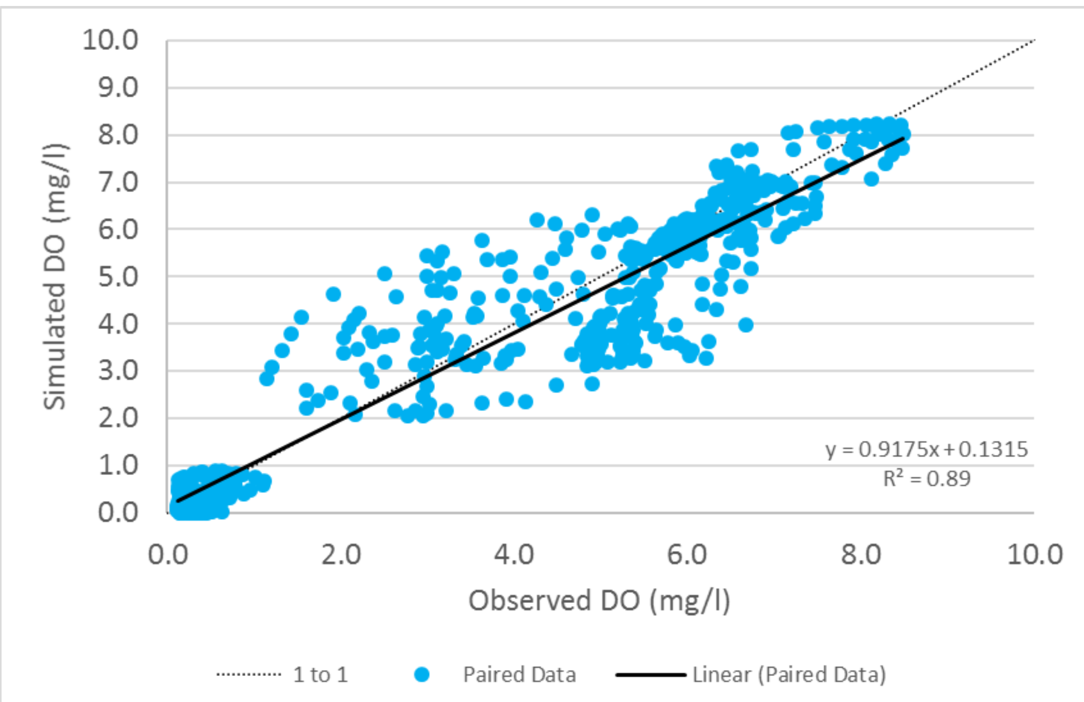


Figure 4-2. SMR QUAL2Kw Paired Hourly Observed and Simulated DO for All Modeling Periods and Both Modeling Extents

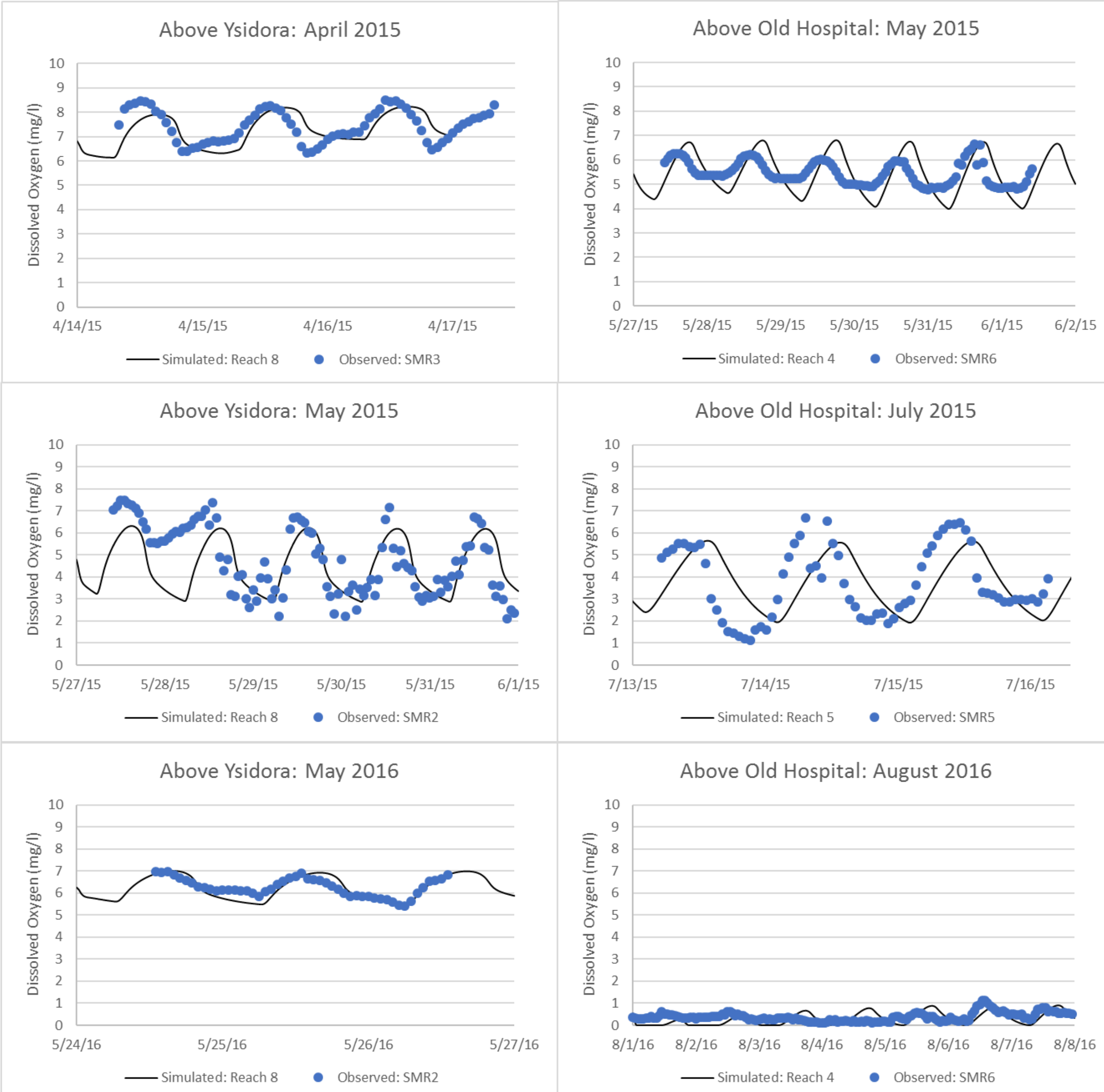


Figure 4-3. Lower SMR QUAL2Kw Simulated DO for All Modeling Periods Above Ysidora and Above Old Hospital Compared to Observed Data at the Downstream End of Each Extent

4.3 QUAL2KW MODEL SENSITIVITY ANALYSIS

Sensitivity analyses were conducted on a single simulation period Above Old Hospital, as well as a single simulation period Above Ysidora. To address sensitivity, several parameters were adjusted by a 20% increase or 20% decrease to explore the relative impact on mean DO concentration, diel swing in DO concentration, and benthic chlorophyll *a* (***Table 4-13***).

Table 4-13. SMR QUAL2Kw Sensitivity Analyses

Sensitivity Test	Parameter
Boundary DO	Hourly DO concentrations associated with upstream boundary flow scaled by +/- 20%
Boundary Flow	Hourly upstream boundary flow scaled by +/- 20%
Boundary Nutrients	Hourly nitrogen and phosphorus constituent concentrations associated with upstream boundary flow scaled by +/- 20%
SOD	Prescribed detrital sediment oxygen demand rate scaled by +/- 20%
Shade	Fraction of stream channel shaded scaled by +/- 20%

Leverage coefficients (as defined in Section 2.6.2) for daily mean DO, DO diel variability, and benthic chlorophyll *a* are presented in Figure 4-4, Figure 4-5, and Figure 4-6 for the Above Ysidora model extent, and Figure 4-7, Figure 4-8, and Figure 4-9 for the Above Old Hospital extent.

Mean DO concentration was most sensitive to SOD due to detrital inputs from upstream in both model extents, with a secondarily high sensitivity to changes in flow conditions instream. Increases in SOD cause decreases in mean DO as there is higher demand on oxygen throughout the day, however, increases in streamflow cause increases in DO due to the higher volume of oxygen present in the water column on which SOD and other forces are exerted as well as increased reaeration rates. Changes in both shade and headwater nutrients had relatively minor effects on mean DO concentrations, although since the model reflects a critical condition simulation, the long-term impact of modified nutrients in the system is not captured by this kind of sensitivity test in the QUAL2Kw model environment.

Sensitivity of DO diel variability was assessed because larger swings in DO can be indicative of detrimental algae growth dominating the riverine system which can negatively impact other aquatic life. The DO swing was most sensitive to changes in flow and SOD in both model extents. DO swing was also reasonably sensitive to changes in headwater nutrients and shade which impact both nitrogen/phosphorus and limit limitations to algal growth instream which control the magnitude of respiration and photosynthesis.

Benthic chlorophyll *a* density was relatively insensitive to most parameters tested due in part to this model variable being highly sensitive to the initial conditions specified for each reach at the beginning of the short simulation period. In general, however, benthic chlorophyll *a* was most sensitive to changes in flow volume and SOD. Decreases in flow were associated with increases in benthic chlorophyll *a* density as shallower relatively slow-moving streams are likely to experience algal proliferation. Increases in SOD were associated with increases in benthic chlorophyll *a* density likely due changes in nutrient availability from detrital decay.

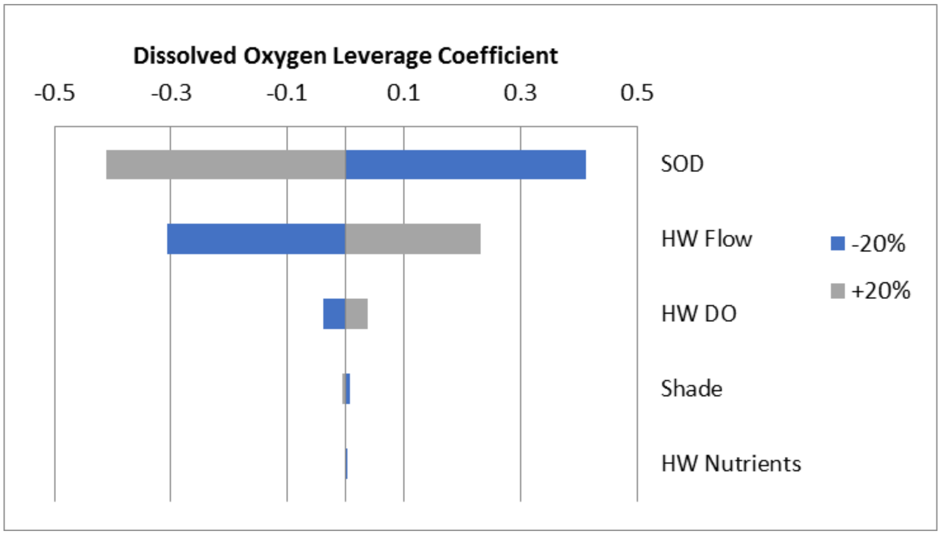


Figure 4-4. May 2016 Above Ysidora QUAL2Kw Model Sensitivity Test Results: Leverage Coefficients for Daily Mean DO Concentrations

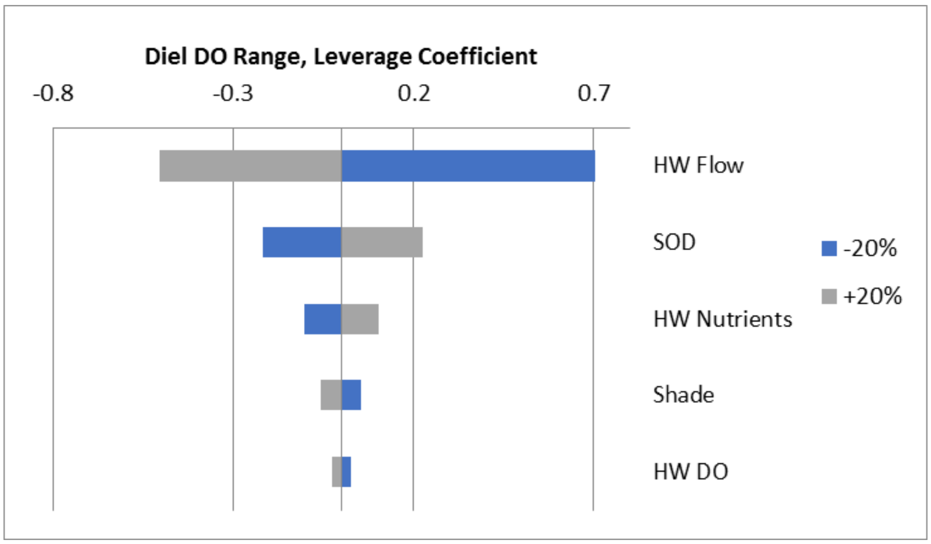


Figure 4-5. May 2016 Above Ysidora QUAL2Kw Model Sensitivity Test Results: Leverage Coefficients for DO Diel Variability

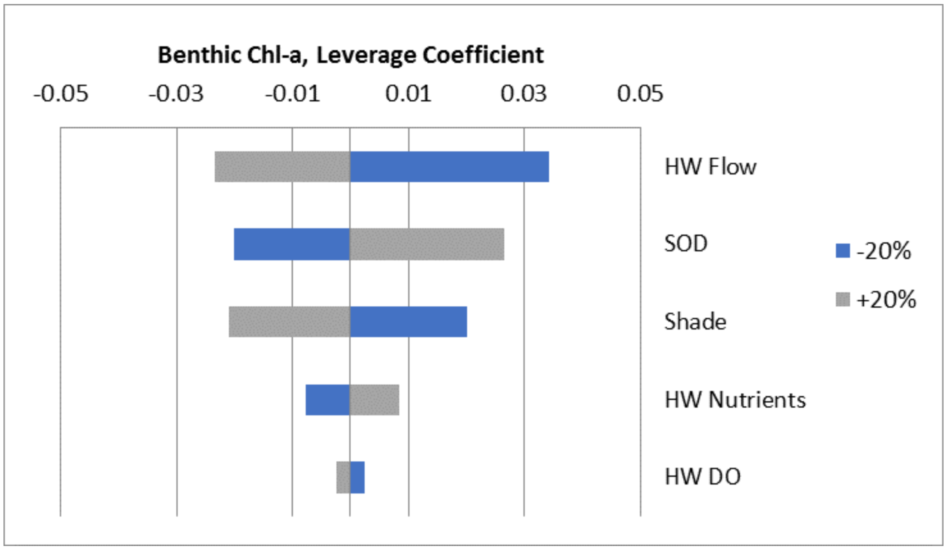


Figure 4-6. May 2016 Above Ysidora QUAL2Kw Model Sensitivity Test Results: Leverage Coefficients for Benthic Algae as Chlorophyll *a*

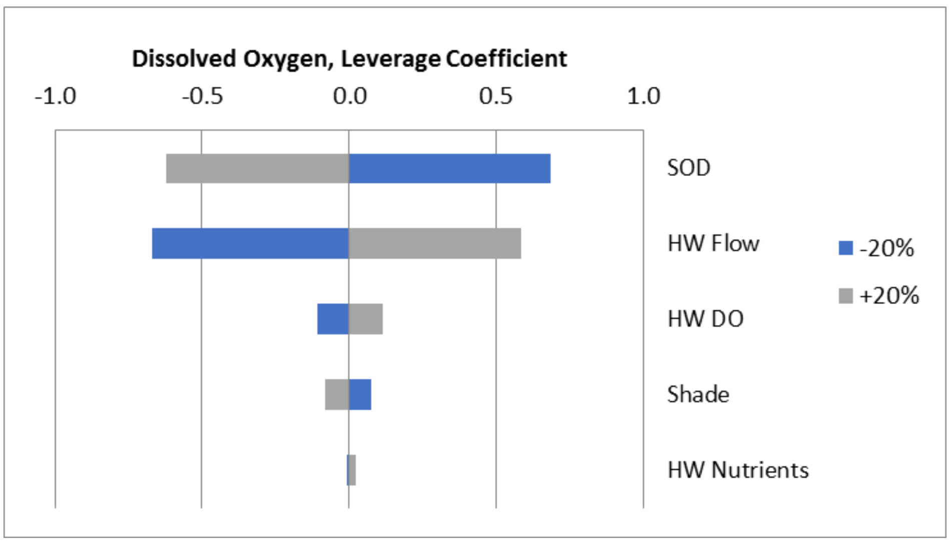


Figure 4-7. July 2015 Above Old Hospital QUAL2Kw Model Sensitivity Test Results: Leverage Coefficients for Daily Mean DO Concentrations

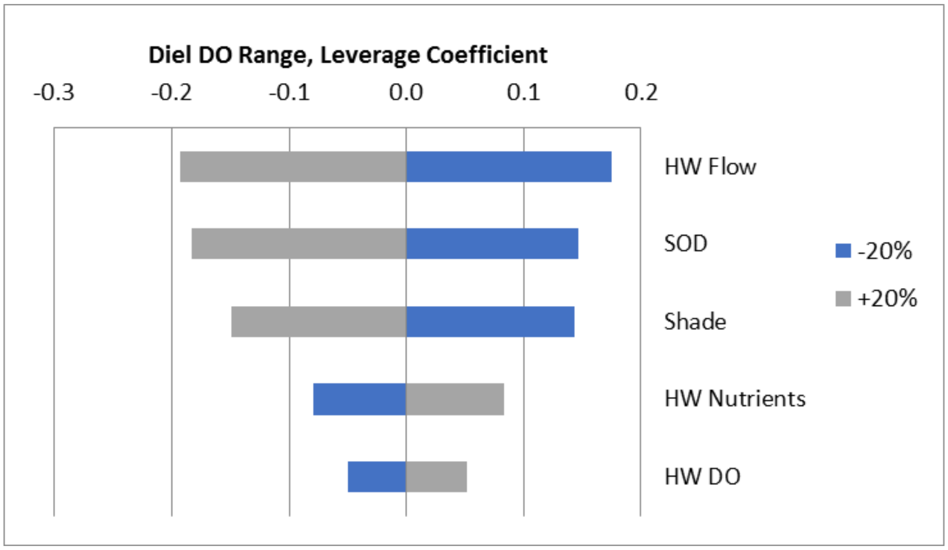


Figure 4-8. July 2015 Above Old Hospital QUAL2Kw Model Sensitivity Test Results: Leverage Coefficients for DO Diel Variability

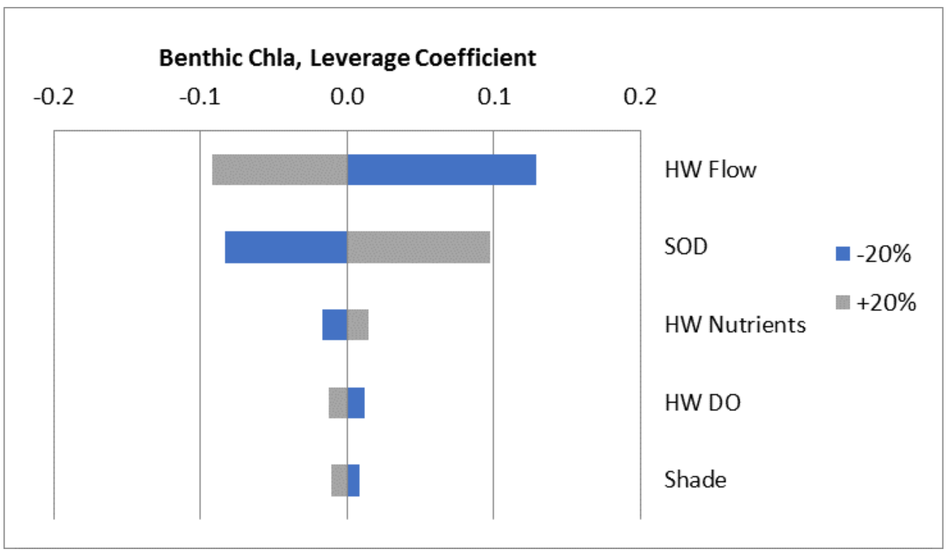


Figure 4-9. July 2015 Above Old Hospital QUAL2Kw Model Sensitivity Test Results: Leverage Coefficients for Benthic Algae as Chlorophyll *a*

4.4 NUTRIENT RESPONSE

Scenarios were conducted for which changes in headwater TN and TP concentrations were used to estimate impacts on the range in diel DO concentration (swing) and benthic chlorophyll *a* density for the Above Ysidora model. The baseline simulation was the calibrated model above Ysidora for the May 2015 period. The calibrated model for this period had a downstream diel DO concentration variation of 2.9 - 6.2 mg/l, or a swing of 3.3 mg/l DO on the final day of the simulation. For this calibrated model, TN and TP concentrations at the headwater were approximately 0.18 and 0.03 mg/l respectively.

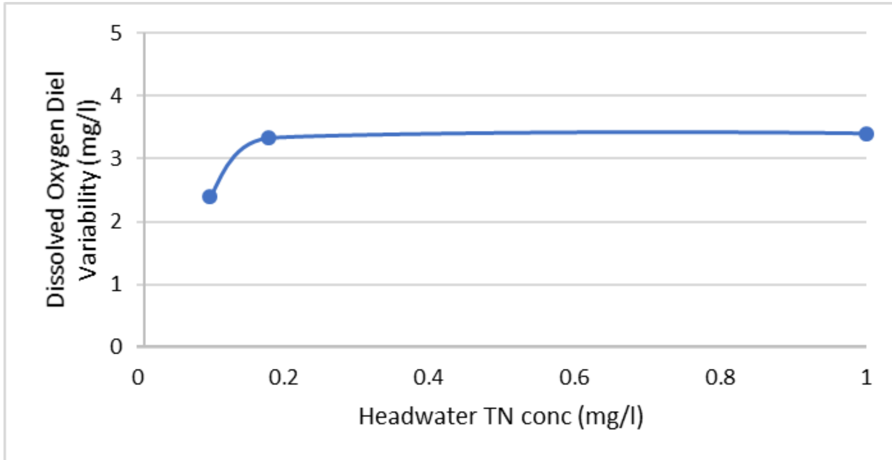
Using the May 2015 Above Ysidora model as a baseline, TN and TP concentrations at the headwaters were modified incrementally to analyze the relative impact on the diel DO variability. Changes in headwater nutrient concentrations have the combined impact of altering bottom plant biomass, and intracellular N (intN) and intracellular P (intP) concentrations available for algae growth and continued photosynthesis and respiration due to luxury uptake. The QUAL2Kw model for SMR Above Ysidora is highly sensitive to initial conditions for bottom algae/plants as these initial conditions are based on the amount of existing biomass growing the system at the start of the short several-day simulation. To examine the impact of changes in headwater concentrations on algal biomass in the system, headwater concentrations were altered for TN and TP, and then the model was run under steady-state conditions for 50 days to establish new initial conditions of plant biomass, intN, and intP which can be supported at the new headwater nutrient concentrations. The results of the changes in plant biomass, intN, intP, mean DO, diel DO swing, and benthic chlorophyll *a* as a response to changes in headwater TN and TP are presented in Table 4-14.

As the results show, when headwater concentrations of TN and TP are decreased to levels below those observed during the simulation period, both separately and simultaneously, the DO swing decreases (Figure 4-10). This is due to there being less benthic algae supported in the system to be present and actively photosynthesizing and respiring. Alternatively, as TN and TP are increased at the headwater boundary, there is an initial response of increase in DO swing due to increased algal respiration. However, as TN continues to increase there is a decline in DO swing because the increasing algae causes an increase in CBOD instream due to algal die-off which decreases both the diel swing and mean DO in the water column.

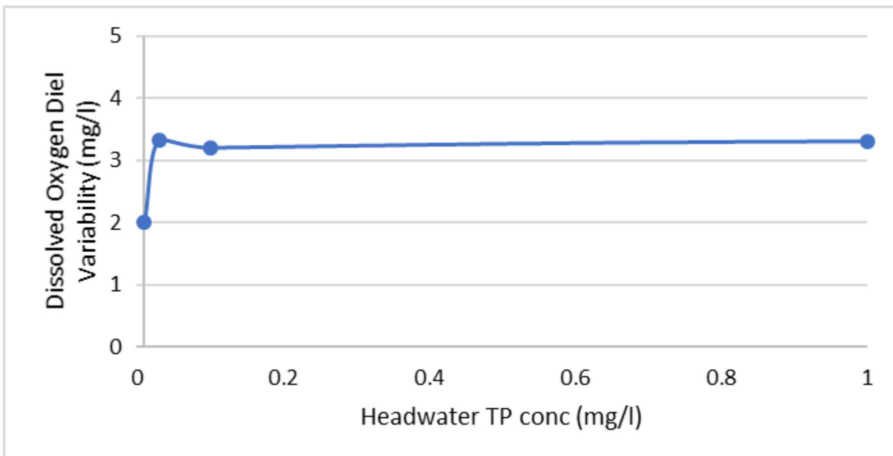
Above Ysidora, increasing both TN and TP headwater concentrations increases benthic chlorophyll *a* as the system can support increased densities as nutrients are added to the system (Figure 4-11). Increasing TP has a more muted impact which levels off, whereas increasing nitrogen to the system continues to increase benthic chlorophyll *a* in the system. Decreases in headwater TN and TP from existing conditions both have the impact of decreasing the benthic chlorophyll *a* that the system can support.

Table 4-14. SMR QUAL2Kw scenario results on diel DO variability (Above Ysidora model extent).

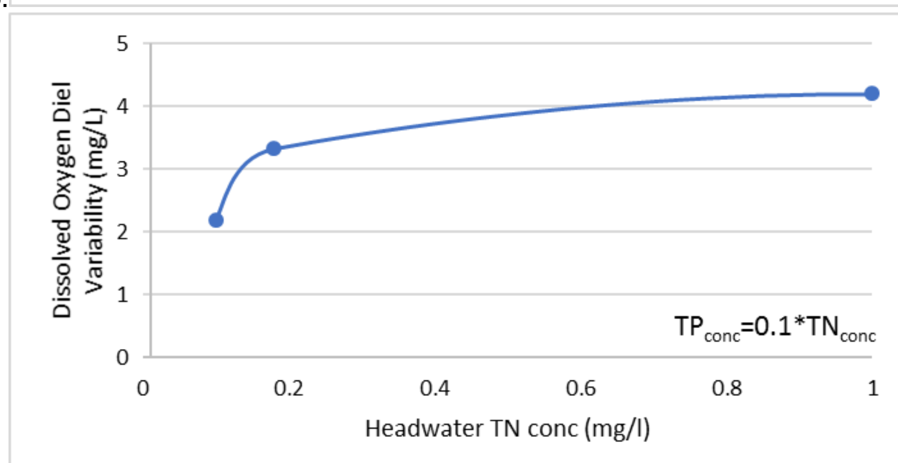
Scenario	Headwater Concentration		Initial Conditions			Mean DO (mg/l)	DO Swing (mg/l)	Benthic Chlorophyll *a* (mgA/m^2)
	TN (mg/l)	TP (mg/l)	Bottom Plant Biomass (gD/m^2)	Int N (mgN/gD)	Int P (mgP/gD)			
May 2015 Baseline	0.18	0.03	22	21	4	4.4	3.3	26.0
1	***0.1***	0.03	***15***	***13***	***5.3***	4.4	2.4	17.6
2	1.0	0.03	25	75	3	3.7	3.4	28.4
3	10	0.03	34	120	2.3	1.3	1.8	40.5
4	100	0.03	37	120	2	0.8	1.2	45.6
5	0.18	0.01	11	28	1.5	4.3	2.0	13.3
6	0.18	0.10	20	20	9	4.5	3.2	24.6
7	0.18	1.0	22	21	14	4.4	3.3	26.0
8	0.18	10	22	21	15	4.4	3.3	26.0
9	***0.1***	0.01	14	13	1.8	4.3	2.2	16.5
10	1.0	0.10	30	75	8.5	3.9	4.2	35.9
11	10	1.0	51	118	15	1.6	2.7	60.4
12	100	10	58	118	15	1.1	1.9	69.1



a.



b.



c.

Figure 4-10. Diel DO Swing Response Due to Changes Above Ysidora in a) TN, b) TP, and c) TN and TP

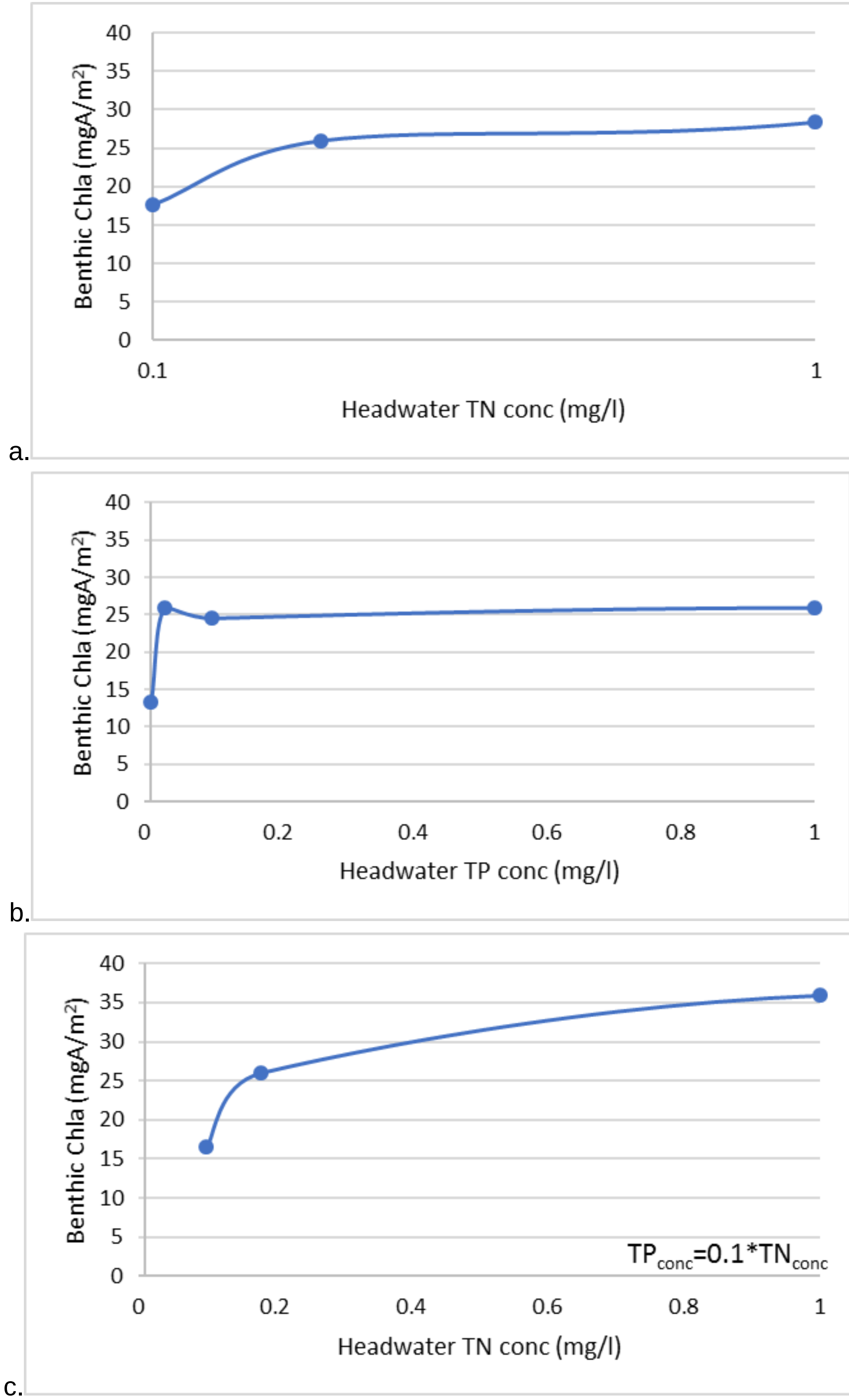


Figure 4-11. Benthic Chlorophyll *a* Response to Changes Above Ysidora in a) TN, b) TP, and c) TN and TP

4.5 QUAL2KW MODEL SUMMARY

Continuous models must reconcile changes in the system and riverine responses over time, however a QUAL2Kw simulation represents a snapshot exploration of the system during critical periods of-interest. Both QUAL2Kw model simulation extents Above Old Hospital and Above Ysidora produce reasonable representations of observed conditions instream during the critical periods simulated. These short-term models cannot however explain what may be occurring in the system between simulation periods. Model results suggest that the water temperature diel heat budget and DO diel patterns are well-simulated based on parameterization and calibration. For both model extents, simulations of mean DO, DO diel variability, and benthic chlorophyll *a* were most sensitive to changes in detrital SOD and total streamflow. There is reason to believe that existing algal biomass instream (and associated local algal cycling) along cannot account for the amount of SOD present along these sections of the lower SMR, so detrital deposition from upstream sources may be the cause of low DO downstream. Changes in streamflow reflect systematic changes in which there is DO available by volume, variations in channel width, velocity, and depth, and changing conditions under which benthic algae may flourish or decline. Since observed nutrient concentrations were quite low during simulation periods, the simulations are relatively insensitive to short-term changes in nutrient concentrations upstream. However, if changes in headwater nutrient concentrations are systematic as seen in the Nutrient Response section, the QUAL2Kw simulations may reach a new steady state condition for which decreased benthic algae and decreased DO diel variability are a response to prolonged decreased boundary condition nutrient concentrations, or vice versa.

APPENDIX 4.A: QUAL2KW RATES TAB INPUTS

The parameterization included in this appendix reflect governing rates, equations, and formulae which were maintained in all lower SMR QUAL2Kw model scenarios. All light and heat parameterization were set to manual-suggested default values and formulae (***Table 4-15***). All other model rate parameterization associated with nutrient cycling, algae and hyporheic biofilm growth, etc. were set based on manual-suggested values, and where possible, adjusted to improve model performance and best reflect the kinetics and water quality observed in this system (***Table 4-16***). Note that all temperature corrections were held at the default value of 1.07.

Table 4-15. SMR QUAL2Kw Model Light and Heat Parameterization

Parameter	Value	Units
Photosynthetically Available Radiation	0.47	None
Background light extinction	0.5	/m
Linear chlorophyll light extinction	0.0088	1/m-(µgA/L)
Nonlinear chlorophyll light extinction	0.054	1/m-(µgA/L)$^{2/3}$
ISS light extinction	0.052	1/m-(mgD/L)
Detritus light extinction	0.174	1/m-(mgD/L)
Macrophyte light extinction	0.015	1/m-(gD/m^3)
Atmospheric attenuation model for solar	Bras	None
Bras solar parameter	2	None
Atmospheric longwave emissivity model	Brunt	None
wind speed function for evaporation and air convection/conduction	Brady-Graves-Geyer	None
coefficient for attenuation of solar radiation by cloud cover	0.65	None
exponent for attenuation of solar radiation by cloud cover	2	None
model equation for cloudy sky adjustment of longwave radiation	Eqn 1	None
coefficient for cloudy sky adjustment of longwave radiation	0.17	None
exponent for cloudy sky adjustment of longwave radiation	2	None
Include evaporation in flow balance	No	None

Table 4-16. SMR QUAL2Kw Model Rates Parameterization

Parameter	Value	Units
Stoichiometry of Carbon: Nitrogen: Phosphorus: Dry Weight: Chlorophyll *a*	333:49:5:833:1:1	gC
Settling velocity	1	m/d
Reaeration model	Tsivoglou-Neal	none
Reaeration wind effect	None	none
O2 for carbon oxidation	1.31	gO2/gC
O2 for NH4 nitrification	8.91	gO2/gN
Oxygen inhib/enhance models	Exponential	none
Oxygen inhib/enhance parameters	0.6	L/mgO_2
Slow CBOD Hydrolysis rate	0.1	/d
Slow CBOD Oxidation rate	0.05	/d
Fast CBOD Oxidation rate	0.3	/d
Organic N Hydrolysis	0.05	/d
Organic N Settling velocity	0.5	m/d
Ammonium Nitrification	3	/d
Nitrate Denitrification	0	/d
Nitrate Sed denitrification transfer coeff	0.5	m/d
Organic P Hydrolysis	0.3	/d
Organic P Settling velocity	1	m/d
Inorganic P Settling velocity	0	m/d
Sed P oxygen attenuation half sat constant	2	mgO_2/L
Phytoplankton: Max Growth rate	0.5	/d
Phytoplankton: Respiration rate	0.1	/d
Phytoplankton: Death rate	0.1	/d
Phytoplankton: Nutrient limitation model for N and P	Minimum	None

Parameter	Value	Units
Phytoplankton: N half sat constant	13	µgN/L
Phytoplankton: P half sat constant	1	µgP/L
Phytoplankton: Inorganic C half sat constant	0.0000013	moles/L
Phytoplankton use HCO3- as substrate	Yes	None
Phytoplankton: Light model	Half saturation	None
Phytoplankton: Light constant	90	langleys/d
Phytoplankton: Ammonia preference	20	µgN/L
Phytoplankton: Settling velocity	0.03	m/d
Include transport of phytoplankton	No	None
Phytoplankton: N uptake water column fraction	1	None
Phytoplankton: P uptake water column fraction	1	None
Bottom Plants: Growth model	Zero-order	None
Bottom Plants: Max Growth rate	50	gD/m^2/d or /d
Bottom Plants: Basal respiration rate	0.2	/d
Bottom Plants: Photo-respiration rate parameter	0.6	unitless
Bottom Plants: Excretion rate	0.1	/d
Bottom Plants: Death rate	0.1	/d
Bottom Plants: External N half sat constant	325	µgN/L
Bottom Plants: External P half sat constant	80	µgP/L
Bottom Plants: Inorganic C half sat constant	0.000075	moles/L
Bottom Plants: use HCO3- as substrate	Yes	None
Bottom Plants: Light model	Half saturation	None
Bottom Plants: Light constant	75	langleys/d
Bottom Plants: Ammonia preference	15	µgN/L
Bottom Plants: Nutrient limitation model for N and P	Minimum	None

Parameter	Value	Units
Bottom Plants: Subsistence quota for N	7.2	mgN/gD
Bottom Plants: Subsistence quota for P	1	mgP/gD
Bottom Plants: Maximum uptake rate for N	350	mgN/gD/d
Bottom Plants: Maximum uptake rate for P	50	mgP/gD/d
Bottom Plants: Internal N half sat ratio	2.5	None
Bottom Plants: Internal P half sat ratio	1.8	None
Bottom Plants: N and P uptake water column fraction	1	None
Detritus Dissolution rate	0.5	/d
Detritus Settling velocity	0.5	m/d
Partial pressure of carbon dioxide	400	ppm
Hyporheic: Model for biofilm oxidation of fast CBOD	Zero-order	None
Hyporheic: Max biofilm growth rate	10	$gO_2/m^2/d$ or /d
Hyporheic: Fast CBOD half-saturation	0.5	mgO2/L
Hyporheic: Oxygen inhib model	Exponential	None
Hyporheic: Oxygen inhib parameter	0.6	L/mgO2
Hyporheic: Respiration rate	0.5	/d
Hyporheic: Death rate	0.1	/d
Hyporheic: External nitrogen half sat constant	15	µgN/L
Hyporheic: External phosphorus half sat constant	2	µgP/L
Hyporheic: Ammonia preference	25	µgN/L
Photosynthetic quotient for NO3 vs NH4 use	1.29	dimensionless
Respiratory quotient	1	dimensionless

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5.0 MODEL CONCLUSIONS AND RECOMMENDATIONS TO SUPPORT THE SANTA MARGARITA NUTRIENT INITIATIVE

Simulation modeling tools to support the Lower SMR main stem analysis have three primary roles:

1. Linking nutrient sources to exposure concentrations: How are nutrient concentrations that cause biostimulatory conditions within the Lower River related to sources of nutrient loads from the land surface, aquifers, and atmosphere?
2. Interpreting indicators and measures: The biological endpoints and a subset of biostimulatory targets are expected to be expressed in multiple metrics, including DO and measures of algal density. How are these target values related to specific ambient nutrient concentrations? How are do these targets link to ambient temperature and flow, both of which are expected to vary as a function of climate change?
3. Demonstration of methods: Which tools are most effective and efficient for supporting decisions to address biostimulatory conditions in flowing waters? This will inform the emerging statewide approach and help lay the groundwork for completing analyses of other California streams impaired by biostimulatory conditions.

In general, all three models exhibited good calibration against observations, with an acceptable error rate. HSPF is a suitable tool for providing boundary conditions to the more detailed receiving water models, and also performs adequately as a receiving water model itself.

Results from all three receiving water model simulations of the lower Santa Margarita River (HSPF, WASP, QUAL2Kw) provide some insight on benthic algae and DO responses to nutrients and other stressors. Daily mean DO was most sensitive to the upstream DO boundary condition and sediment oxygen demand (SOD) – the oxygen demand exerted on the water column by decomposition of organic matter in and on stream sediment. Daily average DO had relatively low sensitivity to algal dynamics associated with changes in N and/or P loads and concentrations. The implication of this finding is that allochthonous (external) sources of organic matter and their biological oxygen demand are driving the mean trend in DO, not live algal biomass produced on site by local ambient TN and TP. This finding is supported by observations of very high AFDM at the Old Hospital and Ysidora sites, despite much lower values of live algal biomass (Sutula et al. 2018). C to N ratios of the benthic organic matter suggest that the carbon source is labile (algal or bacterial) rather than terrestrial woody debris (Sutula et al. 2018).

During daylight hours, DO is replenished through algal photosynthesis, whereas at night DO is consumed by algal respiration. Photosynthesis and respiration are the largest controls on DO diel variability. As a result, diel DO range is much more sensitive to changes in nutrient concentrations than the DO average concentration. Stream segments were shallower and warmer when boundary flow was reduced, increasing DO diel variability significantly. Lower reaeration, SOD, or DO in upstream waters produced larger swings in DO.

As algae are an important control on diel DO range, benthic algae exhibit similar sensitivities to those reported for diel DO. Benthic algal density was shown to be most sensitive to changes in streamflow during dry weather conditions, especially in the intermittent reach near the Ysidora gage. Decreases in flow were associated with increases in benthic algal density (in QUAL2Kw and HSPF, but not in WASP) as shallower relatively slow-moving streams are likely to experience algal proliferation. Benthic algal density was also shown to be sensitive to instream nutrient concentrations by all three models; however, algal density did not demonstrate strong sensitivity to changes in riparian shade.

All three models have potential for supporting decisions to address biostimulatory conditions in flowing waters, although they have different strengths and weaknesses. QUAL2Kw appears to be the model of choice for addressing intermittent and very shallow stream segments, as HSPF turns off important kinetic reactions at very shallow flows while WASP can experience stability problems. QUAL2Kw is also generally less resource intensive to set up and implement as a nutrient response model than the other two options.

HSPF has the advantage of combining watershed loading and nutrient responses in a single modeling framework – although at least as developed for the Santa Margarita River, the spatial scale in the HSPF model is too coarse to resolve finer scale differences in observed water quality responses. HSPF also has other limitations for simulating algal responses. In addition to problems with simulating very shallow streams, HSPF simulates stream reaches in one-dimension only and is not designed to simulate multiple algal groups. WASP provides the potential for greater flexibility in the representation of spatial variability in the system and is also designed to address the interaction of multiple species of macroalgae. In theory this should give the edge to WASP as a tool for representing the full range of biostimulatory responses in a complex system – although further refinements may be needed to optimize WASP as a tool for managing free-flowing reaches of the Santa Margarita River. However, WASP also requires a greater level of effort. Another issue is that the WASP code is not open source and not all internal calculations can be output, making it difficult to diagnose some aspects of model responses.

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