SYSTECH WATER RESOURCES, INC.

ENVIRONMENTAL ENGINEERING AND
WATER RESOURCES SYSTEMS ANALYSIS

South Carolina Department of Health and

Environmental Control, Bureau of Water

Catawba River WARMF Model Calibration

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With SCDHEC Addendums

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1 Introduction

Systech Water Resources, Inc. (Systech) has been tasked to assist the South Carolina Department of Health and Environmental Control (SC DHEC) in updating and calibrating the Catawba River application of the Watershed Analysis Risk Management Framework (WARMF). Model updates were part of Phase I of the project, documented previously by Systech (2013). Phase II of the project began in August 2013. This report describes the work and results associated with Phase II of the project, including some additional model updates, hydrology calibration and water quality calibration. This project was funded by the USEPA under a Section 319 grant through the SC DHEC.

2 Model Updates

Additional model updates for this phase of the project included the subdivision of WARMF catchments for additional urbanized areas, updating the Lake Wylie boundary inflow input file, and testing the impact of periphyton (submerged and attached algae) on predicted nutrients concentrations.

2.1 Subdivision of Urban Areas

For this task, WARMF catchments overlaying additional specified urbanized areas were subdivided and generally include areas west of the Catawba River that contribute to watershed area below Lake Wylie, as well as Charlotte and Rock Hill. Urbanized areas delineated for Phase II are listed in Table 2-1.Urbanized areas east of the river within South Carolina were subdivided as part of Phase I of the project (Figure 2-1).

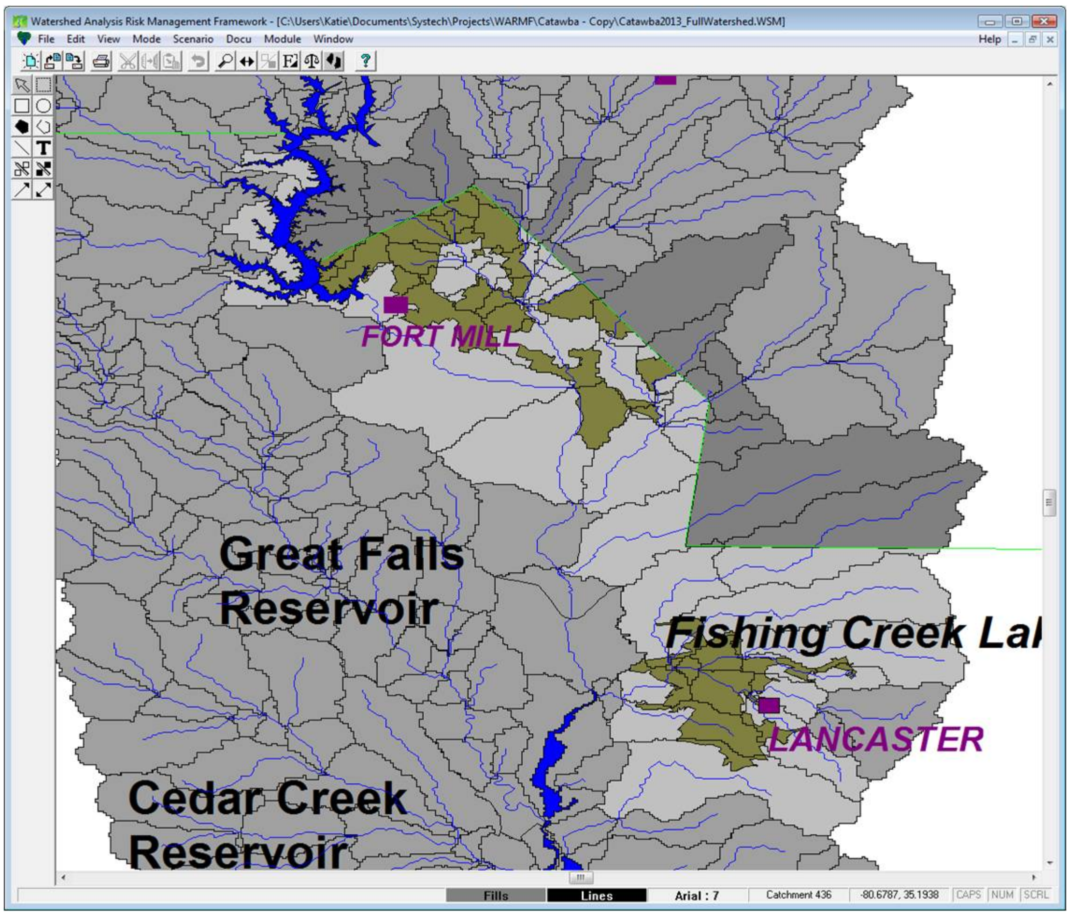

Figure 2-1 WARMF catchments after Phase I subdivision, with urban areas in brown, subdivided catchments in North Carolina in dark gray, and subdivided catchments in South Carolina in light gray.

Table 2-1 Additional Urbanized Areas Delineated for Phase II

Urbanized Area Number	*Developed Area Name*	*WARMF Subwatershed(s)*
1	Rock Hill Urbanized Area	Allison Creek Catawba River above Sugar Creek Fishing Creek Catawba River above Fishing Creek Res.
2	York Urban Cluster	Fishing Creek
3	Chester Urban Cluster	Rocky Creek
4	Winnsboro Urban Cluster	Lake Wateree
5	Clover Urban Cluster	Allison Creek
6	Charlotte Urbanized Area	Sugar Creek Twelve Mile Creek

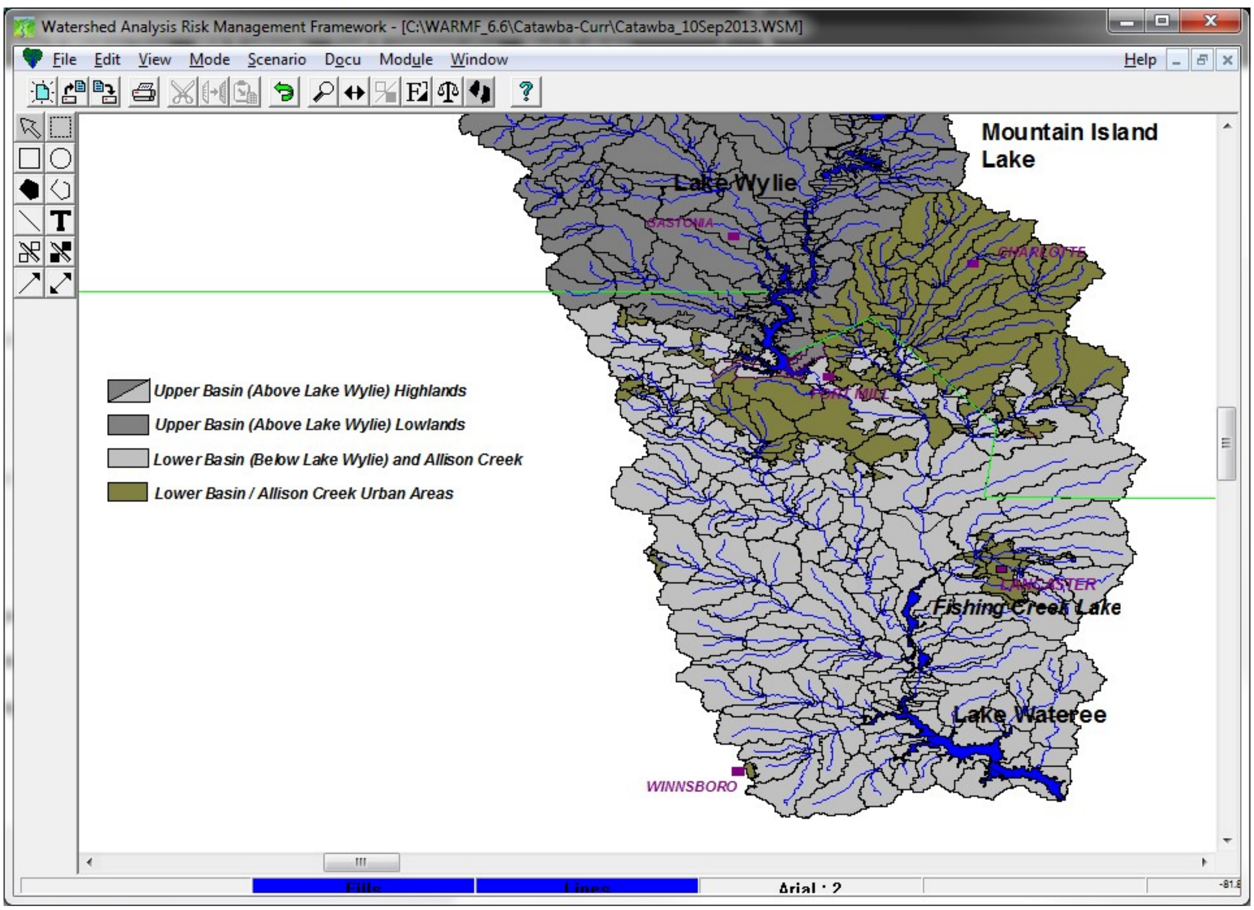

Figure 2-2 WARMF catchments after Phase II subdivision, urban areas in brown, watershed area contributing to the Catawba River below Lake Wylie in light gray, and watershed area above Lake Wylie in dark gray.

Sixty-one WARMF catchments were subdivided for this task. As in Phase I, the subdivisions were performed externally in GIS and later imported back into WARMF. Thus catchment identifiers changed for the 61 subdivided catchments. In Table 2-2, preexisting WARMF catchment identifiers are listed along with the identifiers of all corresponding new subdivided catchments (those which comprise the area of that preexisting catchment). Urban area catchments are indicated by bold type, followed by the number of the urban area corresponding to Table 2-1. Some catchments were subdivided into more than two new catchments due to multiple disconnected pieces (e.g. an urban area in the center was subdivided and left two or more non-urban pieces on opposite sides). Catchments with only one new ID listed were slightly altered by the subdivision of a neighboring area (i.e., the ID changed though the catchment was not subdivided). All catchment input coefficients except for septic system population and catchment width were copied from previous catchments for each corresponding subdivided catchment. System population and catchment width coefficients were calculated proportionally based on area.

Table 2-2 WARMF subdivided catchment IDs (bold (#) = urban area from Table 2-1)

Previous WARMF ID	*New WARMF IDs*						
23	23	**947 (2)**					
53	945	**987 (2)**					
56	983	676	**984 (2)**				
61	908	**906 (1)**					
88	980	**521 (1)**					
218	918						
222	910	**916 (1)**	**911 (1)**	**909 (1)**			
350	925	920	**919 (1)**				
356	1000	**915 (1)**	**913 (1)**				
361	926	**1001 (1)**	**982 (1)**				
362	922	**928 (1)**					
363	**924 (1)**						
364	931	**923 (1)**					
365	**917 (1)**						
372	912	**1002 (1)**	**672 (1)**				
373	**934 (1)**						
374	988	**989 (1)**	**936 (1)**				
375	933	921	**930 (1)**	**927 (1)**			
377	929	**932 (1)**					
385	944	**941 (2)**					
386	981	**943 (2)**					
390	937	**990 (1)**					
391	942	**939 (1)**					

392	1004						
393	938	**940 (2)**					
395	1003						
396	967						
397	949						
398	56	986	950	**946 (2)**			
475	**883 (6)**	**894 (6)**	**976 (6)**	979	971	900	901
503	**952 (6)**	974					
508	**899 (6)**	**879 (6)**	**977 (6)**	823			
521	970	968	994	**1068 (1)**			
529	965	**991 (1)**					
533	**1009 (6)**	898	972	1013	904		
542	**978 (6)**	1014	1008	902			
606	**951 (3)**	905	953				
616	1054	**1051 (4)**					
618	1040	**1027 (4)**					
619	40	**1026 (4)**					
659	**1005 (6)**	955					
668	**954 (6)**	895	892	893			
672	**820 (6)**	**875 (6)**	770				
676	**1007 (6)**	832	877	882	890	973	891
767	**881 (6)**	**995 (6)**	975	885			
769	**769 (6)**	822					
770	878						
773	773	**1017 (1)**					
784	784	1025	**1055 (1)**				
820	**907 (6)**	1018	**767 (1)**				
822	914	**668 (1)**					
823	529						
832	**886 (6)**	884	888	889			
1047	992	966	969				
1048	**963 (5)**	999	962	**996 (1)**			
1059	**659 (5)**	964					
1061	948						
1062	53						
1067	**958 (5)**	1019					
1082	**959 (5)**	**956 (5)**	**961 (5)**	**960 (5)**	985	957	

River segments were subdivided in locations where a new catchment boundary crosses the river segment and the resulting upper and lower portions of the river could be reasonably assumed to receive water from different catchments. In cases where a new catchment boundary is parallel to a river, or is an isolated interior portion of a preexisting catchment, river segments were not subdivided. Instead, the subdivided portion of the catchment remained connected to the same river segment that it was associated with prior to the subdivision. Due to such conditions, only six river segments were subdivided for this phase of the project. Table 2-3 lists the previous river segments that were subdivided, new IDs, new segment states, urban area (if any), and point sources.

Table 2-3 Subdivided river segments and characteristics

Previous ID	*Name*	*New IDs*	*State*	*Urban Area*	*Point Sources*
1047	Little Allison Creek	1047	SC	Rock Hill	None
		897	SC	No	None
88	Big Dutchmans Creek	88	SC	No	None
		1074	SC	Rock Hill	SC0035661,SC0039250
475	West Fork Twelve Mile Creek	475	NC	No	None
		1079	NC	Charlotte	None
533	Little Twelve Mile Creek	533	NC	Charlotte	None
		1075	NC	No	None
850	Tarkill Branch	850	NC	No	None
		1083	NC	No	None
437	Twelve Mile Creek	437	NC	No	None
		1097	NC	No	NC0085359

2.2 Input Data Updates

Tasks in the previous phase of the project focused primarily on updating model inputs including landuse, meteorology, managed flow, point sources and the Lake Wylie boundary inflow to the model. Point sources and the boundary inflow are particularly important for accurate simulation of water quality in the Catawba River below Lake Wylie, SC. Table A-1 in Appendix A lists all point sources in the Lower Catawba Model, including the receiving reservoir or stream segment in the model and the last date for discharge data. Figure A-1 displays the location of point sources on a map of the Lower Catawba Basin. After the first phase of the project was completed, additional data became available to further improve and update some inputs.

Additional water quality data for Lake Wylie at or near the dam outlet were obtained from NCDENR, Mecklenburg County and Duke Energy. These data included depth profiles of temperature, pH and DO, and euphotic samples of other constituents. WARMF boundary inflow data files include single values per time step per constituent. Thus depth-average values of temperature, pH, and DO were calculated from profile data for the WARMF Lake Wylie boundary inflow. Test simulations just downstream of the Lake (Catawba River below Wylie, SC, WARMF ID 89) produced good results for all constituents except DO and pH. Since these two water quality parameters often vary considerably with depth, a depth-average value may not accurately capture the true value in the water being released from the dam (at a fixed elevation, but variable depth). Thus a second approach was tested using data for these two parameters from the nearest downstream sampling location, assuming this data better represented the water actually released from the dam. Simulations using this approach replicated DO and pH values at the downstream gage. Test simulations of DO and pH from the two approaches are compared in Figure 2-3 and Figure 2-4.

After the initial model review, comments indicated that the simulation of TN and TP downstream of Lake Wylie was not adequate. Data in the lake were available for a single depth, however concentrations for these constituents can also vary with depth. Thus the actual concentration released to the river downstream is better represented by data at the nearest downstream station. The data from the downstream station for ammonia, nitrate, total nitrogen and total phosphorus were also used in the Lake Wylie boundary inflow in place of samples from the lake.

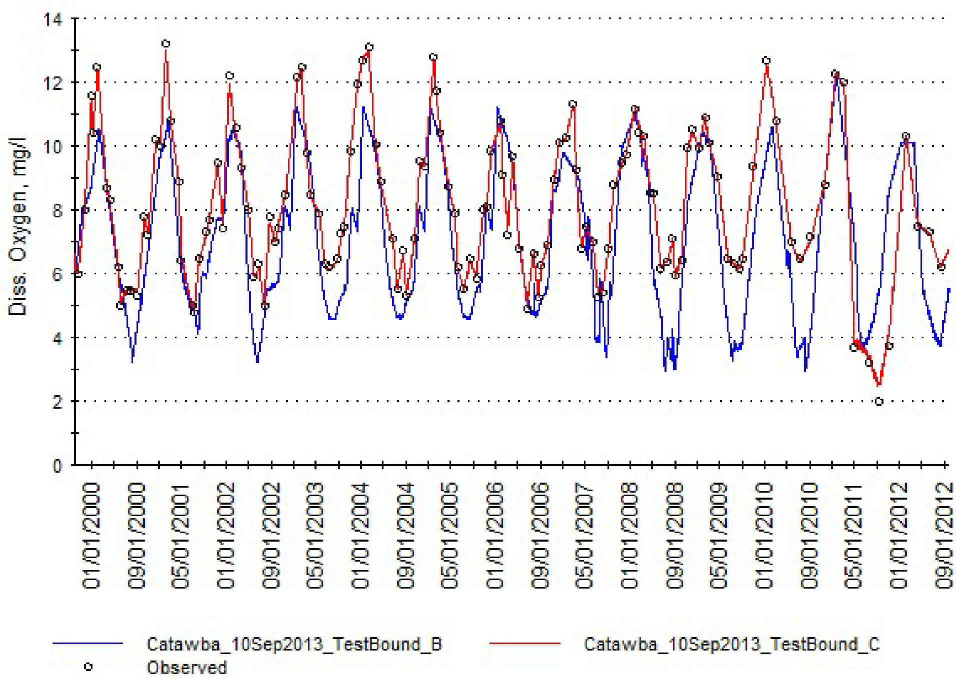

Figure 2-3 Dissolved oxygen simulation comparison at Catawba River below Lake Wylie using depth-average profile data from Lake Wylie (blue) versus nearest downstream sampling data (red) to populate the WARMF Lake Wylie boundary inflow input file.

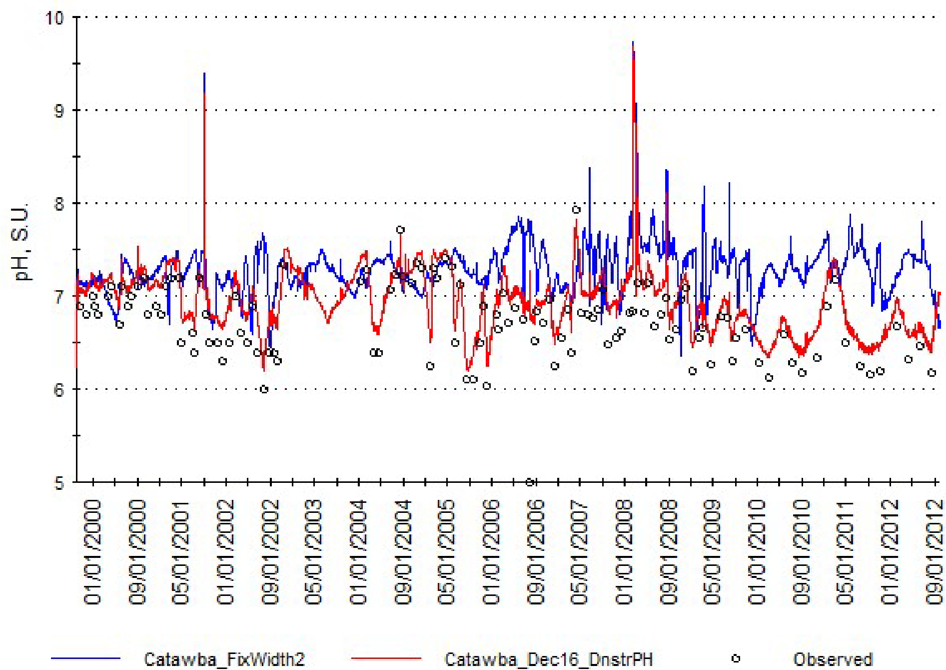

Figure 2-4 pH simulation comparison at Catawba River below Lake Wylie using depth-average profile data from Lake Wylie (blue) versus nearest downstream sampling data (red) to populate the WARMF Lake Wylie boundary inflow input file.

2.3 Periphyton Testing

WARMF includes the capability to simulate periphyton, or submerged and attached algae, in streams. In previous versions of the Catawba River WARMF application, the periphyton growth rate was assumed zero for all segments. In order to test the impact of this assumption, and the potential contribution of periphyton to nutrients levels in the system, a test simulation was run with periphyton growth rates, respiration rates, and mortality rates set to default WARMF values in the main stem reaches of the Catawba River from Lake Wylie to Fishing Creek Reservoir. The reaction rates used for the periphyton test simulation are listed in Table 2-4.

Table 2-4 Periphyton Reaction Rates used in Test Simulations

Reaction	*Value*
Periphyton Growth, 1/d	2.8
Periphyton Mortality, 1/d	1.3
Periphyton Settling, m/d	0.2

Sensitivity results indicate that periphyton primarily effects dissolved oxygen and nitrogen species, as shown in Figure 2-5 through Figure 2-10 for the Catawba River at SC-9. The variation in dissolved oxygen becomes larger, with higher peaks and lower troughs due to the growth (DO release) and decay (DO consumption) of the periphyton. Periphyton consumes both ammonia and nitrate during growth, but only releases ammonia during decay. Thus simulations of ammonia are higher with periphyton, while simulations of nitrate are lower, resulting in a slight net reduction in total nitrogen. Periphyton also causes a small net reduction in total phosphorus. The impact on nutrient levels (TN and TP) and algae in Fishing Creek Reservoir are minimal as shown in Figure 2-11 through Figure 2-13. Thus periphyton does not significantly contribute to total net nutrient levels in the Catawba River and downstream reservoirs. For this reason, and because the periphyton had a negative effect on the DO calibration, periphyton were turned off in WARMF.

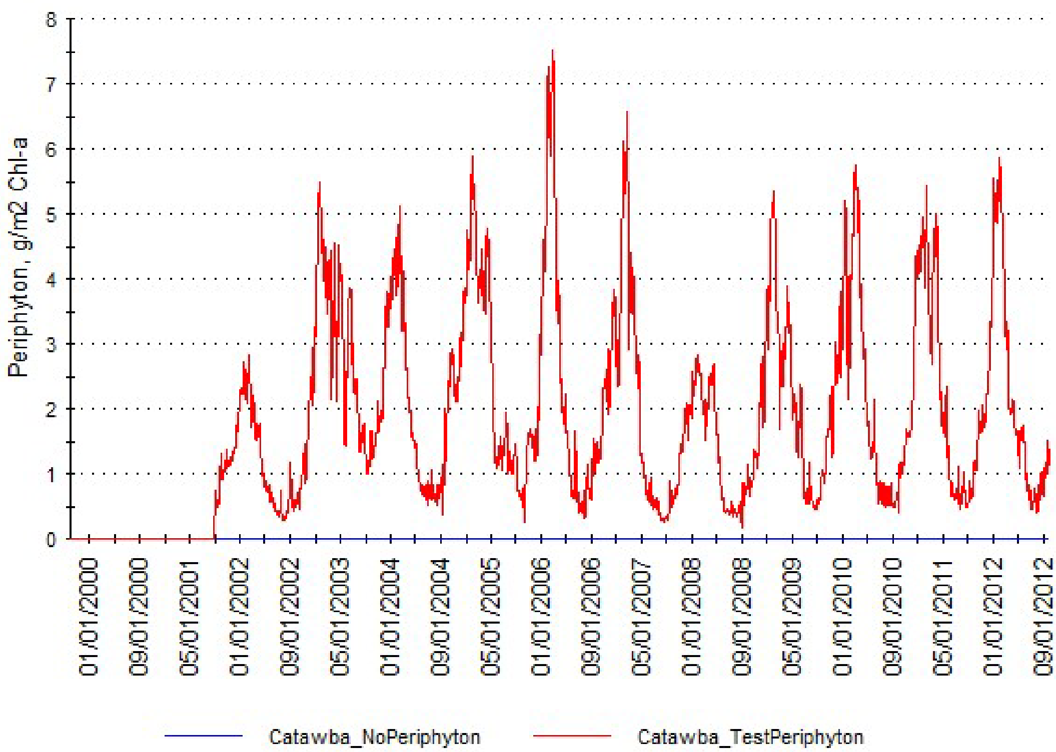

Figure 2-5 Periphyton simulation results with zero growth rate (blue) and typical growth rate (red) - Catawba River at SC-9 (WARMF ID 48)

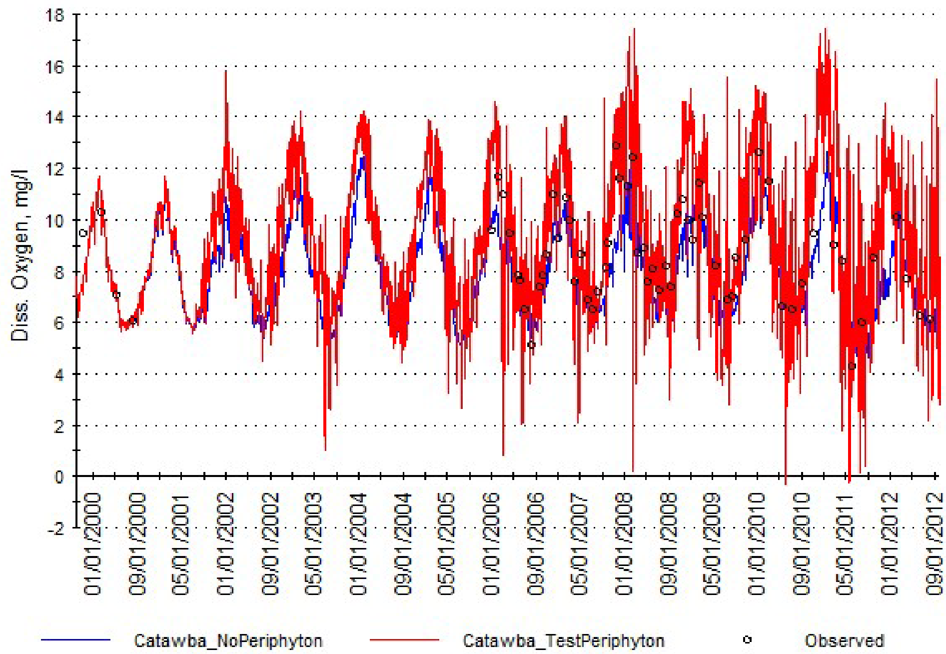

Figure 2-6 Dissolved oxygen simulation results with (red) and without (blue) periphyton - Catawba River at SC-9 (WARMF ID 48)

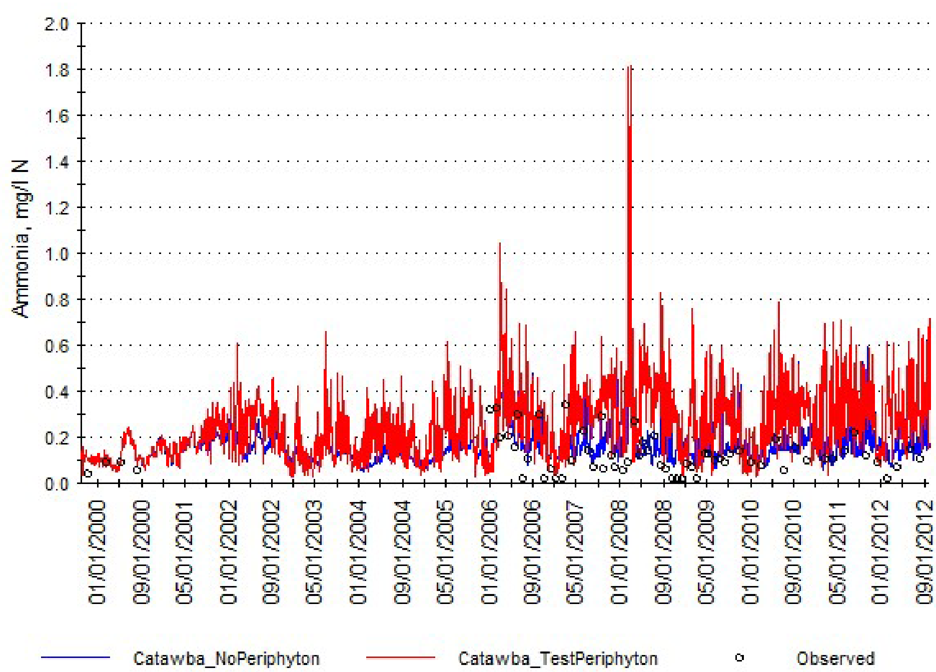

Figure 2-7 Ammonia simulation results with (red) and without (blue) periphyton - Catawba River at SC-9 (WARMF ID 48)

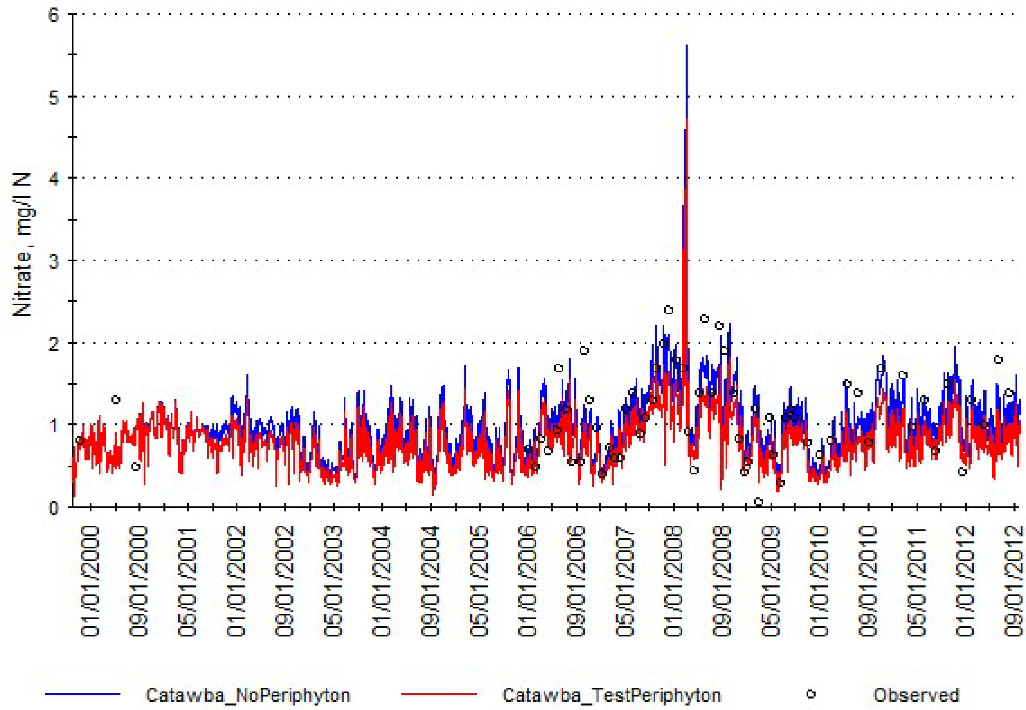

Figure 2-8 Nitrate simulation results with (red) and without (blue) periphyton - Catawba River at SC-9 (WARMF ID 48)

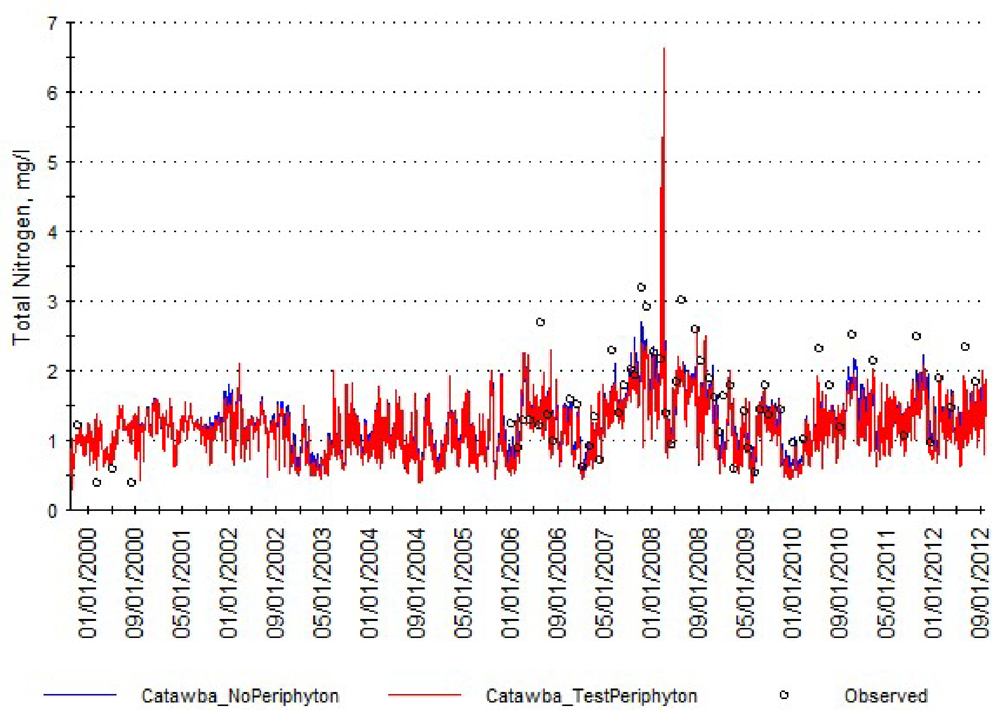

Figure 2-9 Total nitrogen simulation results with (red) and without (blue) periphyton - Catawba River at SC-9 (WARMF ID 48)

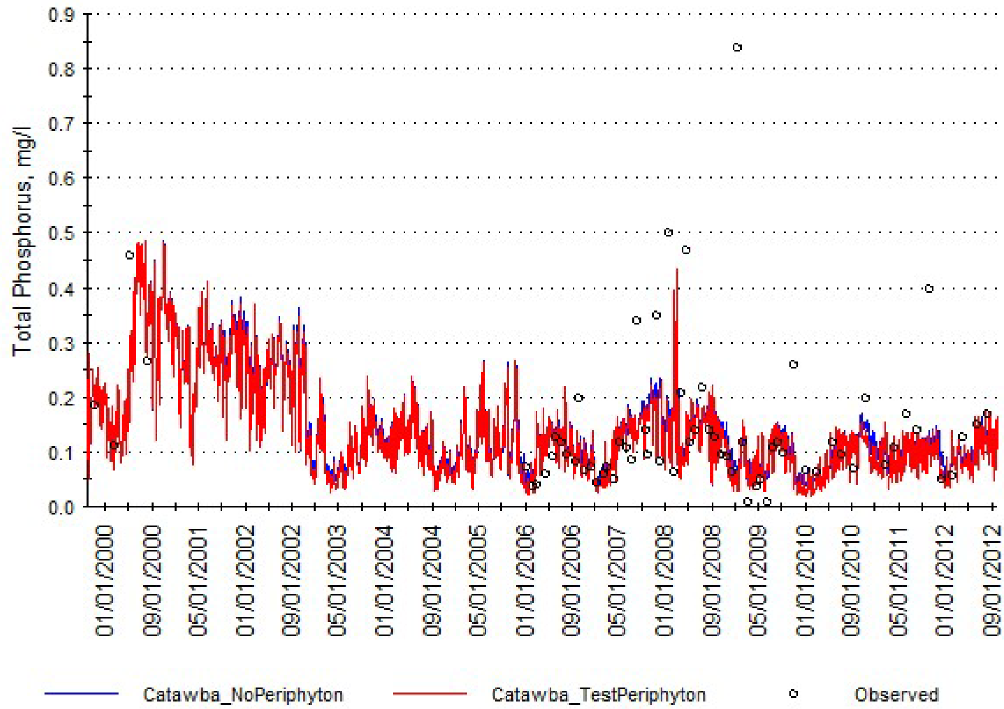

Figure 2-10 Total phosphorus simulation results with (red) and without (blue) periphyton - Catawba River at SC-9 (WARMF ID 48)

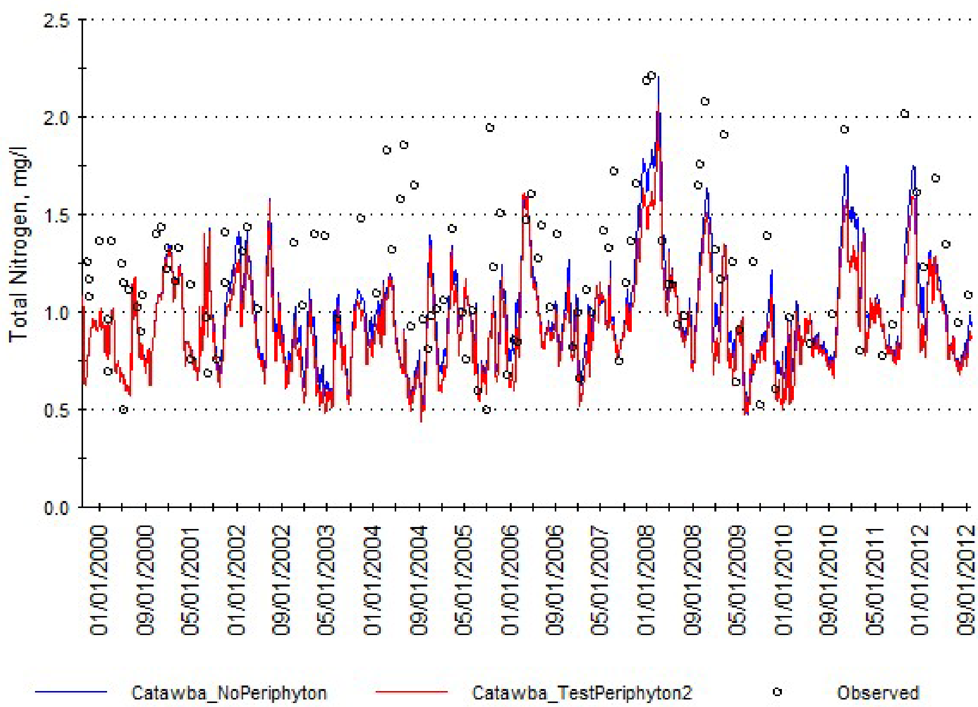

Figure 2-11 Total nitrogen simulation results with (red) and without (blue) periphyton – Fishing Creek Reservoir

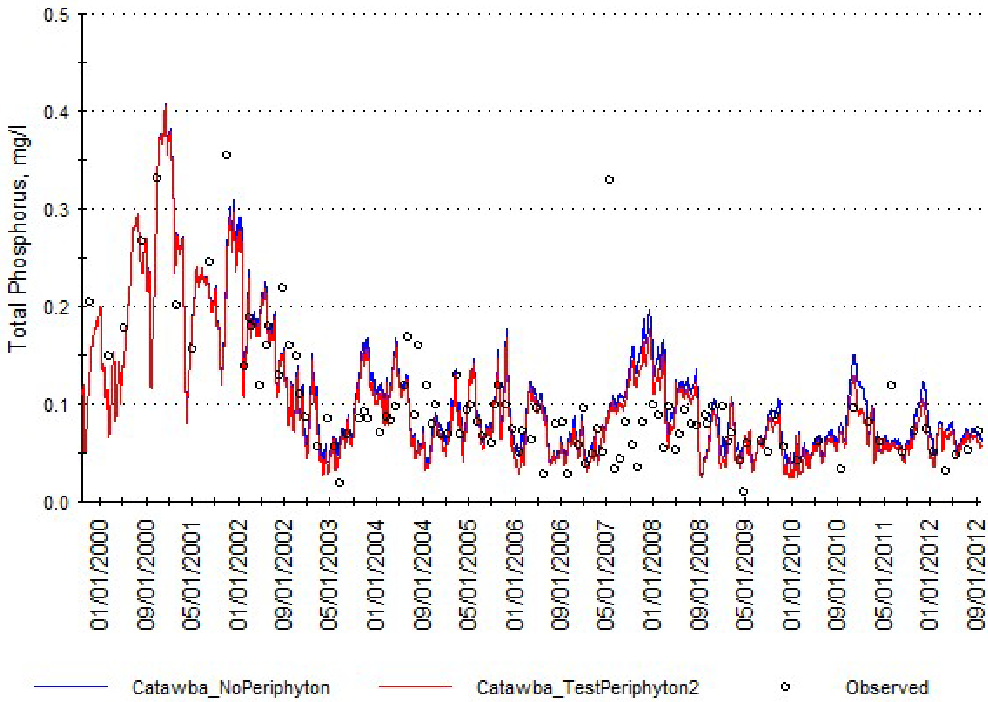

Figure 2-12 Total phosphorus simulation results with (red) and without (blue) periphyton – Fishing Creek Reservoir

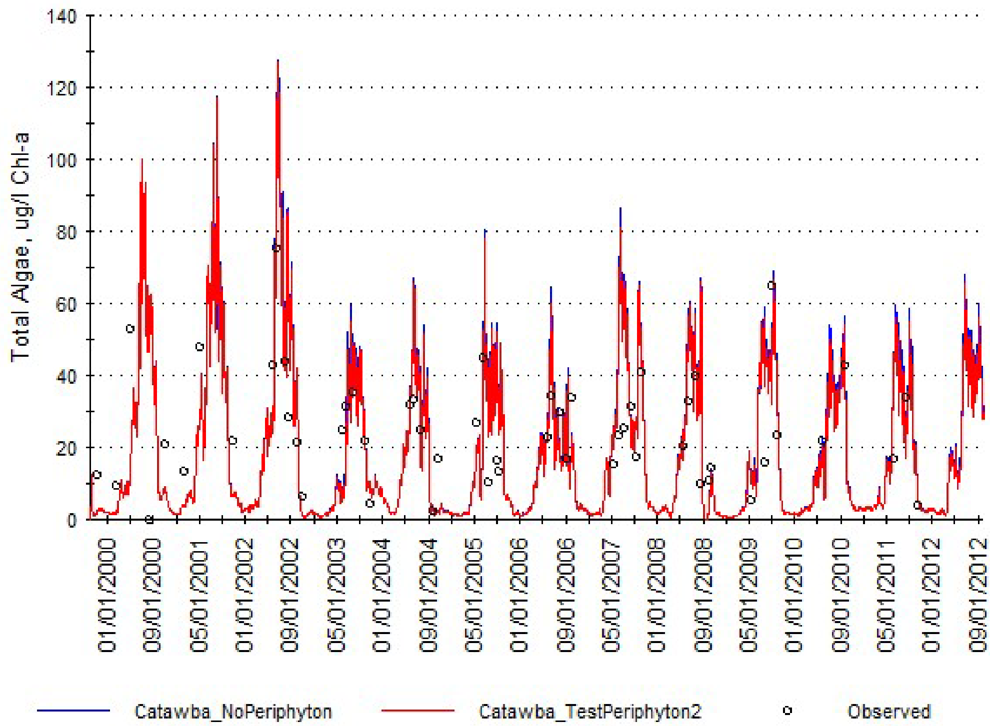

Figure 2-13 Total algae simulation results with (red) and without (blue) periphyton – Fishing Creek Reservoir

3 WARMF Model Calibration

3.1 Procedure

Given the available meteorological and operational data, the Catawba River Model simulated stream flow and water quality at various river segments. At locations where monitoring data were collected, the model predictions should generally match the measured stream flow and water quality. Initially, some model coefficients such as physical properties of the watershed are known. Other coefficients are left at default or typical literature values. Model calibration was performed by adjusting model coefficients within acceptable ranges to improve the match between model predictions and observed data. Acceptable ranges are reported in literature for some coefficients, other are determined by prior experience.

The model predictions and observed data were compared graphically. In the graph, the time series of model predictions were plotted in a curve along with measured data points. The first step of calibration is assessing how well the simulated curve passes through the observed data points by visual inspection of the plots. In cases with very little observed data available, graphical comparison is the best means of evaluating the model performance. In such cases standard statistical measures of model fit can include significant bias and not convey useful information about the calibration (Moriasi, 2007).

Where possible, the model predictions and observed data were also compared statistically to further evaluate the model performance. The differences between the predicted and observed values are the model residuals, also often referred to as model errors. The WARMF model automatically calculates a selection of statistics that summarize and quantify the difference between the predicted and observed values for all model steps where an observed value was available. These statistics include relative error (E_R), absolute error (E_A), root mean square error (RMSE), and coefficient of determination (R^2). The E_R and E_A are the primary statistics used in this model calibration, as they are the most informative for long term trends. Both RMSE and R^2 have the disadvantage that they tend to overemphasize error at the extreme values and some literature recommends against using these measures in model evaluation (Moriasi, 2007). Since they are readily available in the software, RMSE and R^2 were reviewed during calibration along with E_R and E_A, however more emphasis was placed on the latter two to guide coefficient adjustments.

$$E_R = \frac{\sum (simulated - observed)}{n}$$

$$E_A = \frac{\sum |simulated - observed|}{n}$$

The relative error cancels out errors greater than and less than observed and is thus a measure of overall model accuracy or bias. Negative relative error indicates that simulated values are less than observed, while positive relative error indicates that the simulated values are greater than observed. The absolute error measures the total magnitude of the difference between observed and simulated values and is therefore a measure of model precision. Both can be expressed as a percent by dividing by the average observed value.

Due to budget restrictions, the calibration process was limited to using only the statistics calculated within the WARMF software for guidance. Three additional commonly used statistics were calculated for additional information by request of the South Carolina Department of Health and Environmental Control after completion of the calibration. These include the Nash-Sutcliffe Efficiency (NSE), percent bias (PBIAS), and the ratio of the root mean square error to the standard deviation of measured data (RSR). These statistics were calculated for each location and parameter reported below by exporting data from WARMF and calculating the statistics in Microsoft Excel. Again, these statistics are presented to evaluate the performance of the calibrated WARMF model, but were not used to inform the calibration process due to the amount of time required to calculate the statistics for each location and parameter.

The NSE (Nash & Sutcliffe, 1970) provides a quantitative measure of how well the plot of observed versus simulated data fits the 1:1 line. The statistic is a commonly used evaluator of watershed model performance and calculated as:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]$$

where Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the ith simulated value for the constituent being evaluated, Y^{mean} is the mean of the observed data for the constituent being evaluated, and *n* is the total number of observations. The NSE ranges between -∞ and 1.0, with NSE=1 indicating a perfect model fit to the observed data and NSE>0 indicating that the difference between the simulated and observed value is less than the difference between the mean of the observed data and the observed value. Generally, values between 0 and 1 are considered acceptable (Moriasi et al, 2007). Values of NSE of 0.5 or greater have been reported as the guideline for a “good” calibration for models run on a monthly time step, while shorter time steps require less stringent bounds on the acceptable ranges of statistical measures (Moriasi et al, 2007). WARMF is run on a daily time step, which should be taken into account when evaluating the model performance.

Similar to relative error, the PBIAS measures the average tendency of the simulated data to be greater than or less than their observed counterparts (Gupta, Sorooshian, & Yapo, 1999). PBIAS is calculated as:

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * 100}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$

where Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the *i*th simulated value for the constituent being evaluated, and *n* is the total number of observations. The optimal value for PBIAS is 0.0, with low magnitude values indicating accurate model simulation of observed values.

Positive PBIAS values indicate a bias toward model underestimation while negative values indicate a model overestimation bias (opposite of relative error).

The RSR statistic standardizes the RMSE using the standard deviation of the observations, thereby creating a value that can be compared to RSR values calculated for other locations and constituents (Singh, Knapp, & Demissie, 2004). The RSR is calculated as:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]}$$

where Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the ith simulated value for the constituent being evaluated, Y^{mean} is the mean of the observed data for the constituent being evaluated, and *n* is the total number of observations. The RSR statistic is evaluated the same way that the RMSE statistic is evaluated, with 0.0 indicating perfect fit between observed and simulated values, and values increasing with decreasing model performance.

Both graphical and statistical comparisons were made throughout the calibration process using the standard WARMF output. WARMF has a scenario manager, where each scenario is a set of model input coefficients and corresponding simulation results. Scenario 1 may be used to represent a set of numerical values of model coefficients used in the simulation. Scenario 2 may be used to represent a second set of modified model coefficients used in the simulation. After the simulation, WARMF can plot the observed data as well as the model predictions for both scenarios on the same graph. By visual inspection, it is relatively easy to see whether the changes to model coefficients improve the match. Likewise, WARMF calculates the values of various error terms for the model predictions. The comparison of the numerical values of errors for two scenarios can lead the user to adjust the model coefficients in the right way to reduce the errors. In some cases, the observed data is too sparse for the statistical calculations of model fit to be meaningful. If the observations do not represent daily average values and do not cover the full range of observable values (e.g., data is collected only during high or low flows, or is a monthly average), a direct comparison to the simulated values is not truly valid. However, in common practice these limitations are balanced by the need to use all available information to improve the model calibration as much as possible. As such, statistical measures of model performance are often calculated and presented for all possible locations and parameters, as we do here. However the observed data quantity, quality and representativeness is important to consider when assessing the results.

The process of model calibration followed a logical sequence. Hydrological calibration was performed first, because an accurate flow simulation is a pre-requisite for accurate water quality simulation. The calibrations for temperature and conservative substances were performed before the calibration of nutrients (phosphate, ammonia, and nitrate), algae and dissolved oxygen concentrations.

Only a few model coefficients were adjusted for each calibration. For hydrological calibration, the boundary river inflows were checked for their accuracy by direct comparison with downstream measured hydrology. Evapotranspiration coefficients, soil thickness, field capacity, saturated moisture, and hydraulic conductivity were then adjusted so that the simulated runoff from catchments could account for flow in headwater tributaries and thus for increases in flow between the monitoring stations located within the Catawba River watershed between Lake Wylie and Lake Wateree. For water quality calibration, coefficients used for model calibration include reaction rates, initial concentrations in the soil, and properties of each land use such as productivity. If the model does not match observed data after adjusting model coefficients, an investigation may find another cause of the mismatch, such as a surface water diversion or errors in reported point source discharge or water quality.

3.2 Model Coefficients

There are thousands of model coefficients in the Catawba River WARMF model, including chemical reaction rates, soil depths and hydraulic conductivities, soil mineral compositions, temperature correction factors (to dynamically adjust rates for temperature changes), and many others. Some apply throughout the watershed (referred to as "system coefficients"), some apply to individual land uses, and others apply to individual catchments and river segments. Many of the coefficients do not have an appreciable impact on simulation results and therefore could be safely left at default literature values unless there was specific information to enter. Coefficients to which the model is more sensitive had to be calibrated. WARMF contains default values of those parameters which were used as the initial values for the model. These initial values were adjusted during the model calibration process in order to better match the simulations of stream flow and water quality with observations. The model coefficients that were calibrated are described in more detail in the following sections.

3.2.1 System Coefficients

The system coefficients (i.e. those that apply to the entire system) can be viewed by double-clicking on the white space on the WARMF map. For the Catawba River model, evaporation-related coefficients were calibrated while other system coefficients relating to hydrology, such as snow melt rates, were left at default values. Table 3-1 lists the evaporation coefficients, along with the typical ranges within which the coefficients vary. The last column is the value used for the Catawba River calibration.

Table 3-1 Calibrated System Coefficients

Coefficient	*Units*	*Description*	*Range*	*Calibrated Value*
Evaporation Magnitude	None	Multiplier of potential evapotranspiration calculated from temperature, humidity, and latitude	0.6 – 1.4	1.1
Evaporation Skewness	None	Seasonal adjustment of evapotranspiration calculations	0.6 – 1.4	1.3

There are a number of model system coefficients which have values for each land use. These coefficients define how the different land uses receive anthropogenic model inputs such as irrigation and respond to natural model inputs such as atmospheric deposition. These coefficients are accessed in WARMF the same way as the coefficients above, by double-clicking in the white space on the WARMF map. These were set based on literature values and agricultural practice. The land use coefficients are under the land use tab of the ensuing dialog box. For nutrient simulations, the model is most sensitive to the coefficients shown in Table 3-2.

Table 3-2 Calibrated System Land Use Coefficients.

	Impervious Fraction	*Cropping Factor*	*Productivity*	*N Trunk Composition*	*Leaf Area Index*
Units	None	none	kg/m2/yr	mg/g N	none
Description	Portion of each land use which is paved	"C" factor of Universal Soil Loss Equation	Net creation of vegetation	N content of vegetation matter	Ratio of leaf area to land area (varies monthly)
Typical Range	0 - 1	0 - 1	0 – 3	0-38	0 - 14
Values used in the Catawba River WARMF Model:					
Deciduous Forest	0	0.1	1.2	10	2.5
Evergreen Forest	0	0.1	1.3	10	14
Mixed Forest	0	0.1	1.25	10	8.5
Grassland	0	0.2	0.65	20	1.5
Shrub / Scrub	0	0.2	0.65	10	1.5
Wetlands	0	0	3	10	2.5
Herbaceous Wetland	0	0.2	0.65	10	1.5
Pasture	0	0.2	0.96	20	1.5
Cultivated	0	0.5	0.7	13	2.5
Recr. Grasses	0	0.2	0.6	38	1.5
Low Int. Develop.	0.5	0.2	0.5	38	1.5
Medium Int. Develop.	0.5	0.2	0.5	38	1.5
High Int. Develop.	1	0.2	0	0	0
Barren	0	1	0	0	0
Water	1	0	0	0	0

3.2.2 Catchment Coefficients

Catchment coefficients are the coefficients that apply to individual catchments throughout the modeled watershed area. These coefficients are important for simulating shallow groundwater flow and nonpoint source load. They can be set to different values for each catchment if they have different properties or lumped together with the same values. The coefficients for each individual catchment can be viewed and edited in WARMF by double-clicking on a catchment.

The catchment area, slope, and aspect were calculated from digital elevation models and are not subject to calibration. Meteorology coefficients were calculated based on meteorology station data. In a few cases where it was evident that the total volume of rainfall was consistently too high or too low, the meteorology coefficients were further adjusted during the calibration process. Land uses were calculated by overlaying a land use shapefile with catchment boundaries. The remaining coefficients that require calibration are primarily soil properties and reaction rates.

Calibration of the soil properties (listed in Table 3-3) is essential to adequately match the simulated with the observed quantity and timing of streamflow. Four soil layers were used in the Catawba River application. These layers represent the shallow groundwater that interacts with surface waters, which is the focus of watershed modeling. Deep groundwater, which does not usually interact with surface water, is not included in the model. The Catawba River WARMF application includes 314 individual catchments in the currently modeled region below Lake Wylie. However, observed streamflow data was not available at the outlet of every catchment. Therefore streamflow calibration was performed only where observed data was available. In particular, calibration efforts were focused on headwater tributaries where local area runoff is the sole source of streamflow and the impacts of soil coefficient adjustments are greatest. In catchments further downstream or below a reservoir, inflow to the catchment is much larger than local shallow groundwater runoff. Thus the effects of coefficient adjustments are masked. In cases where multiple catchments were located upstream of a tributary streamflow station, the soil coefficients of all upstream catchments were assigned the same values and calibrated together.

Table 3-3 Calibrated Catchment Soil Coefficients

Coefficient	*Units*	*Range of Calibrated Values*
Layer Thickness (soil layers 1-4)	cm	5 – 500
Field Capacity (soil layers 1-4)	none	0.1-0.5
Saturation Moisture Content (soil layers 1-4)	cm	0.2-0.6
Initial Moisture Content (soil layers 1-4)	none	0.2-0.57
Horizontal Hydraulic Conductivity (soil layers 1-4)	cm/d	3 – 16000
Vertical Hydraulic Conductivity (soil layers 1-4)	cm/d	0.5 – 50000
Root Distribution (fraction reaching the layer, soil layers 1-4)	none	0.0 – 0.8

Reaction rates are important coefficients for water quality simulations. The reaction rates of most significance for the Catawba River model are shown in Table 3-4. These rates are dynamically adjusted during the simulation based on changes in temperature. Reactions only occur under the proper dissolved oxygen concentration, for example nitrification under oxic conditions and denitrification when dissolved oxygen is near zero. In the Catawba River WARMF application, reaction rates were set the same value for all catchments during calibration. Not enough data were available at locations not affected by point sources to vary the catchment reaction rates across the watershed.

Table 3-4 Important Catchment Reaction Rate Coefficients

Reaction Rate	*Units*	*Typical Range*	*WARMF Default*	*Calibrated Value*
BOD Decay	1/d	0.05-0.5	0.1	0.05
Organic Carbon Decay	1/d	0-0.1	0.01	0.008

Nitrification	1/d	0-0.1	0.01	0.05
Denitrification	1/d	0-0.1	0.1	0.01
Sulfate Reduction	1/d	0-0.5	0.05	0.01

The other important parameters for calibrating the water quality of the shallow groundwater are the initial concentrations of each chemical constituent in each soil layer of each catchment (Table 3-5). The initial concentrations weren't calibrated, but were set based on a balance over the course of the simulation. The initial concentrations were set individually for each catchment and soil layer to match the ending concentrations of the simulation under the assumption that the actual soil chemistry in the Catawba River watershed is in relative equilibrium rather than undergoing a trend of increasing or decreasing concentration.

Table 3-5 Catchment Initial Soil Pore Water Concentrations

Constituent	*Units*	*Range of Calibrated Values*
Ammonia	mg/l as N	0.001-0.1
Calcium	mg/l	4 - 20
Magnesium	mg/l	1 – 7
Potassium	mg/l	1 – 5
Sodium	mg/l	0.2 – 10
Sulfate	mg/l	3 – 30
Nitrate	mg/l as N	0.01 – 0.1
Chloride	mg/l	0.5 – 7
Phosphate	mg/l as P	0.01 – 0.22
Organic Carbon	mg/l	3 – 12
Dissolved Oxygen	mg/l	4 – 8

3.2.3 River Coefficients

Physical data for river segments, including upstream and downstream elevations and lengths, are derived from digital elevation model data. Default stage-width curves and roughness coefficients (i.e. Manning's n) were used for each river segment since no data were available to calculate these values. An initial value for the Manning's n coefficient of 0.04 was used as recommended by Rosgen (1996). The Manning's n value was increased for the majority of river segments because it improved the simulation results when compared with observed data. Chemical and biological reaction rates and sediment particle settling velocities influence the simulated concentration of chemical constituents, sediment and algae in each river segment. Table 3-6 shows the typical ranges, WARMF default values and calibrated values (or ranges of values if it varied across the watershed) for reactions rates in the Catawba River WARMF application.

Table 3-6 River Reaction Rate Coefficients

Reaction Rate	*Units*	*Typical Range*	*WARMF Default*	*Calibrated Value (or Range of Values)*
BOD Decay	1/d	0.1-1	0.5	0.2
Organic Carbon Decay	1/d	0.01-0.1	0.1	0.05
Nitrification	1/d	0.01-1	0.1	0.1 – 1
Denitrification	1/d	0-1	0	0 – 0.1
Sulfate Reduction	1/d	0-0.5	0	0 – 0.1
Clay Settling	m/d	>0	0.3456	0.3456
Silt Settling	m/d	>0	8.64	8.64
Sand Settling	m/d	>0	1036.8	1036.8
Diatom Growth	1/d	0-5	1	0.8-1.8
Diatom Respiration	1/d	0.1-0.5	0.15	0.15
Diatom Mortality	1/d	0.1-0.5	0.05	0.05
Diatom Settling	m/d	0-1	0.2	0.1
Detritus Decay	1/d	0-1	0.1	0.1
Detritus Settling	m/d	0-1	0.1	0.1
Settled Detritus Decay	1/d	0-0.1	0.1	0.1

Sediment transport in rivers is affected by the settling rates shown above as well as scour from the river bed. Scour is controlled by the shear velocity of the water next to the river bed. Above the critical shear velocity, scour is calculated in the form aV^b, where a is the multiplier and b is the exponent. For river segments in the Catawba River WARMF application, multiplier a ranged from 1.0×10^{-6} to 5.0×10^{-6} and exponent b ranged from 1.6-1.8. Adsorption coefficients control the partitioning between the dissolved phase of each constituent and the portion adsorbed to suspended sediment. The values shown in Table 3-7 were used in all Catawba River segments. With the exception of the value for phosphate, these are the WARMF default values. The phosphate adsorption isotherm was adjusted from the default to better match orthophosphate observations in Sugar Creek.

Table 3-7 Adsorption Isotherm Coefficients

Constituent	*Units*	*Value Used*
Ammonia	L/kg	6233.81
Aluminum	L/kg	0
Calcium	L/kg	472.552
Magnesium	L/kg	404.556
Potassium	L/kg	197.971
Sodium	L/kg	20.7365
Sulfate	L/kg	16.3
Nitrate	L/kg	0

Chloride	L/kg	0
Phosphate	L/kg	22000
Alkalinity	L/kg	0
Org. Carbon	L/kg	107.184

3.2.4 Reservoir Coefficients

The relationship between water depth and reservoir surface area was defined from reservoir bathymetry data. Table 3-8 shows the default reaction rates that were used as a starting point for each of the reservoir segments. The default coefficients were adjusted to optimize the simulation statistics when and where observed data were available for comparison.

Table 3-8 Reservoir Reaction Rate Coefficients

Reaction Rate	*Units*	*Typical Range*	*WARMF Default*	*Calibrated Value or Range*
BOD Decay, 1/d	1/d	0.1-1	0.5	0.1
Organic Carbon Decay, 1/d	1/d	0.01-0.1	0.01	0.001
Nitrification, 1/d	1/d	0.01-1	0.01	0.01
Denitrification, 1/d	1/d	0-1	0.1	0.1
Sulfate Reduction, 1/d	1/d	0-0.5	0.05	0.1
Sediment 1 Settling, m/d	m/d	>0	0.3456	0.08-0.3456
Sediment 2 Settling, m/d	m/d	>0	8.64	5-8.64
Sediment 3 Settling, m/d	m/d	>0	1036.8	1036.8
BlueGreen Growth, 1/d	1/d	0-5	1	1.1-1.8
Diatom Growth, 1/d	1/d	0-2	1	1-1.5
Green Algae Growth, 1/d	1/d	0-2	1	0.8-1.25
BlueGreen Respiration, 1/d	1/d	0-0.5	0.15	0.15
Diatom Respiration, 1/d	1/d	0-0.5	0.15	0.15
Green Algae Respiration, 1/d	1/d	0-0.5	0.15	0.15
BlueGreen Mortality, 1/d	1/d	0-0.5	0.05	0.05
Diatom Mortality, 1/d	1/d	0-0.5	0.05	0.15
Green Algae Mortality, 1/d	1/d	0-0.5	0.05	0.03
BlueGreen Settling, m/d	m/d	0-1	0.1	0.5
Diatom Settling, m/d	m/d	0-1	0.2	0.5

Green Algae Settling, m/d	m/d	0-1	0.2	0.5
Detritus Decay, 1/d	1/d	0-0.1	0.1	0.1
Detritus Settling, m/d	m/d	0-10	0.1	0.5
Settled Detritus Decay, 1/d	1/d	0-0.1	0.1	0.1
Coliform Decay, 1/d	1/d	0-1	1	0.2

4 Hydrology Calibration Results

Hydrologic calibration is the process of adjusting the coefficients of the rainfall-runoff model within WARMF so that the simulations of streamflow match the observations as well as possible. There are three levels of hydrologic calibration: global, seasonal, and event. Global calibration is the process of matching the simulated annual volume of water passing a gage to the volume measured at the gage. In seasonal calibration, the simulated seasonal variation of streamflow is compared and adjusted to follow the same pattern on a measured hydrograph (i.e., a graph of streamflow rising and falling over time). The measured hydrograph typically has a period of high flow during the rainfall season and a recession to base flow during the dry season. Event calibration is the process of matching the simulated peak flows to the observed peaks during precipitation events. There are more than 30 active streamflow gaging stations on rivers and streams located within the Catawba River Watershed between Lake Wylie and Lake Wateree. Some of these stations have very little data, many are on very small streams, and most are in urban areas. Hydrology calibration focused on the locations with the most complete data records. The remaining locations were used for additional comparison and check of the calibration. These locations are labeled in Figure 4-1 and listed in Table 4-1.

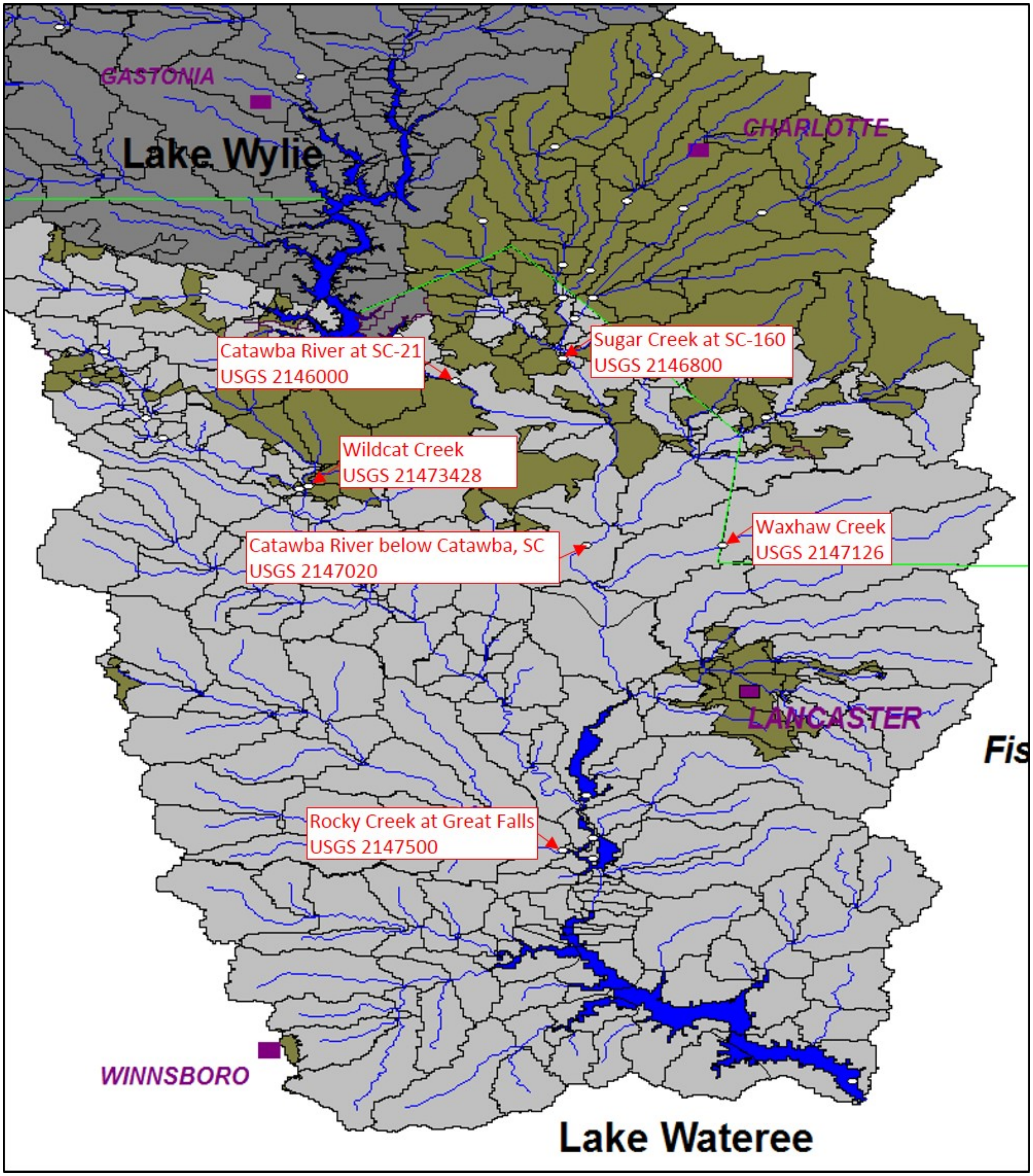

Figure 4-1 Catawba River WARMF model main hydrology calibration locations (red text labels) and additional comparison locations (white dots)

Calibration results are shown in Figure 4-2 through Figure 4-7 below. Simulated flow is shown with a blue line and observed data with black circles. Ideally, the blue lines pass through all the black circles. However this does not always occur due to a combination of input data error, streamflow measurement error, and model error. During the calibration process, coefficients were adjusted so that large systematic differences were removed and an overall balance was achieved between positive and negative errors (i.e. simulations were not consistently too high or too low indicating that differences are due primarily to random errors in data rather than coefficient values).

In addition to visual inspection, statistical error measurements were used to evaluate how well the simulation results matched the observations (under the assumption that the observations are error-free). The statistics calculated for each of the hydrologic calibration locations are listed in Table 4-1. The primary statistics used to quantitatively evaluate model performance were relative error and absolute error as described in the Section 3. Relative error is the average of the deviations between simulated and observed. Absolute error is the average of the absolute differences between model predictions and observations. A low relative error is indicative of a good water balance, which was the calibration priority. Simulating the correct quantity of water is important in determining the sources of pollutants including nutrients and sediment. The value of some statistics listed in Table 4-1 (e.g. R^2) are dominated high flows and errors in timing of peaks. Since the primary concern for reservoir water quality is long-term pollutant load, the exact timing of peaks is not as important as the total quantity of discharge. If the model were simulating exactly twice as much flow as observed, R^2 would be very high but the calibration would be very poor due to incorrect water balance. As discussed in Section 3, additional statistics were calculated external to WARMF after completion of calibration to enable further assessment and presentation of the results. These include the NSE, RSR, and PBIAS statistics and are also listed in Table 4-1. Because these additional statistics are not automatically calculated by WARMF, they were not used to guide calibration. Project constraints limited the calibration task to using only those statistics readily available within the software due to the time required to export and recalculate additional statistics for each iterative model run. Calibration was performed at each location until the relative error was less than 10% and/or coefficient adjustments were no longer making any improvements to the simulation.

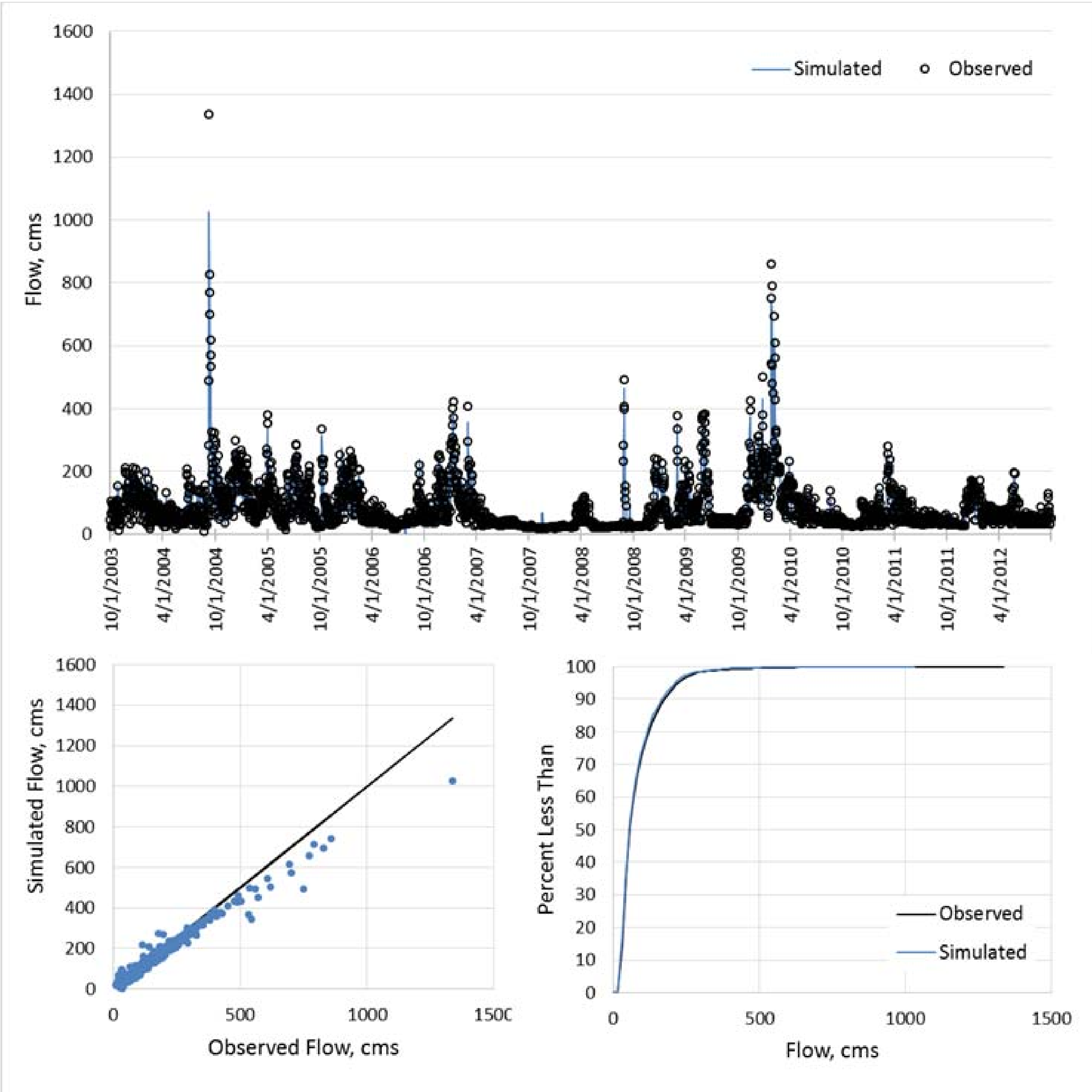

Figure 4-2 Hydrology simulation results, Catawba River at SC-21 (USGS 2146000, WARMF ID 89)

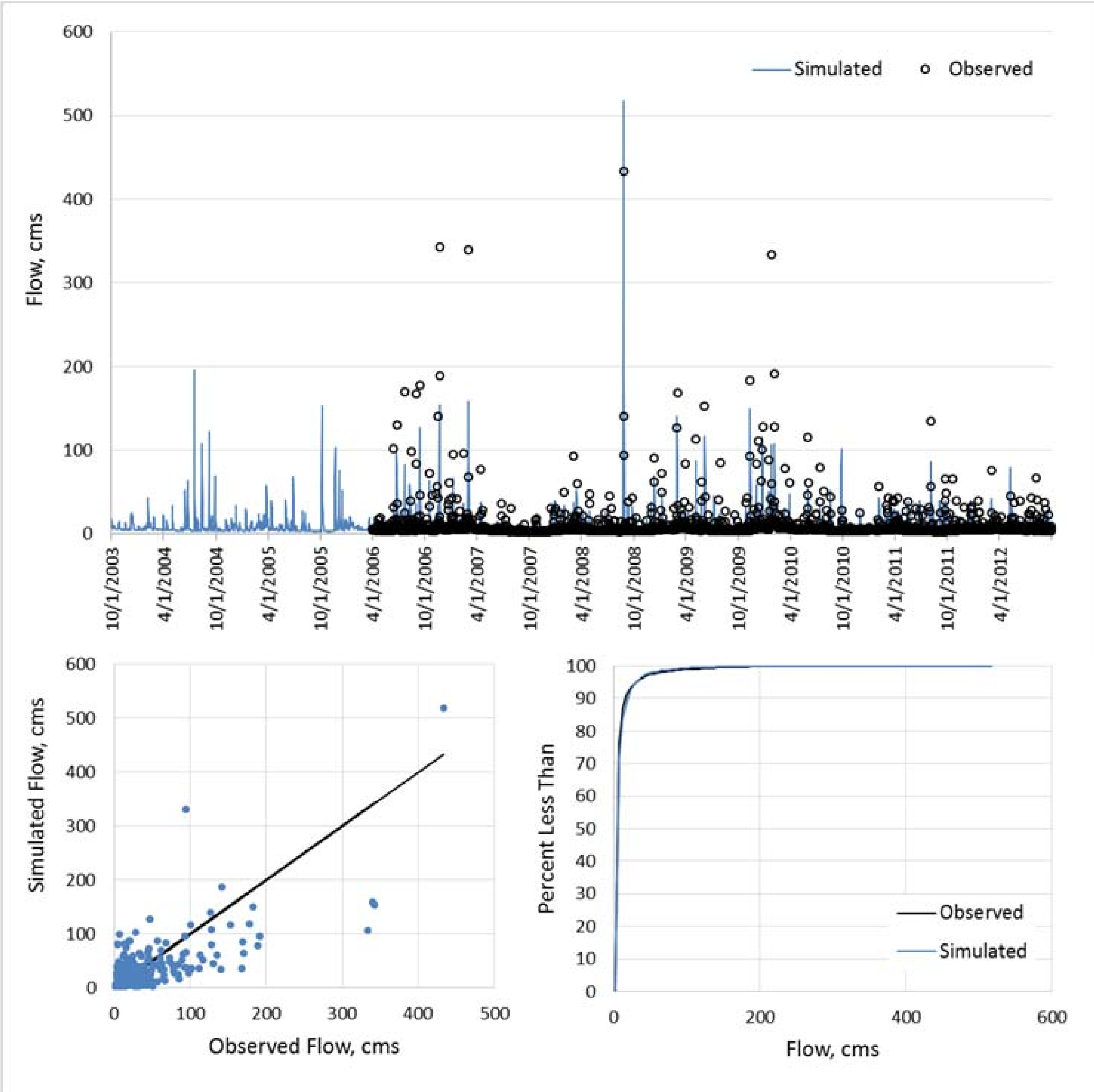

Figure 4-3 Hydrology simulation results, Sugar Creek at SC-160 (USGS 2146800, WARMF ID 246)

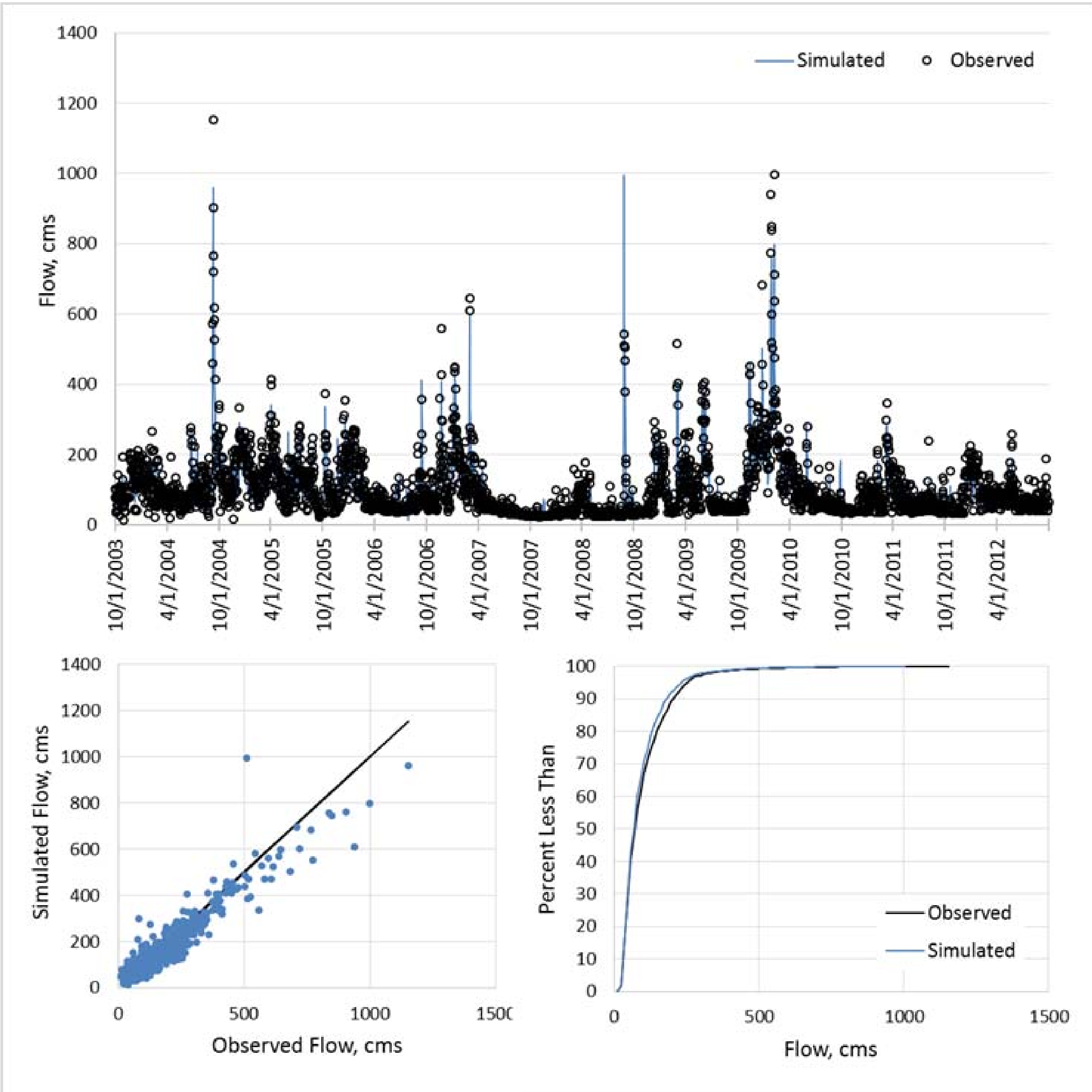

Figure 4-4 Hydrology simulation results, Catawba River below Catawba, SC (USGS 2147020, WARMF ID 61)

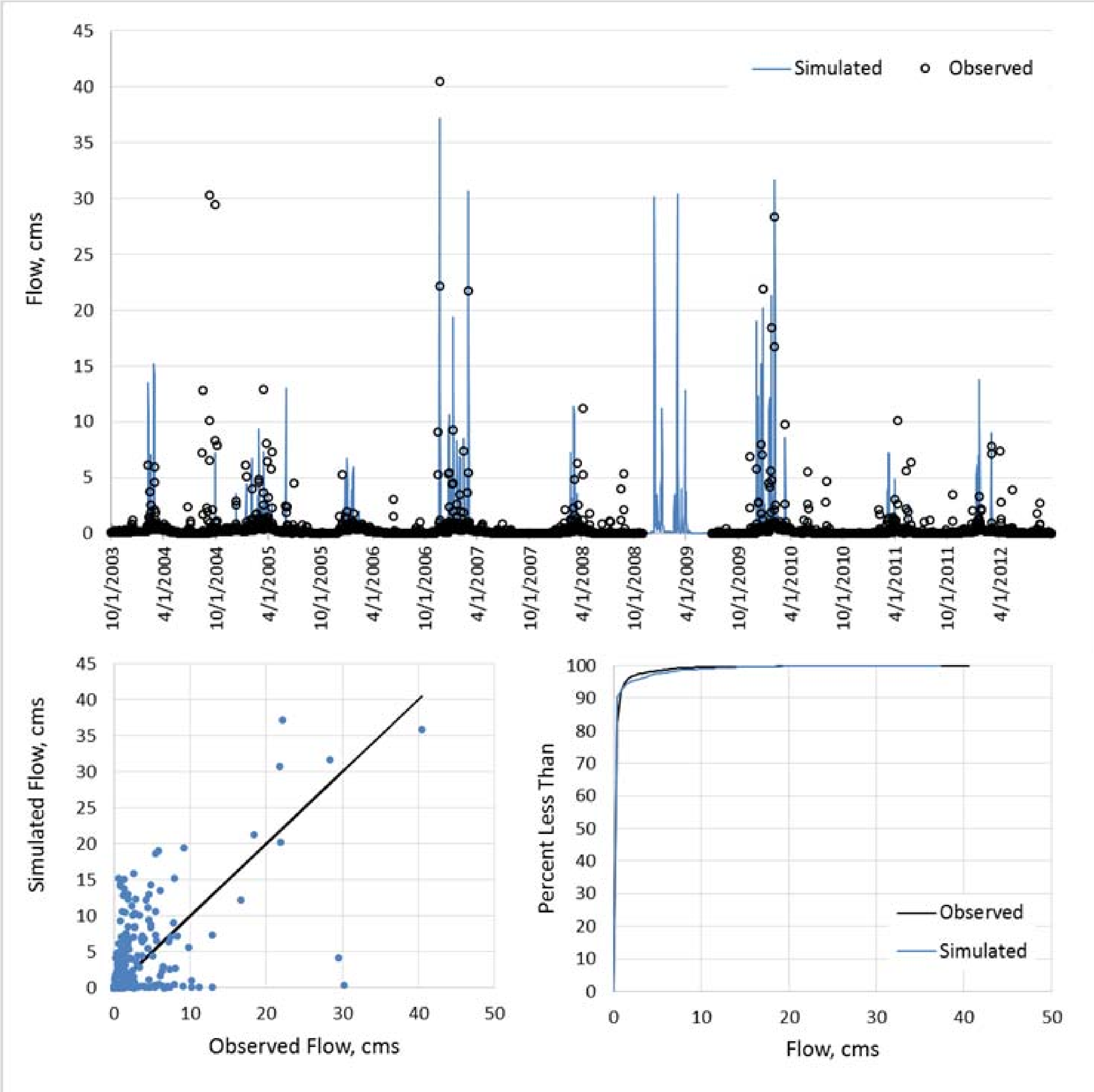

Figure 4-5 Hydrology simulation results, Waxhaw Creek (USGS 2147126, WARMF ID 846)

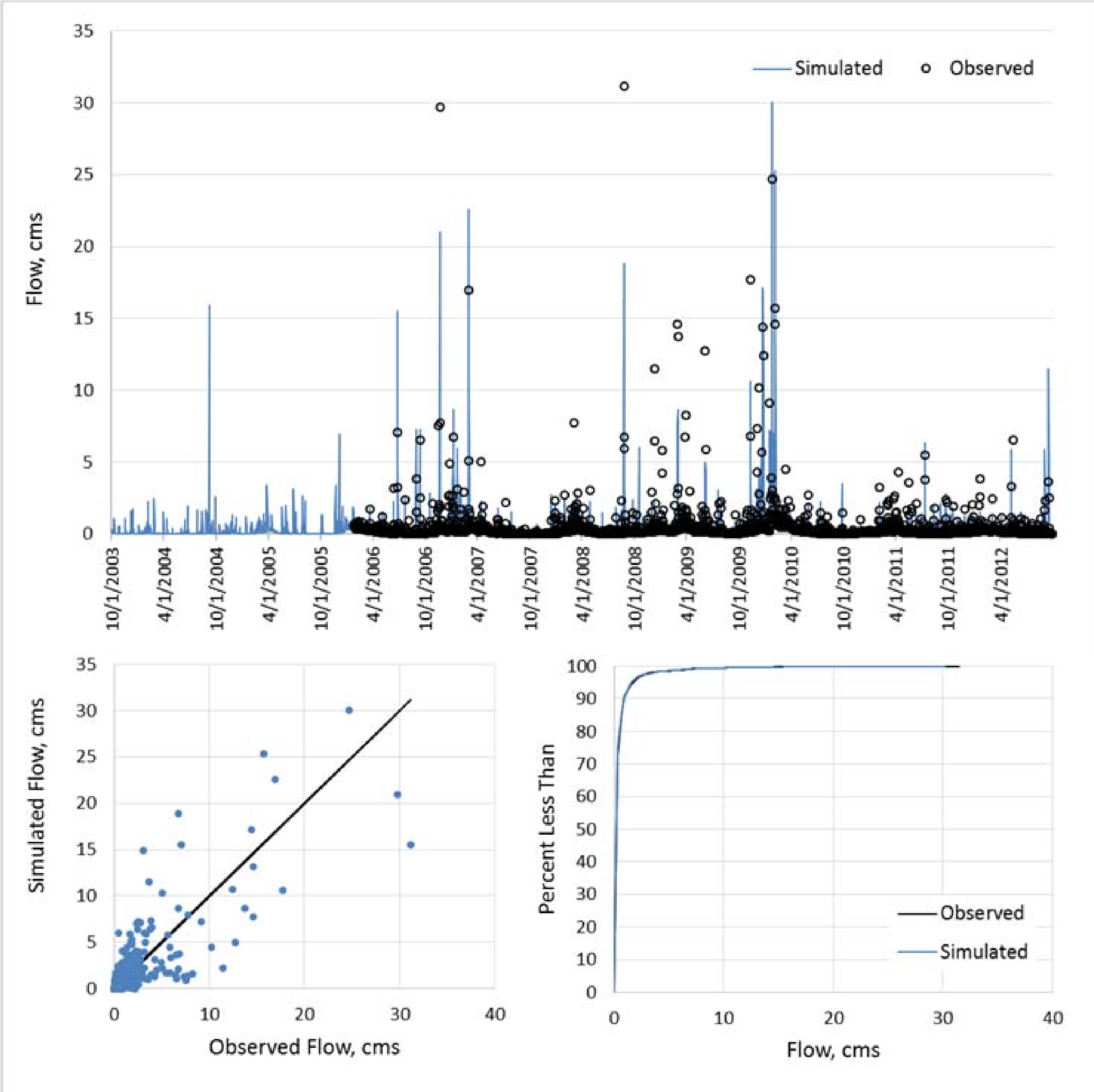

Figure 4-6 Hydrology simulation results, Wildcat Creek (USGS 21473428, WARMF ID 362)

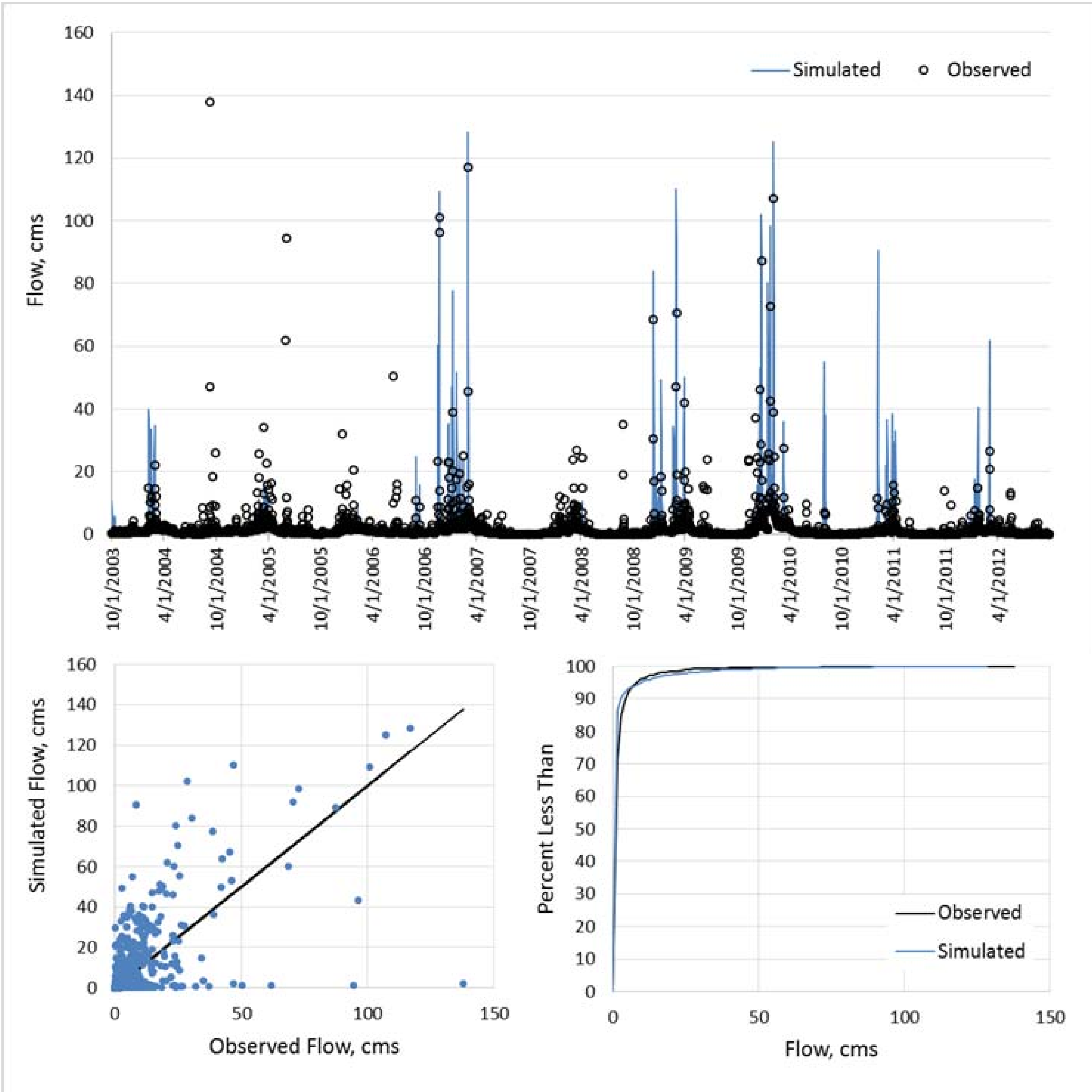

Figure 4-7 Hydrology simulation results, Rocky Creek at Great Falls (USGS 2147500, WARMF ID 551)

Table 4-1 Hydrology calibration statistics

Location	Observed Flow (cms)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21 USGS 2146000	8.8	1338.0	83.1	0.97	4.55	0.17	-4.5%	6.8%	13.41	0.98
Sugar Creek at SC-160 USGS 2146800	2.5	433.3	10.1	0.58	3.40	0.65	-3.4%	45.9%	14.27	0.59
Catawba R below Catawba, SC USGS 2147020	12.8	1153.0	100.5	0.91	7.46	0.30	-7.5%	15.7%	27.15	0.92
Waxhaw Creek USGS 2147126	0.0003	40.5	0.4	0.15	-7.29	0.92	7.3%	100.7%	1.60	0.44
Wildcat Creek USGS 21473428	0.001	31.1	0.5	0.66	10.44	0.59	-10.4%	58.8%	0.92	0.68
Rocky Creek at Great Falls USGS 2147500	0.0003	138.0	2.2	0.17	0.62	0.91	-0.6%	81.7%	6.18	0.46

Table 4-2 Hydrology performance criteria for the four tributary locations

	Performance Criteria							
Gaged Streams	Total Vol	Mean Flow	Total of highest 10% flows:	Total of lowest 50% flows:	Summer Vol	Fall Vol	Winter Vol	Spring Vol
Recommended Criteria	Percent Difference							
	10	10	10	15	30	30	30	30
Rocky Creek	-0.9	-0.9	19	-5.9	-26	-2.3	17	-137
Sugar Creek	-3.5	-3.5	-14	-7.8	2	-3	-9.5	-2.5
Waxhaw Creek	7.6	7.6	26	-48	-444	27	30	-215
Wildcat Creek	-12	-12	-8.7	-67	-1.2	-27	8.3	-53

The observed data plotted in each of the figures (Figure 4-2 through Figure 4-7) illustrate that the Catawba River and its tributaries can be characterized by relatively short lag time between the centroid of precipitation and peak hydrograph discharge, large peak discharge values, and short hydrograph recession times. Watersheds that exhibit these characteristics are often referred to as "flashy" in nature. A flashy hydrograph response to precipitation can be caused by natural topography, soils with either very high or low hydraulic conductivity characteristics, and/or large quantities of impervious land cover. A review of the State Soils Geographic Database (STATSGO) indicates that there is a significant amount of low-permeability soils located within Catawba River watershed between Lake Wylie and Lake Wateree. In addition, subcatchments that drain directly to the Catawba River, as well as Sugar Creek and

Cane Creek, have higher percentages of developed land within their boundaries. Urban watersheds with impervious surfaces and catchments with impermeable soils behave similarly to precipitation because precipitation cannot infiltrate into the soils. This results in increased overland flow producing storm hydrographs characterized by high peak discharge and short hydrograph duration. WARMF was calibrated to simulate these processes primarily by reducing vertical hydraulic conductivity of one or more soil layers. Additional changes to the soil layer thickness, horizontal hydraulic conductivity, soil saturation moisture content, and the distribution of vegetation roots in the different soil layers were made to increase maximum stream discharge and decrease the duration of the storm hydrograph.

The relative error statistics provided in Table 4-1 indicate that WARMF is simulating the total amount of stream discharge well. The relative error is 10% or less at each of the hydrology calibration locations. As previously mentioned, minimization of relative error was the primary objective of the hydrology calibration because simulation of the total quantity of water is an essential component of accurate nutrient and sediment load calculation. Absolute error is greater than the relative error in all cases though is still reasonable. Simulation errors (both absolute and relative) are generally greater for tributaries that for the main stem of the Catawba River. Flow in the Catawba River is dominated by releases from Lake Wylie which have been incorporated into the simulation, while flow in the tributaries is simulated from meteorology data and watershed runoff characteristics, both of which have considerable associated uncertainty. The density of the available meteorology network is low for a watershed this size. Several subwatersheds do not have a single meteorology station located within the subwatershed boundary (e.g. Rocky Creek, Waxhaw Creek). Thus data at the available stations may be a poor representation the actual precipitation occurring in those areas, particularly during the summer, when rainfall events are largely convective with high spatial variability. In addition, the smaller rural tributary subwatersheds have extended periods of very low and near zero flow. During very low flows, model and/or data error is far more pronounced than during higher flows and unaccounted seepage losses may become important. Due to the above factors, a better calibration is expected for the main stem locations than the tributary locations.

5 Water Quality Calibration Results

Water quality calibration was performed after the hydrologic calibration. As stated in the scope of work, the objective of this effort is to develop a watershed model capable of simulating temperature, dissolved oxygen, total suspended sediment, nutrients and algae in the Catawba River watershed between Lake Wylie and Lake Wateree. Given this objective the water quality calibration followed a certain order, reflecting the interdependence between water quality constituents (e.g. suspended sediment affects ammonia and ortho-phosphate). Generally, temperature and total suspended sediment were calibrated first, followed by nutrients (ammonia, phosphate, and nitrate). Following initial calibration of these water quality parameters, simulated algae (chlorophyll-a) concentrations in the Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir and Lake Wateree were calibrated by adjusting the reservoir algae growth, mortality rates, and optimum growth temperatures.

There are 85 locations in the Catawba River watershed between Lake Wylie and Lake Wateree where some water quality samples have been collected. The data were provided to Systech by SC DHEC, the North Carolina Department of Natural Resources, the Charlotte-Mecklenburg Utilities, Duke Energy, and Charlotte-Mecklenburg Storm Water Services (NC). The number of samples collected at each location ranges from a single sample for a single parameter to weekly samples of multiple constituents collected over many years. The locations of all of these stations are illustrated in Figure 5-1 as white dots. The locations that were the focus of water quality calibration are labeled in red text. These locations were selected from the larger set of water quality monitoring stations based the number of samples collected for each of the parameters of interest, as well as their geographic location within the watershed and dominant land use patterns (e.g. Rocky Creek is predominantly rural, while Sugar Creek is mostly urban). The following sections describe the calibration results for the water quality parameters of interest at the sites labeled in Figure 5-1. For each water quality parameter, the simulated results (blue lines) and observed data (black circles) are plotted together and presented from the most upstream station to the most downstream station.

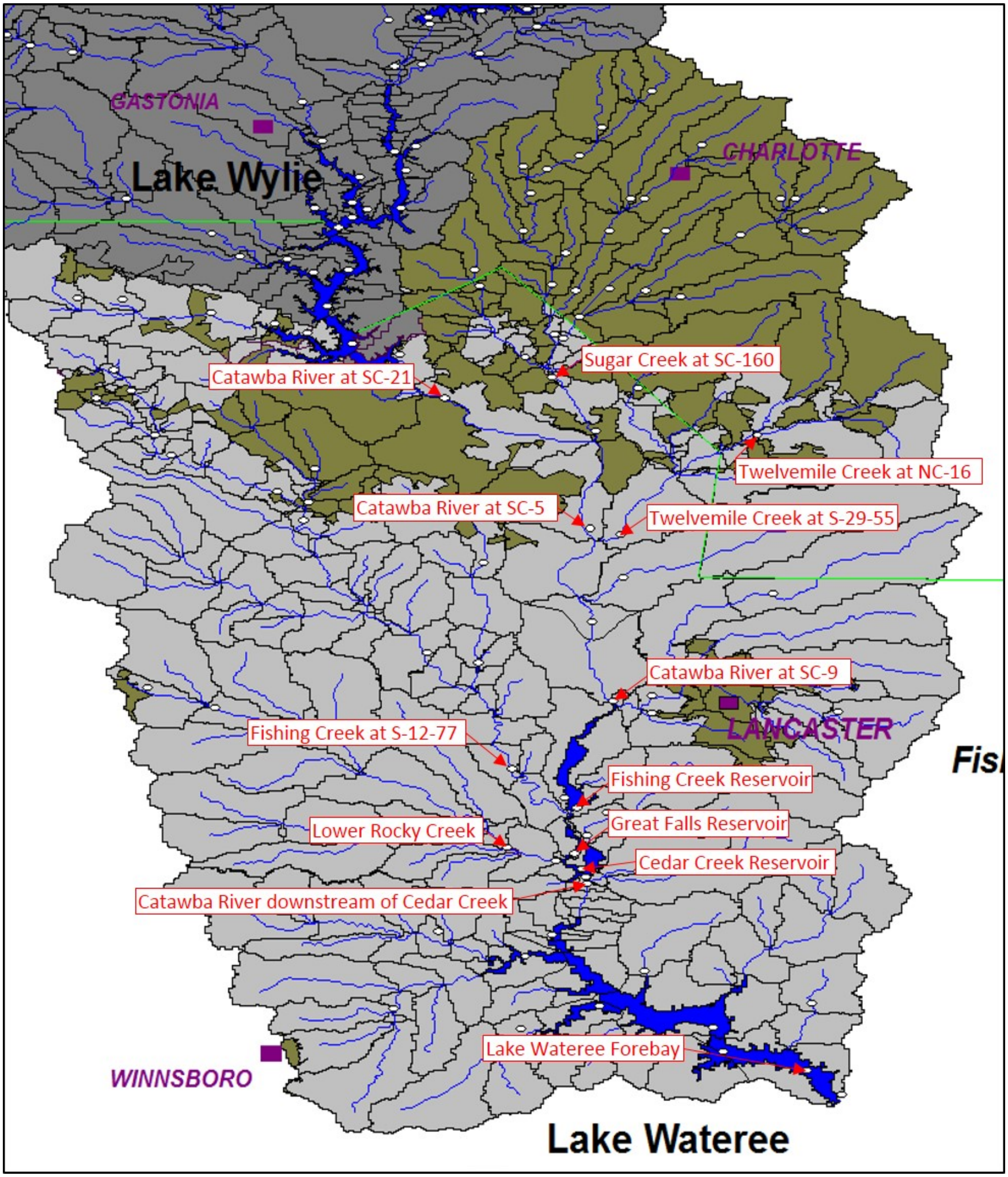

Figure 5-1 Catawba River WARMF water quality calibration locations

5.1 Temperature

Differences between observed and simulated water temperatures were analyzed at seven locations within the WARMF Catawba River model domain. From upstream to downstream, these locations include Catawba River at SC-21, Sugar Creek at SC-160, Catawba River at SC-5, Fishing Creek Reservoir, Fishing Creek near S-12-77, Lower Rocky Creek, Great Falls Reservoir, Cedar Creek Reservoir, Catawba River below Cedar Creek, and Lake Wateree Forebay. Figure 5-2 through Figure 5-11 show the time series of simulated and observed water temperature at the selected stations within the Lower Catawba River watershed. Each of these figures contains a time series plot of the simulated versus the observed data, a scatter plot of simulated versus observed temperature, and a plot of the frequency distribution of observed and simulated temperature. The figures illustrate that the WARMF model temperature simulation is accurately tracking the observed seasonal variations of water temperature during the simulation time period (water years 2004-2012).

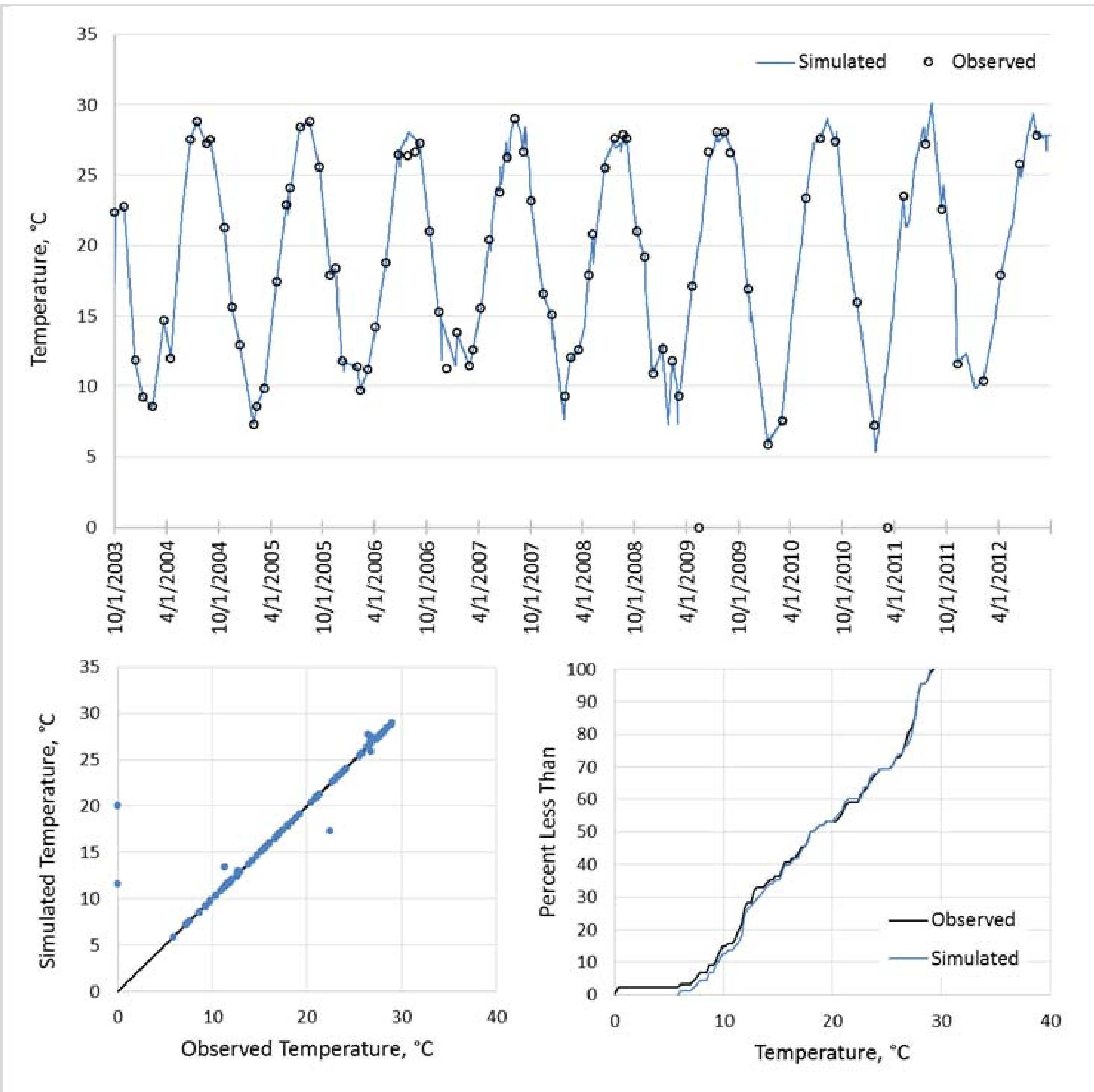

Figure 5-2 Temperature simulation results, Catawba River at SC-21 (WARMF ID 89)

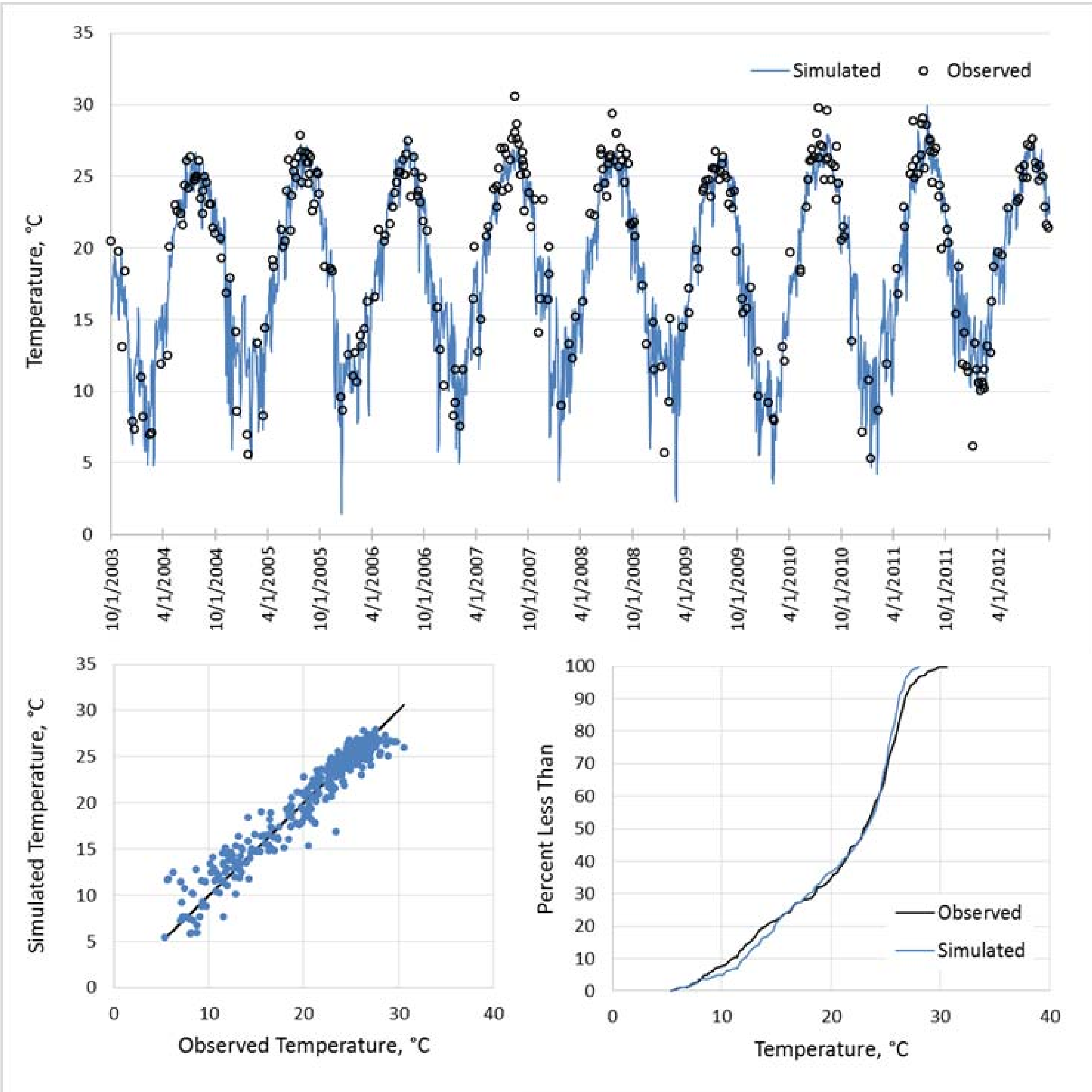

Figure 5-3 Temperature simulation results, Sugar Creek at SC-160 (WARMF ID 246)

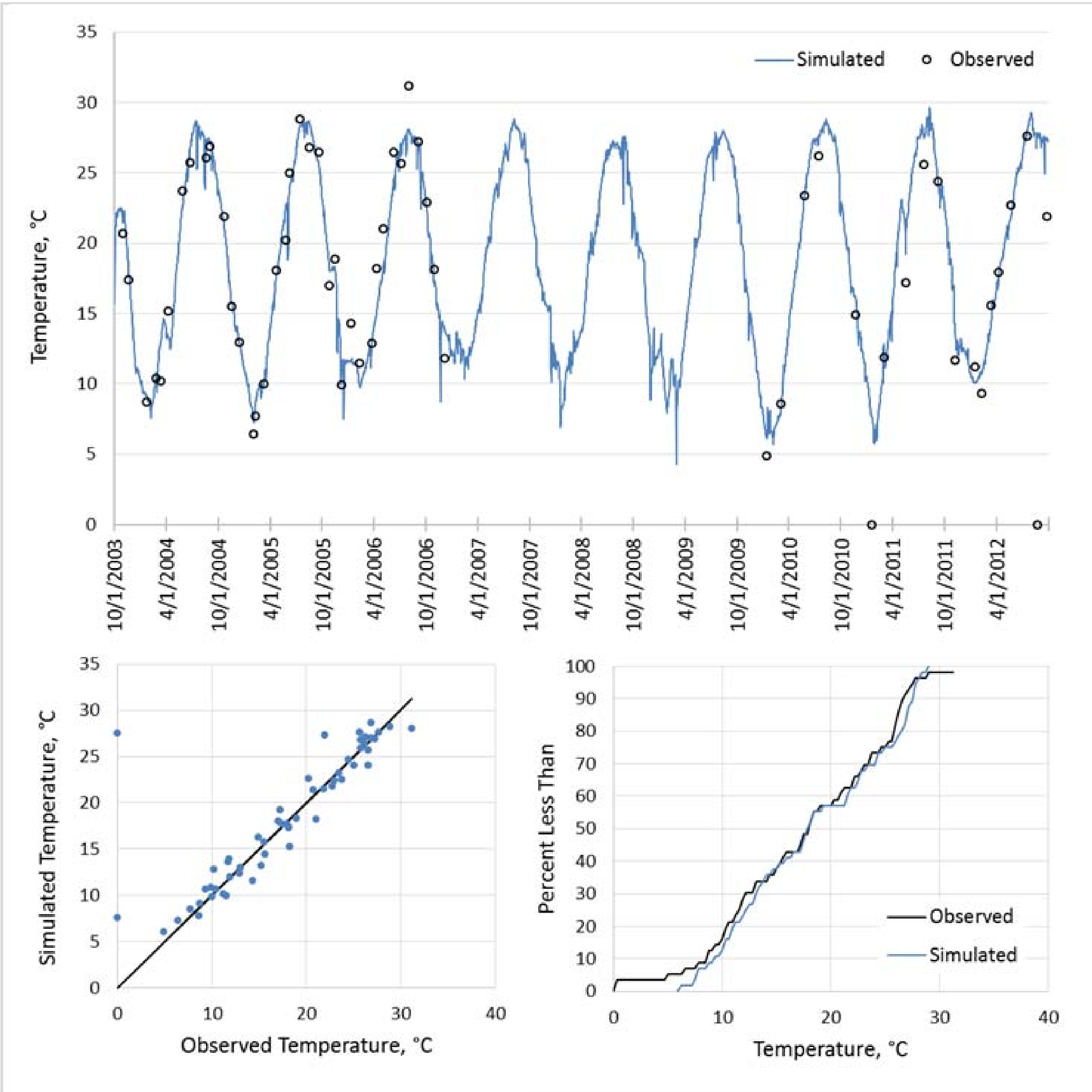

Figure 5-4 Temperature simulation results, Catawba River at SC-5 (WARMF ID 69)

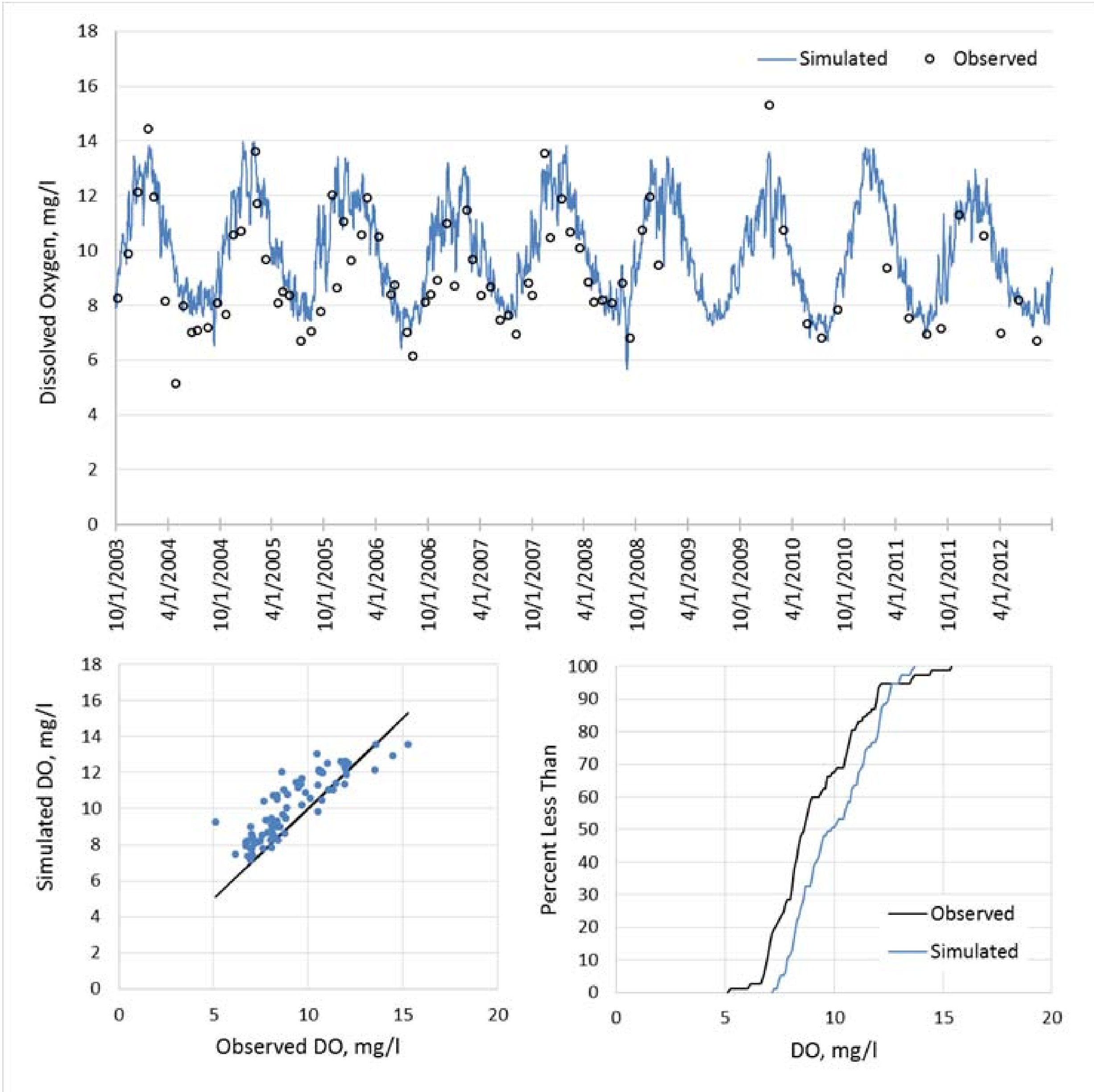

Figure 5-5 Temperature simulation results, Fishing Creek near S-12-77 (WARMF ID 149)

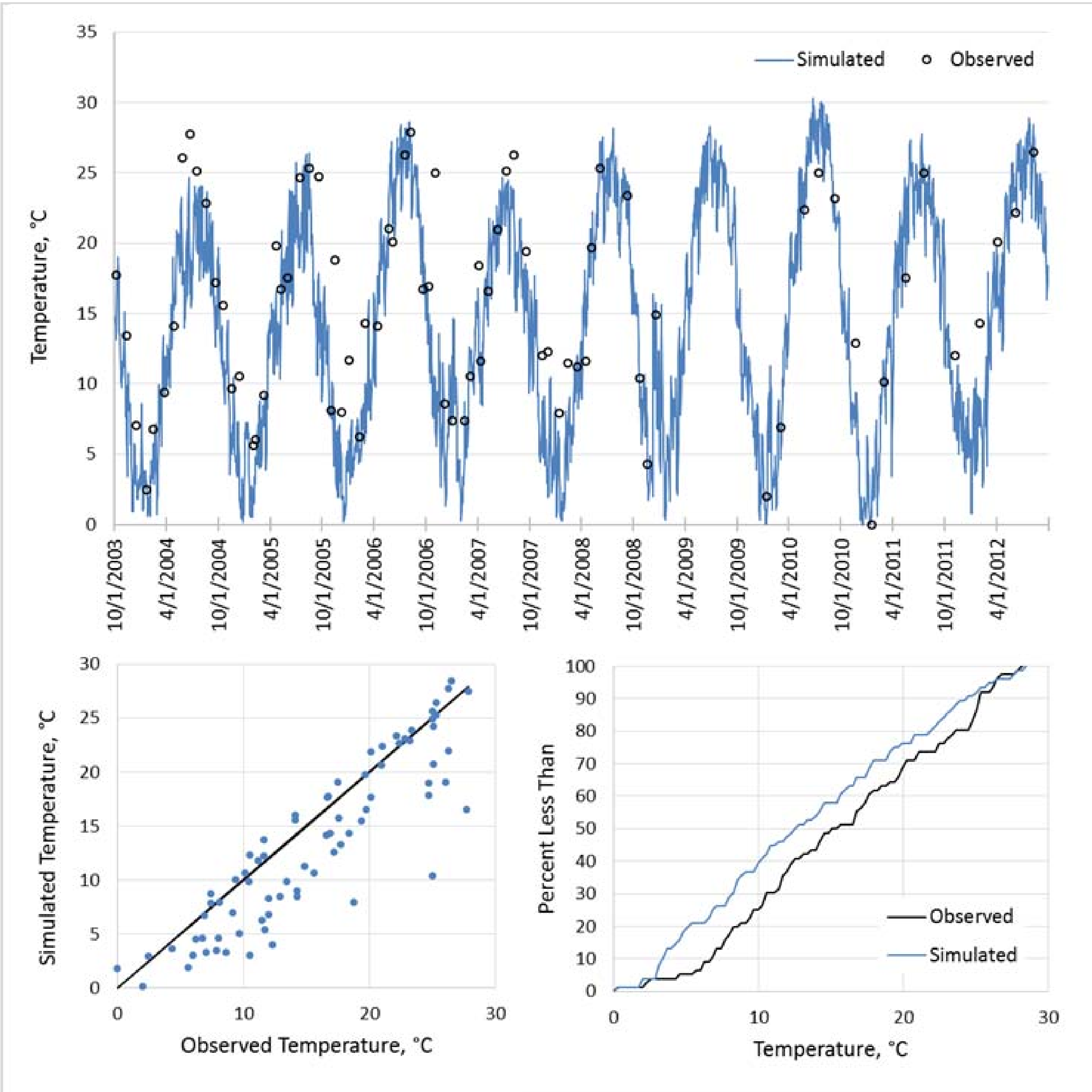

Figure 5-6 Temperature simulation results, Lower Rocky Creek (WARMF ID 160)

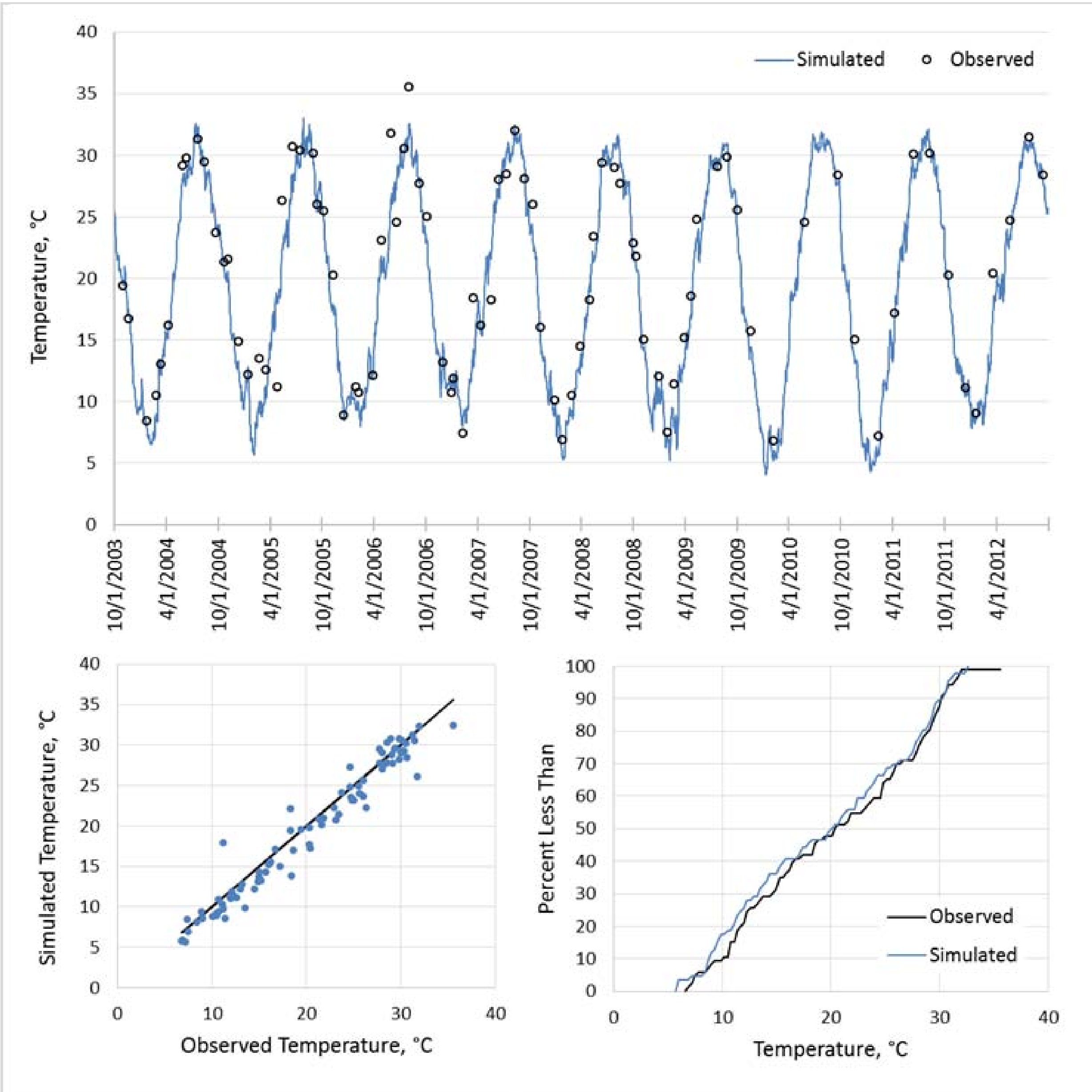

Figure 5-7 Temperature simulation results, Fishing Creek Reservoir (WARMF ID 1562)

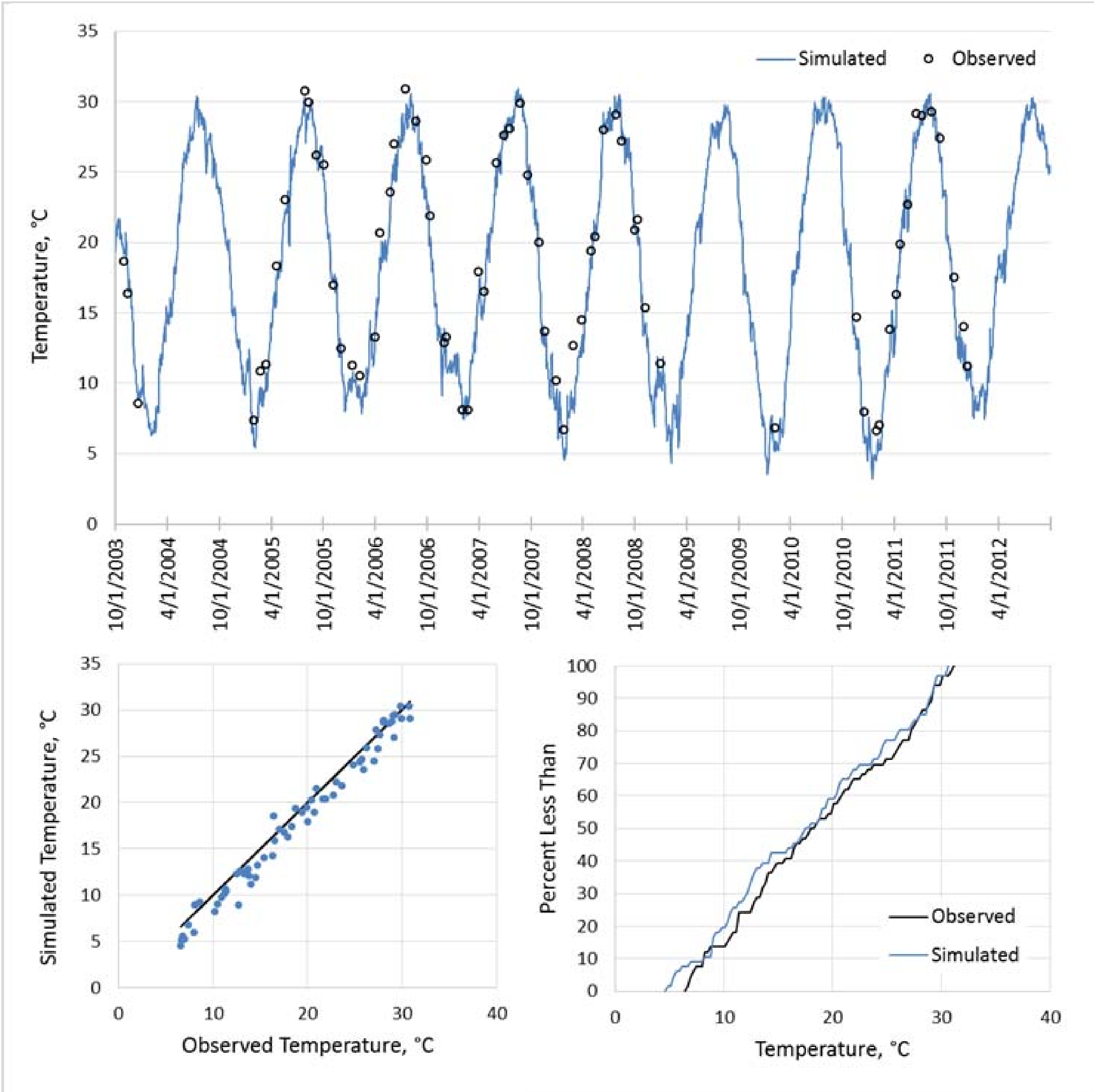

Figure 5-8 Temperature simulation results, Great Falls Reservoir (WARMF ID 1563)

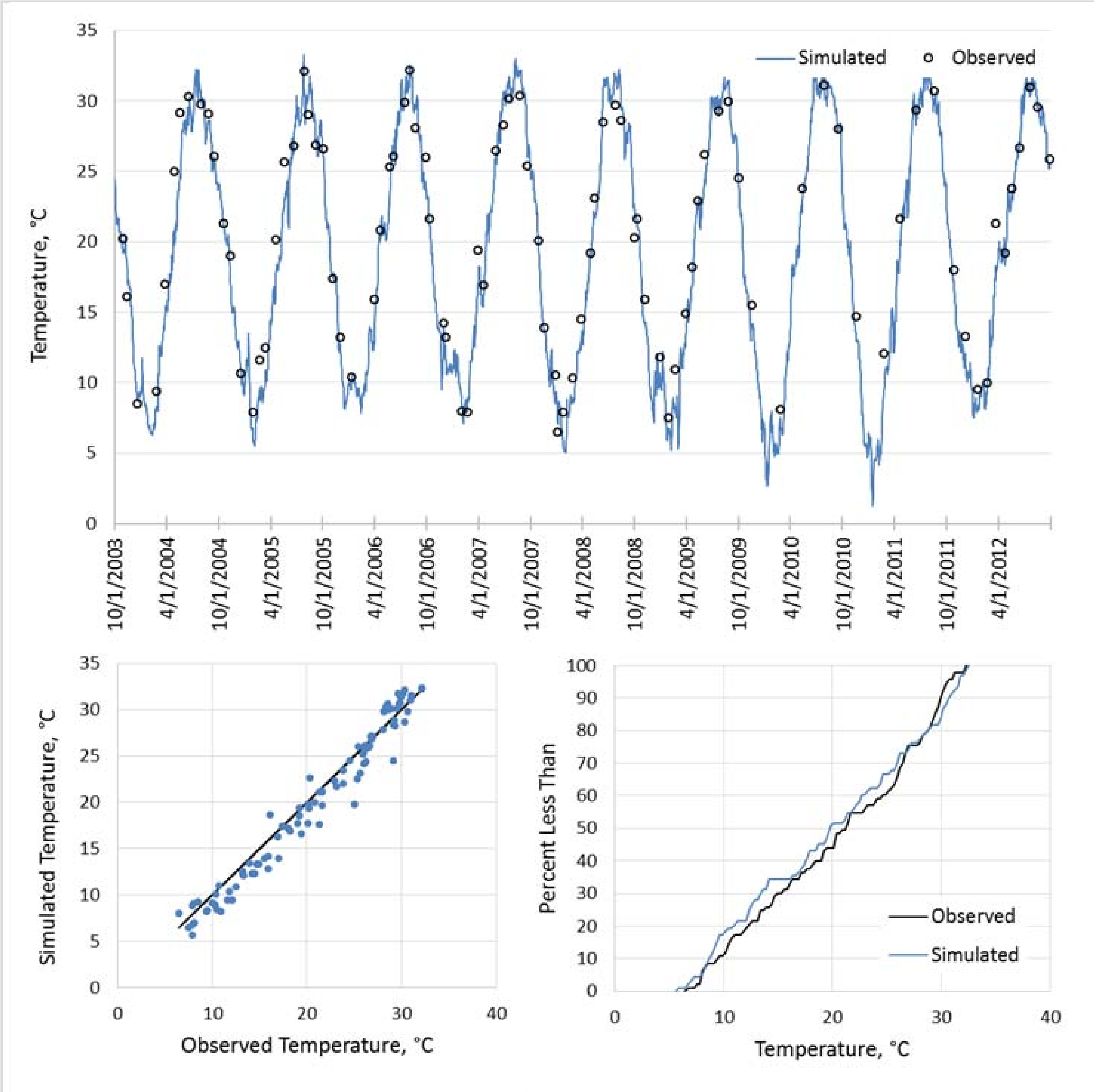

Figure 5-9 Temperature simulation results, Cedar Creek Reservoir (WARMF ID 1567)

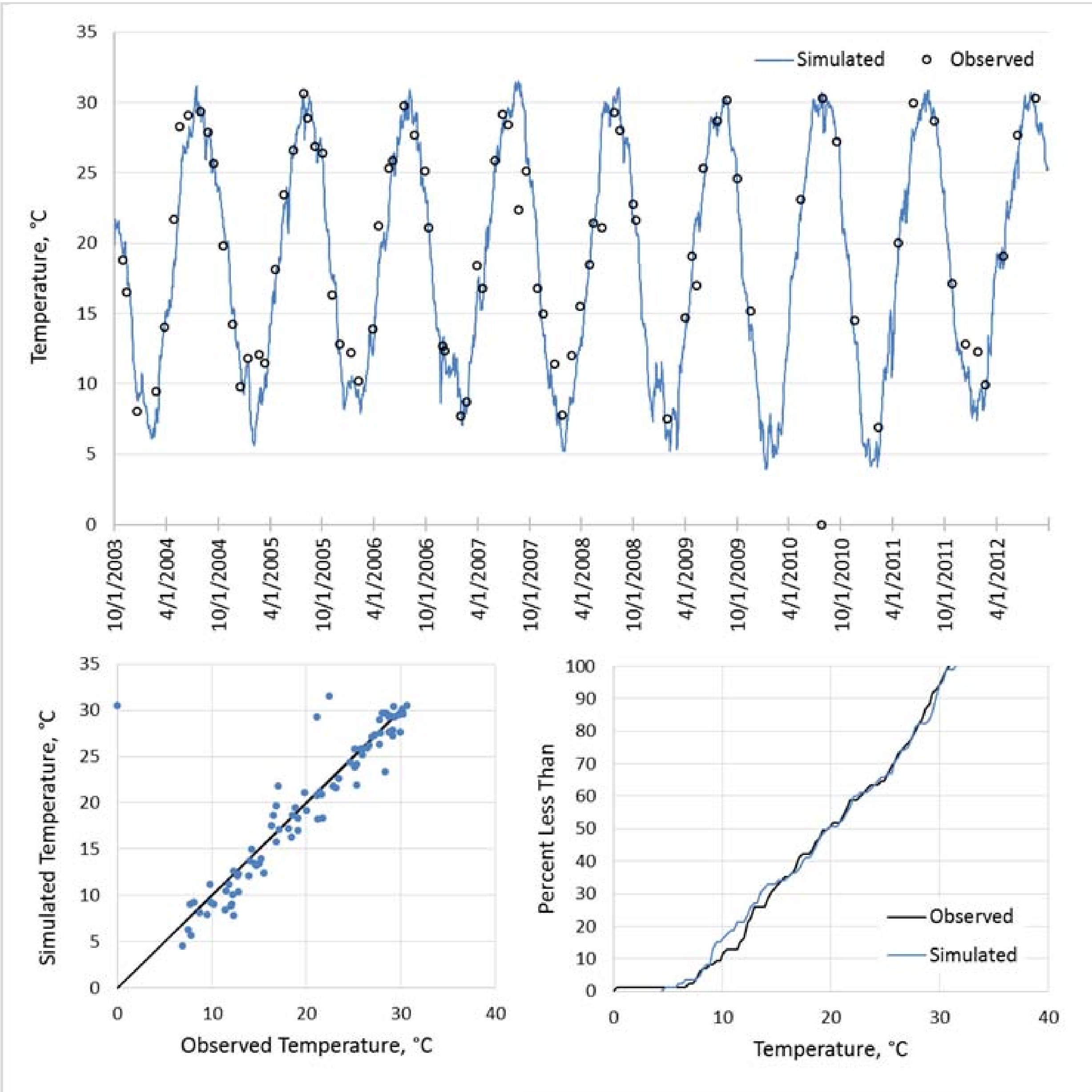

Figure 5-10 Temperature simulation results, Catawba River below Cedar Creek (WARMF ID 624)

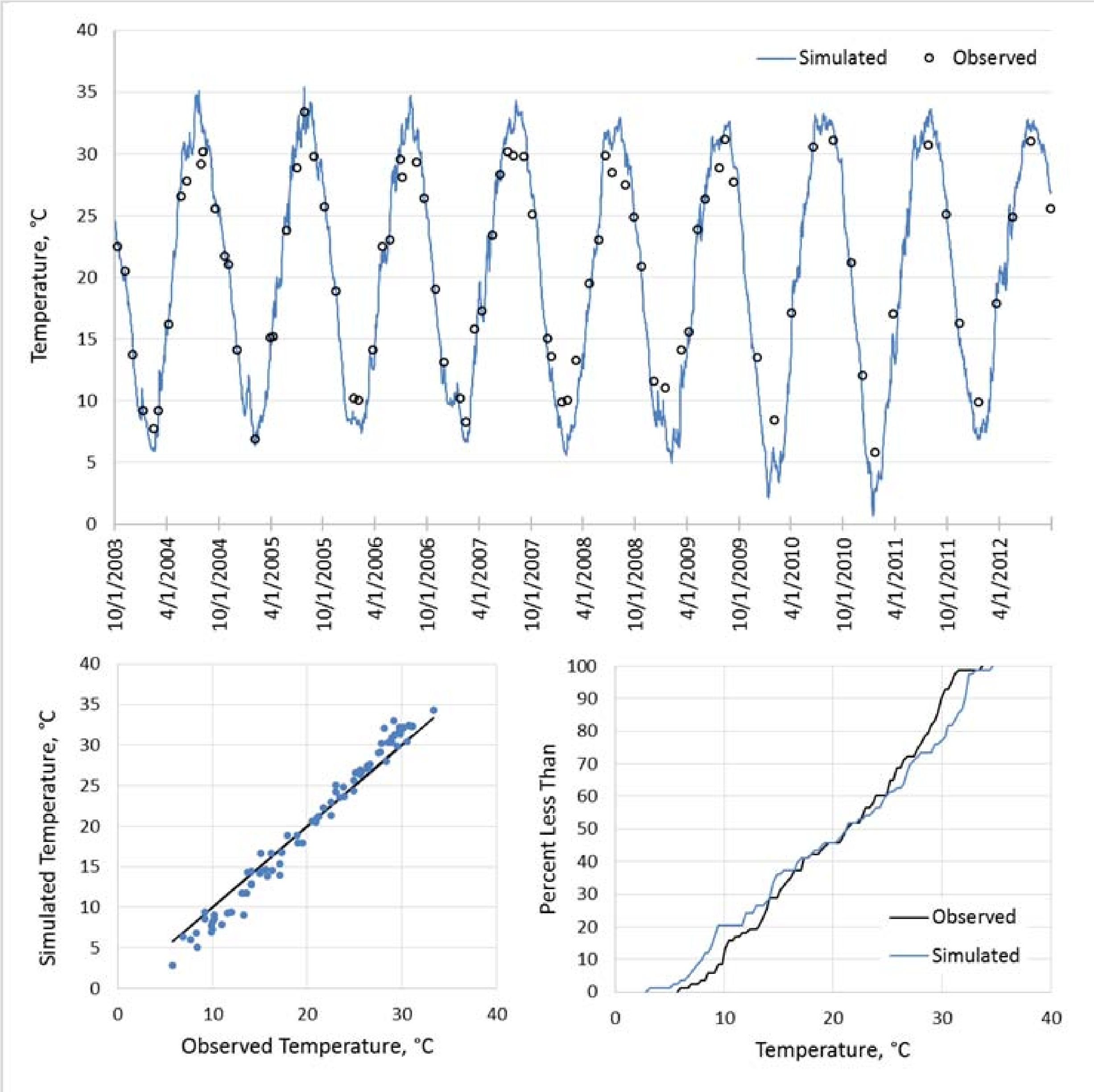

Figure 5-11 Temperature simulation results, Lake Wateree Forebay (WARMF ID 2292)

Table 5-1 provides a summary of temperature calibration statistics for the specified locations. As previously mentioned, the primary goal of calibration was to minimize the relative error. At each location, relative and absolute errors are less than 20% indicating that the WARMF model is simulating temperature in tributaries to the Catawba River, the main stem of the Catawba River, and in the reservoirs with a high degree of accuracy and precision. The relative error is negative at each location where simulation results were compared with observed data, indicating that there is a very slight (< 1°C) systematic under-prediction of water temperature. The discrepancy between simulated and observed temperature may be related to the distribution of land cover within the watersheds, urban runoff,

runoff partitioning between surface and soil flow, non-uniform variability of air temperature between meteorology stations, or other factors.

Table 5-1 Temperature calibration statistics

Location	Observed data (°C)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	5.9	29.0	19.0	0.99	0.09	0.09	-0.1%	0.8%	0.63	0.99
Sugar Creek at SC-160	5.3	30.6	20.8	0.93	0.14	0.27	-0.1%	5.9%	1.64	0.93
Catawba River at SC-5	4.9	31.2	18.3	0.95	-0.54	0.23	0.5%	6.3%	1.55	0.95
Fishing Creek at S-12-77	2.0	28.0	16.8	0.74	13.44	0.51	-13.4%	15.6%	3.59	0.86
Lower Rocky Creek	2.0	27.9	15.8	0.66	14.49	0.58	-14.5%	18.9%	4.11	0.80
Fishing Creek Reservoir	6.8	35.6	20.3	0.95	3.78	0.23	-3.8%	6.8%	1.83	0.96
Great Falls Reservoir	6.6	30.9	18.6	0.97	4.67	0.18	-4.7%	6.2%	1.38	0.98
Cedar Creek Reservoir	6.5	32.2	20.5	0.95	3.21	0.21	-3.2%	6.3%	1.63	0.97
Catawba River below Cedar Creek	6.9	30.6	19.9	0.91	2.29	0.30	-2.3%	7.5%	2.16	0.93
Lake Wateree Forebay	5.8	33.4	20.5	0.95	0.07	0.22	-0.1%	6.9%	1.69	0.99

5.2 Total Suspended Sediment

Total suspended sediment (TSS) data are available in varying quantity at Sugar Creek at SC-160, Catawba River at SC-5, Twelvemile Creek at NC-16, Twelvemile Creek at S-29-55, Catawba River at SC-9, and Catawba River below Cedar Creek. Calibration and subsequent evaluation of model performance are limited for TSS by several factors. Mostly notably, the quantity of data available is very low in both number and distribution of samples. In most locations with data, few if any samples of high concentrations were available. This severely limited the potential for calibrating sediment concentrations resulting from land surface erosion and transport during larger rainfall events. Further, since rainfall intensity greatly impacts erosion rates, modeling at a daily time step inherently limits the TSS calibration. In general, when the number and range of values available in the observed data is low, statistical measures of model performance are not an appropriate means to evaluate the model performance (Moriasi, 2007). Calibration of TSS thus relied entirely on visual inspection of the simulated versus observed time series plots. Since very little information was present in the data to guide calibration of peak flow concentrations, the primary focus was on calibration of base flow concentrations while attempting to maintain a reasonable range of mid to higher concentrations based on individual data points where possible. Low flow conditions are the periods when nutrient concentrations stemming from point source loads are highest (due to less dilution). Thus the quality of the low flow sediment calibration is important for ensuring that reasonable partitioning occurs between dissolved and adsorbed phases of constituents from point sources. The results of the WARMF TSS calibration are presented graphically in Figure 5-12 through Figure 5-17. Statistics were also calculated and are presented in Table 5-2 by request and for consistency with other parameters. However the statistics were not used to guide calibration.

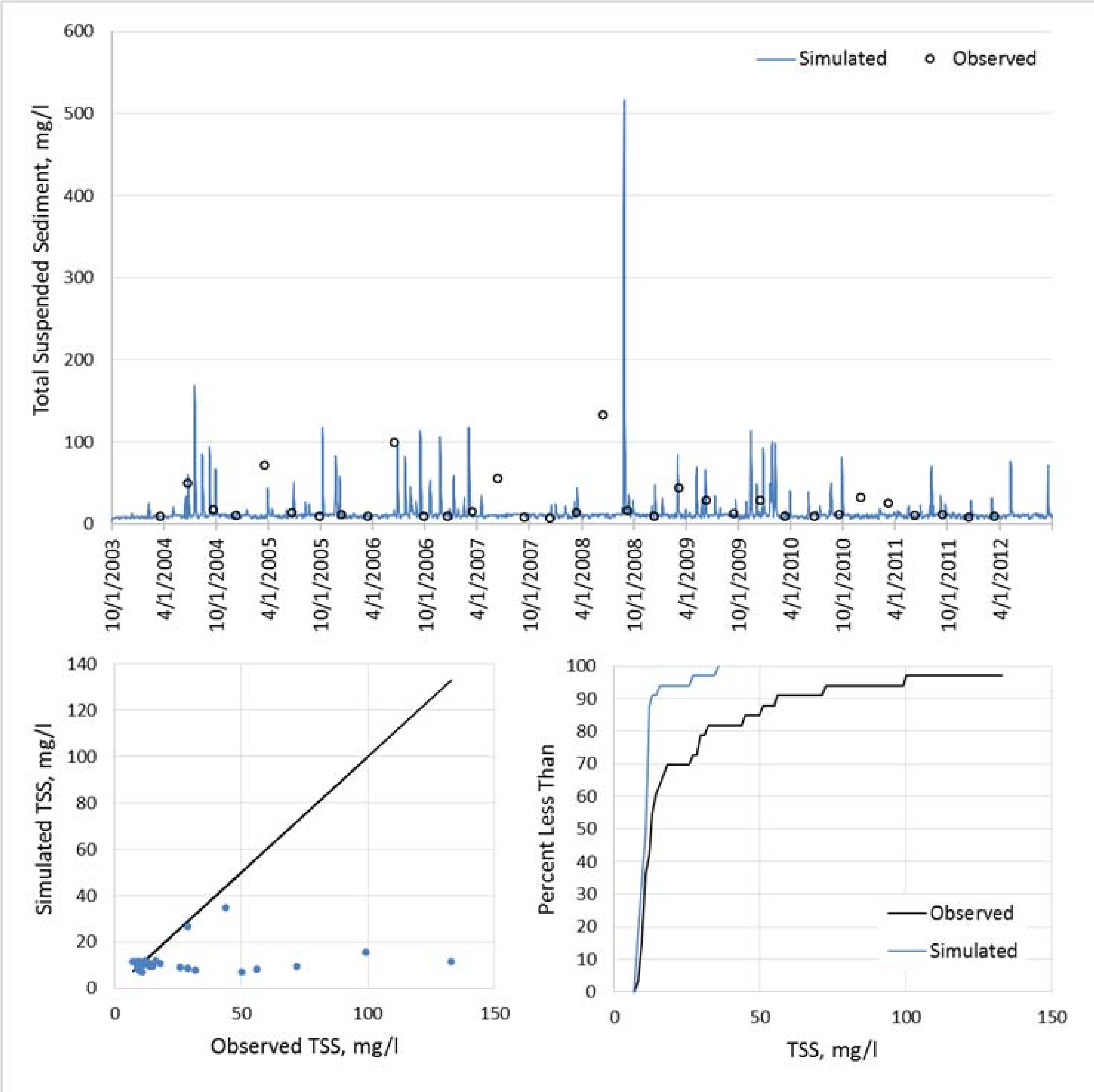

Figure 5-12 TSS simulation results, Sugar Creek at SC-160 (WARMF ID 246)

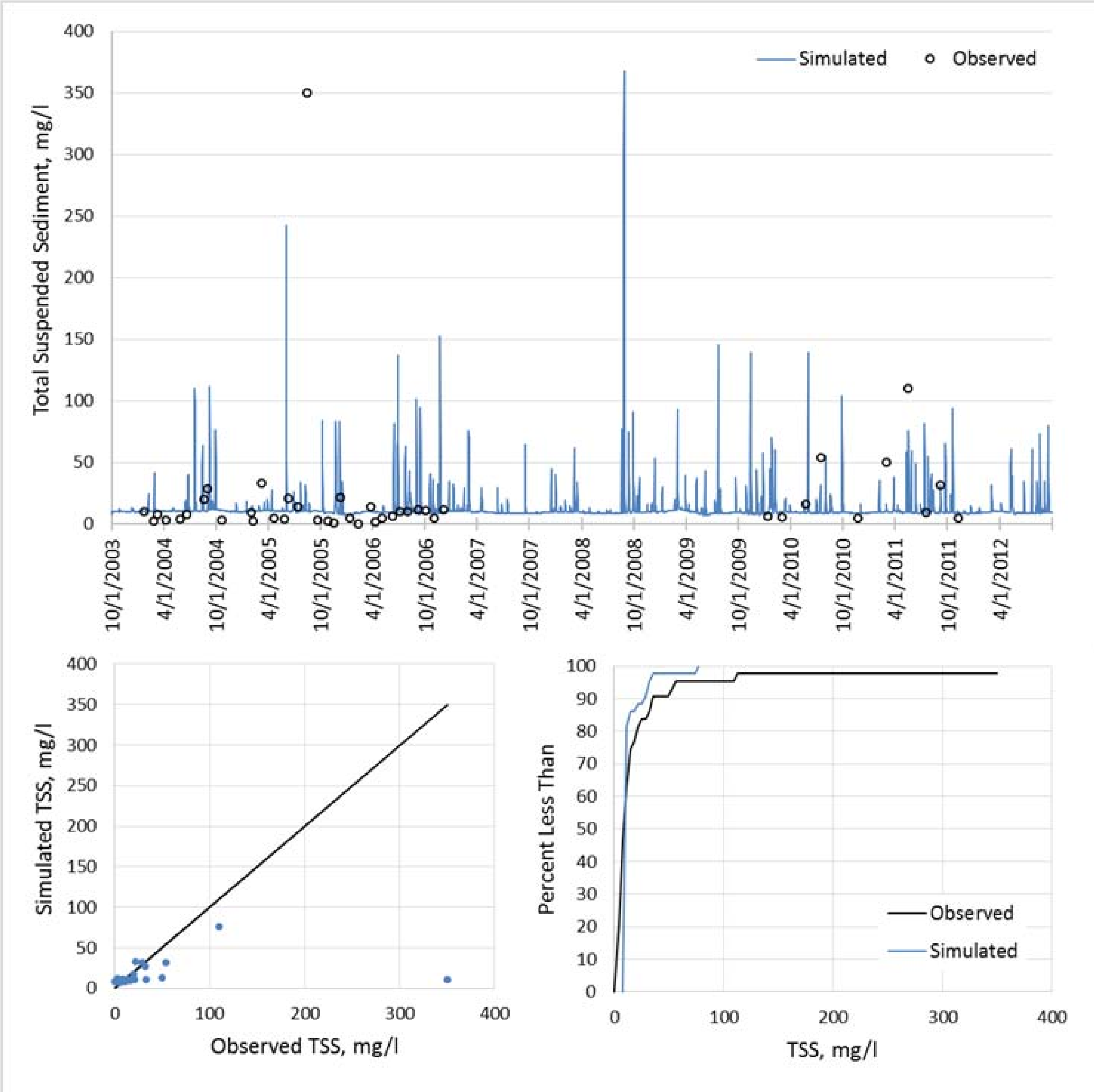

Figure 5-13 TSS simulation results, Catawba River at SC-5 (WARMF ID 69)

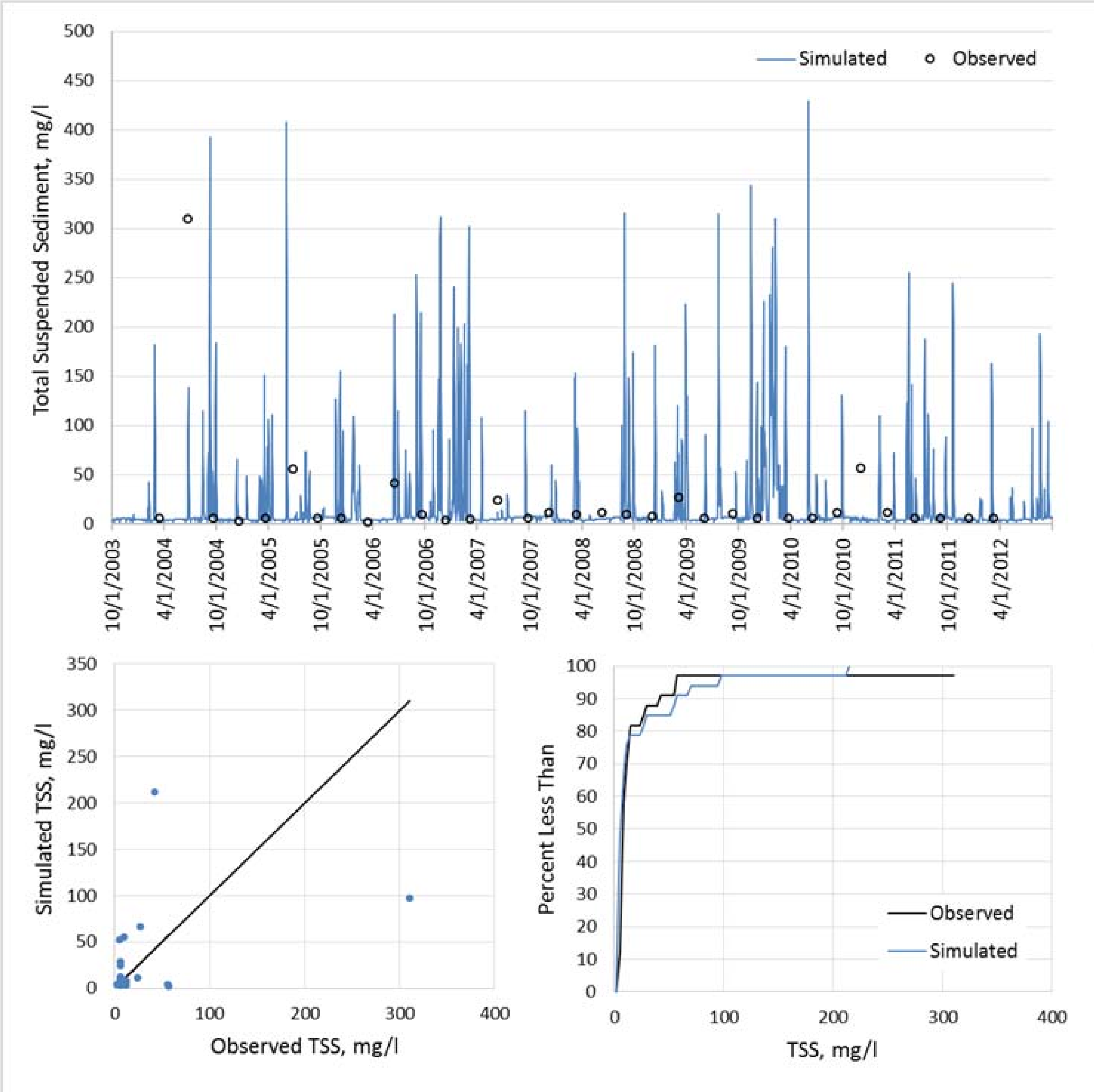

Figure 5-14 TSS simulation results, Twelvemile Creek at NC-16 (WARMF ID 1097)

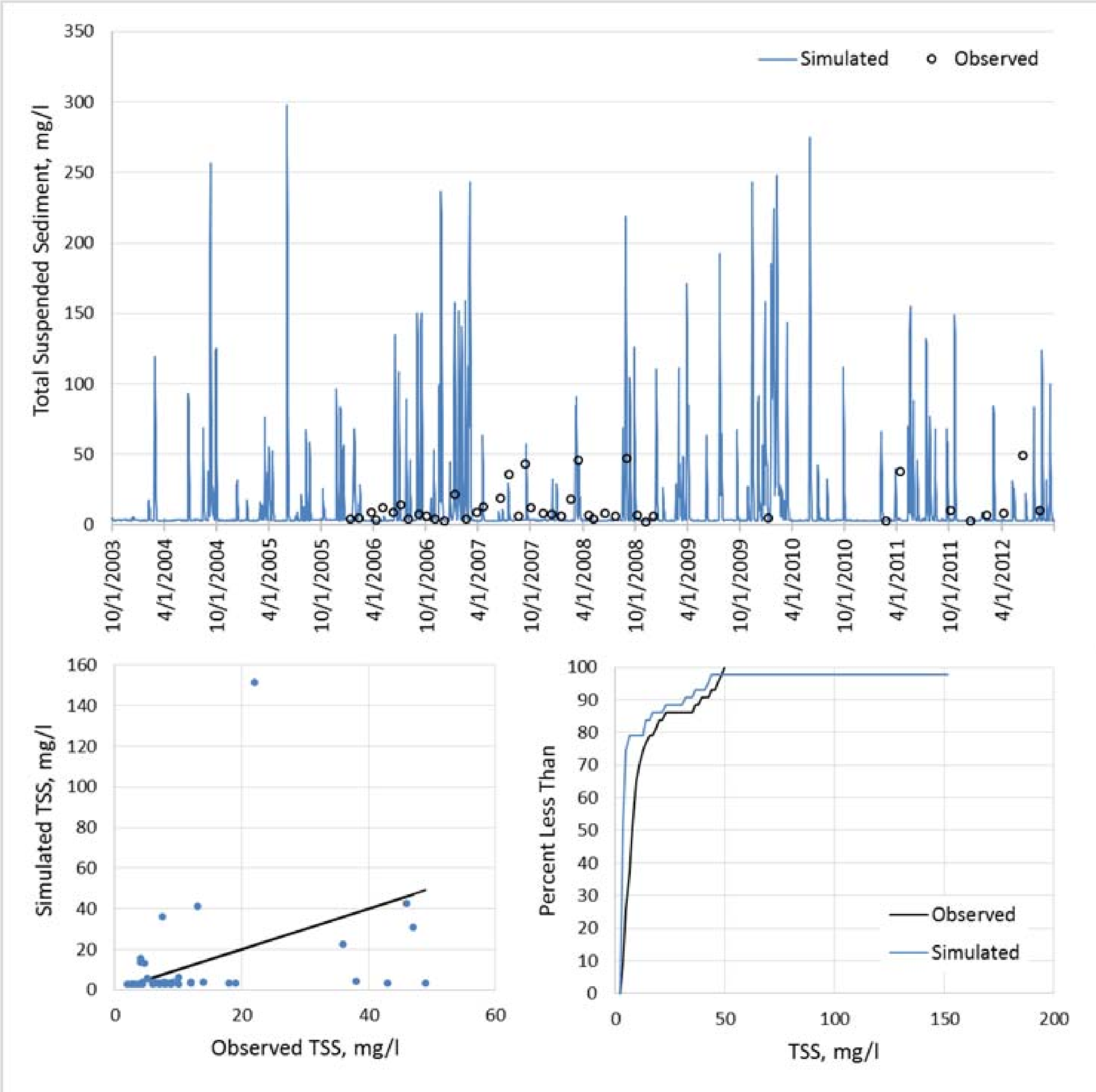

Figure 5-15 TSS simulation results, Twelvemile Creek at S-29-55 (WARMF ID 18)

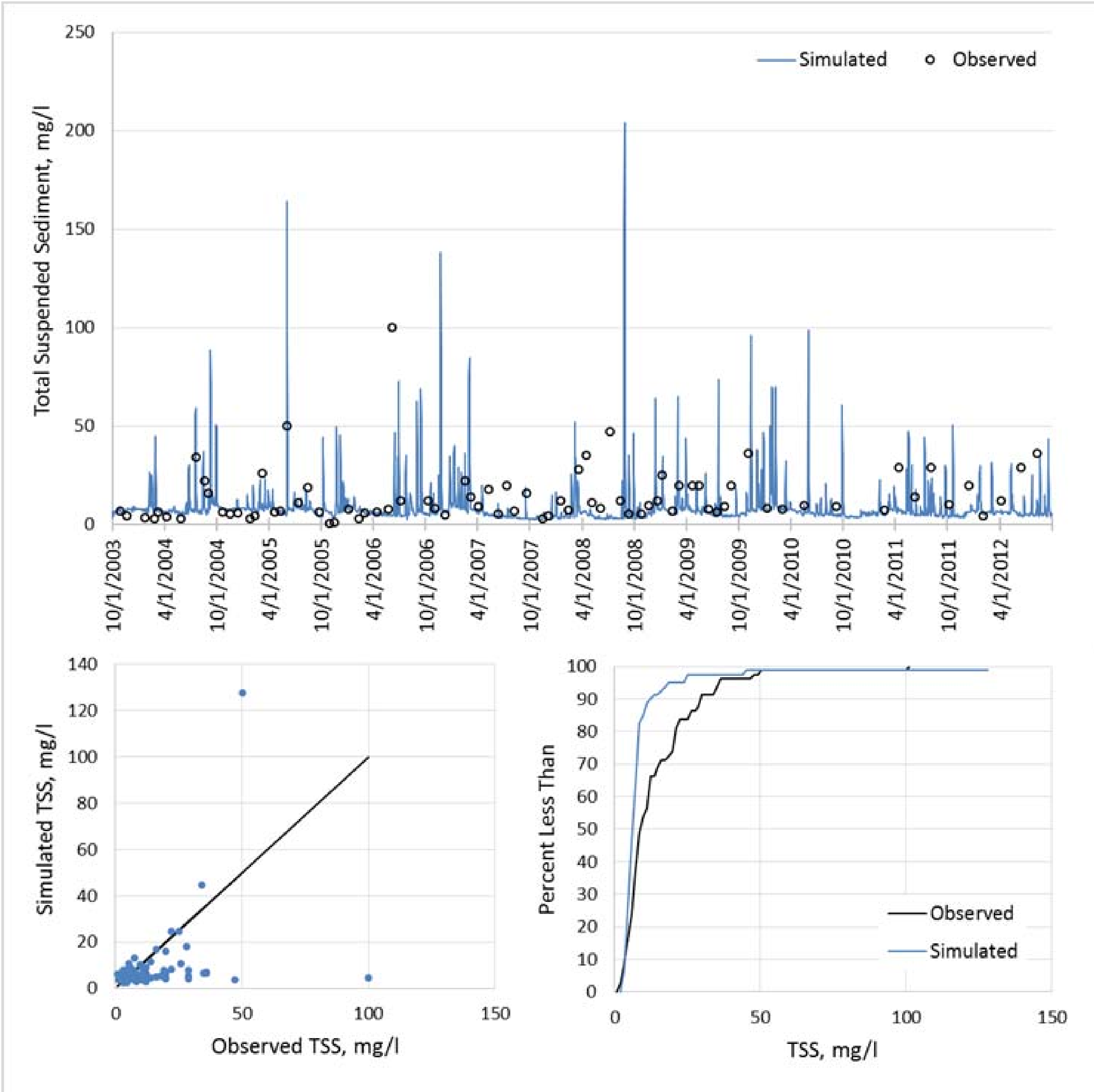

Figure 5-16 TSS simulation results, Catawba River at SC-9 (WARMF ID 48)

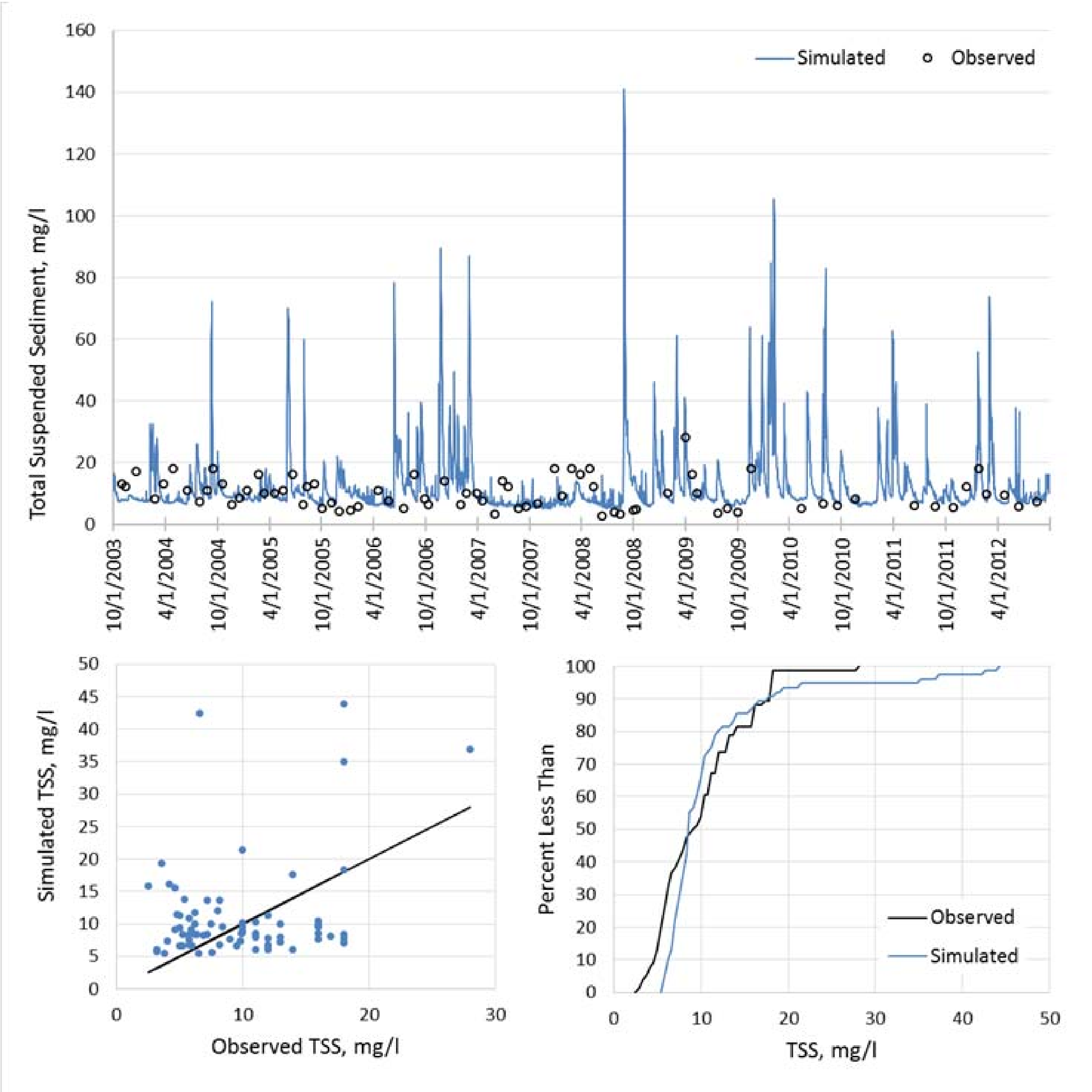

Figure 5-17 TSS simulation results, Catawba River below Cedar Creek (WARMF ID 624)

Table 5-2 Total suspended sediment calibration statistics

Location	Observed data (mg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Sugar Creek at SC-160	7.3	133	25.1	-0.21	55.0	1.1	-55.0%	59.0%	30.83	0.03
Catawba River at SC-5	0.5	350	21.9	0.03	41.6	1.0	-41.6%	67.6%	53.34	0.06
Twelvemile Creek at NC-16	2.5	310	21.6	0.05	3.5	1.0	-3.5%	104.5%	51.39	0.17
Twelvemile Creek at S-29-55	2	49	12.9	-2.42	12.4	1.8	-12.4%	91.2%	24.11	0.07
Catawba River at SC-9	0.8	100	14.2	-0.52	40.6	1.2	-40.6%	65.0%	17.55	0.11
Catawba River below Cedar Creek	2.5	28	9.8	-1.53	-12.2	1.6	12.2%	55.7%	7.86	0.08

5.3 Nitrate-Nitrogen

Model simulations of nitrate-N were evaluated and compared to observed data at seven locations in the watershed. These locations exemplify results for the main stem of the Catawba River, for tributaries including Sugar Creek, Rocky Creek and Fishing Creek, and for the four reservoirs. Figure 5-18 through Figure 5-27 demonstrate the comparison of simulated and observed nitrate-N at these locations. Associated calibration statistics are listed in Table 5-3. Overall the model performs well for simulations of nitrate from the Lake Wylie boundary to Fishing Creek Reservoir. At the Catawba River downstream of the Lake Wylie and Sugar Creek at SC-160, the simulated closely matches the observed and both relative and absolute errors are low. At the next downstream comparison location, the Catawba River at SC-5, visual inspection shows a good match, though the statistical errors are higher than the previous two locations. The observed data is sparse in this location and might not capture the lower end of the oscillating pattern that is clearly seen upstream in the Sugar Creek data, thus causing the statistics to show an artificially large negative relative error.

In the two west side tributaries – Fishing and Rocky Creeks – nitrate simulations are high for much of the simulation. However the periods of most significant over-simulation occur during very low to near zero flow. A comparison between upstream point source releases in Rocky Creek and downstream data during the lowest flow periods (e.g. Fall 2007) indicate the stream losses are occurring (i.e., point source releases are greater than measured flow at the downstream gage). Thus it is possible that outflow from the soil, which is low in nitrate and would further dilute the in-stream concentrations, was underestimated during hydrology calibration (i.e. without information on channel losses, observed data indicated low to zero baseflow). In addition, it's been shown that denitification occurs at a higher rate during low flows conditions (Alexander, et al., 2009), which is not captured within the model dynamics. Given that the largest error occurs during low flow conditions, a test was performed to check the sensitivity of downstream simulations to error in Rocky and Fishing Creeks' simulations. To do this, simulated flow and water quality were replaced during the simulation by interpolated observed data at Rocky Creek and Fishing Creek (for the latter only water quality was available and used to replace simulations). The resulting change in nitrate concentrations in the reservoirs downstream was very minimal, as shown in Figure 5-28. The same minimal sensitivity was found for all constituents, for which results are included in Appendix A. Thus for current modeling objectives additional effort to improve nitrate simulations in Rocky and Fishing Creek is not warranted.

Given the very minimal impact of Rocky and Fishing Creeks on the reservoir simulations described above, the calibration in Fishing Creek Reservoir indicates how well the model is accounting for the majority of the nutrient loads entering the reservoir system from the major upstream river reaches (i.e., from the major tributaries and the main stem Catawba River). Calibration results for nitrate in Fishing Creek Reservoir are very good in both visual inspection and in the calculated model statistics. Thus the model is capturing upstream loads well. The model is somewhat over-predicting nitrate in the other three reservoirs below Fishing Creek. However the overall trends and reduction in nitrate moving downstream through the reservoir system are simulated well. Some distinct short periods of over-simulation at Lake Wateree may be due to an underestimation of algae growth during cooler months, as will be discussed further in Section 1065.8.

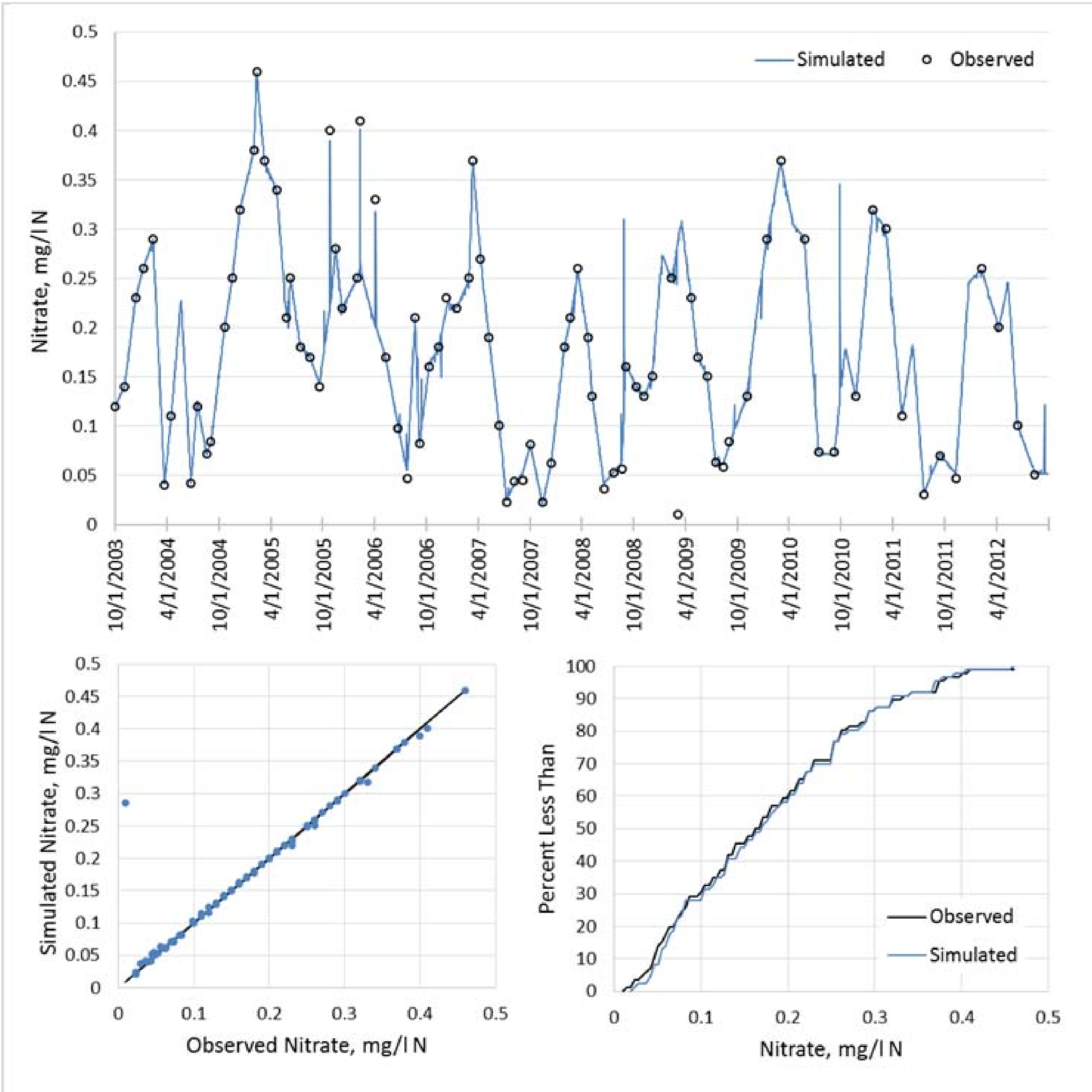

Figure 5-18 Nitrate-Nitrogen simulation results, Catawba River at SC-21 (WARMF ID 89)

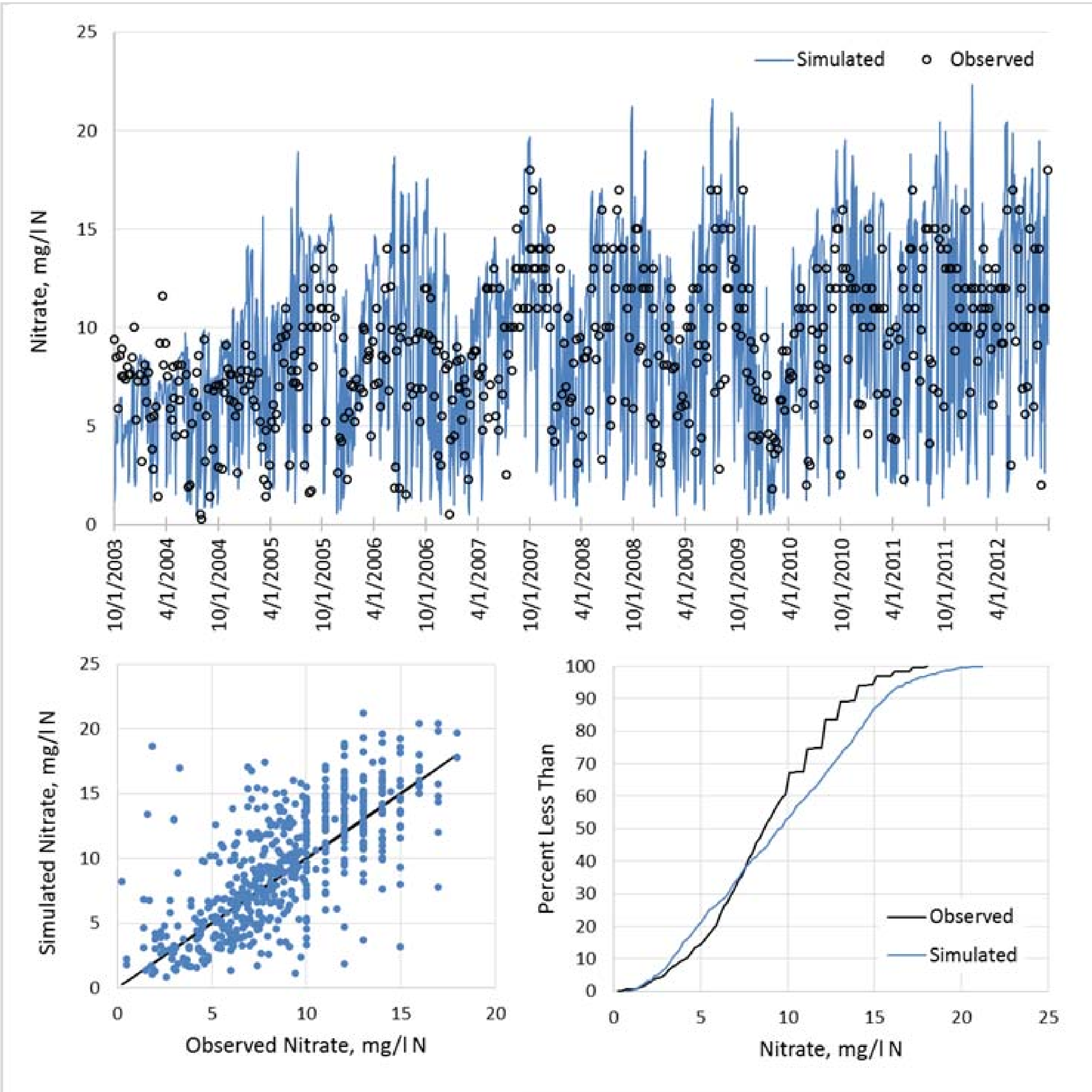

Figure 5-19 Nitrate-Nitrogen simulation results, Sugar Creek at SC-160 (WARMF ID 246)

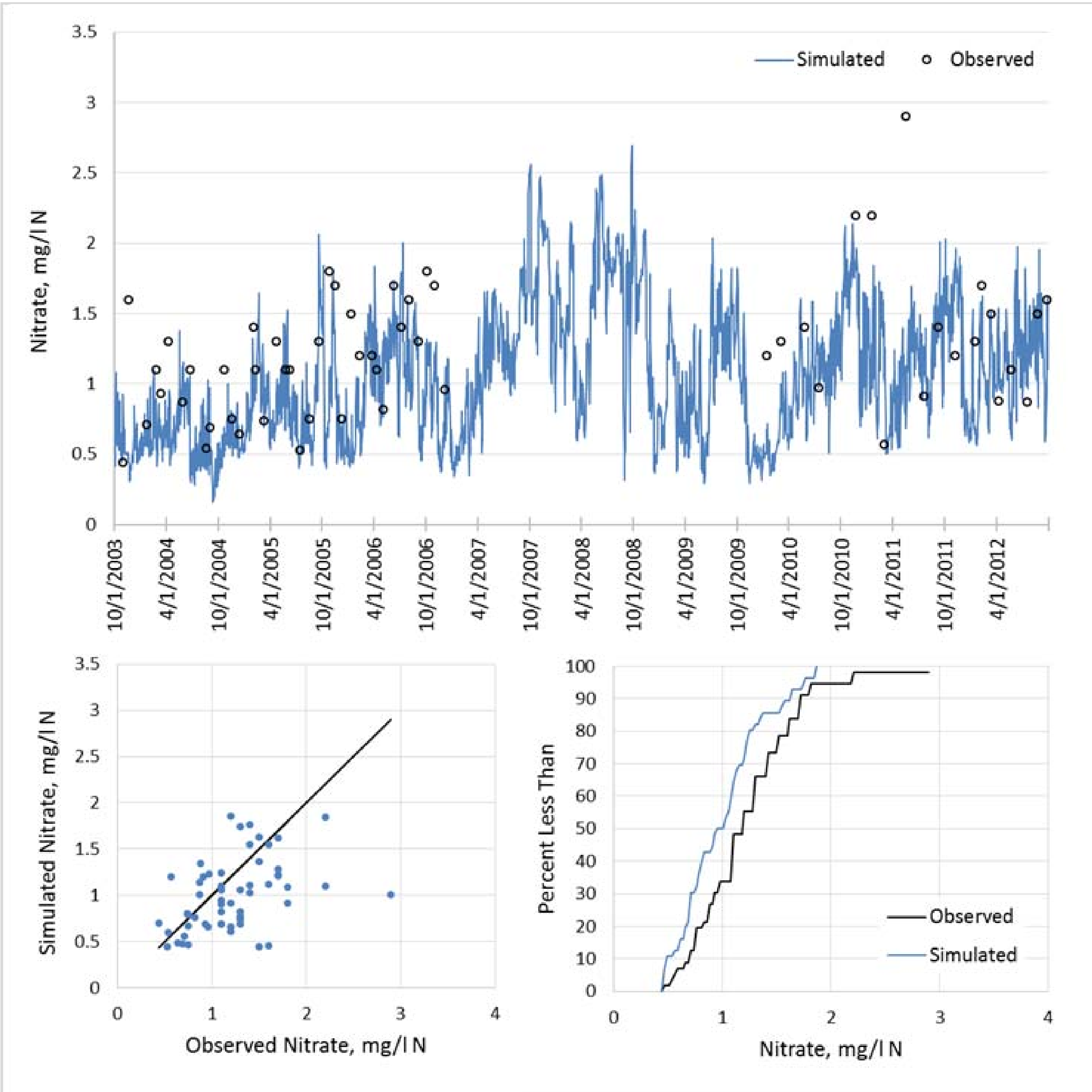

Figure 5-20 Nitrate-Nitrogen simulation results, Catawba River at SC-5 (WARMF ID 69)

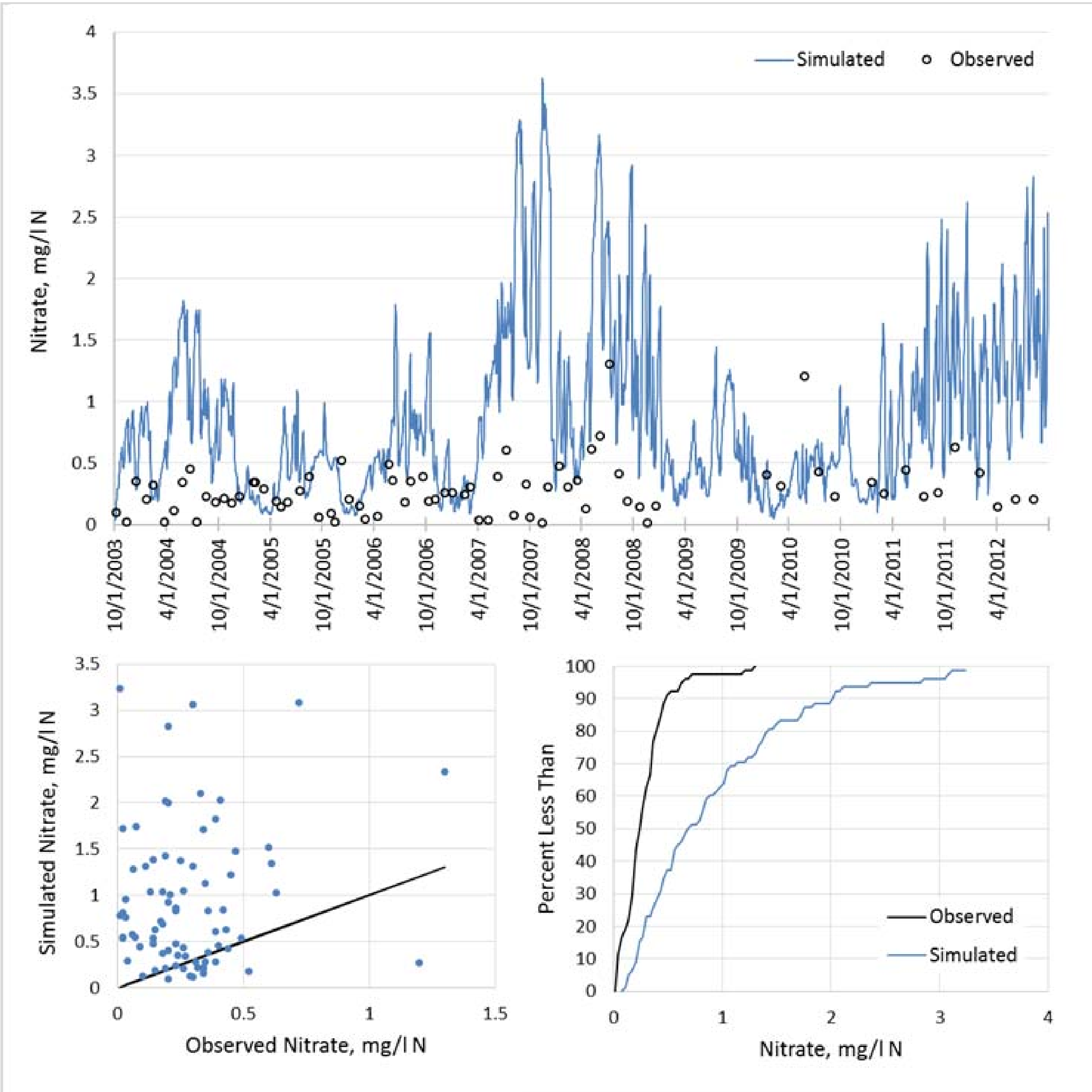

Figure 5-21 Nitrate-Nitrogen simulation results, Fishing Creek near S-12-77 (WARMF ID 149)

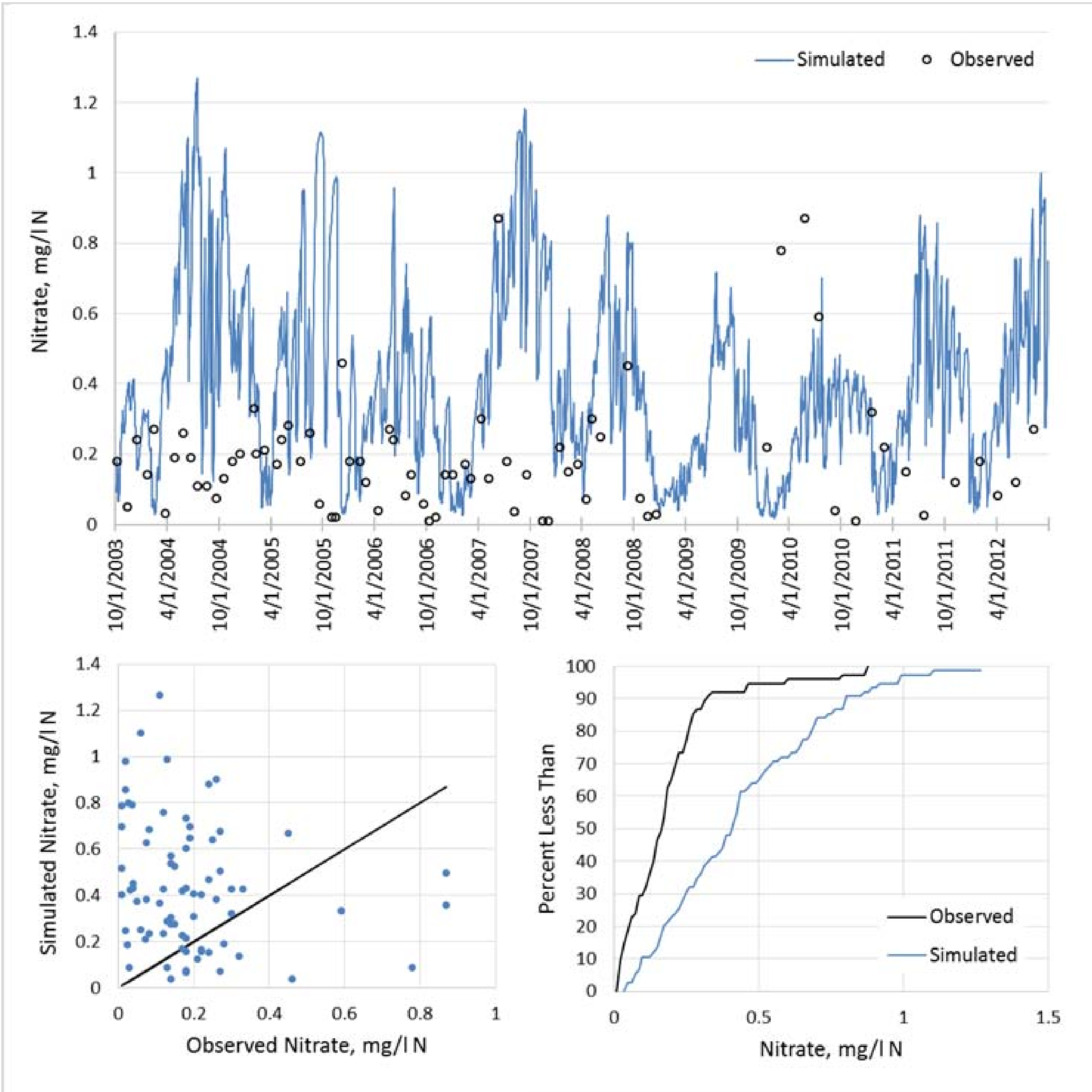

Figure 5-22 Nitrate-Nitrogen simulation results, Lower Rocky Creek (WARMF ID 160)

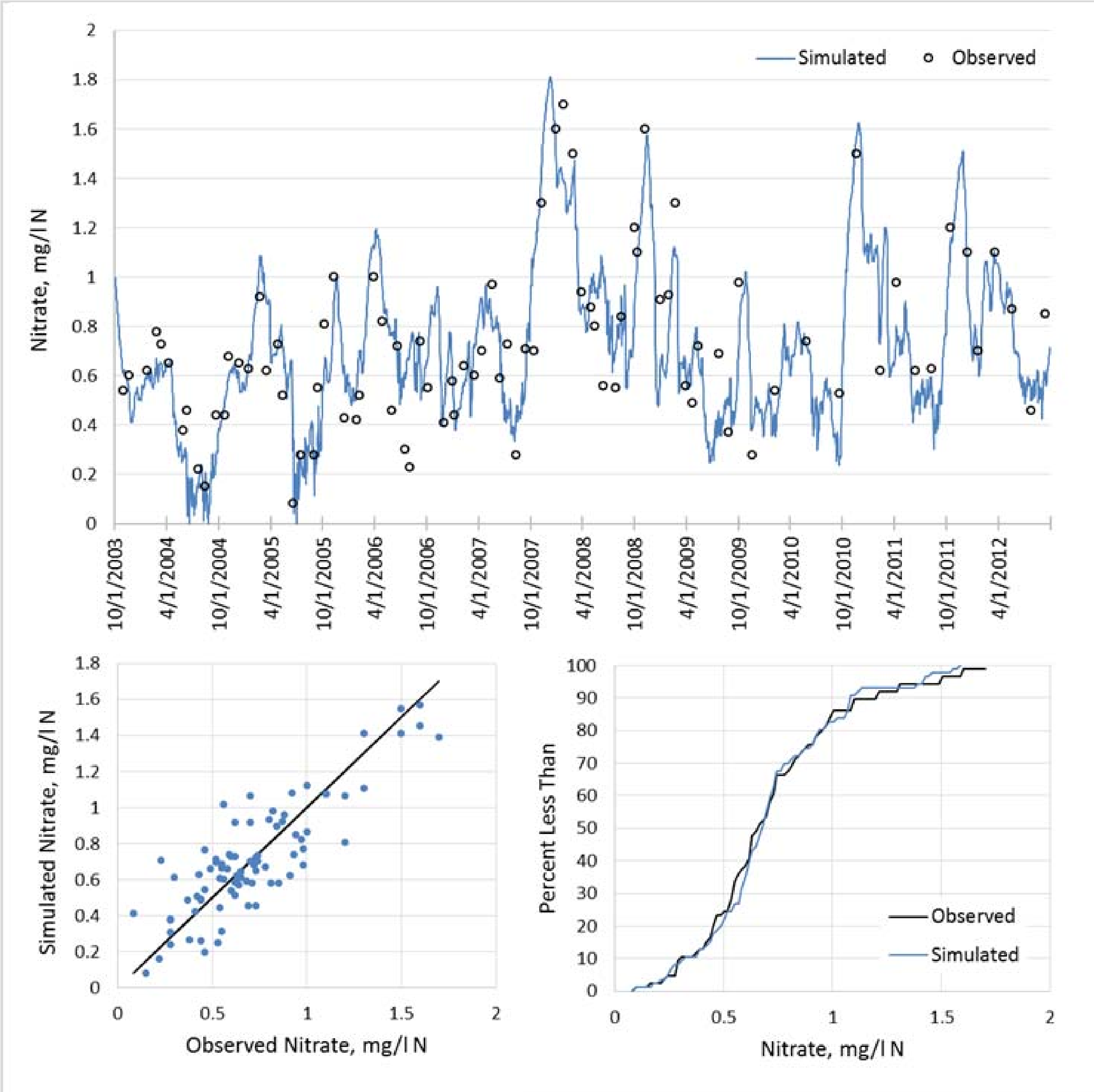

Figure 5-23 Nitrate-Nitrogen simulation results, Fishing Creek Reservoir (WARMF ID 1562)

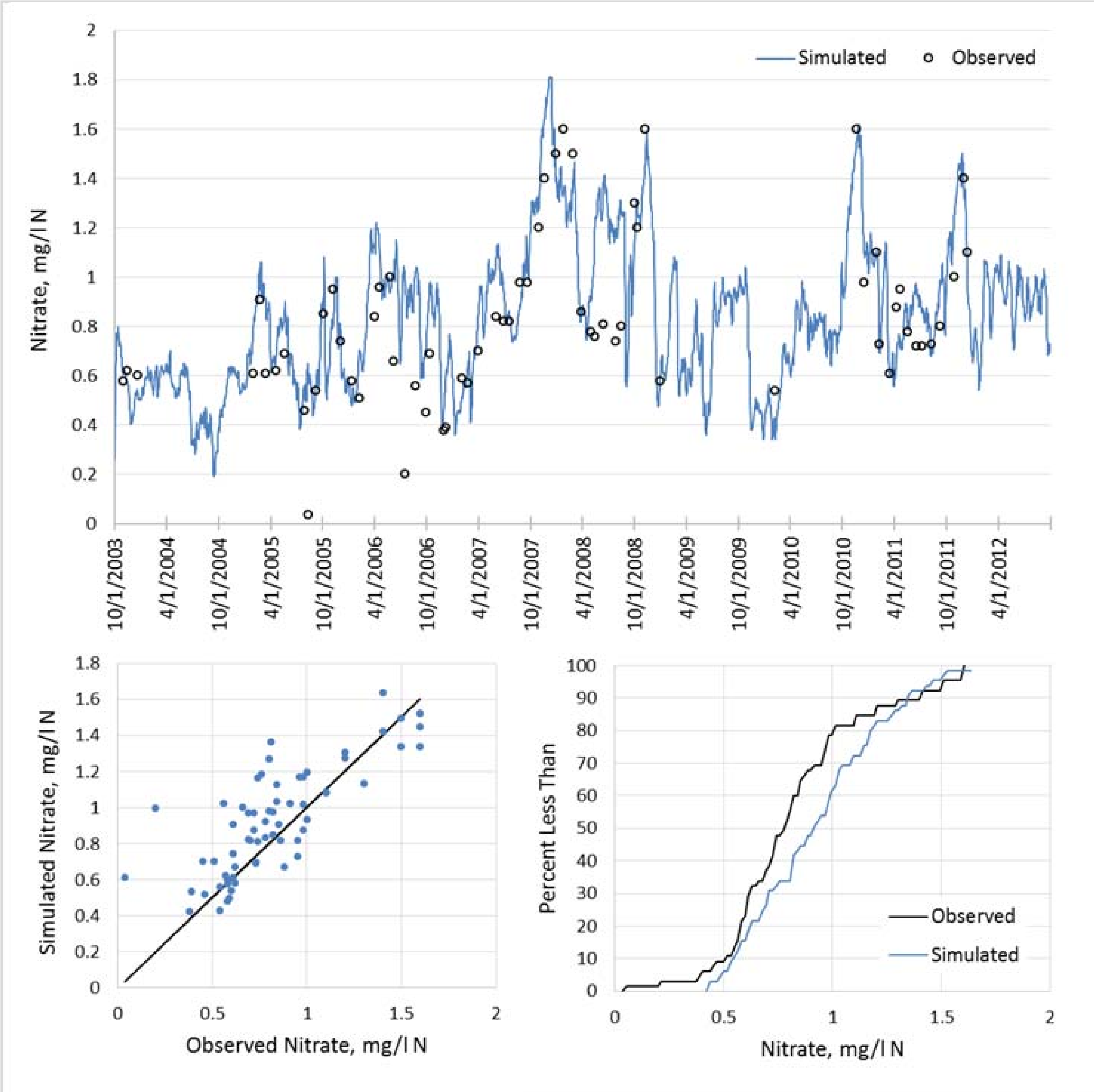

Figure 5-24 Nitrate-Nitrogen simulation results, Great Falls Reservoir (WARMF ID 1563)

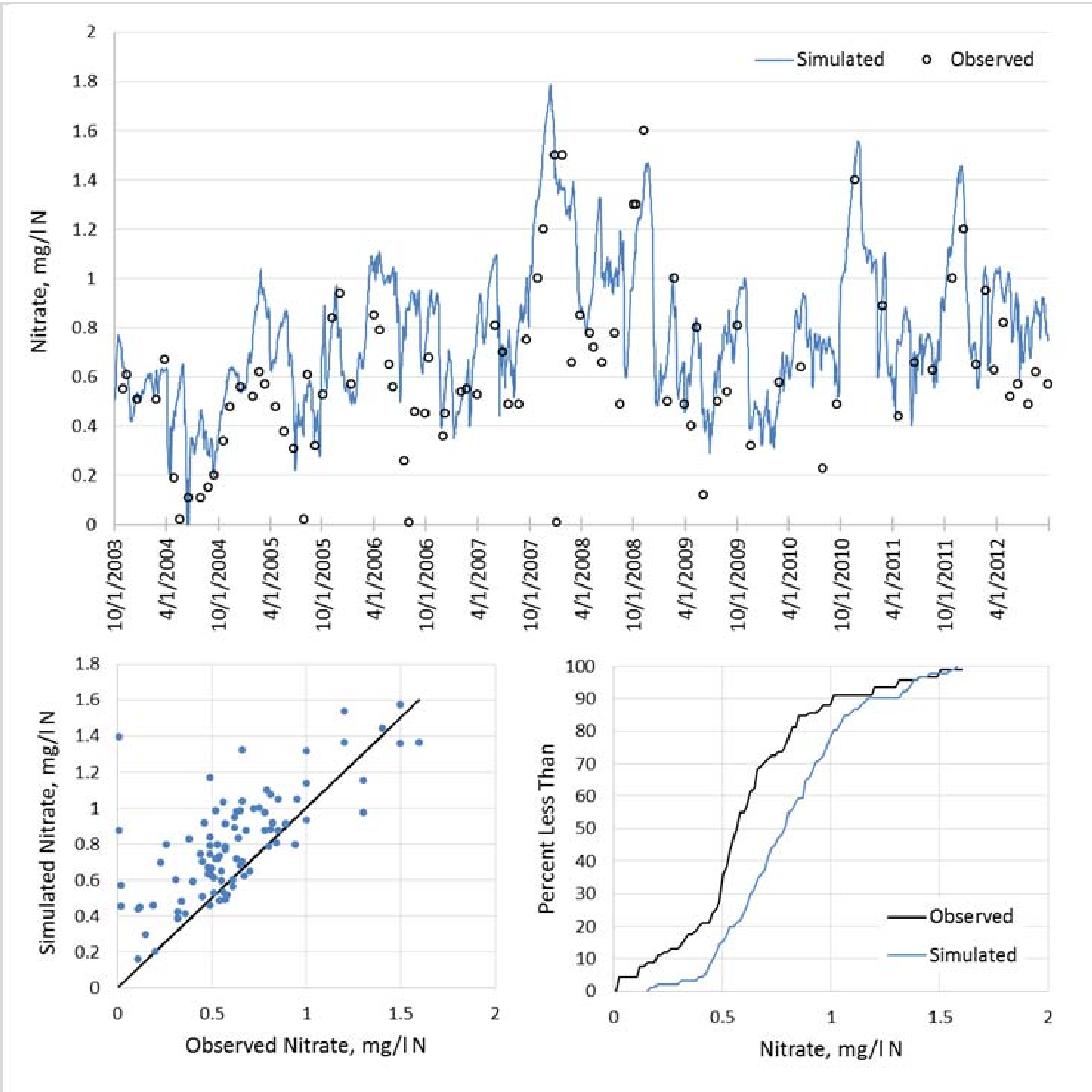

Figure 5-25 Nitrate-Nitrogen simulation results, Cedar Creek Reservoir (WARMF ID 1567)

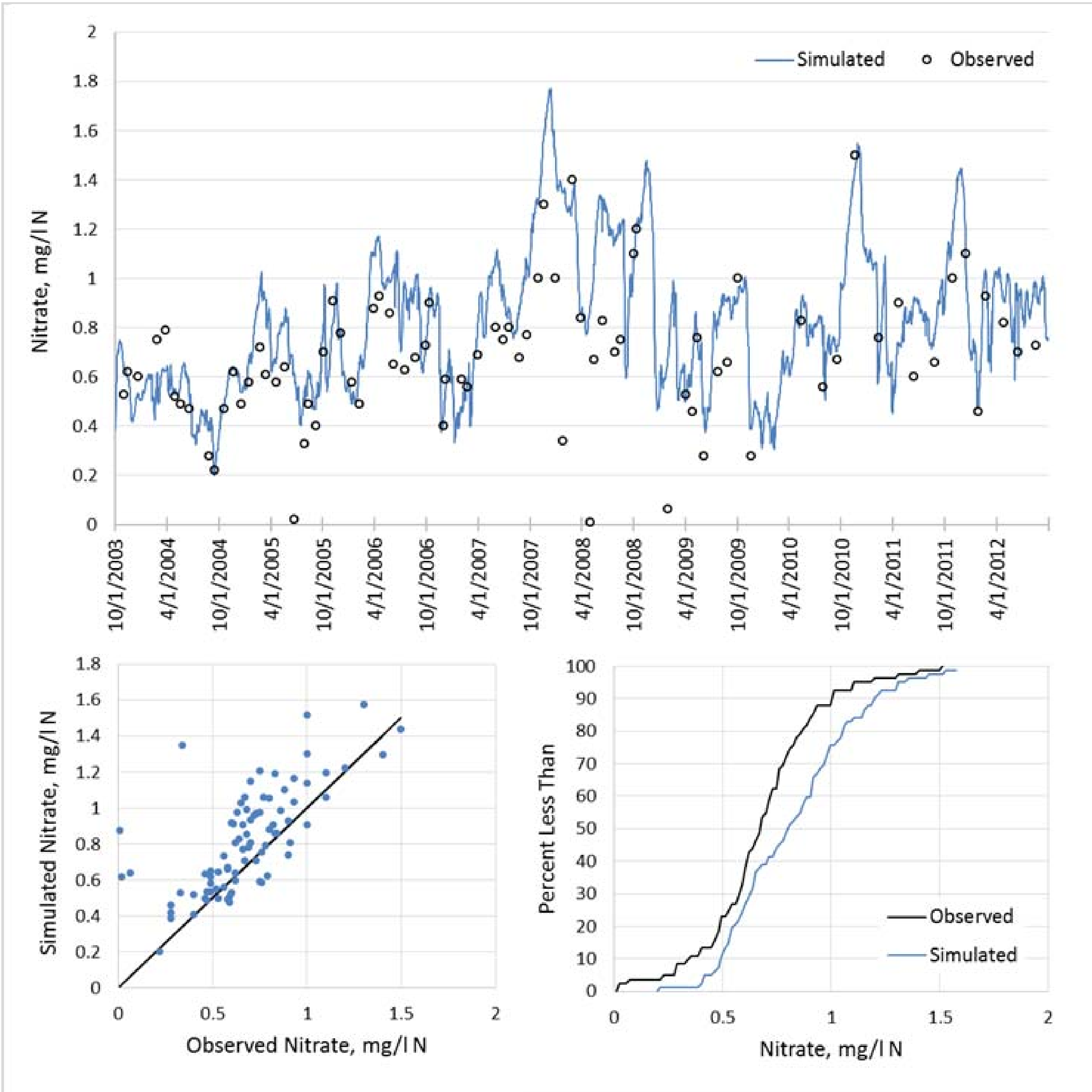

Figure 5-26 Nitrate-Nitrogen simulation results, Catawba River below Cedar Creek (WARMF ID 624)

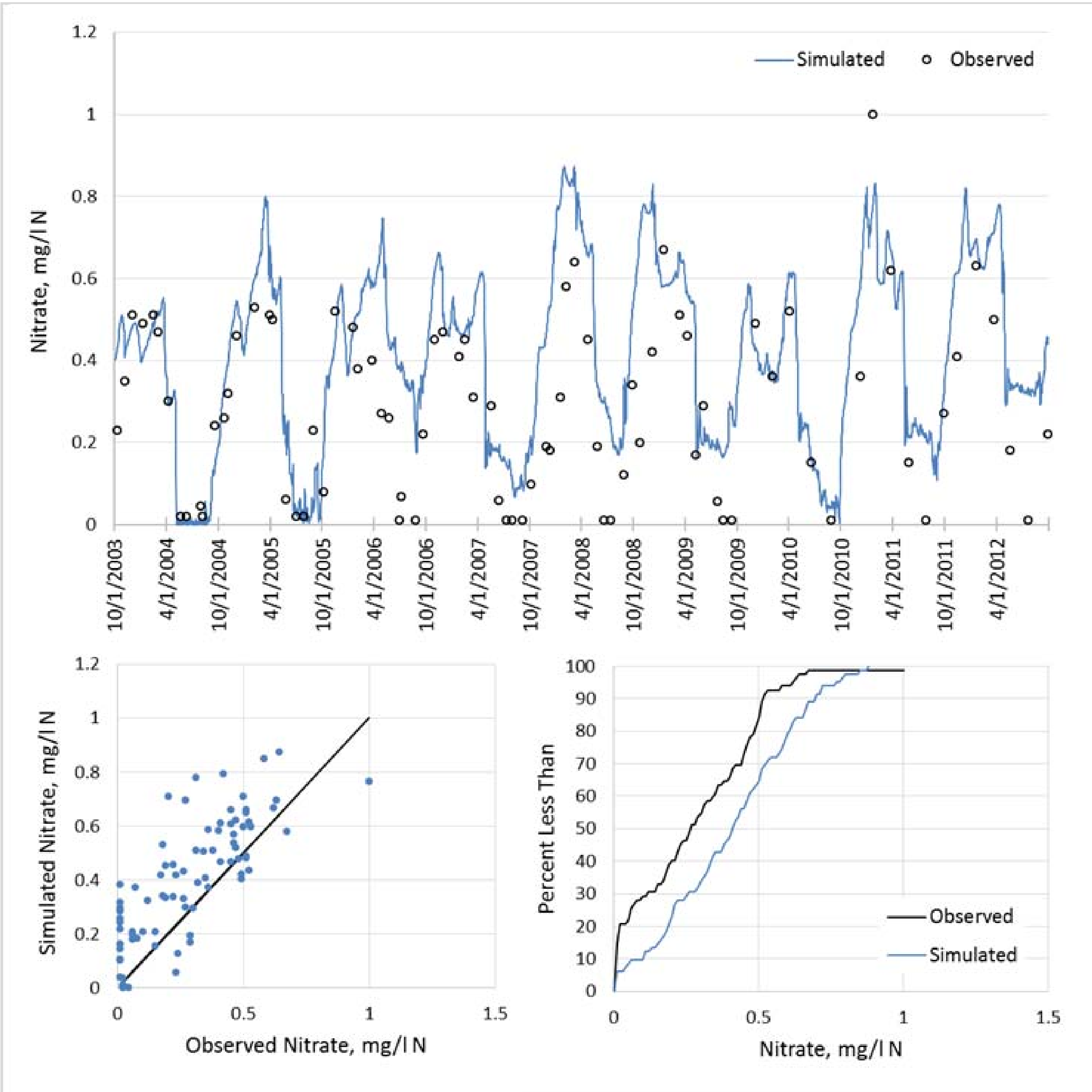

Figure 5-27 Nitrate-Nitrogen simulation results, Lake Wateree Forebay (WARMF ID 2292)

Table 5-3 Nitrate-Nitrogen calibration statistics

Location	Observed data (mg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	0.01	0.46	0.18	0.92	-1.8	0.28	1.8%	3.1%	0.03	0.92
Sugar Creek at SC-160	0.25	18.00	8.82	0.11	-8.4	0.94	8.4%	28.7%	3.39	0.50
Catawba River at SC-5	0.44	2.90	1.22	-0.20	18.2	1.10	-18.2%	31.0%	0.51	0.18
Fishing Creek at S-12-77	0.01	1.30	0.28	-18.81	-231.5	4.45	231.5%	254.9%	0.99	0.02
Lower Rocky Creek	0.01	0.87	0.19	-5.16	-131.5	2.48	131.5%	179.5%	0.43	0.04
Fishing Creek Reservoir	0.08	1.70	0.72	0.72	0.1	0.52	-0.1%	19.2%	0.17	0.73
Great Falls Reservoir	0.04	1.60	0.82	0.52	-12.1	0.70	12.1%	20.0%	0.23	0.62
Cedar Creek Reservoir	0.01	1.60	0.62	0.31	-28.4	0.83	28.4%	33.8%	0.27	0.62
Catawba River below Cedar Creek	0.01	1.50	0.68	0.11	-21.1	0.94	21.1%	26.6%	0.25	0.51
Lake Wateree Forebay	0.01	1.00	0.29	0.27	-39.4	0.86	39.4%	49.9%	0.18	0.63

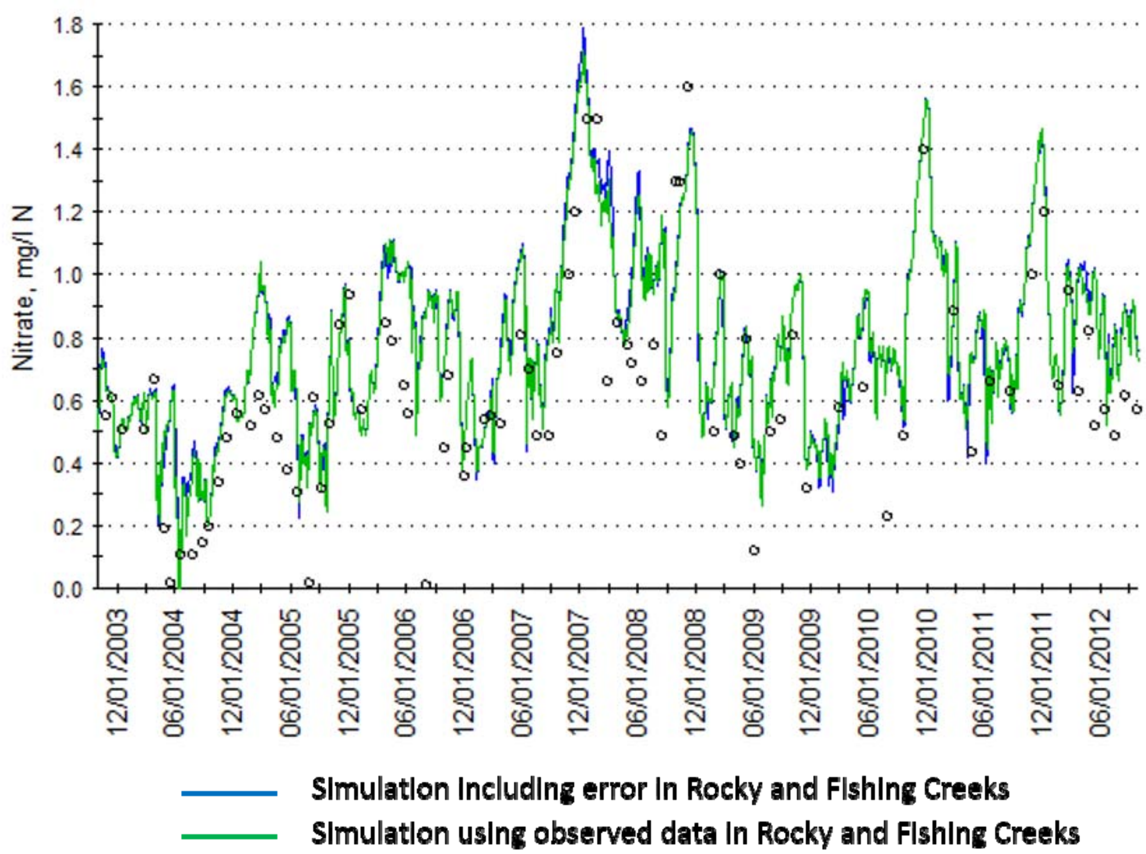

Figure 5-28 Nitrate-nitrogen concentration in Lake Wateree with (blue) and without (green) nitrate simulation error in Rocky and Fishing Creeks

5.4 Ammonia-Nitrogen

Observed data of ammonia-N concentrations were prevalent throughout the watershed. Model simulations of ammonia were evaluated and compared to observed data in the same ten locations as they were for nitrate. Calibration plots are included in Figure 5-29 to Figure 5-38. The figures show that the pattern in observed ammonia data appears to change around the year 2007, with overall higher concentrations before 2007 and lower concentrations after 2007. The model generally does not simulate changes in overall constituent pattern (i.e., mean) unless caused by a point source, managed flow (diversion) or large differences in meteorological conditions. The change in pattern in 2007 is not consistently found in the point source data nor in the hydrology, thus does not appear in the simulations. The calibration focused on matching the ammonia concentrations after 2007. Calibration statistics based on the entire run period for ammonia are presented in Table 5-4. The higher concentrations in the observed data prior to 2007 cause a large negative relative error in most locations. The statistics were recalculated for just the period after 2007 which improved results significantly in most locations (Table 5-5).

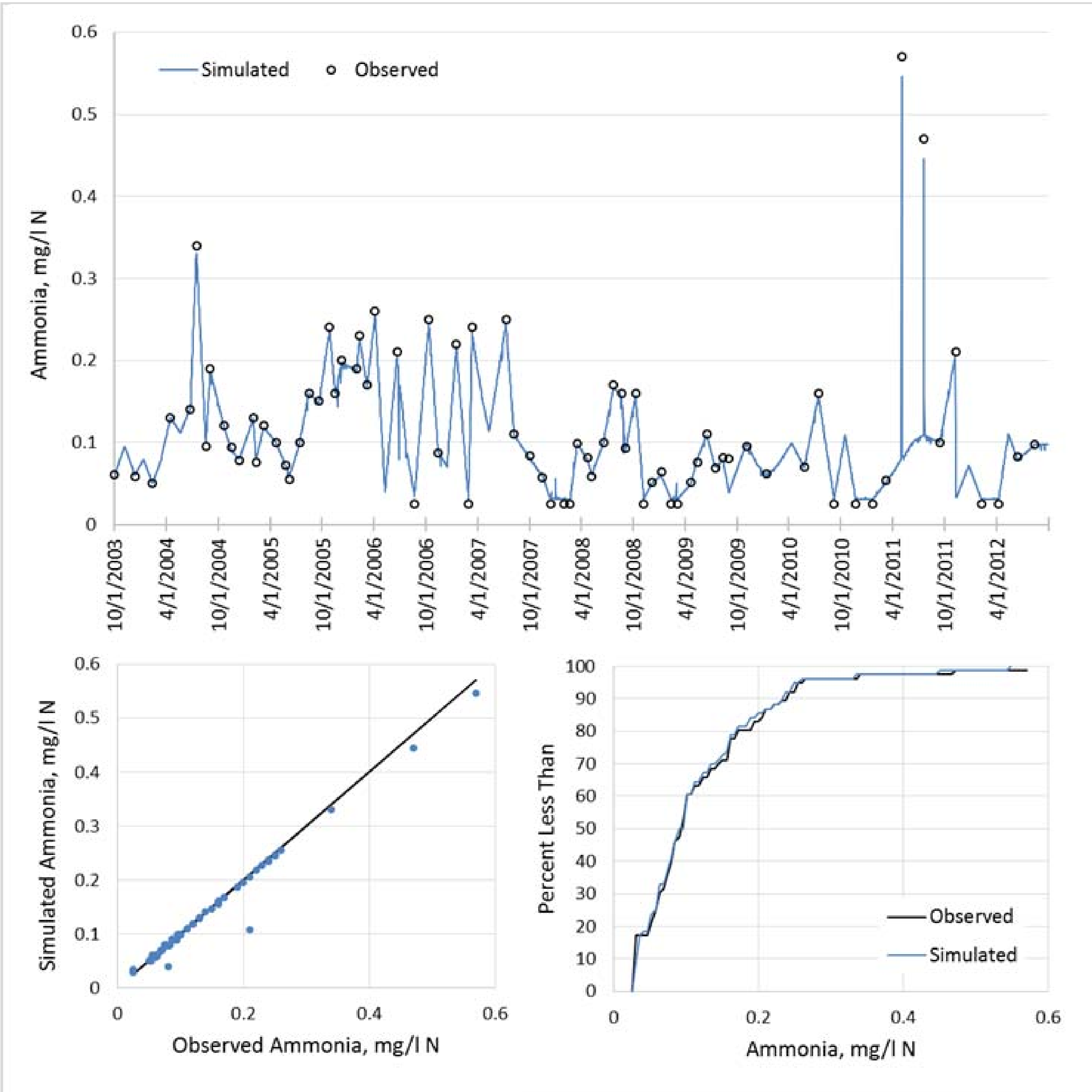

Figure 5-29 Ammonia-Nitrogen simulation results, Catawba River at SC-21 (WARMF ID 89)

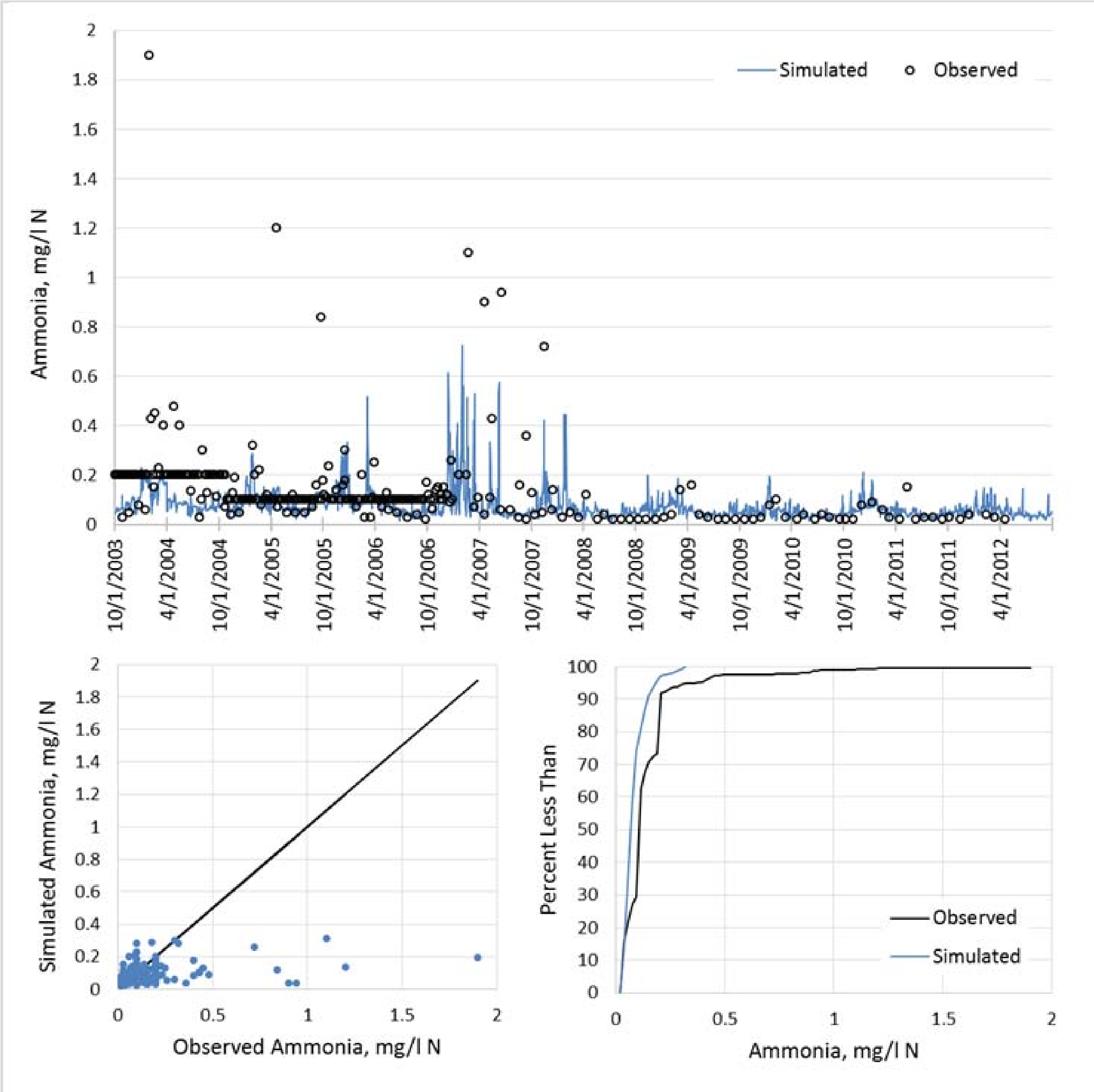

Figure 5-30 Ammonia-Nitrogen simulation results, Sugar Creek at SC-160 (WARMF ID 246)

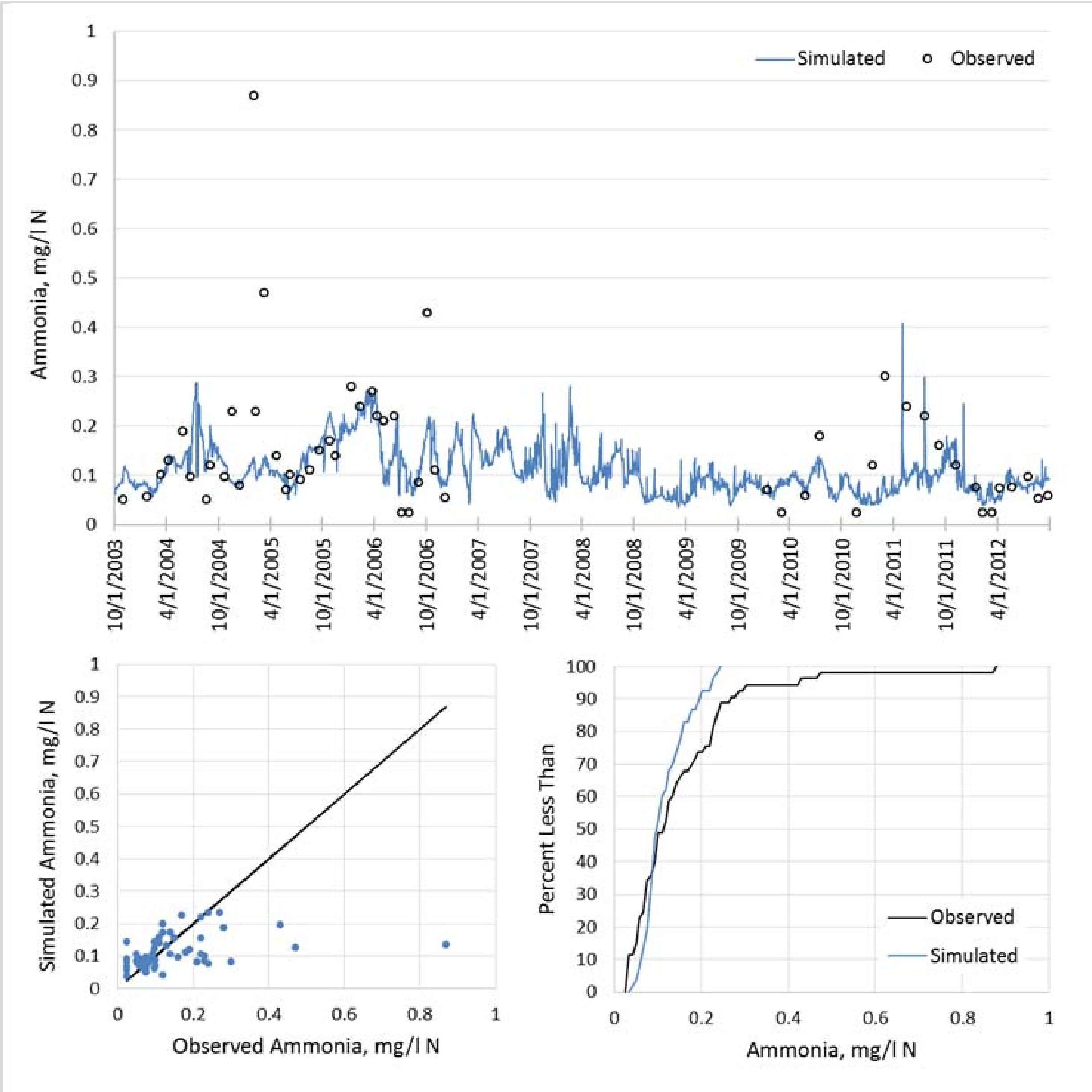

Figure 5-31 Ammonia-Nitrogen simulation results, Catawba River at SC-5 (WARMF ID 69)

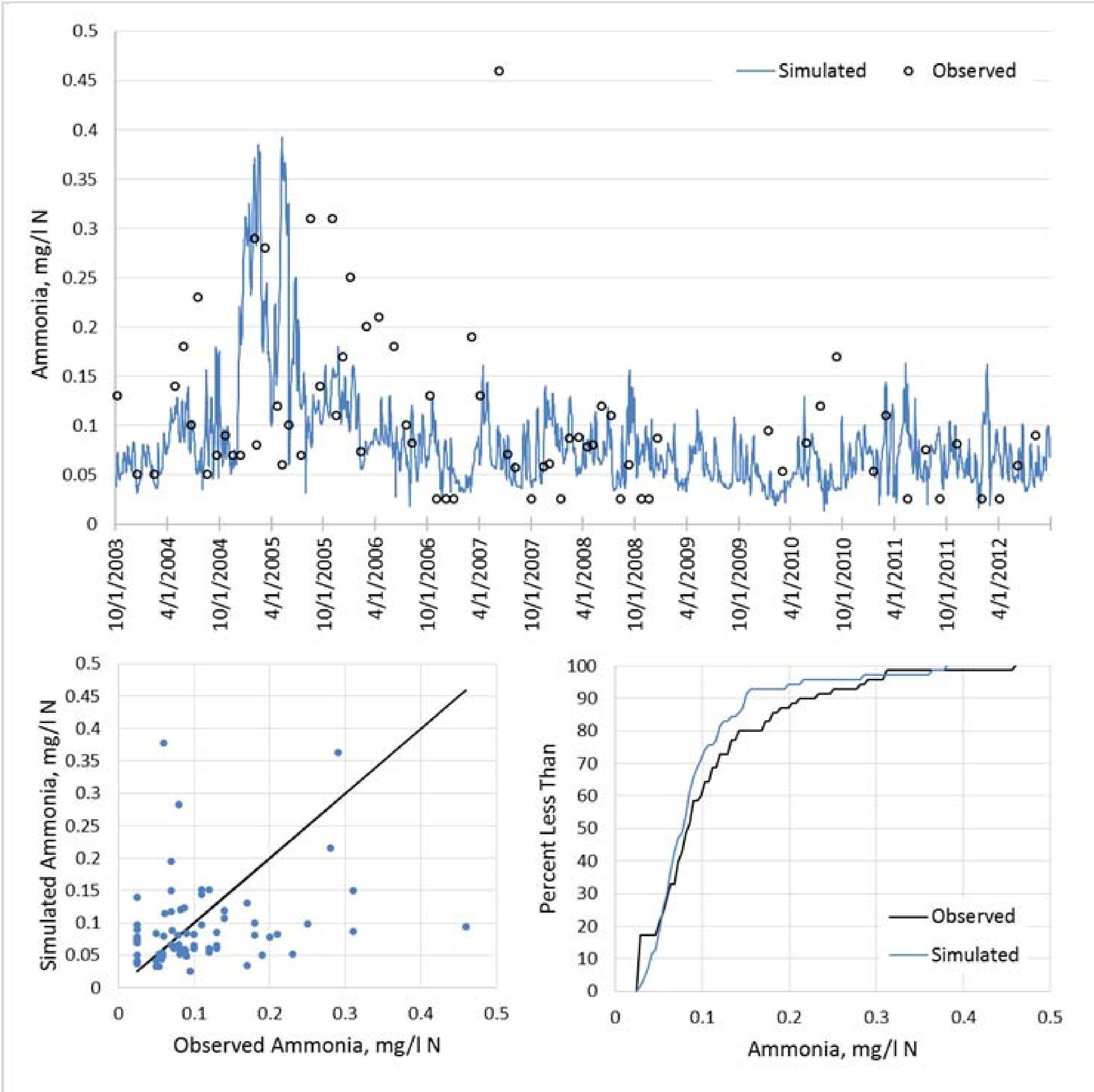

Figure 5-32 Ammonia-Nitrogen simulation results, Fishing Creek near S-12-77 (WARMF ID 149)

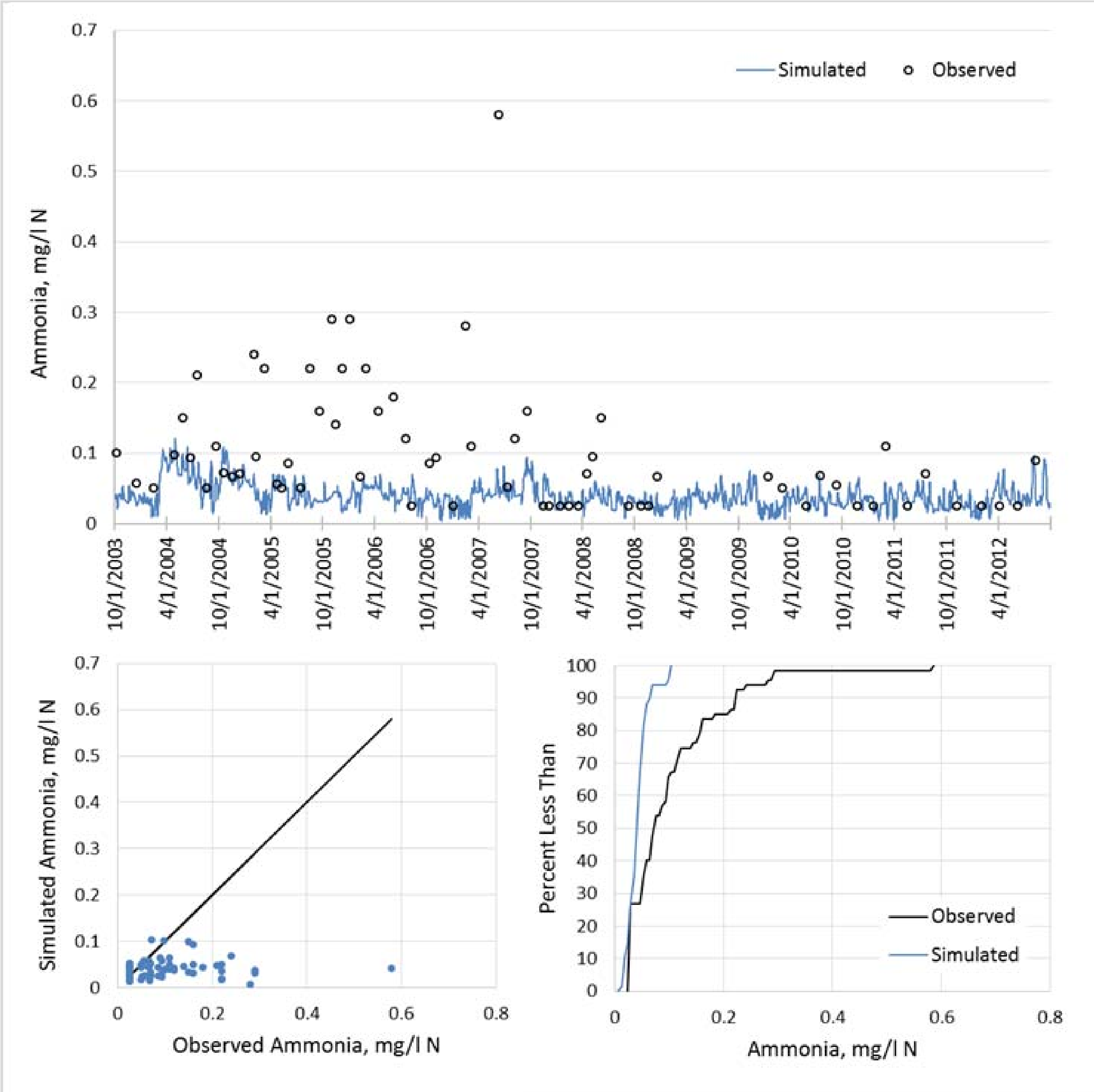

Figure 5-33 Ammonia-Nitrogen simulation results, Lower Rocky Creek (WARMF ID 160)

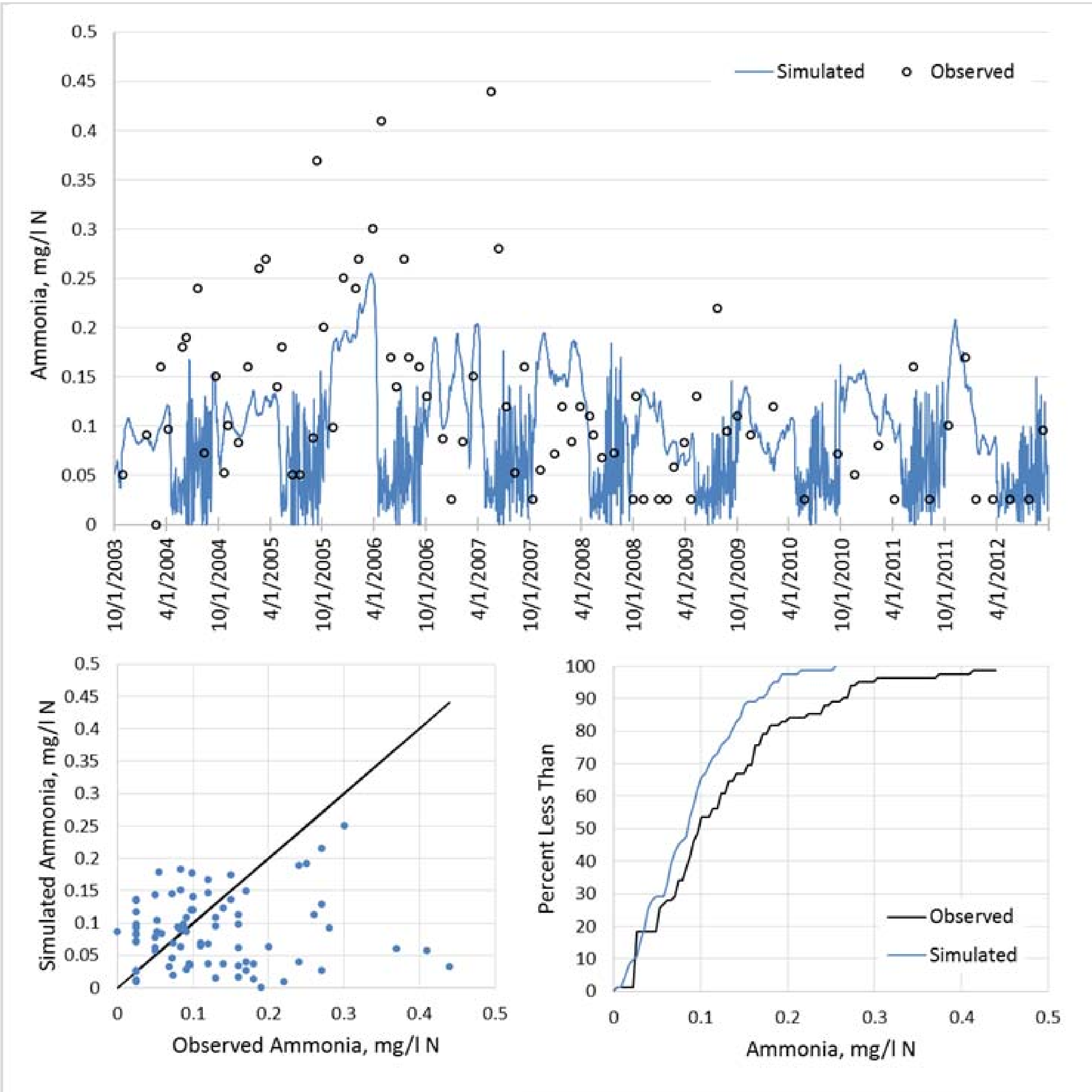

Figure 5-34 Ammonia-Nitrogen simulation results, Fishing Creek Reservoir (WARMF ID 1562)

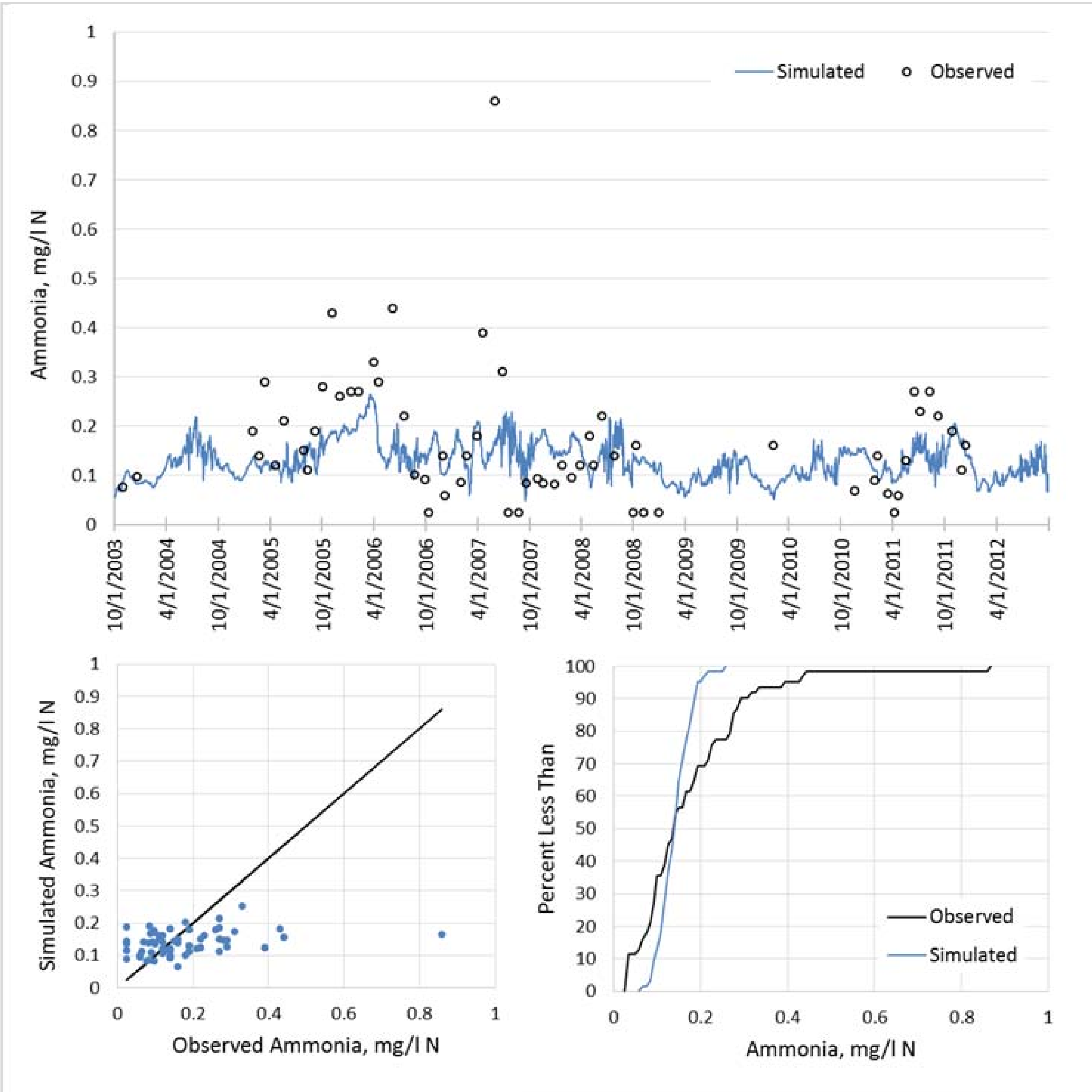

Figure 5-35 Ammonia-Nitrogen simulation results, Great Falls Reservoir (WARMF ID 1563)

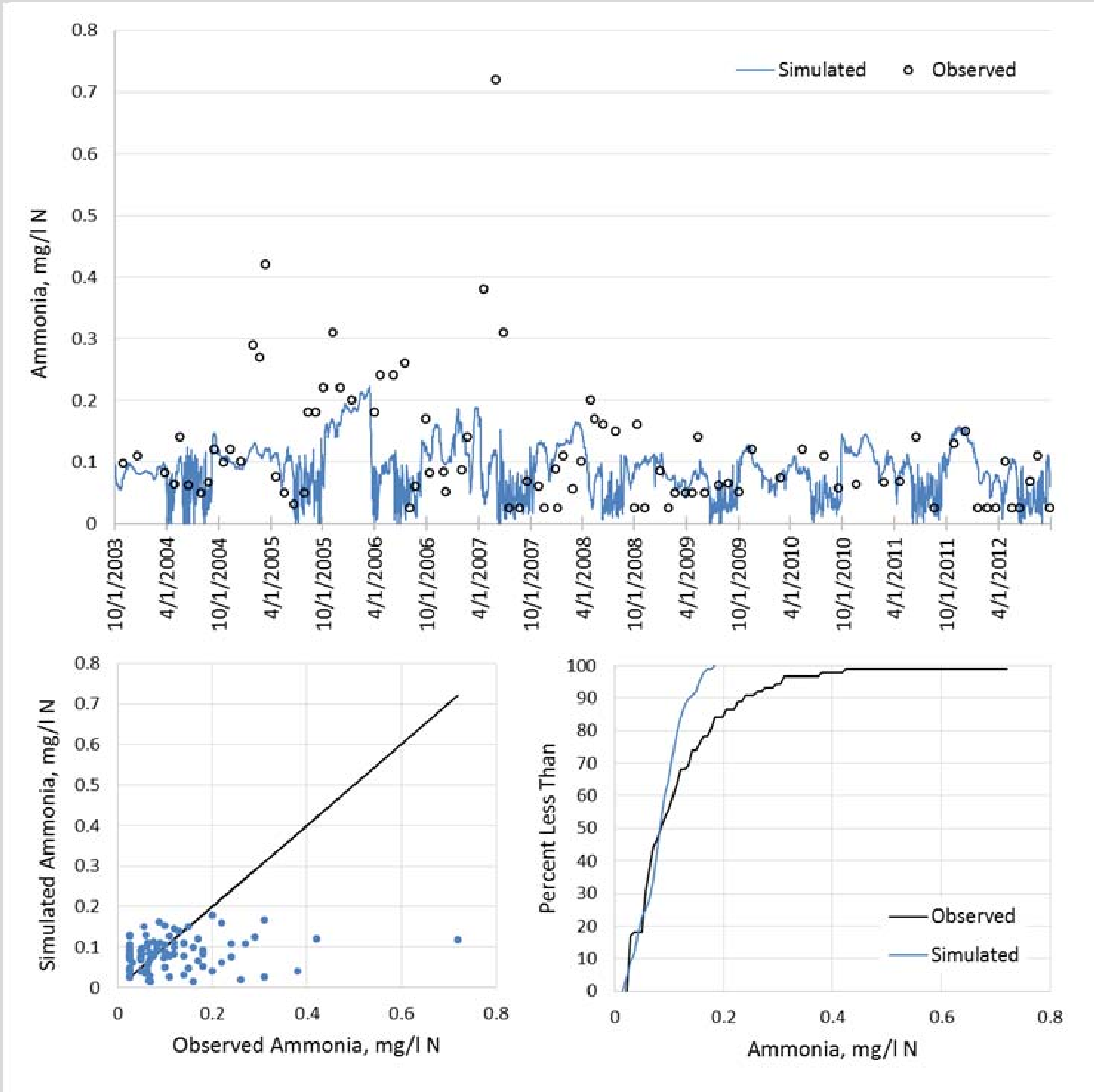

Figure 5-36 Ammonia-Nitrogen simulation results, Cedar Creek Reservoir (WARMF ID 1567)

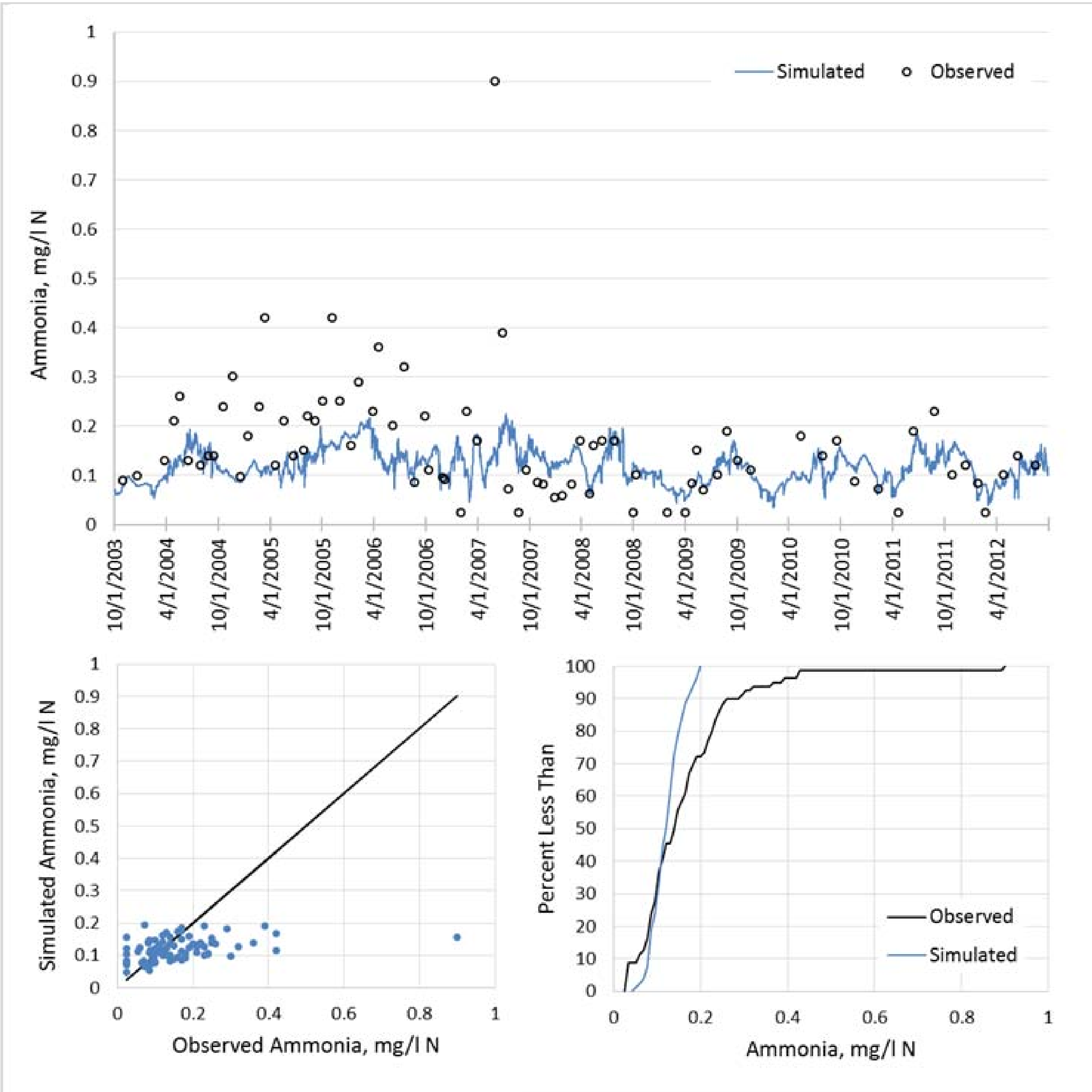

Figure 5-37 Ammonia-Nitrogen simulation results, Catawba River below Cedar Creek (WARMF ID 624)

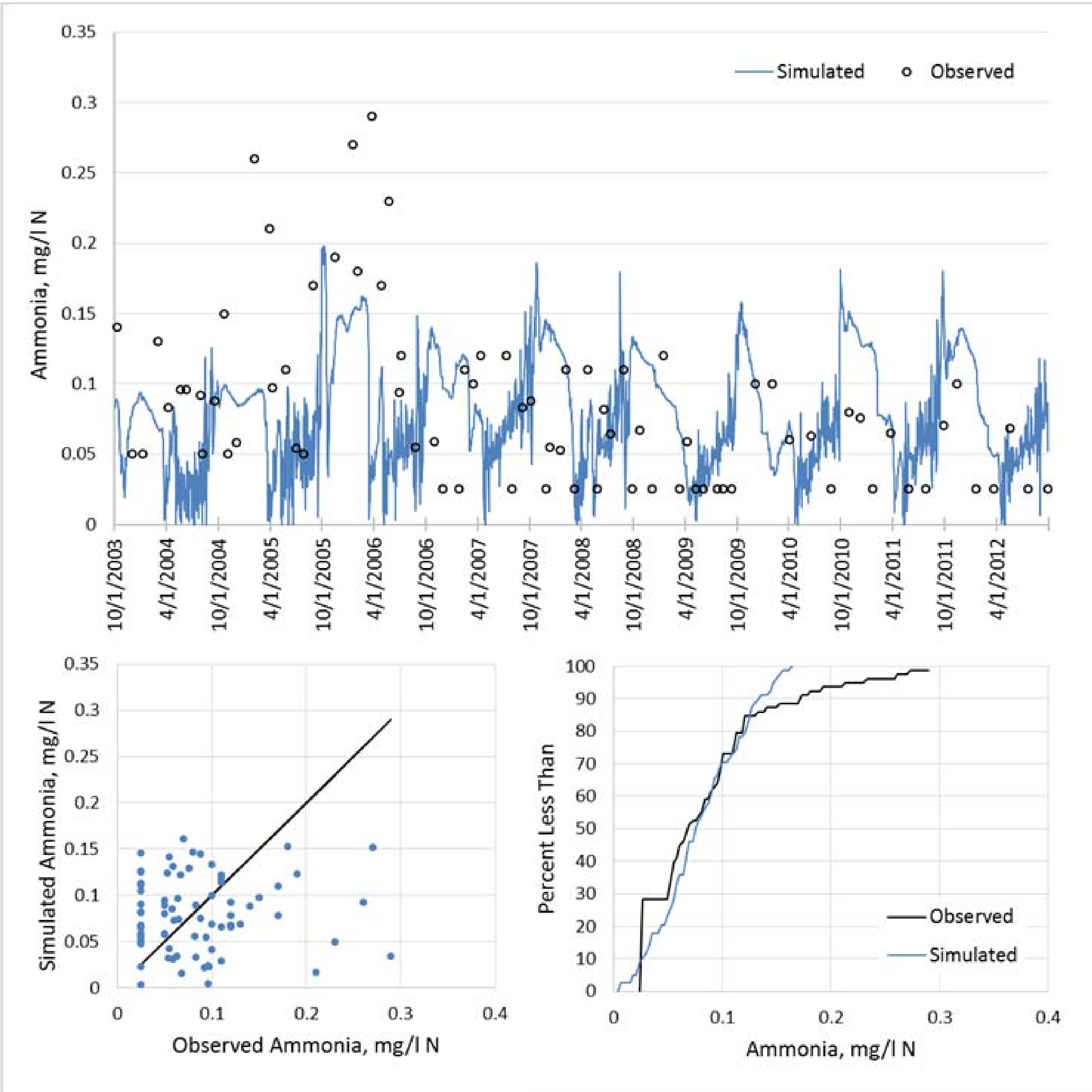

Figure 5-38 Ammonia-Nitrogen simulation results, Lake Wateree Forebay (WARMF ID 2292)

Table 5-4 Ammonia-nitrogen calibration statistics, water years 2003-2012

Location	Observed data (mg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	0.03	0.57	0.12	0.98	2.19	0.14	-2.2%	4.6%	0.01	0.98
Sugar Creek at SC-160	0.02	1.90	0.14	0.00	43.14	1.00	-43.1%	59.2%	0.18	0.12
Catawba River at SC-5	0.03	0.87	0.15	0.08	22.99	0.96	-23.0%	48.2%	0.13	0.14
Fishing Creek at S-12-77	0.03	0.46	0.11	-0.27	12.87	1.13	-12.9%	58.6%	0.09	0.06
Lower Rocky Creek	0.03	0.58	0.10	-0.44	58.89	1.20	-58.9%	66.3%	0.11	0.00
Fishing Creek Reservoir	0.03	0.44	0.12	-0.47	29.87	1.21	-29.9%	63.5%	0.11	0.00
Great Falls Reservoir	0.03	0.86	0.17	0.04	17.08	0.98	-17.1%	50.6%	0.13	0.09
Cedar Creek Reservoir	0.03	0.72	0.12	-0.10	26.97	1.05	-27.0%	59.0%	0.11	0.03
Catawba River below Cedar Creek	0.03	0.90	0.16	0.02	24.57	0.99	-24.6%	45.0%	0.12	0.14
Lake Wateree Forebay	0.03	0.29	0.08	-0.35	3.92	1.16	-3.9%	66.1%	0.07	0.00

Table 5-5 Ammonia-nitrogen calibration statistics, water years 2007-2012

Location	Observed data (mg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	0.03	0.57	0.10	0.97	4.17	0.17	-4.2%	8.1%	0.02	0.97
Sugar Creek at SC-160	0.02	0.72	0.06	0.44	-2.04	0.75	2.0%	67.3%	0.07	0.59
Catawba River at SC-5	0.03	0.30	0.11	0.00	23.06	1.00	-23.1%	54.2%	0.08	0.10
Fishing Creek at S-12-77	0.03	0.17	0.07	-0.82	-1.35	1.35	1.4%	55.5%	0.05	0.01
Lower Rocky Creek	0.03	0.15	0.05	-0.15	23.68	1.07	-23.7%	54.0%	0.04	0.02
Fishing Creek Reservoir	0.03	0.22	0.08	-1.08	-9.62	1.44	9.6%	72.6%	0.07	0.00
Great Falls Reservoir	0.03	0.27	0.13	-0.12	-7.05	1.06	7.1%	50.1%	0.07	0.01
Cedar Creek Reservoir	0.03	0.20	0.08	-0.63	-3.46	1.28	3.5%	63.3%	0.06	0.00
Catawba River below Cedar Creek	0.03	0.23	0.11	0.16	-0.73	0.92	0.7%	38.5%	0.05	0.18
Lake Wateree Forebay	0.03	0.12	0.05	-1.96	-58.91	1.72	58.9%	83.9%	0.05	0.07

5.5 Total Nitrogen

Total nitrogen in WARMF is calculated as the sum of the dissolved and adsorbed concentrations of simulated nitrogen species (ammonia and nitrate), plus organic nitrogen, which is calculated as a proportion of organic carbon. The calibration results for total nitrogen thus will be of similar quality as the nitrate and ammonia calibration. When there are issues in the total nitrogen calibration that are not present in either the ammonia or nitrate calibration, the cause is typically inaccurate simulation of organic carbon or the adsorbed portion of ammonia, or an inappropriate proportionality multiplier used to estimate the organic nitrogen portion of organic carbon.

To evaluate the calibration of total nitrogen, model simulations were compared to observed data for the same ten locations that were used for nitrate and ammonia calibration assessment. Graphical results are presented in Figure 5-39 through Figure 5-48 and calibration statistics are presented in Table 5-6. As expected, the model performs well in simulating total nitrogen where it performed well in simulating nitrate and ammonia. Likewise, the issues present in the nitrate and ammonia simulations at some locations are also apparent in the total nitrogen simulations. In the Catawba River at SC-21 (downstream of Lake Wylie) simulated total nitrogen matches the observed very well since the downstream data was used as the boundary condition. At Sugar Creek at SC-160, the simulated total nitrogen also matches the observed data relatively well. In the Catawba River downstream of the confluence with Sugar Creek (Catawba River at SC-5), the simulated total nitrogen appears reasonable however calibration statistics indicate a slight under-simulation. Like mentioned previously for nitrate results, observed data is sparse at this location and is not likely fully capturing the oscillating pattern of total nitrogen concentration stemming from Sugar Creek. In Fishing Creek, total nitrogen is over-predicted as a result of the error in the nitrate simulation. However, like for nitrate, error in total nitrogen predictions in Fishing Creek had a nearly indiscernible effect on total nitrogen predictions in the reservoir downstream. In contrast, the total nitrogen predictions in Rocky Creek were much better than the nitrate predictions, with low relative error. The over-simulation of nitrate is likely being balanced by an under-simulation of organic carbon (from which organic nitrogen is calculated) to result in lower relative error in total nitrogen simulations.

The calibration results for total nitrogen for the reservoir system are similar to the results of nitrate in the reservoirs. In Fishing Creek Reservoir, simulated total nitrogen follows the trend in the observed data well, as apparent in both plots and statistics. In Great Falls Reservoir, Cedar Creek Reservoir and the Catawba River below Cedar Creek, a slight over-simulation is present, however the simulations largely follow the trend and range in the observed data. In Lake Wateree Forebay, simulations follow the overall seasonal pattern in observed data well. Over-simulation of the winter/spring peaks in some years stems from the nitrate simulation, while over-simulation of the summer troughs (which is less apparent in either the nitrate or ammonia simulation results) may be due to a localized change in the relationship between organic nitrogen and organic carbon.

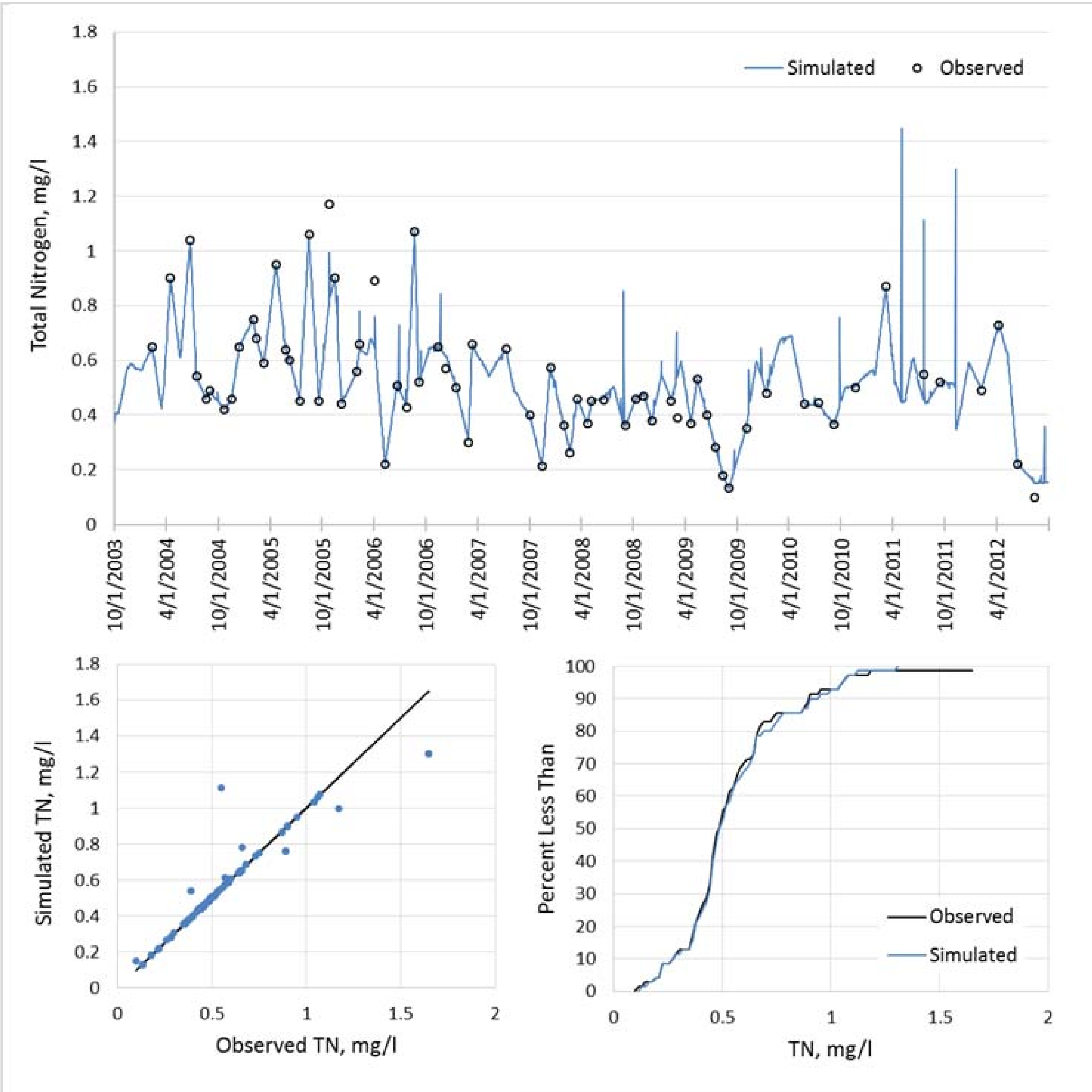

Figure 5-39 Total nitrogen simulation results, Catawba River at SC-21 WARMF ID 89)

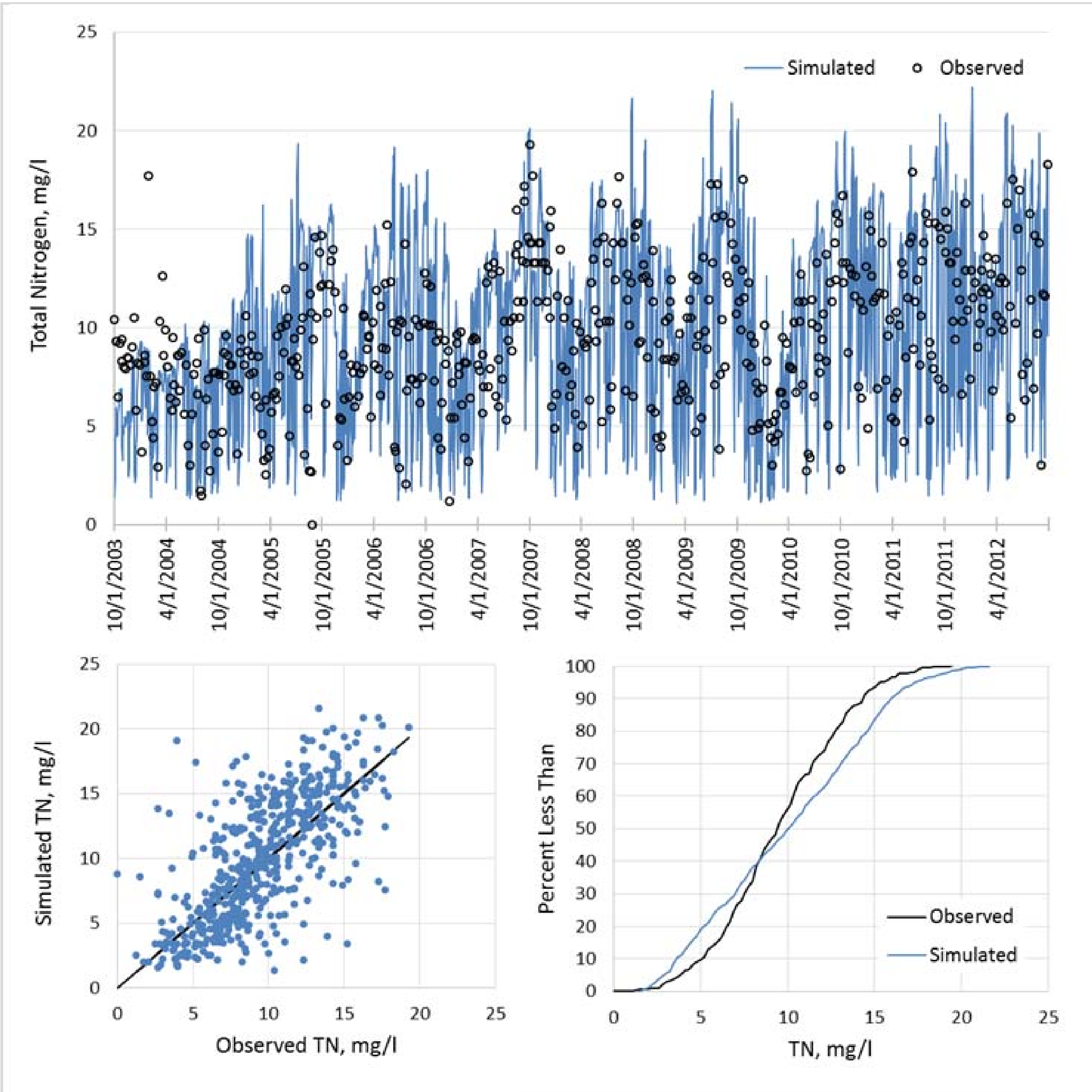

Figure 5-40 Total nitrogen simulation results, Sugar Creek at SC-160 (WARMF ID 246)

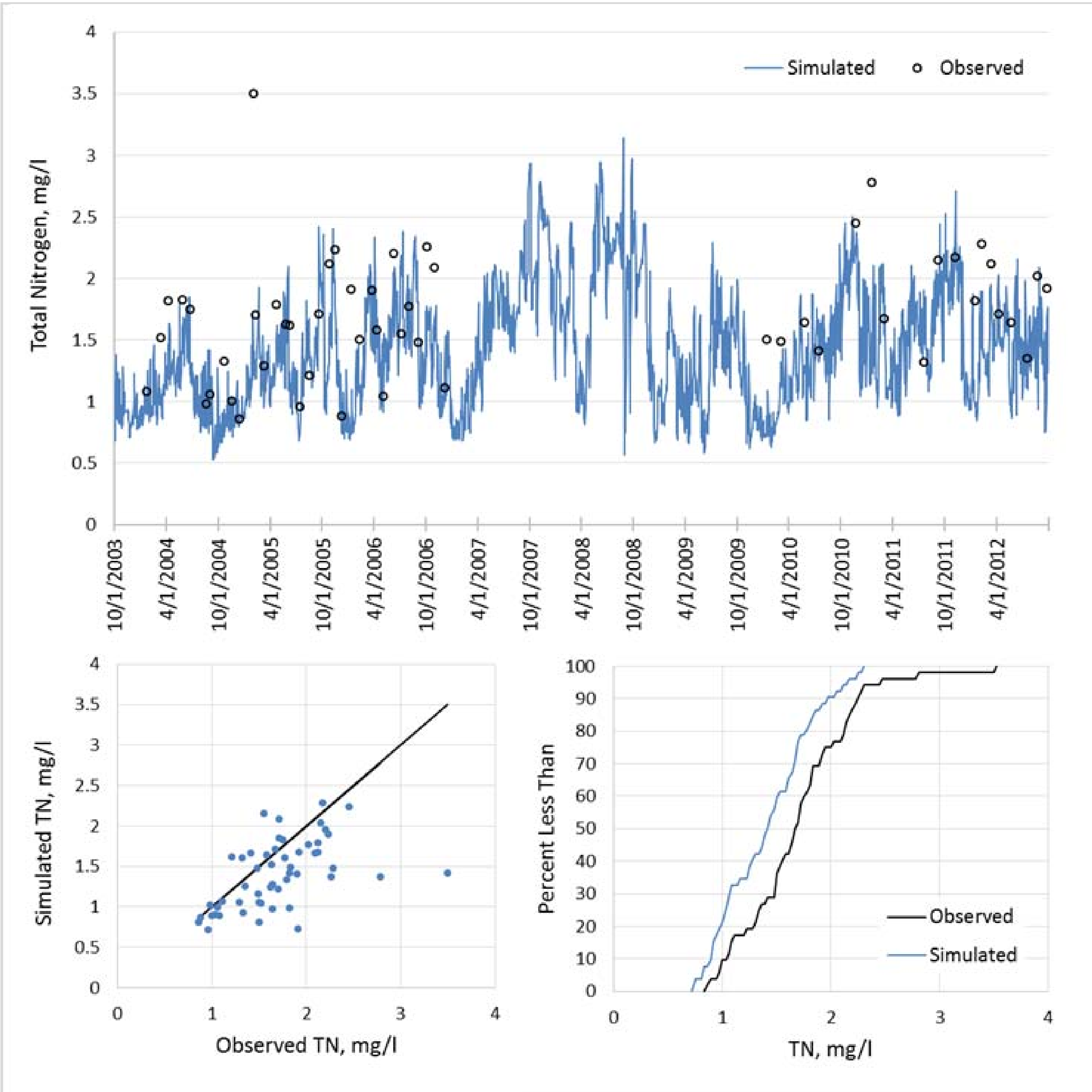

Figure 5-41 Total nitrogen simulation results, Catawba River at SC-5 (WARMF ID 69)

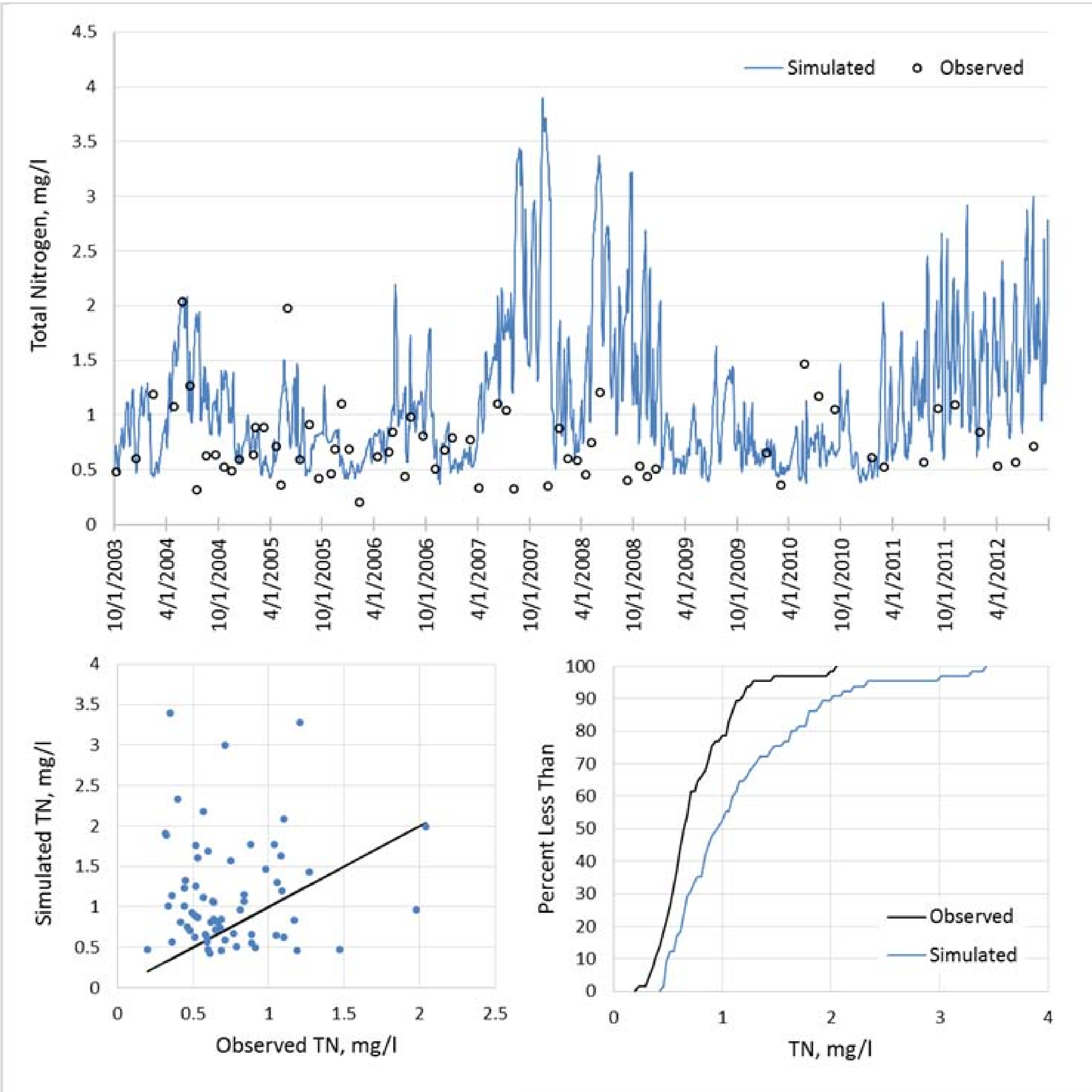

Figure 5-42 Total nitrogen simulation results, Fishing Creek near S-12-77 (WARMF ID 149)

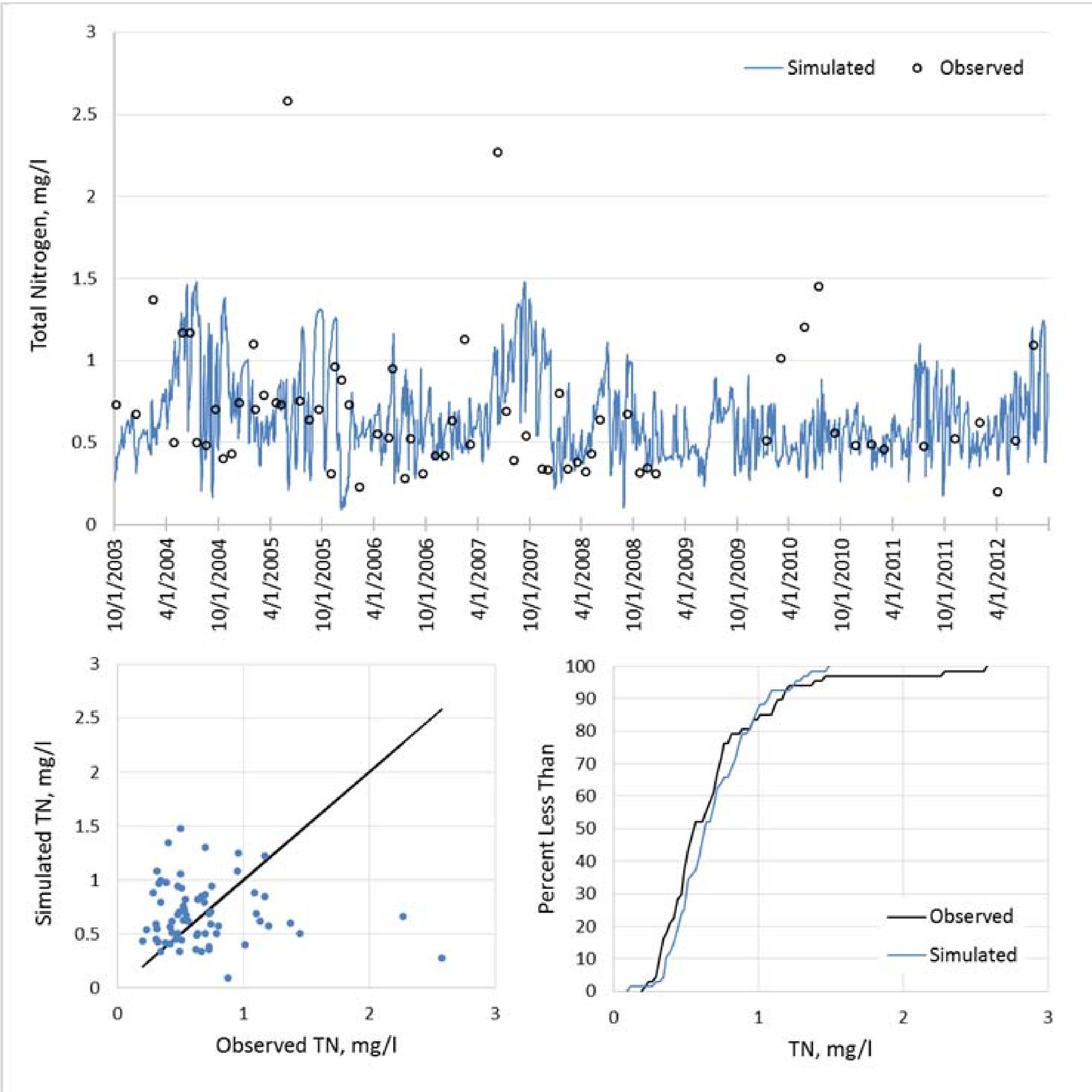

Figure 5-43 Total nitrogen simulation results, Lower Rocky Creek (WARMF ID 160)

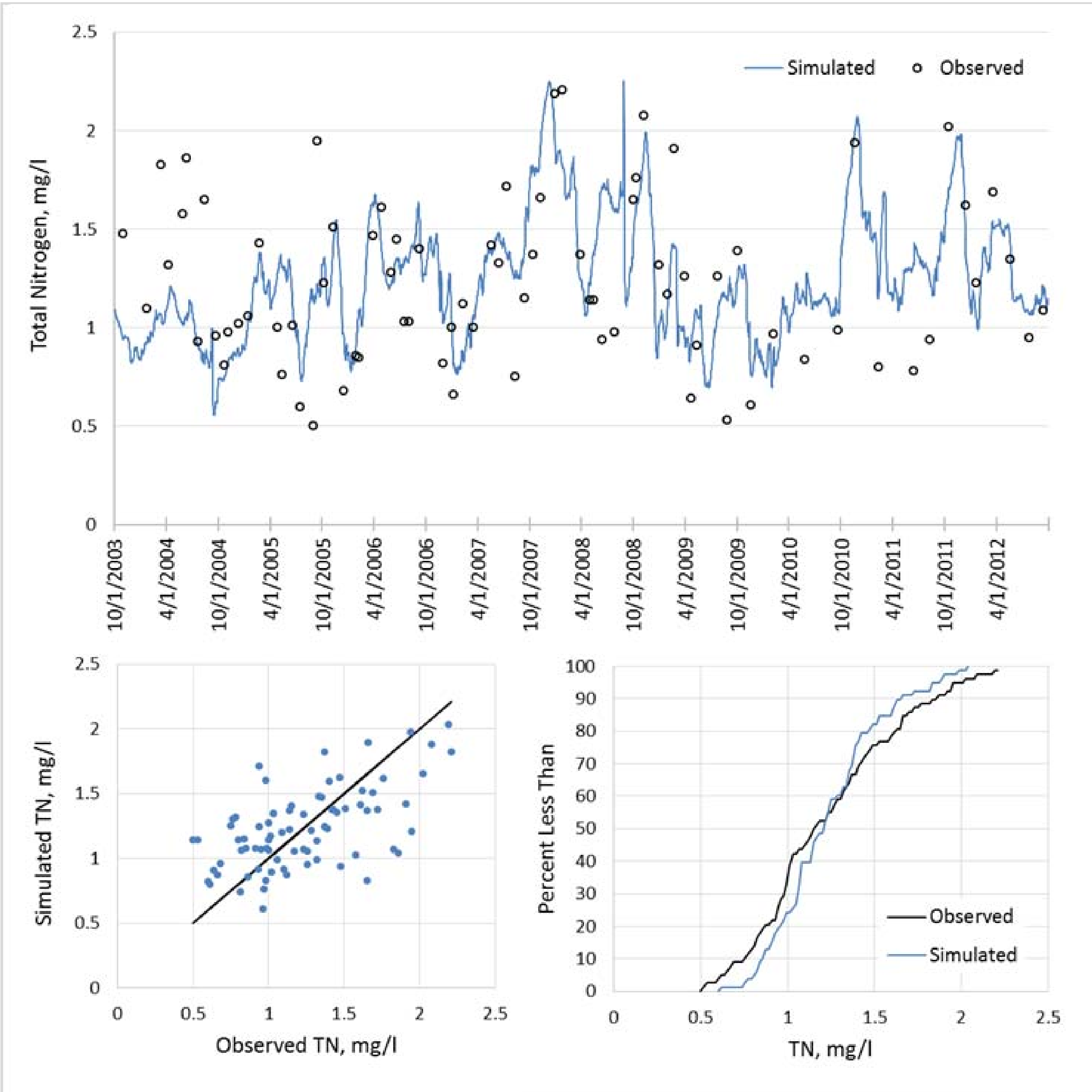

Figure 5-44 Total nitrogen simulation results, Fishing Creek Reservoir (WARMF ID 1562)

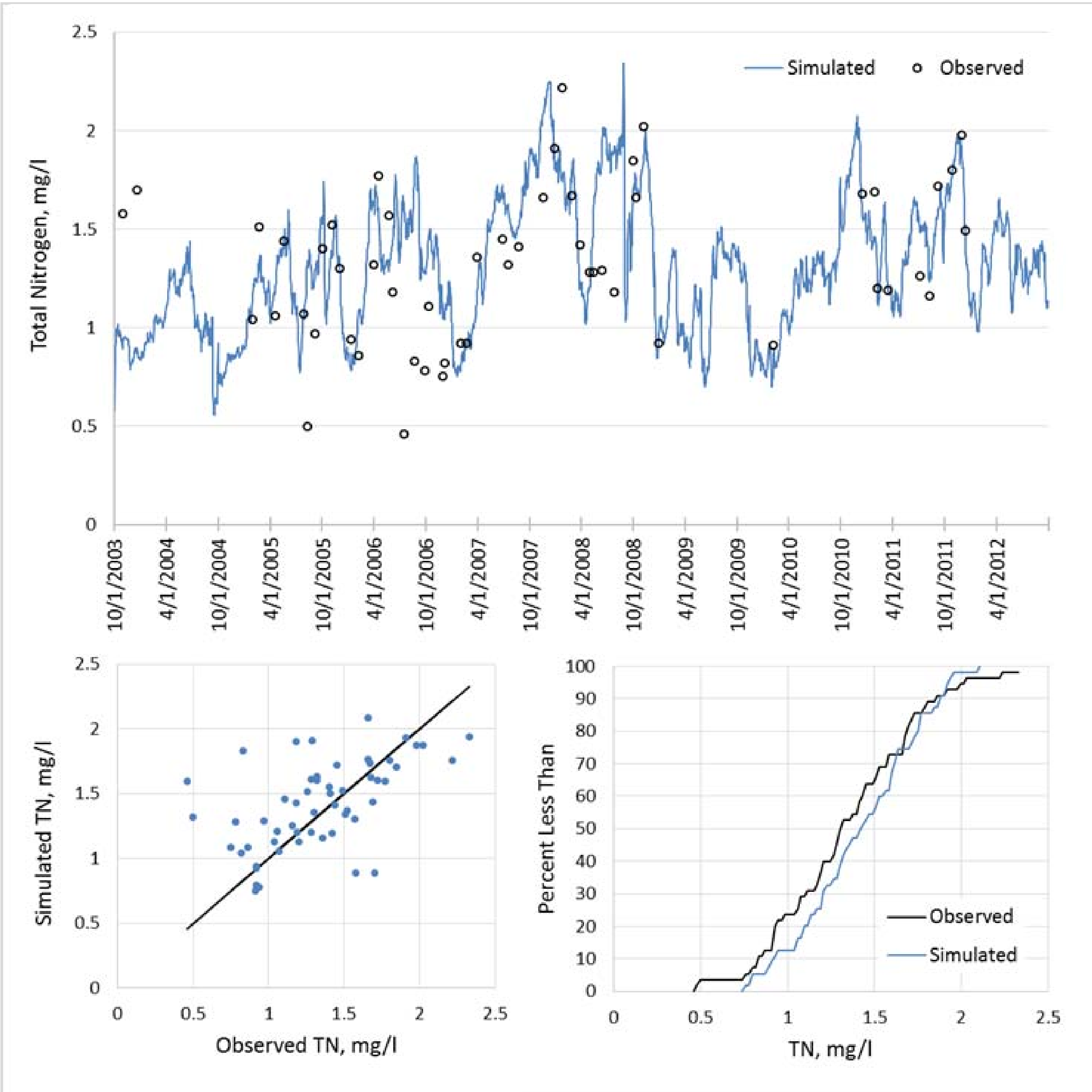

Figure 5-45 Total nitrogen simulation results, Great Falls Reservoir (WARMF ID 1563)

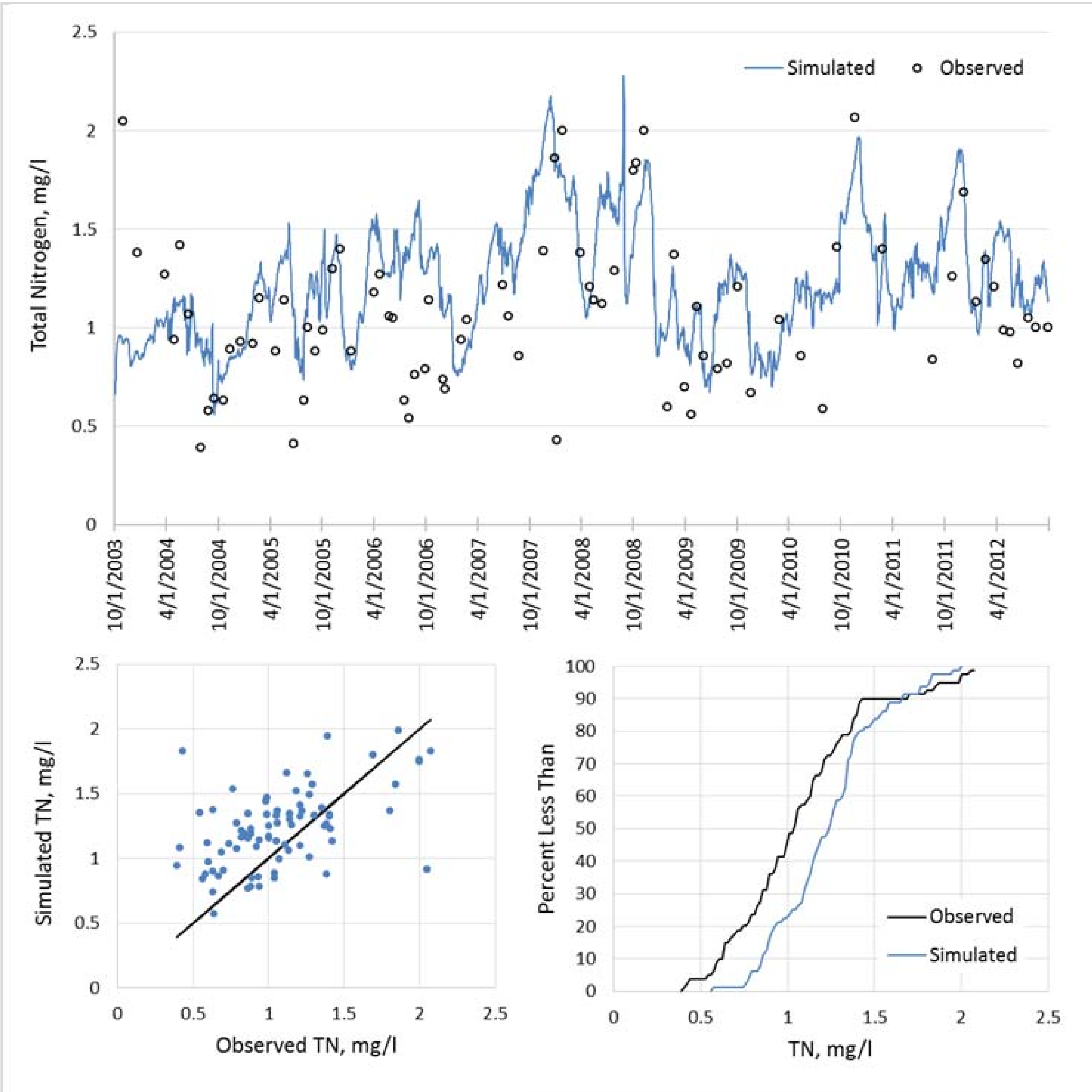

Figure 5-46 Total nitrogen simulation results, Cedar Creek Reservoir (WARMF ID 1567)

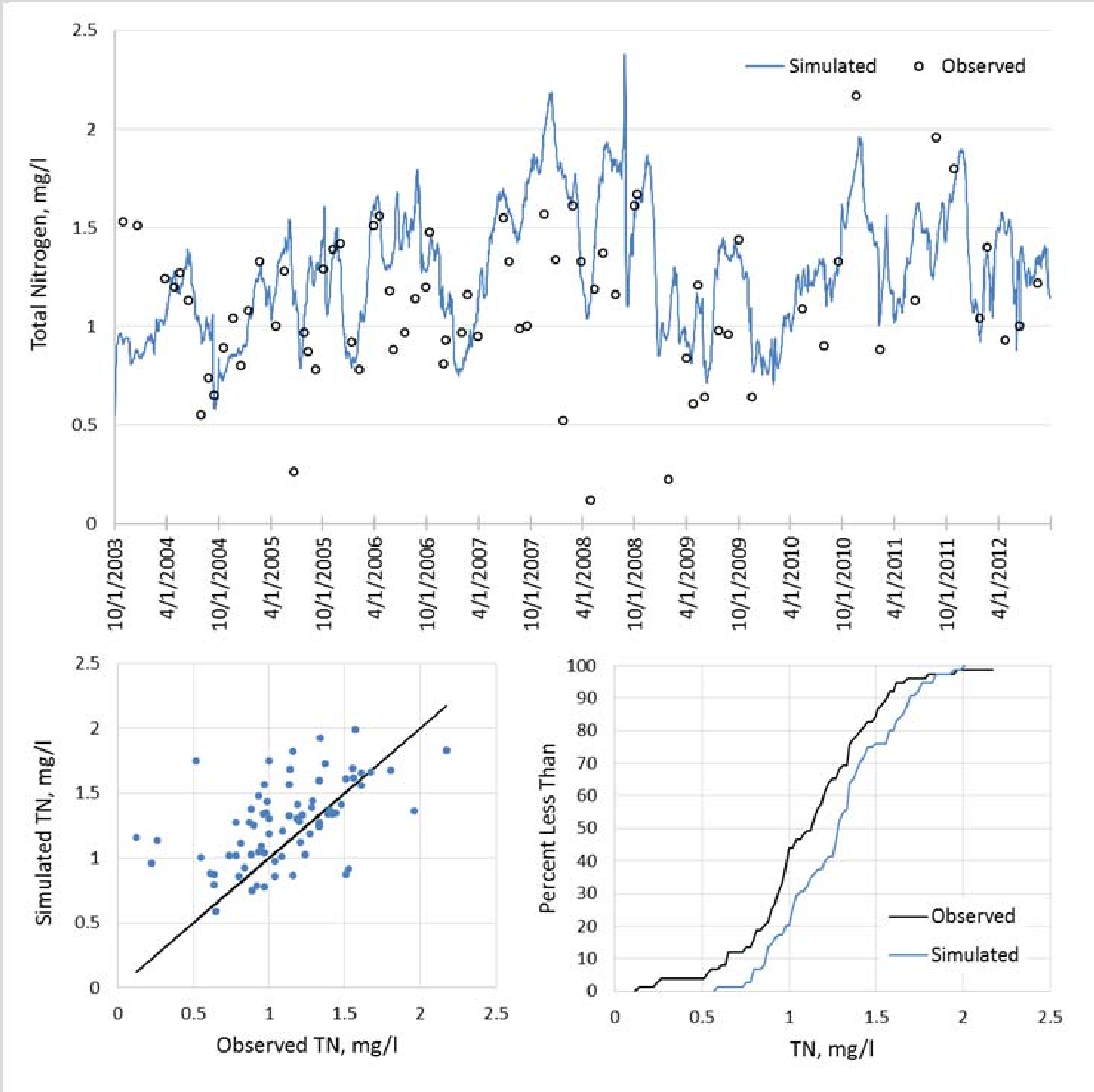

Figure 5-47 Total nitrogen simulation results, Catawba River below Cedar Creek (WARMF ID 624)

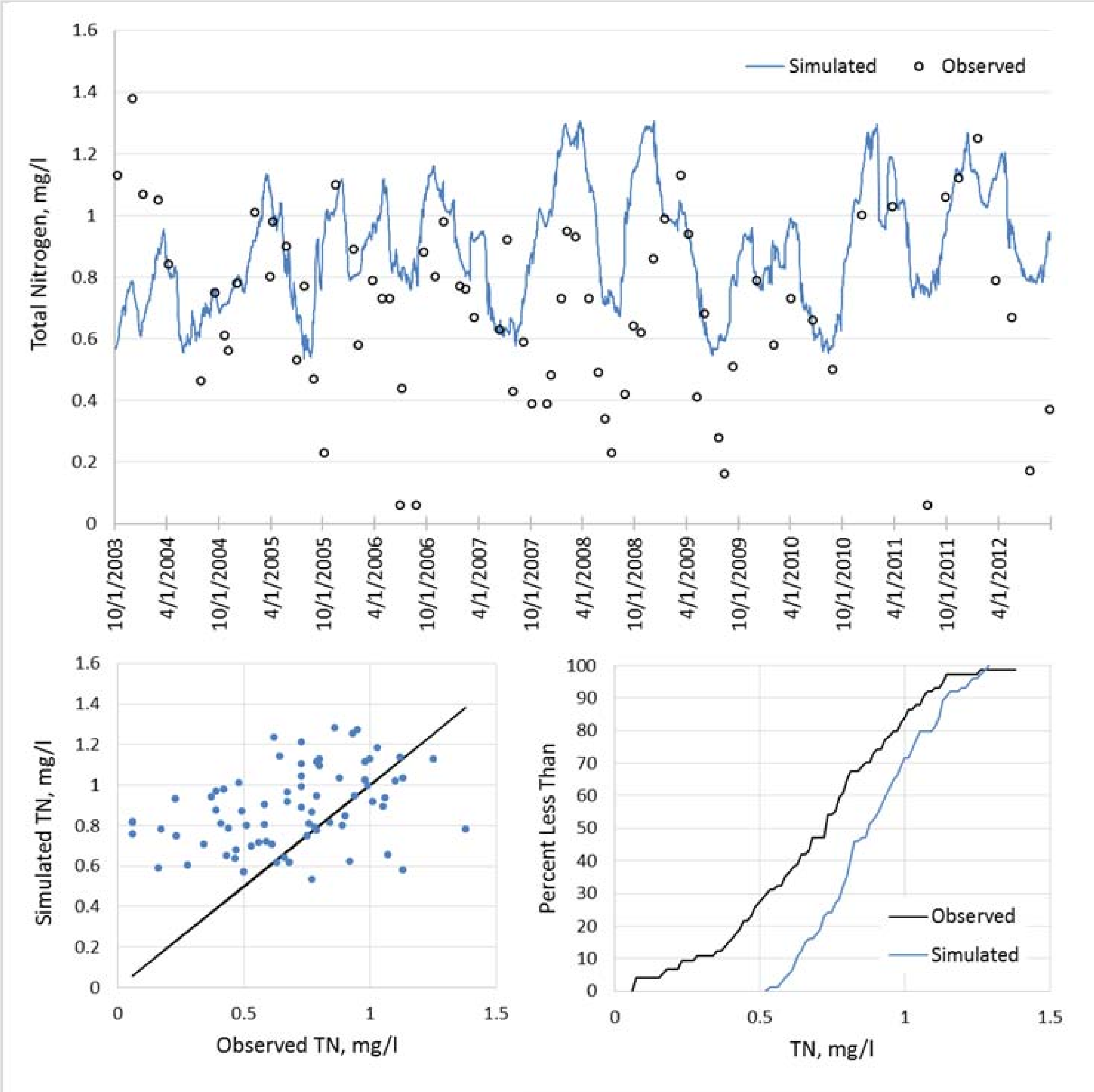

Figure 5-48 Total nitrogen simulation results, Lake Wateree Forebay (WARMF ID 2292)

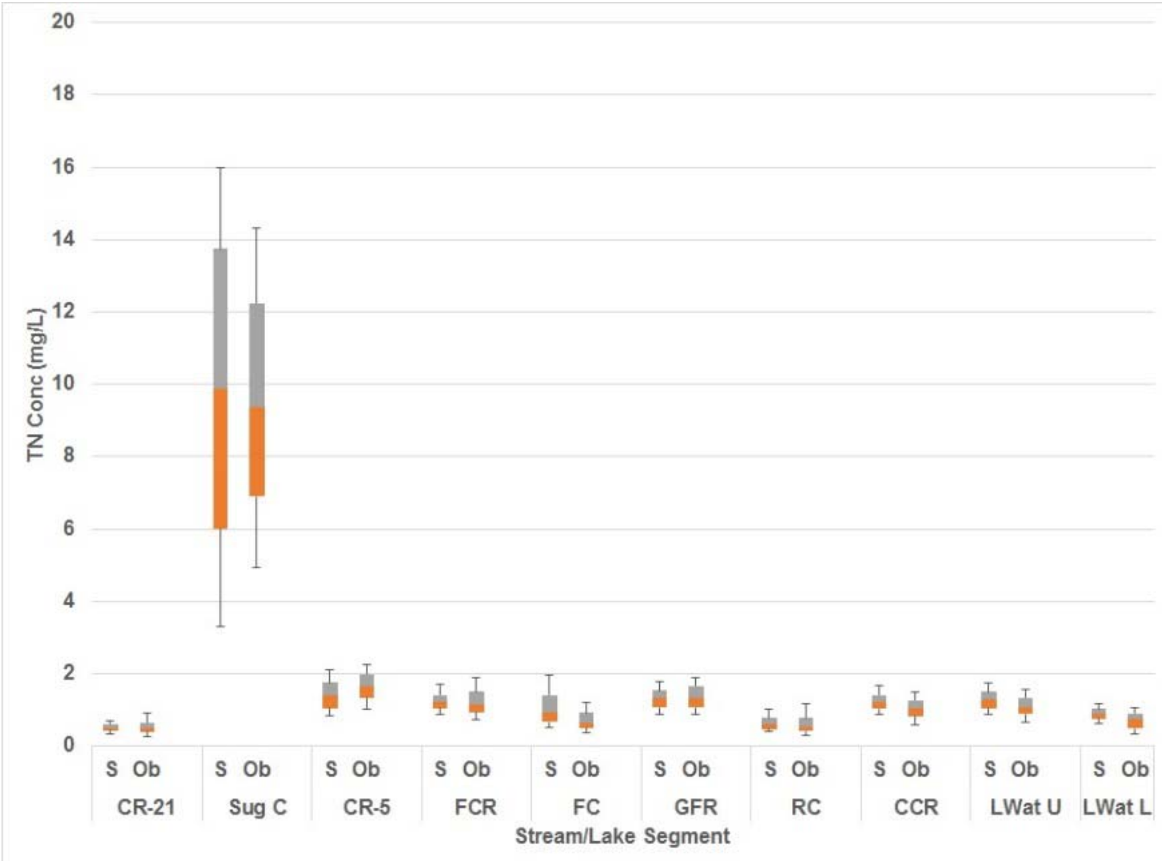

Figure 5-49a Longitudinal box and whisker plot of all total nitrogen simulation and observed data. Boxes represent 1st quartile, median, and 3rd quartiles; whiskers represent 10th and 90th percentiles.

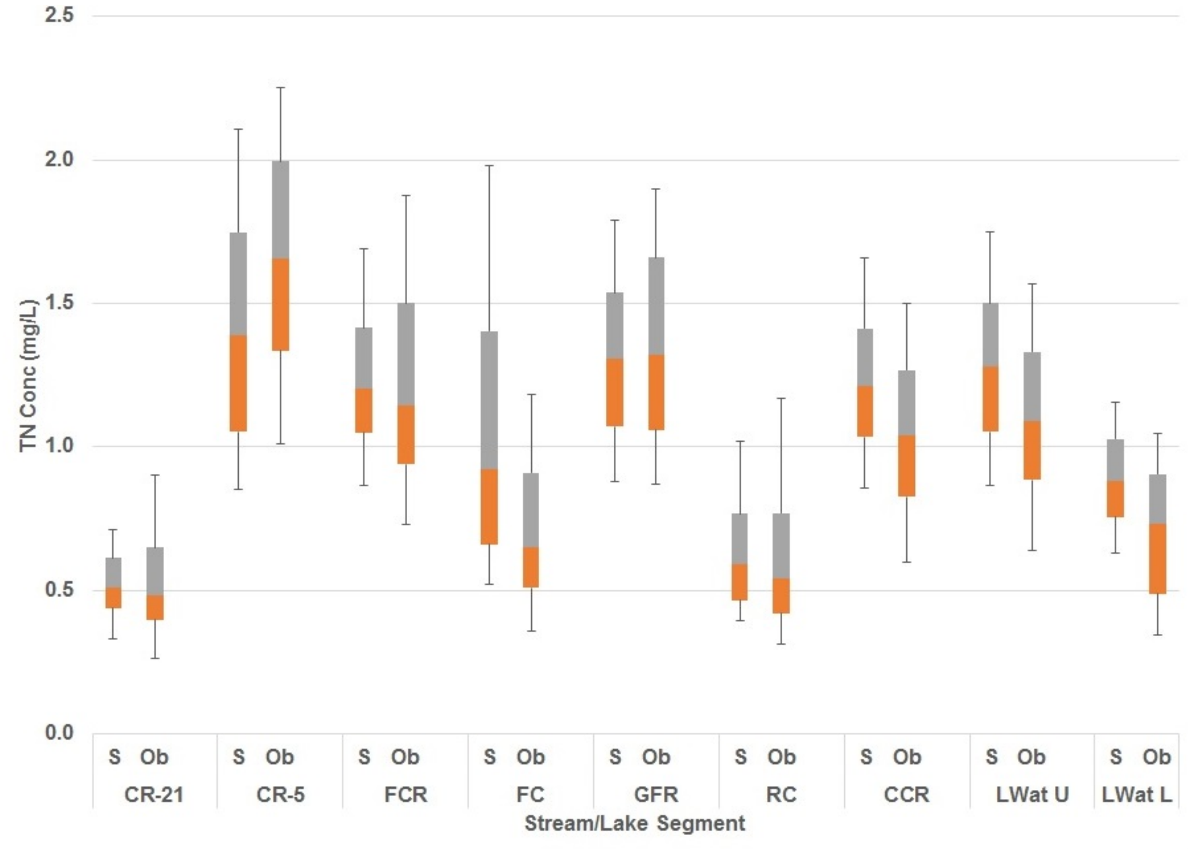

Figure 5-50b Longitudinal box and whisker plot of all total nitrogen simulation and observed data except for Sugar Creek. Boxes represent 1st quartile, median, and 3rd quartile; whiskers represent 10th and 90th percentiles.

Table 5-6 Total nitrogen simulation statistics

Location	Observed data (mg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	0.10	1.65	0.54	0.89	-0.8	0.34	0.8%	4.7%	0.09	0.89
Sugar Creek at SC-160	1.20	19.30	9.55	0.07	-4.7	0.97	4.7%	26.8%	3.38	0.49
Catawba River at SC-5	0.86	3.50	1.69	-0.12	16.7	1.06	-16.7%	22.2%	0.53	0.28
Fishing Creek at S-12-77	0.20	2.04	0.74	-4.73	-55.3	2.39	55.3%	80.4%	0.85	0.00
Lower Rocky Creek	0.20	2.58	0.68	-0.57	-0.7	1.25	0.7%	52.6%	0.52	0.01
Fishing Creek Reservoir	0.50	2.21	1.23	0.33	-0.2	0.82	0.2%	22.0%	0.34	0.35
Great Falls Reservoir	0.46	2.33	1.34	0.19	-5.7	0.90	5.7%	19.5%	0.36	0.31
Cedar Creek Reservoir	0.39	2.07	1.07	0.03	-15.2	0.98	15.2%	27.5%	0.38	0.27
Catawba River below Cedar Creek	0.12	2.17	1.11	-0.02	-14.6	1.01	14.6%	25.2%	0.38	0.27
Lake Wateree Forebay	0.06	1.38	0.71	-0.38	-25.1	1.17	25.1%	37.0%	0.33	0.14

5.6 Ortho-Phosphate

A substantial number of phosphate samples have been collected at Sugar Creek at SC-160 by Charlotte-Mecklenburg Utilities, enabling comparison between the simulated and observed values. The calibration plots are presented in Figure 5-51. Visual inspection of the plots provided in Figure 5-51 indicates that WARMF is simulating the trends in phosphate concentration reasonably well. The simulation statistics, provided in Table 5-7, confirm that the model is simulating ortho-phosphate in Sugar Creek with a high degree of precision and accuracy. The percent bias and the relative error indicate that the simulated values are on average about 12% greater than the observed. In WARMF, primary sources of phosphate load to the Sugar Creek subwatershed are point sources (78%) and land application on the developed and recreational grass land use areas (15%) (i.e., the non-point source load). The non-point source load mainly reaches the stream during rainfall events that produce surface runoff in the model. The 12% relative error in the simulation comes from error primarily on days with lower flow and higher concentration. In the model, the main source of phosphate on such days is point sources. Thus few factors other than phosphate concentration in point sources and sediment adsorption rates had any impact on reducing simulation error. The primary model coefficient used to calibrate ortho-phosphate was the adsorption isotherm in river segments.

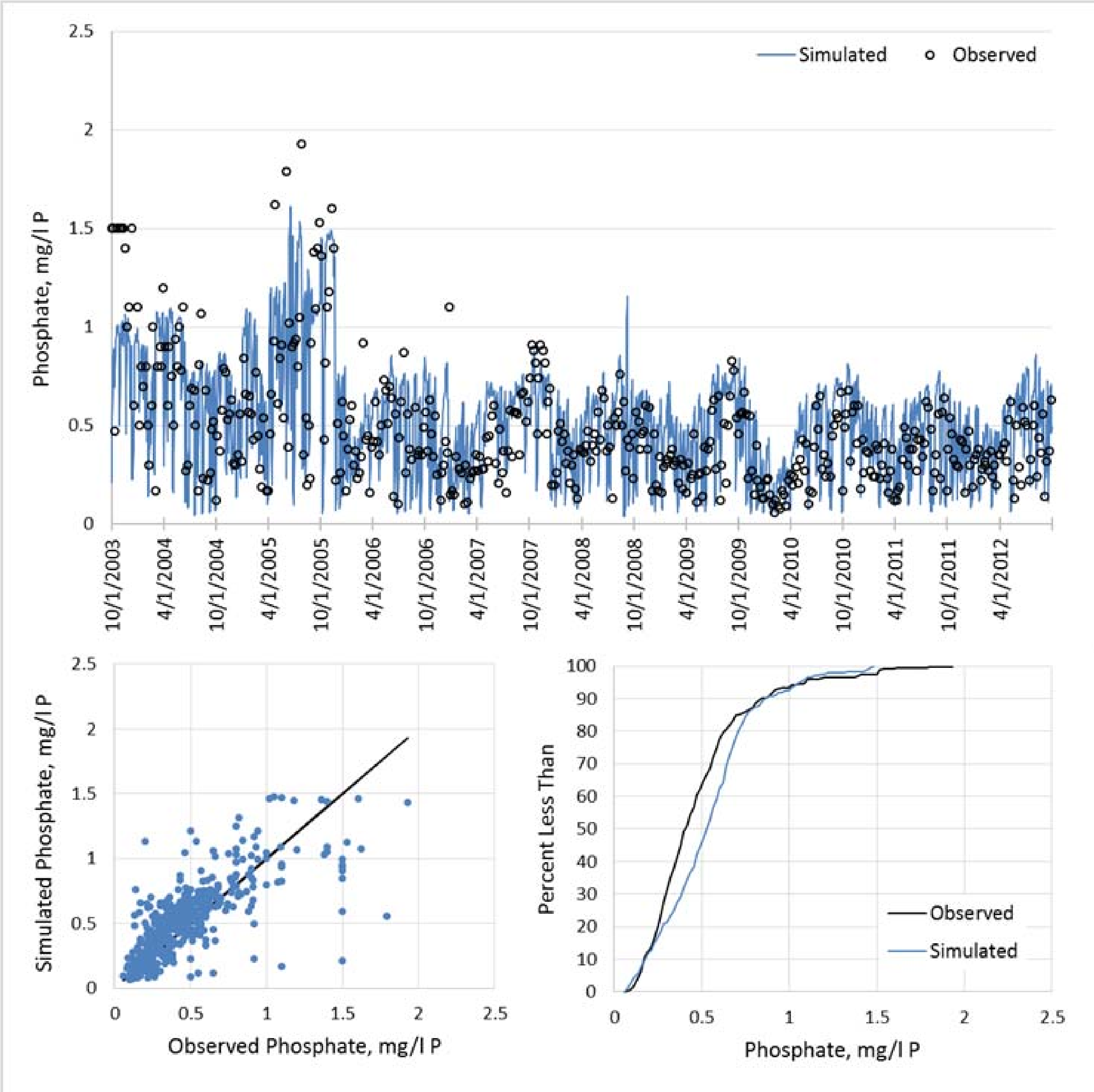

Figure 5-51 Phosphate simulation results, Sugar Creek at SC-160 (WARMF ID 246)

Table 5-7 Ortho-phosphate calibration statistics

Location	Observed Data			NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
	Minimum	Maximum	Mean							
Sugar Creek at SC-160	0.06	1.93	0.48	0.47	-11.79	0.73	11.8%	32.4%	0.22	0.54

5.7 Total Phosphorus

Like the other nutrients, the results of the WARMF calibration for total phosphorus concentration are presented for ten locations. From upstream to downstream, these locations include Catawba River at SC-21, Sugar Creek at SC-160, Catawba River at SC-5, Fishing Creek near S-12-77, Lower Rocky Creek, Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, Catawba River below Cedar Creek, and Lake Wateree Forebay. The total phosphorus simulation results are presented graphically in Figure 5-52 through Figure 5-61. Table 5-8 presents the total phosphorus simulation statistics. The model is generally simulating the correct magnitude and seasonal trends in total phosphorus concentration. Total phosphorus simulation in Sugar Creek (Figure 5-53) is better than some of the other locations because the observed hydrology and water quality dataset is extensive enough to enable a more thorough calibration of all the water quality parameters that affect phosphorus transport. Over all, low bias and relative error in most locations confirm that WARMF is simulating the correct amount of total phosphorus over the simulation timeframe. In Lake Wateree Forebay, where the average observed concentration decreases by half as compared to upstream (Table 5-8), the low relative error demonstrates that the model is effectively simulating the net loss of total phosphorus from the water column.

The locations where relative error is higher have either very few observed data points (e.g. Catawba River at SC-5) or inconsistent patterns in the observed data that cannot be replicated by the model. For example, in both Rocky and Fishing Creeks, the observed data shows a distinct increase in the overall trend in total phosphorus concentrations around 2010. If this trend is correct, it would have to be caused by an increase in loading from point or non-point sources in the local subwatersheds. Like for ammonia (discussed in Section 5.4), the point source data provided in these areas do not reflect a consistent load increase around this time. Non-point source loadings such as fertilizer application are static inputs to the model and cannot change for individual years or portions of the simulation. Thus the change in overall trend of total phosphorus around 2010 cannot be replicated by the model. However the test of downstream sensitivity to errors in Rocky and Fishing Creek demonstrated that these errors have very minimal impact on total phosphorus concentration in the reservoirs (see Appendix A).

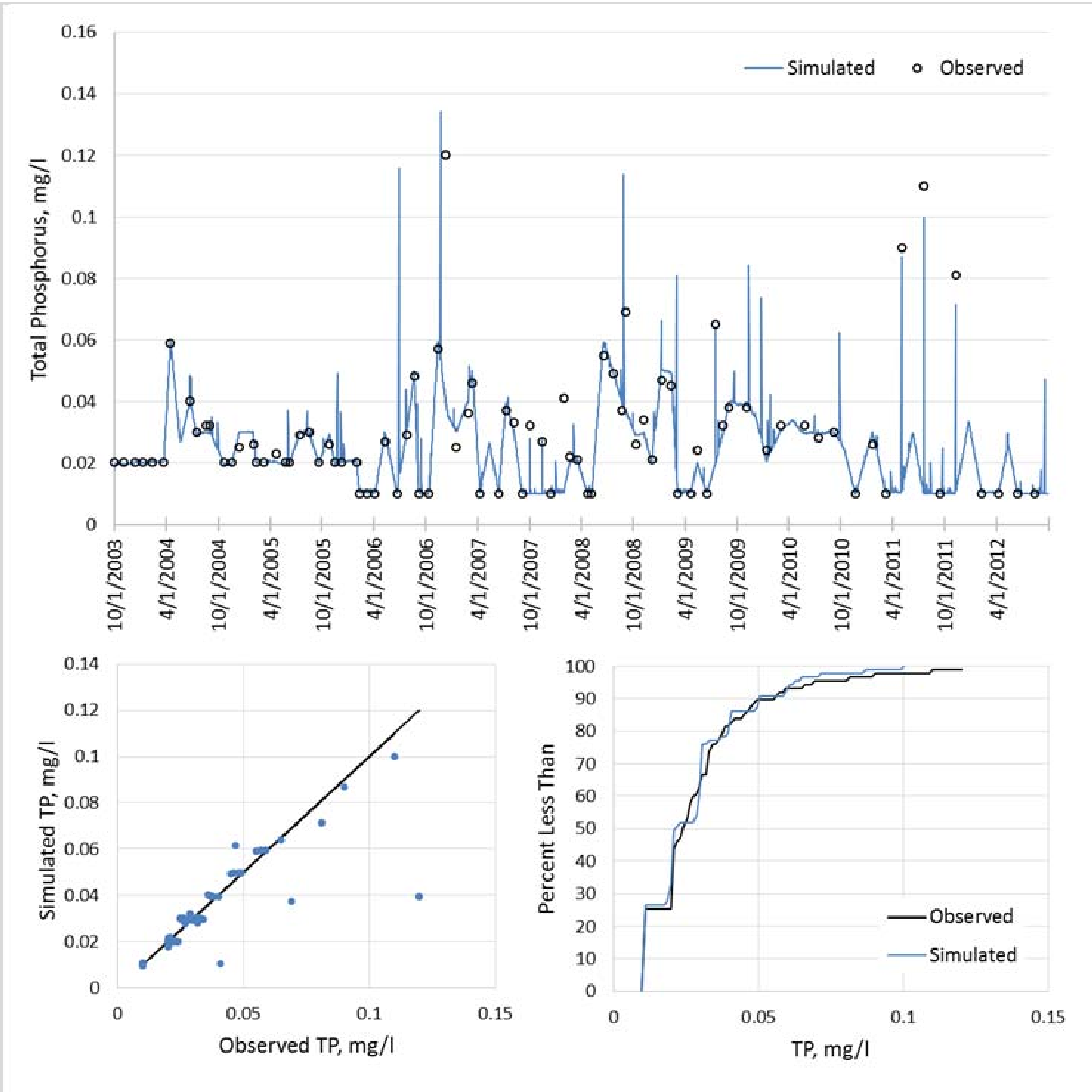

Figure 5-52 Total phosphorus simulation results, Catawba River at SC-21 (WARMF ID 89)

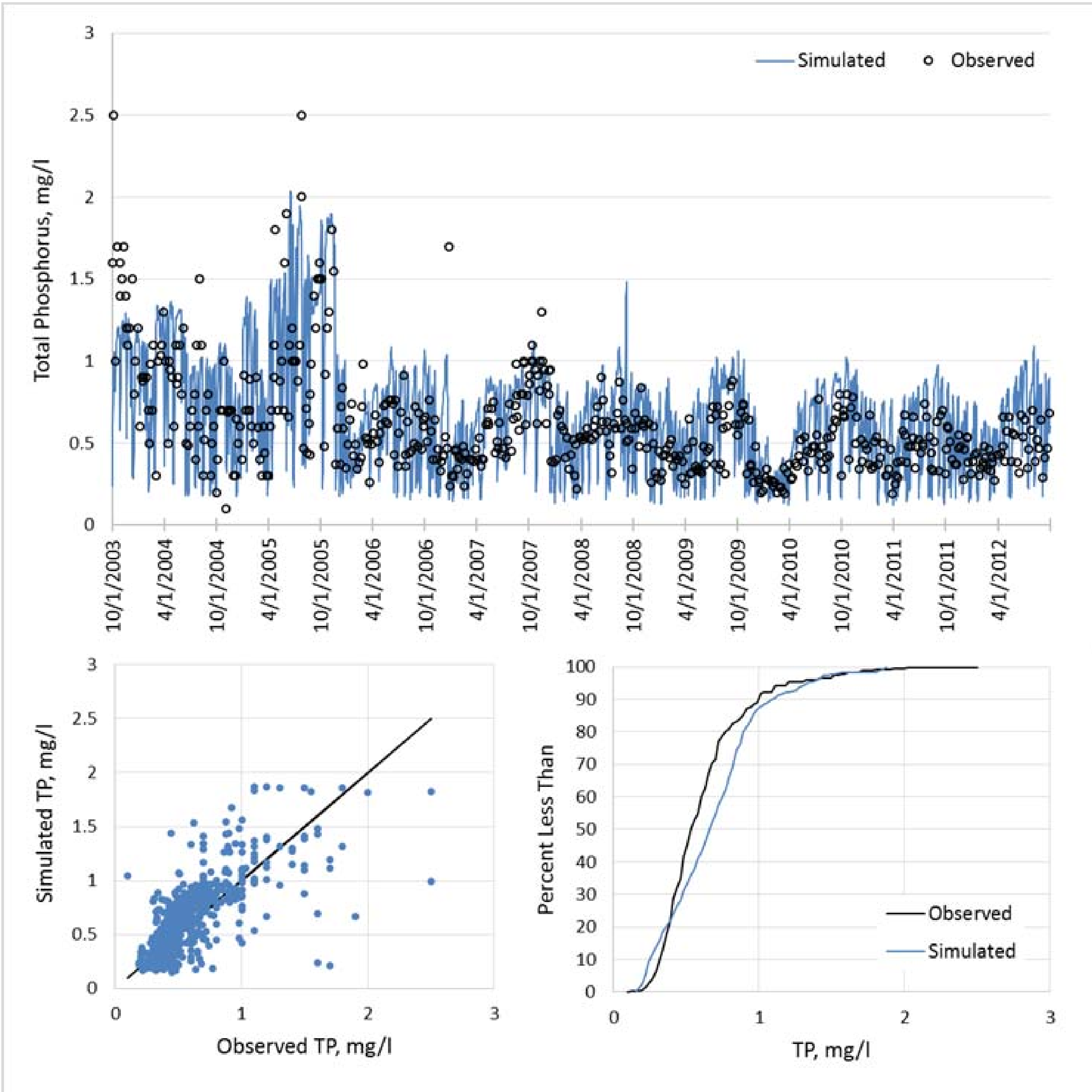

Figure 5-53 Total phosphorus simulation results, Sugar Creek at SC-160 (WARMF ID 246)

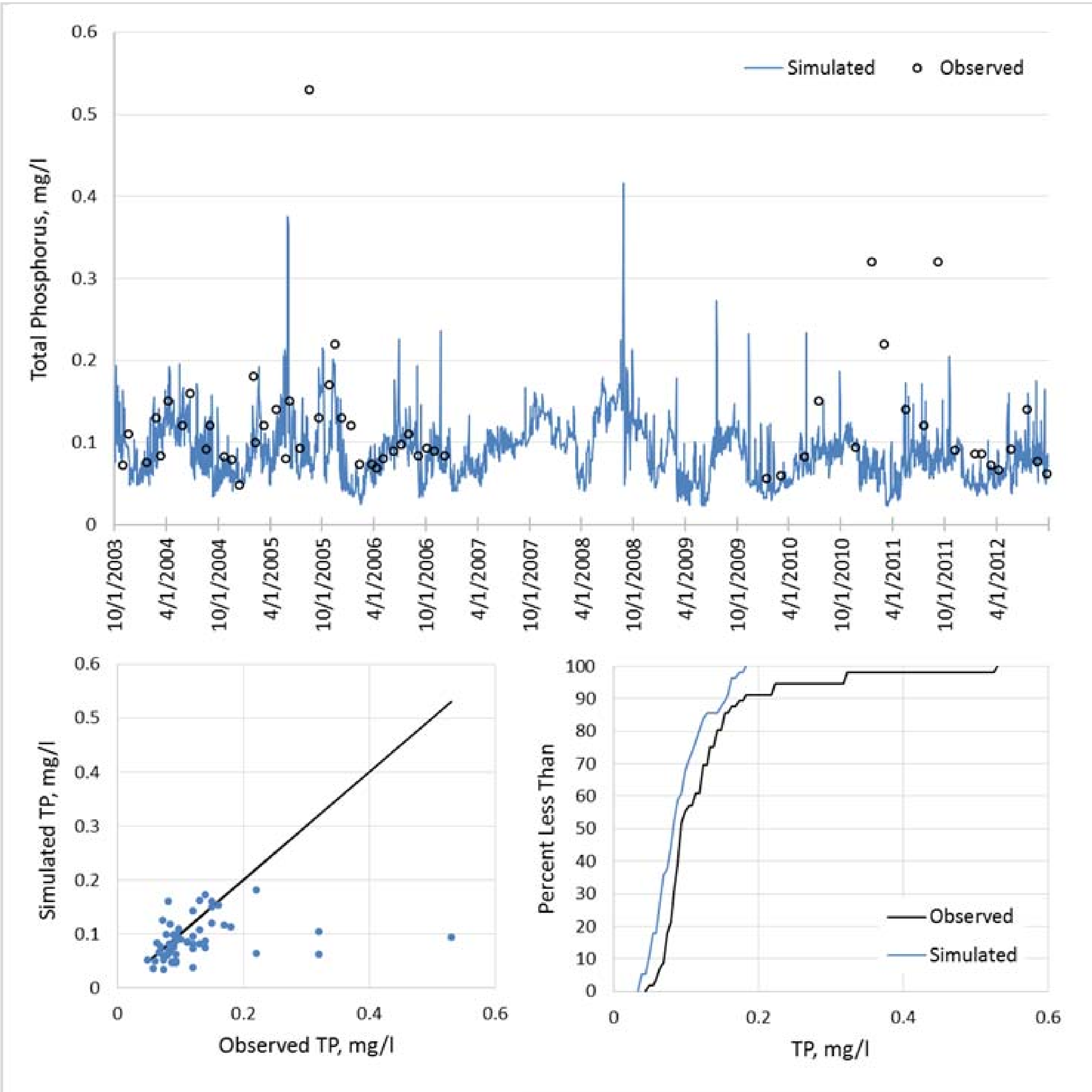

Figure 5-54 Total phosphorus simulation results, Catawba River at SC-5 (WARMF ID 69)

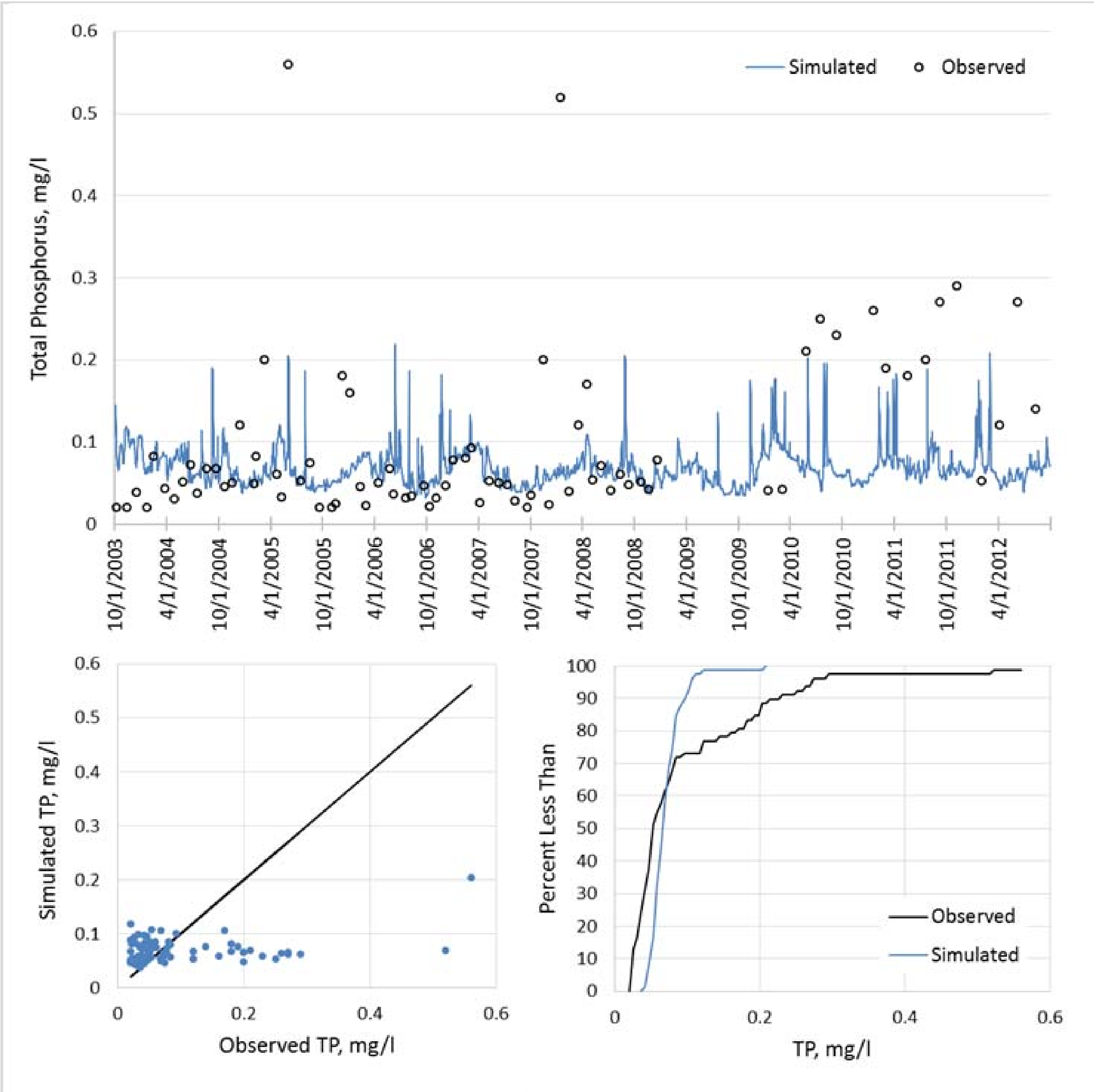

Figure 5-55 Total phosphorus simulation results, Fishing Creek near S-12-77 (WARMF ID 149)

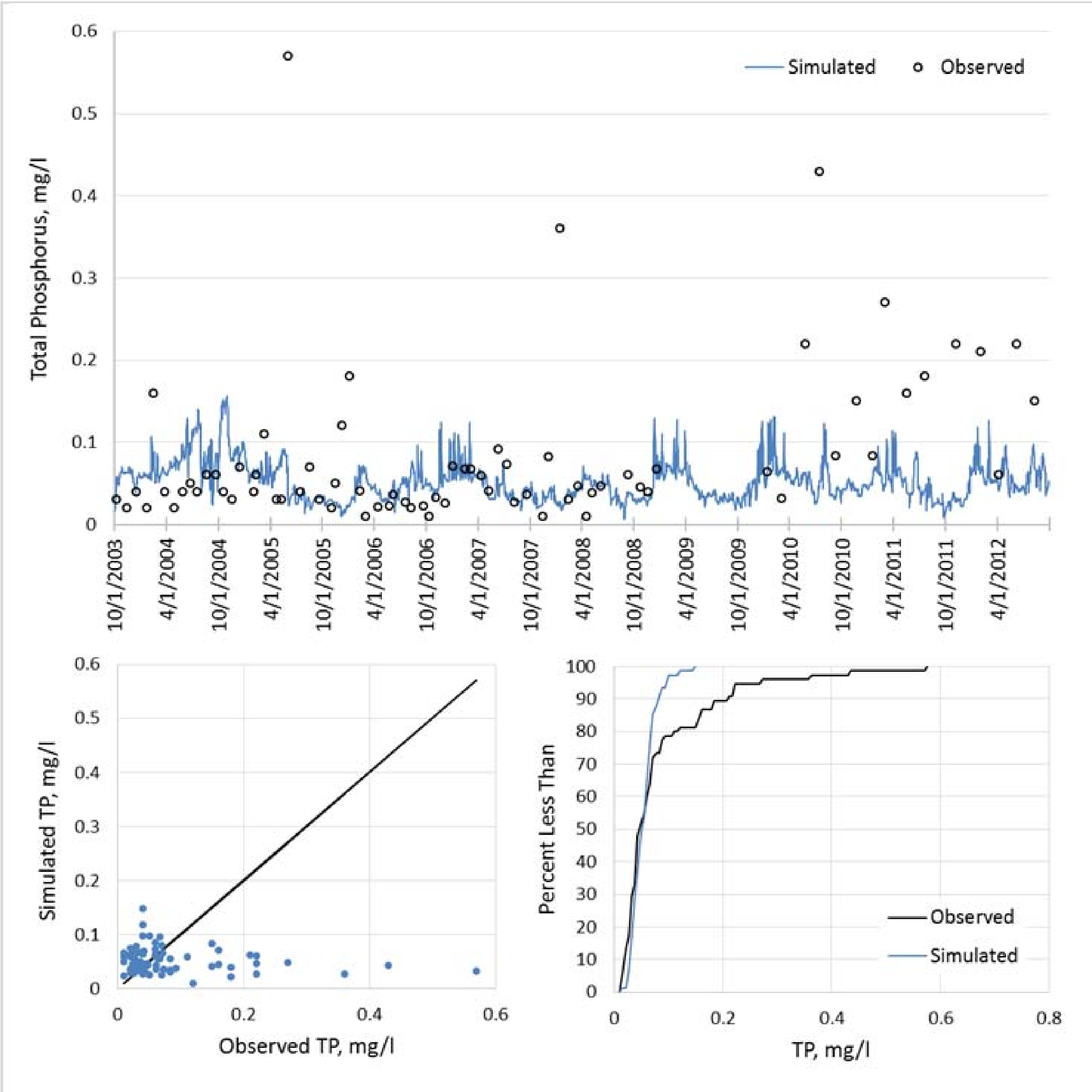

Figure 5-56 Total phosphorus simulation results, Lower Rocky Creek (WARMF ID 160)

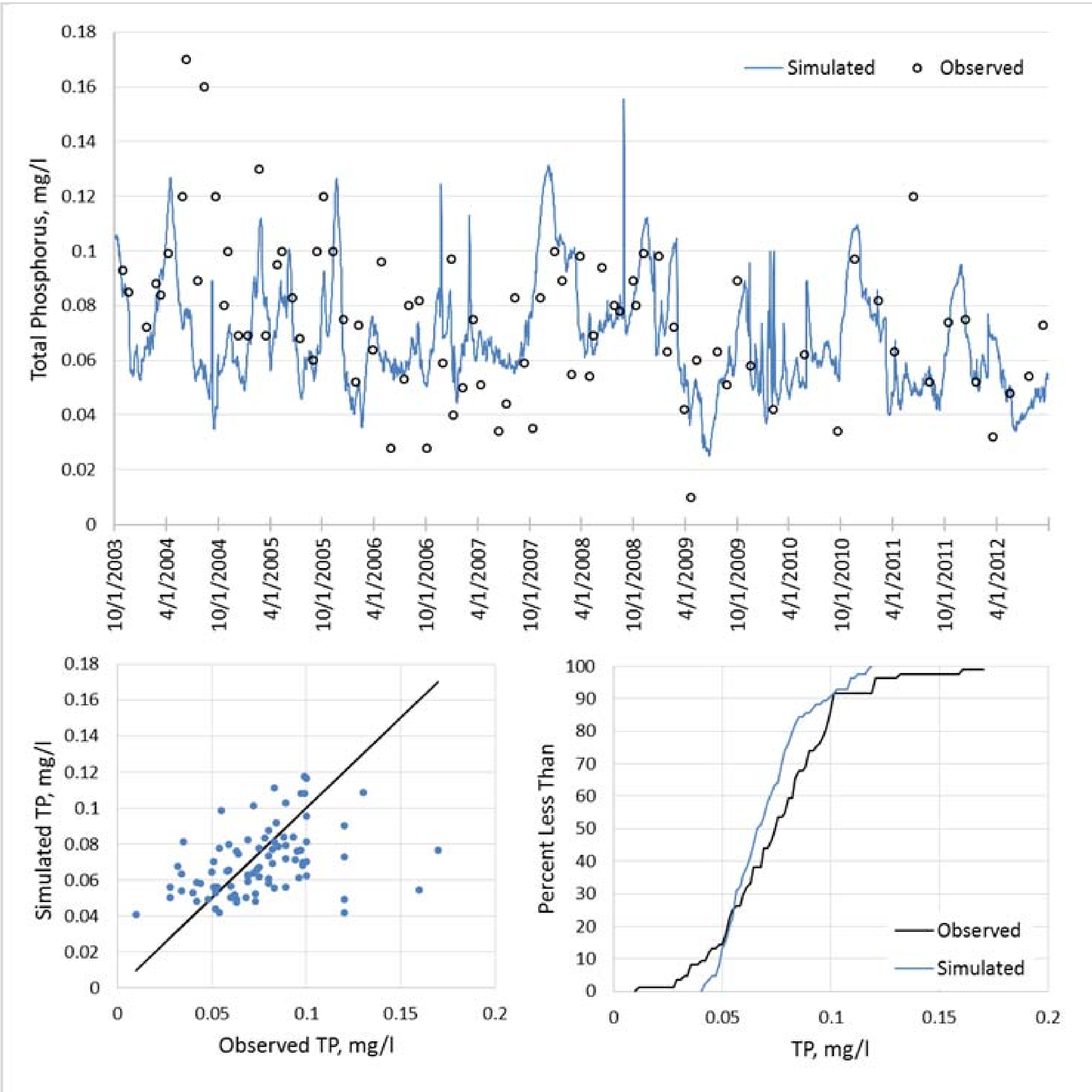

Figure 5-57 Total phosphorus simulation results, Fishing Creek Reservoir (WARMF ID 1562)

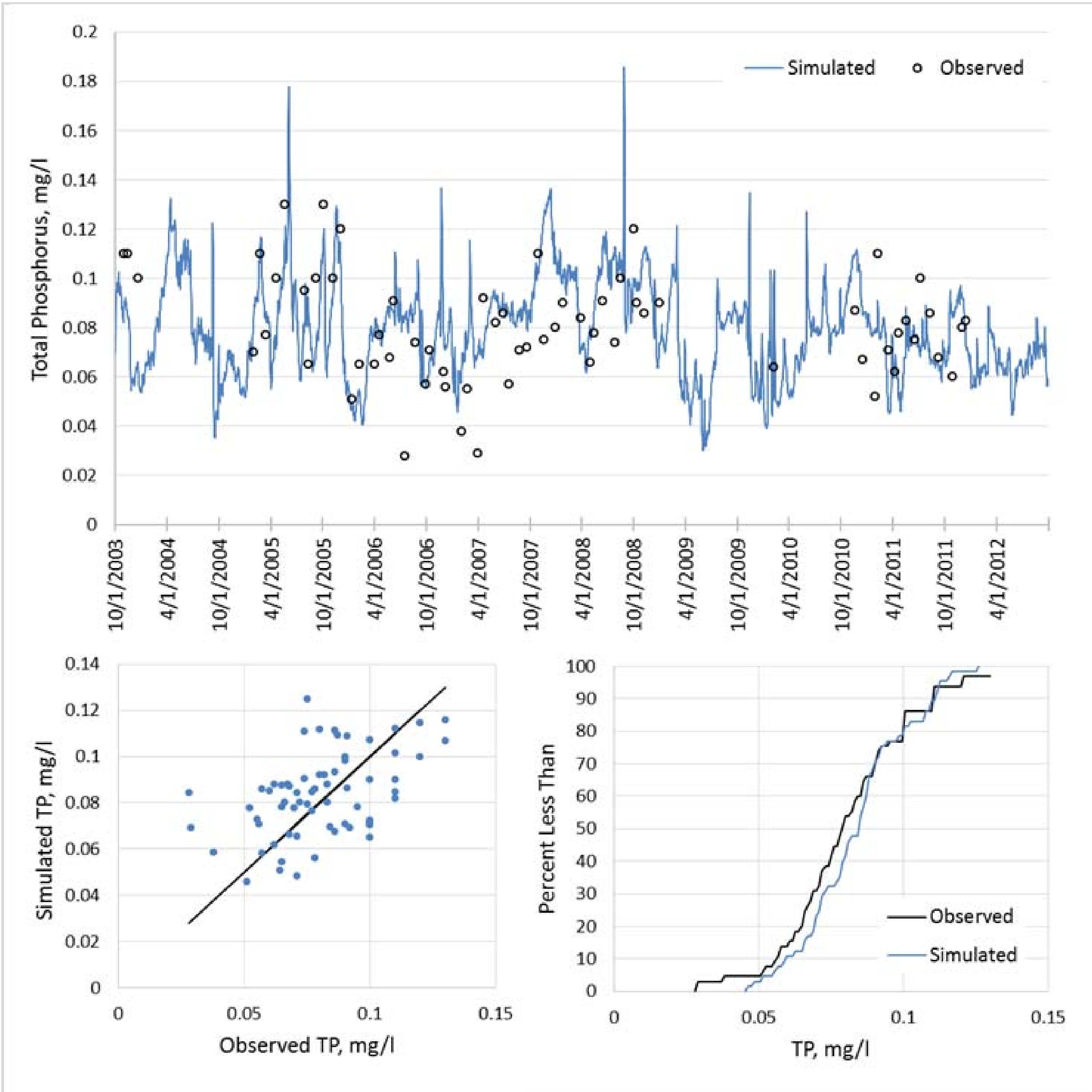

Figure 5-58 Total phosphorus simulation results, Great Falls Reservoir (WARMF ID 1563)

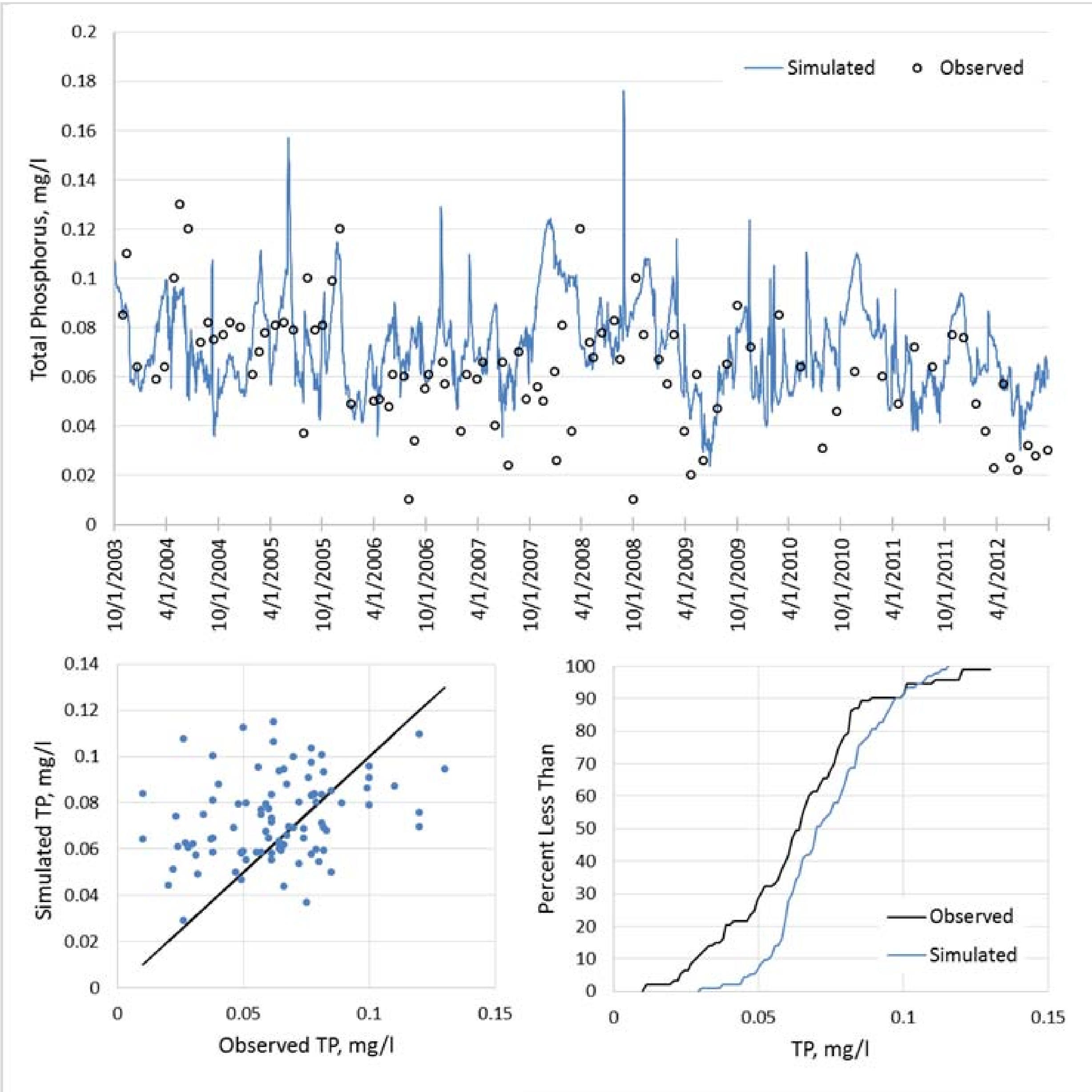

Figure 5-59 Total phosphorus simulation results, Cedar Creek Reservoir (WARMF ID 1567)

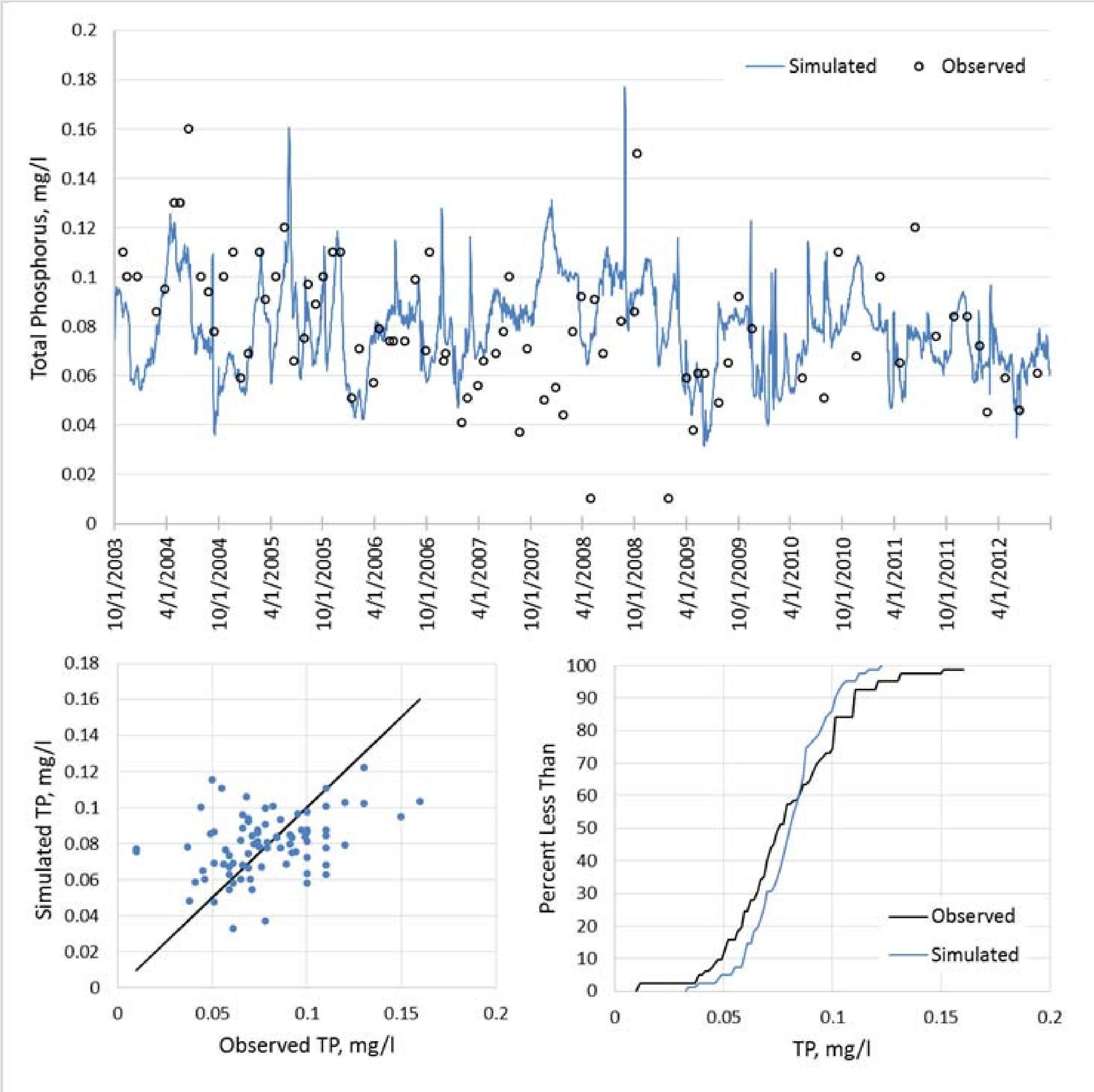

Figure 5-60 Total phosphorus simulation results, Lake Wateree Headwaters (CW-231) (WARMF ID 624)

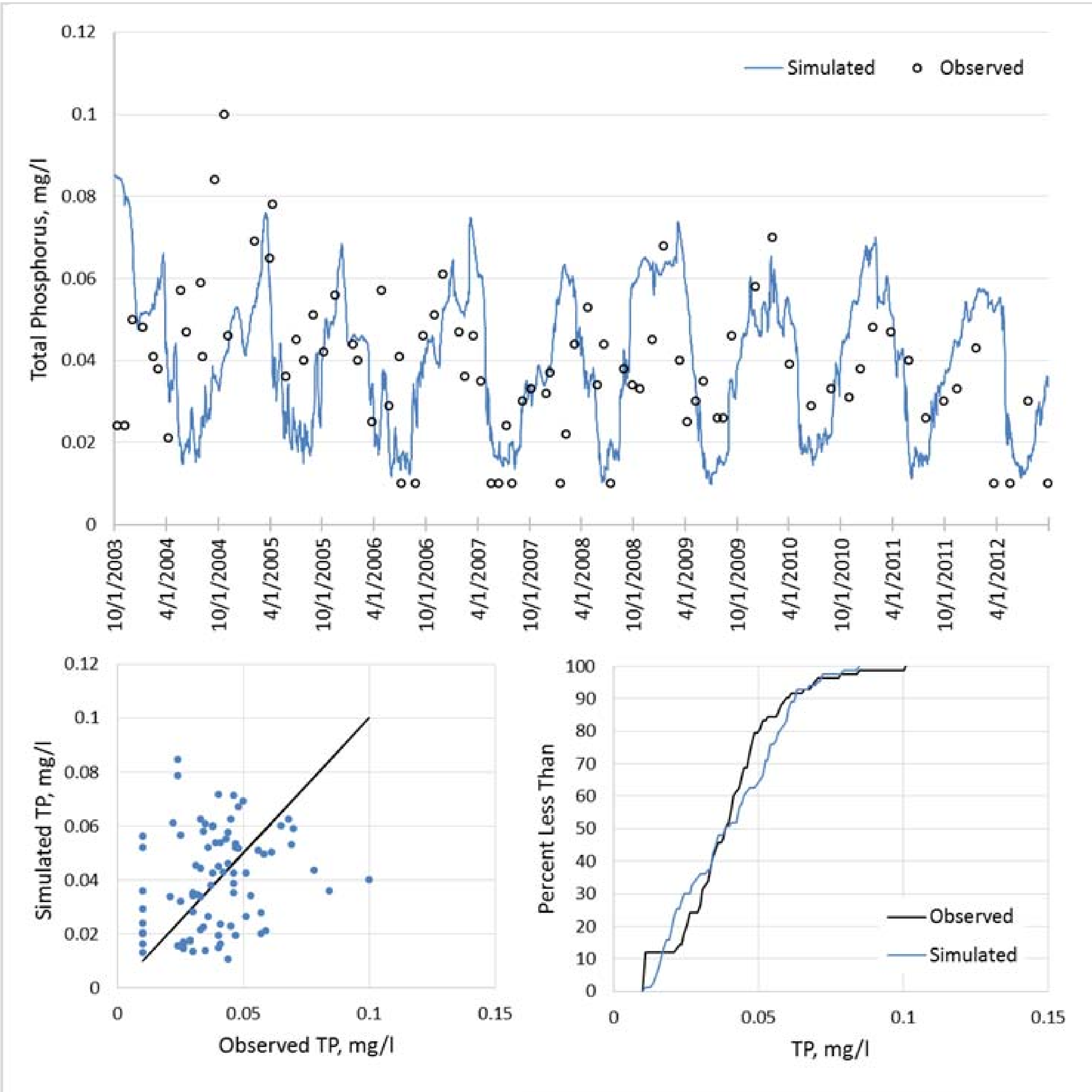

Figure 5-61 Total phosphorus simulation results, Lake Wateree Forebay (CL-089) (WARMF ID 2292)

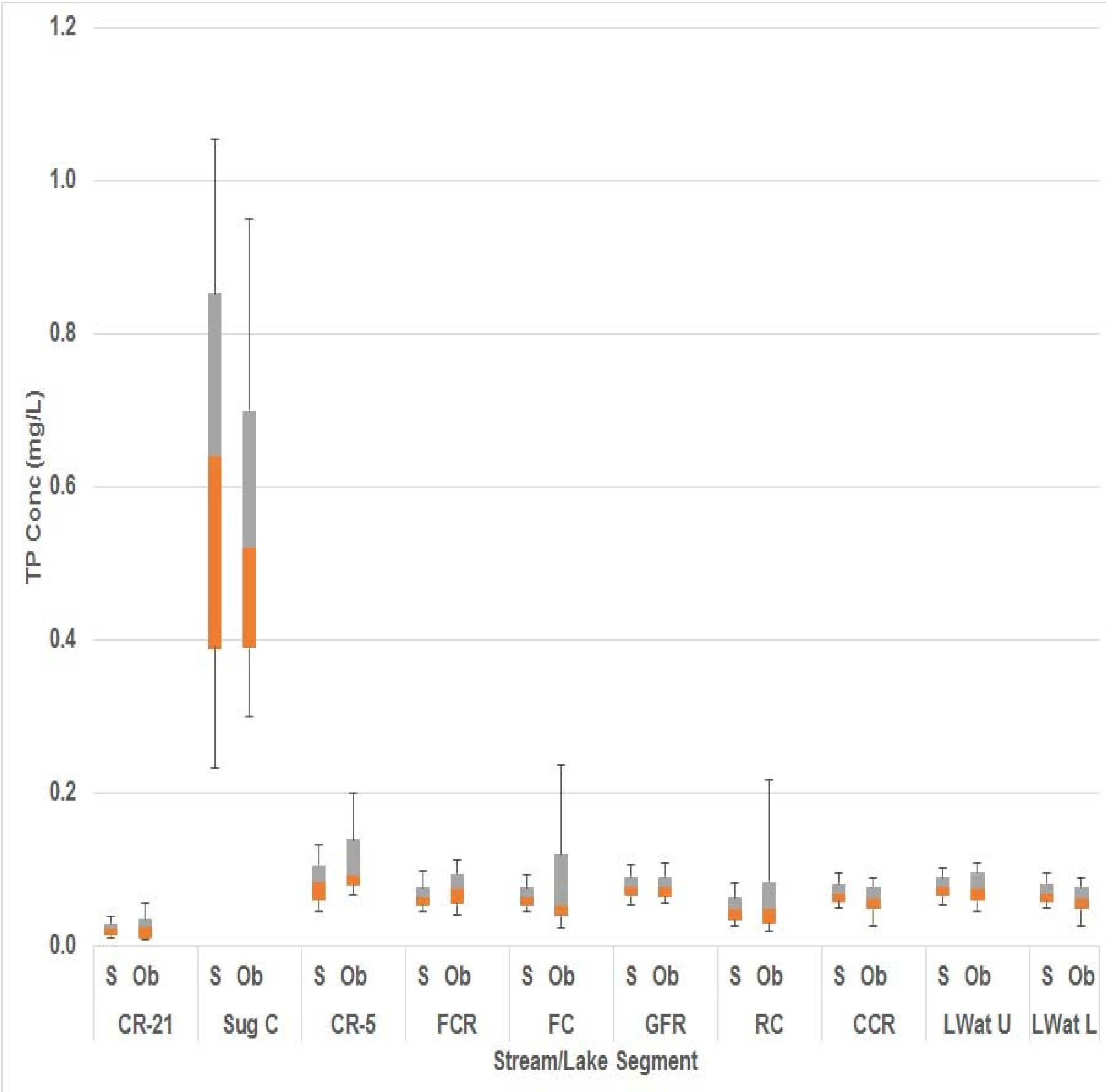

Figure 5-62a Longitudinal box and whisker plot of all total phosphorus simulation and observed data. Boxes represent 1st quartile, median, and 3rd quartile; whiskers represent 10th and 90th percentiles.

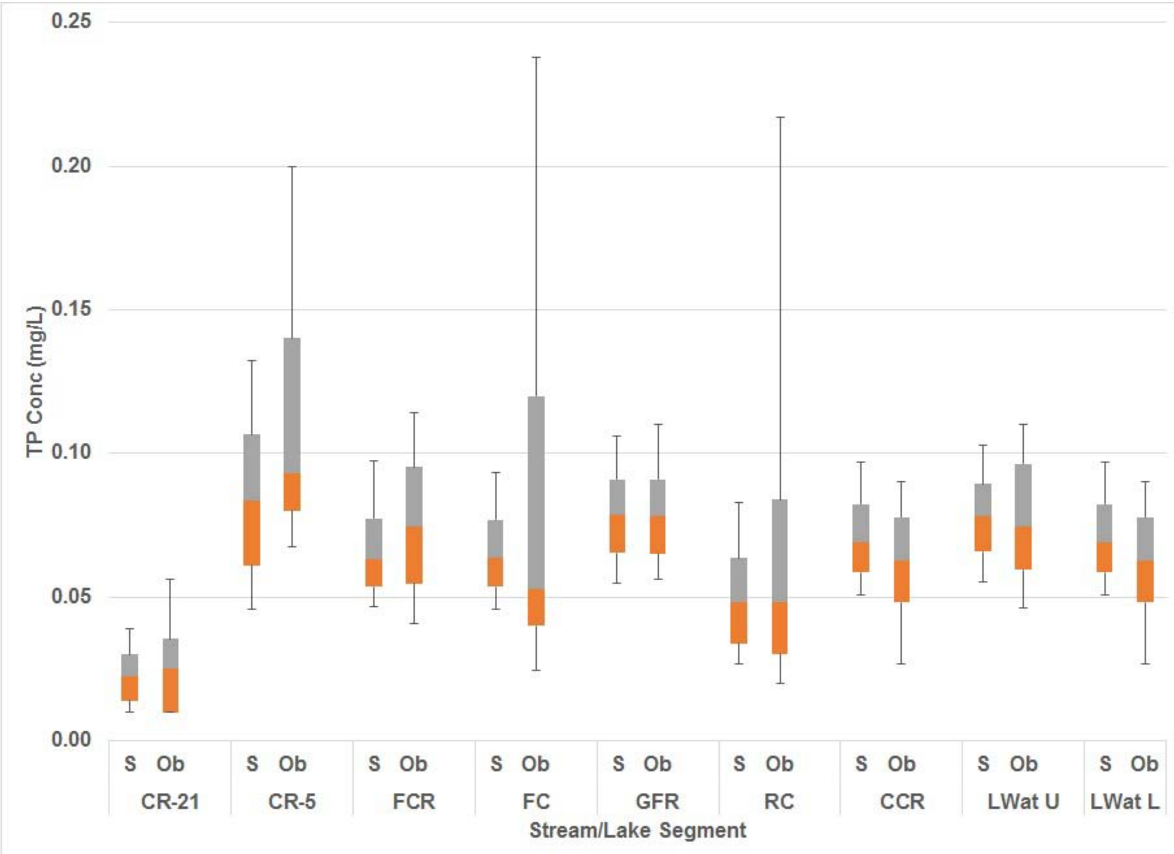

Figure 5-63b Longitudinal box and whisker plot of all total phosphorus simulation and observed data except for Sugar Creek. Boxes represent 1st quartile, median, and 3rd quartiles; whiskers represent 10th and 90th percentiles.

Table 5-8 Total phosphorus simulation statistics

Location	Observed data (mg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	0.01	0.12	0.03	0.76	4.8	0.49	-4.8%	11.8%	0.01	0.77
Sugar Creek at SC-160	0.10	2.50	0.61	0.31	-10.8	0.83	10.8%	30.7%	0.27	0.49
Catawba River at SC-5	0.05	0.53	0.12	-0.15	25.8	1.07	-25.8%	36.4%	0.08	0.06
Fishing Creek at S-12-77	0.02	0.56	0.10	0.03	27.2	0.99	-27.2%	64.6%	0.10	0.10
Lower Rocky Creek	0.01	0.57	0.08	-0.25	36.1	1.12	-36.1%	72.9%	0.11	0.04
Fishing Creek Reservoir	0.01	0.17	0.08	0.04	7.37	0.98	-7.4%	26.3%	0.03	0.15
Great Falls Reservoir	0.03	0.13	0.08	0.08	-4.1	0.96	4.1%	21.3%	0.02	0.23
Cedar Creek Reservoir	0.01	0.13	0.06	-0.25	-16.6	1.12	16.6%	33.6%	0.03	0.10
Catawba River below Cedar Creek	0.01	0.16	0.08	0.06	-1.0	0.97	1.0%	25.4%	0.03	0.13
Lake Wateree Forebay	0.01	0.10	0.04	-0.59	-2.6	1.26	2.6%	45.2%	0.02	0.06

5.8 Algae (Chlorophyll *a*)

WARMF was calibrated to measured algae concentrations at five locations: Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, Catawba River below Cedar Creek and Lake Wateree Forebay. The algae simulation results are presented graphically in Figure 5-64 through Figure 5-68. The figures indicate that the WARMF model is doing an acceptable job of simulating the annual pattern and magnitude of algae concentrations in both of the reservoirs and in the Catawba River. Algae simulation statistics are provided in Table 5-9. In assessing results of algae simulations, it is important to consider that in reservoirs, the measured algae concentrations represent the amount of algae present at one location at a specific point in time. The simulated concentration that is used for statistical comparison represents the simulated daily algae concentration in the surface layer averaged over the area of that lake layer. Direct statistical comparison of simulated and measured concentrations in reservoirs is therefore somewhat misleading. In reservoirs, the most important consideration in evaluating model performance should be whether the simulated concentrations follow the correct seasonal trends and approximate magnitude of the observations. The WARMF simulation of algae in Fishing Creek Reservoir and Lake Wateree performs well when evaluated by these metrics.

In the locations with largest error (Great Falls Reservoir and Catawba River below Cedar Creek), algae concentrations are dominated by the concentrations released through the upstream dam. The concentrations released depend on the concentrations existing at the specified depth of the turbine intake. Though WARMF is simulating a reasonable depth profile, concentrations released are still higher than downstream observations. Additional factors not included in the model may be affecting algae concentrations passing through the turbines to downstream segments.

Another significant factor limiting the calibration potential for total algae is the quantity of data. Data is very limited in all locations with only a handful of observations available each year. Furthermore, data is only available from May through September each year, providing no information to guide the calibration of algae concentrations in late fall and early spring. Other constituents such as nutrients and dissolved oxygen show evidence of algae blooms (e.g. drop in nutrient concentrations, rise in DO) as early as February in Lake Wateree. However the lack of chlorophyll-a data prior to May each year limited the feasibility of calibrating spring algae blooms.

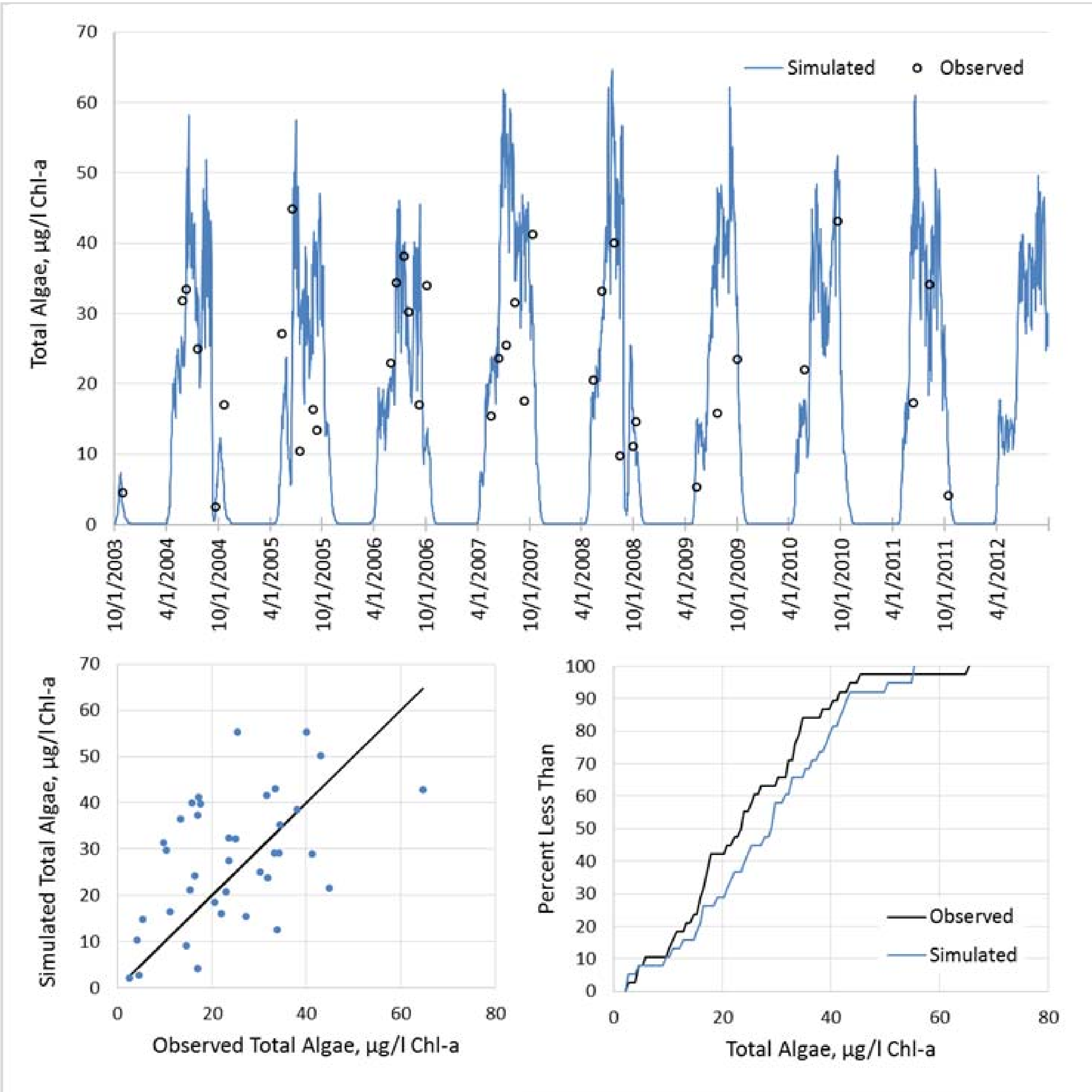

Figure 5-64 Total Algae simulation results, Fishing Creek Reservoir (WARMF ID 1562)

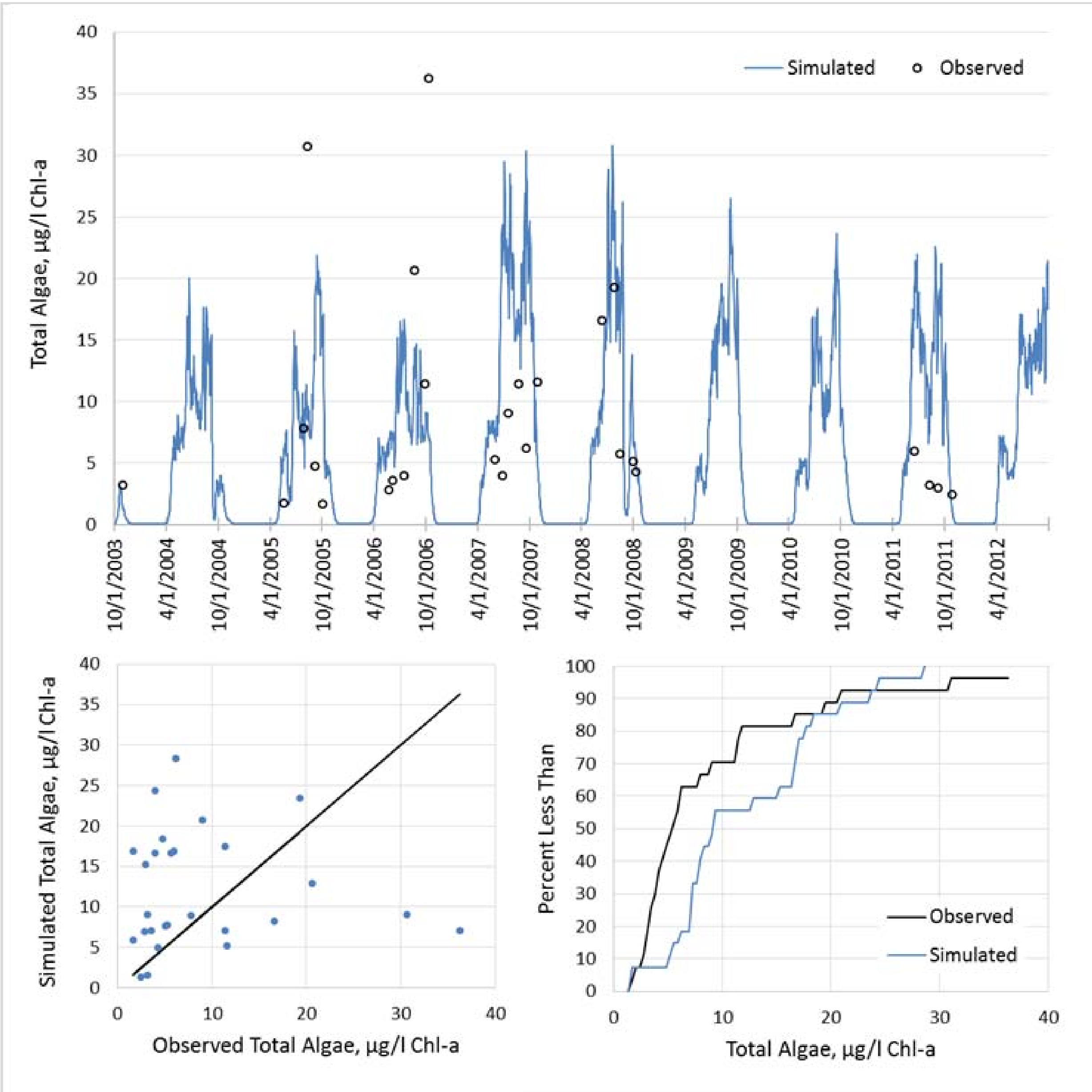

Figure 5-65 Total Algae simulation results, Great Falls Reservoir (WARMF ID 1563)

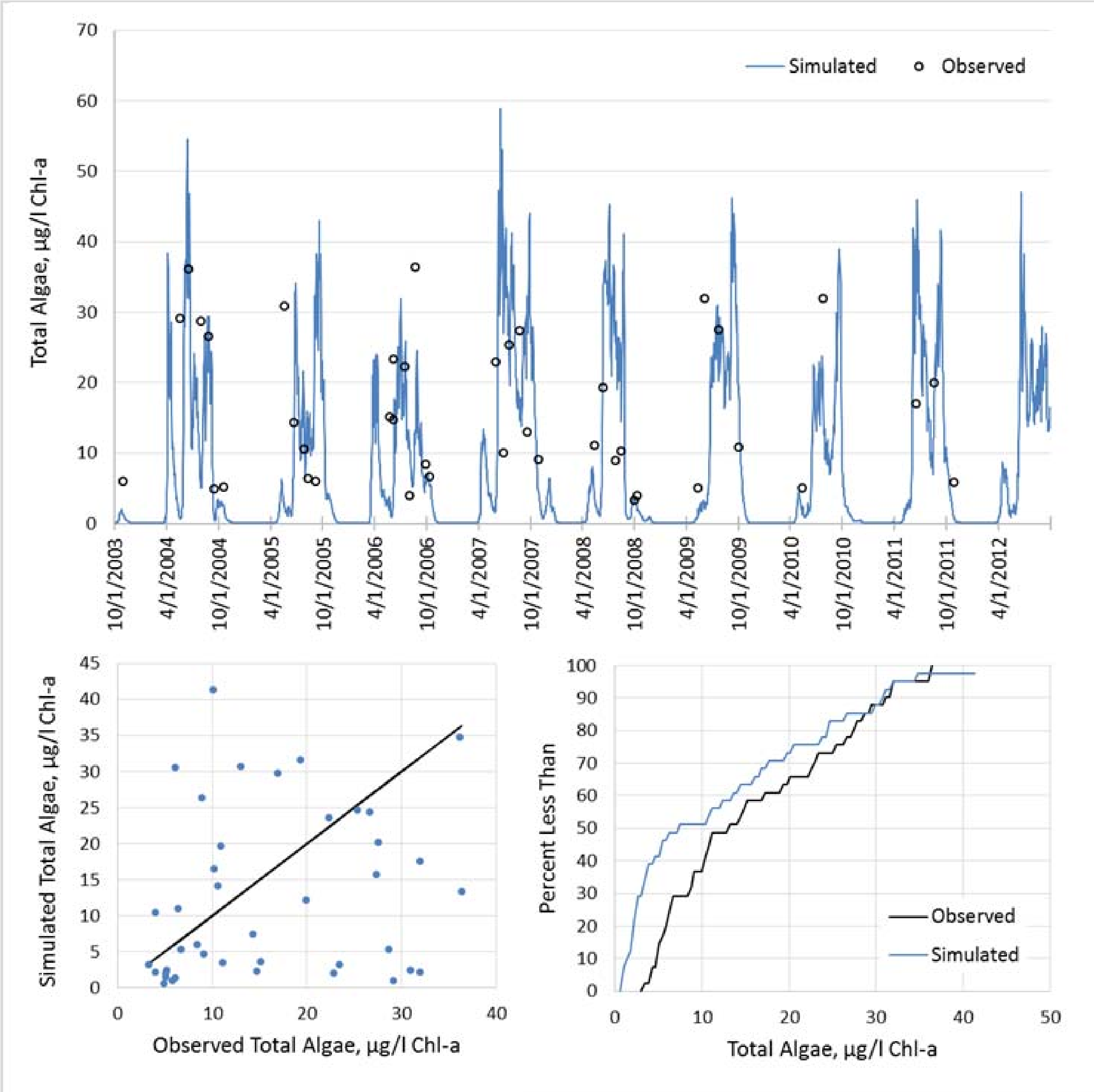

Figure 5-66 Total Algae simulation results, Cedar Creek Reservoir (WARMF ID 1567)

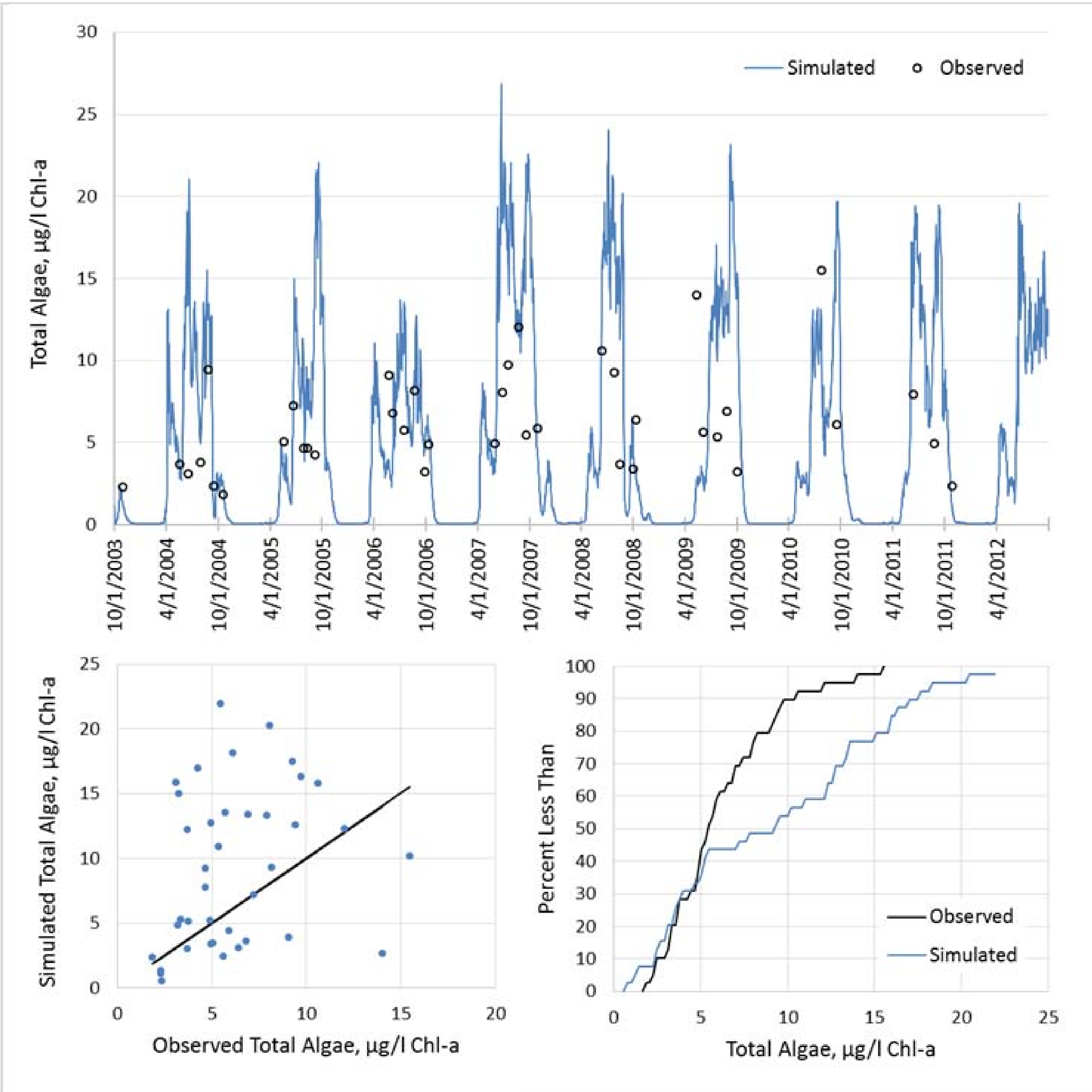

Figure 5-67 Total Algae simulation results, Catawba River below Cedar Creek (WARMF ID 624)

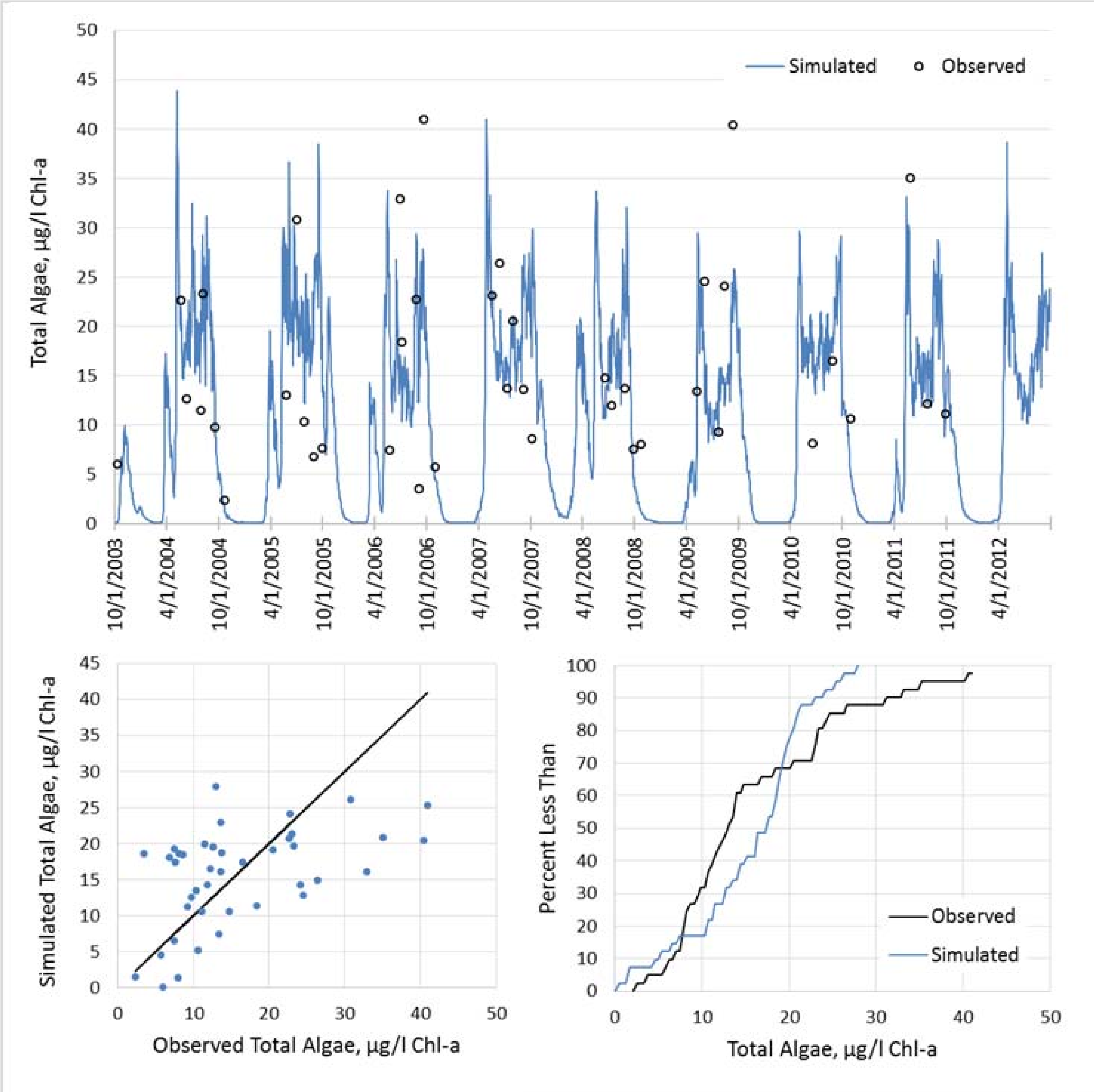

Figure 5-68 Total Algae simulation results, Lake Wateree Forebay (WARMF ID 2292)

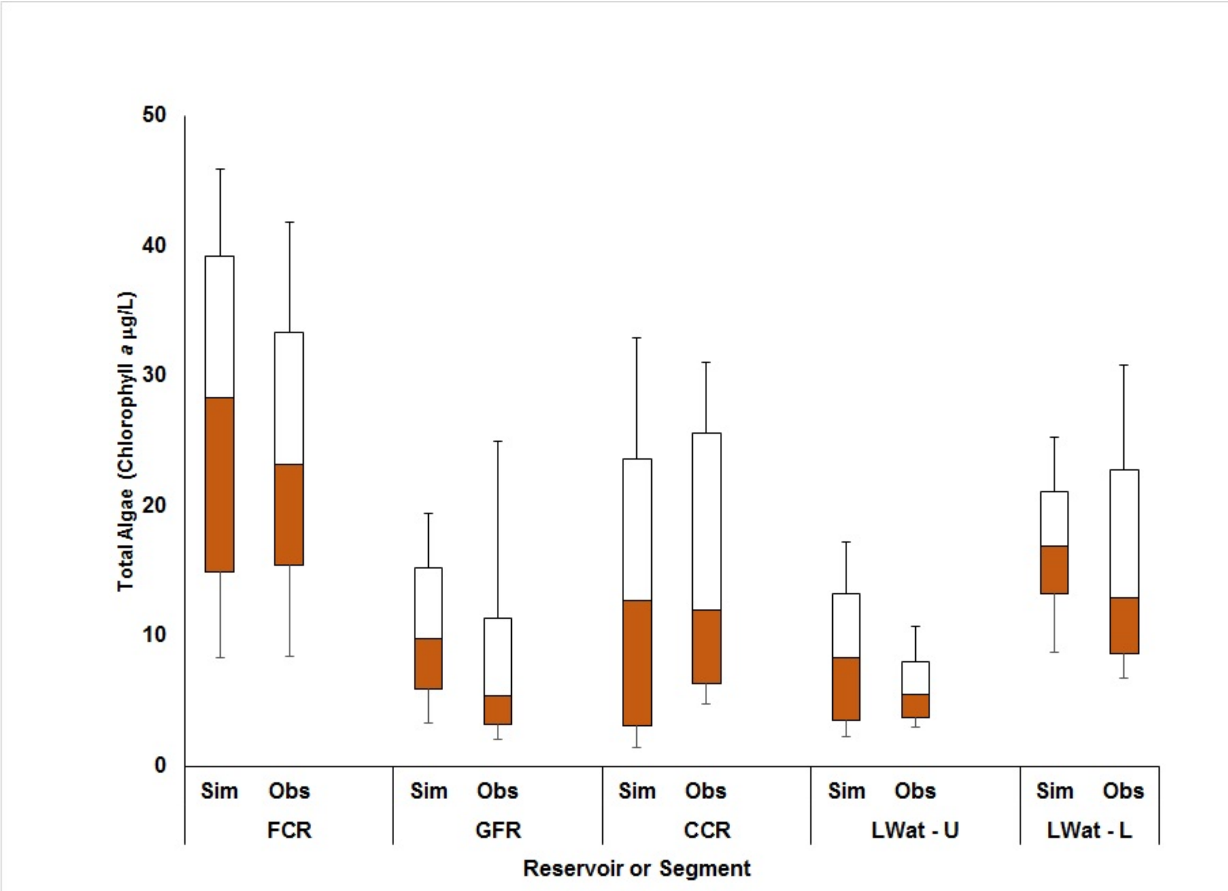

Figure 5-69a Longitudinal box and whisker plot of growing season simulated and observed total algae (chlorophyll-*a*) data in the reservoirs. Boxes represent 1st quartile, median, and 3rd quartiles; whiskers represent 10th and 90th percentiles.

Table 5-9 Total algae (as chlorophyll-a) simulation statistics

Location	Observed data (µg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Fishing Creek Reservoir	2.5	64.8	24.1	-0.11	-15.2	1.05	15.2%	46.5%	13.9	0.25
Great Falls Reservoir	1.6	36.3	8.9	-0.84	-35.1	1.36	35.1%	101.7%	11.7	0.00
Cedar Creek Reservoir	3.3	36.4	16.0	-0.91	22.0	1.38	-22.0%	66.8%	14.1	0.05
Catawba River below Cedar Creek	1.8	15.5	6.2	-3.50	-48.8	2.12	48.8%	82.4%	6.7	0.07
Lake Wateree Forebay	2.4	41.0	16.0	0.21	3.0	0.89	-3.0%	43.2%	8.6	0.25

5.9 Dissolved Oxygen

A sufficient number of dissolved oxygen concentration measurements have been made at a variety of locations throughout the watershed to enable statistical evaluation of model performance. These locations include the Catawba River at SC-21, Sugar Creek at SC-160, Catawba River at SC-5, Fishing Creek near s-12-77, Lower Rocky Creek, Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, Catawba River below Cedar Creek and Lake Wateree Forebay. Calibration plots are presented in Figure 5-70 through Figure 5-79. The dissolved oxygen simulation statistics are presented in Table 5-10. The figures and statistics indicate that overall the model is simulating dissolved oxygen well. With the exception of one location (Catawba River below Cedar Creek), relative error ranges between -10% and 10%, indicating a high degree of accuracy in the simulated long term trends of DO. As compared to river segments, simulation of dissolved oxygen in the reservoirs is significantly more complex due to the effects of algae growth and respiration. Also an important consideration for dissolved oxygen is the model time step. Diurnal fluctuations in DO are not captured with a daily time step, the simulated concentrations are an average daily concentration whereas the observations are point measurements in time. This discrepancy introduces greater error in calibrations statistics for dissolved oxygen in reservoirs.

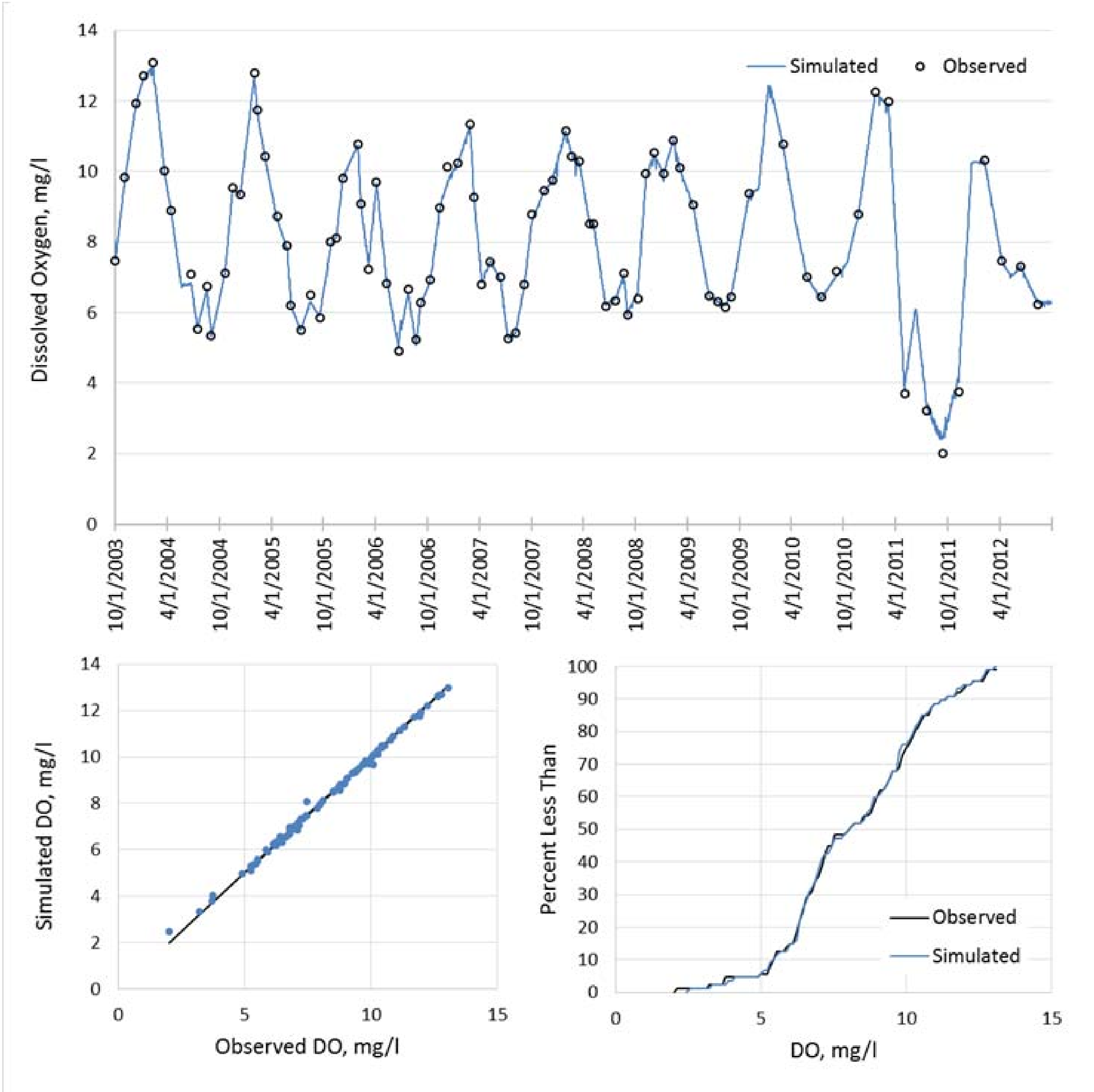

Figure 5-70 Dissolved oxygen simulation results, Catawba River at SC-21 (WARMF ID 89)

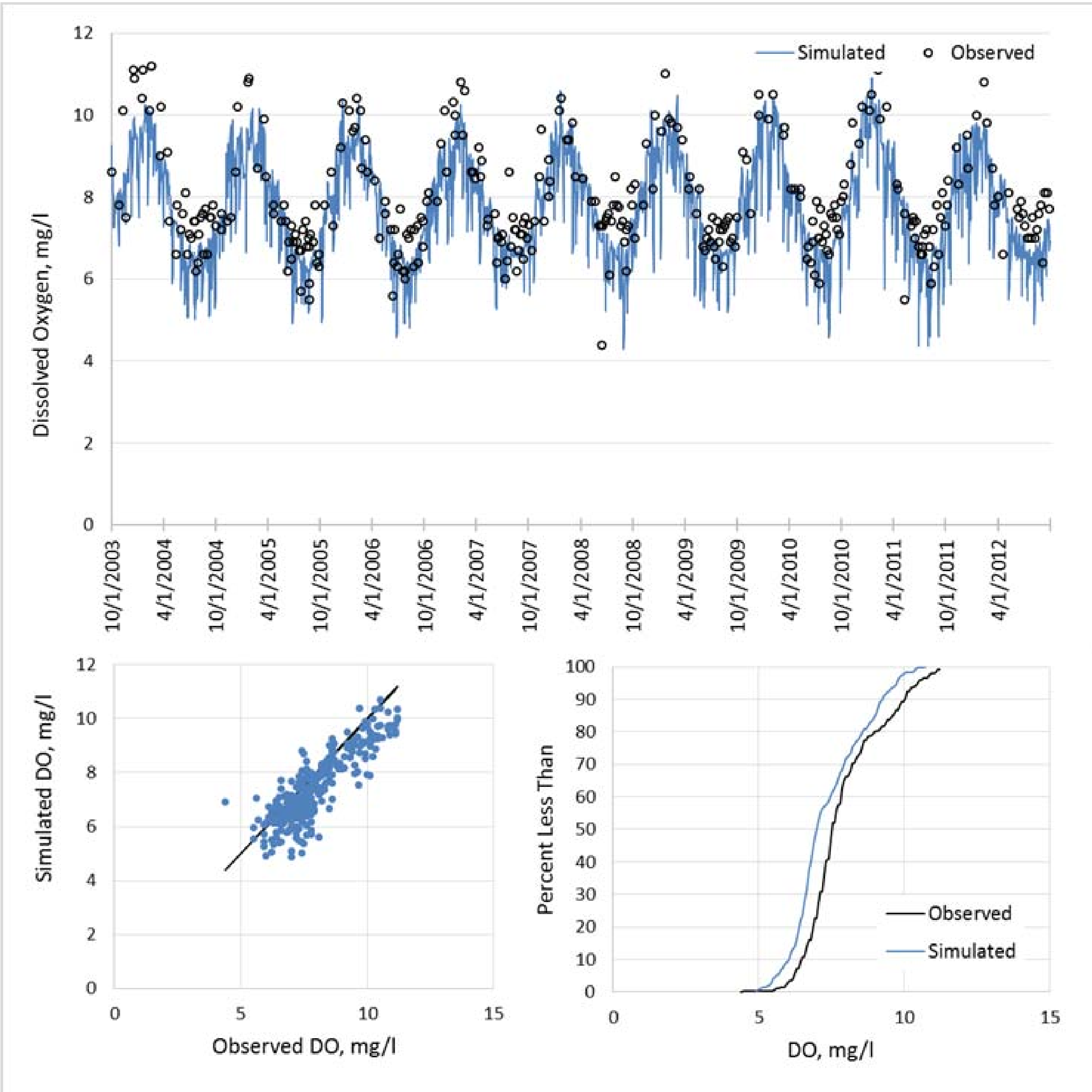

Figure 5-71 Dissolved oxygen simulation results, Sugar Creek at SC-160 (WARMF ID 246)

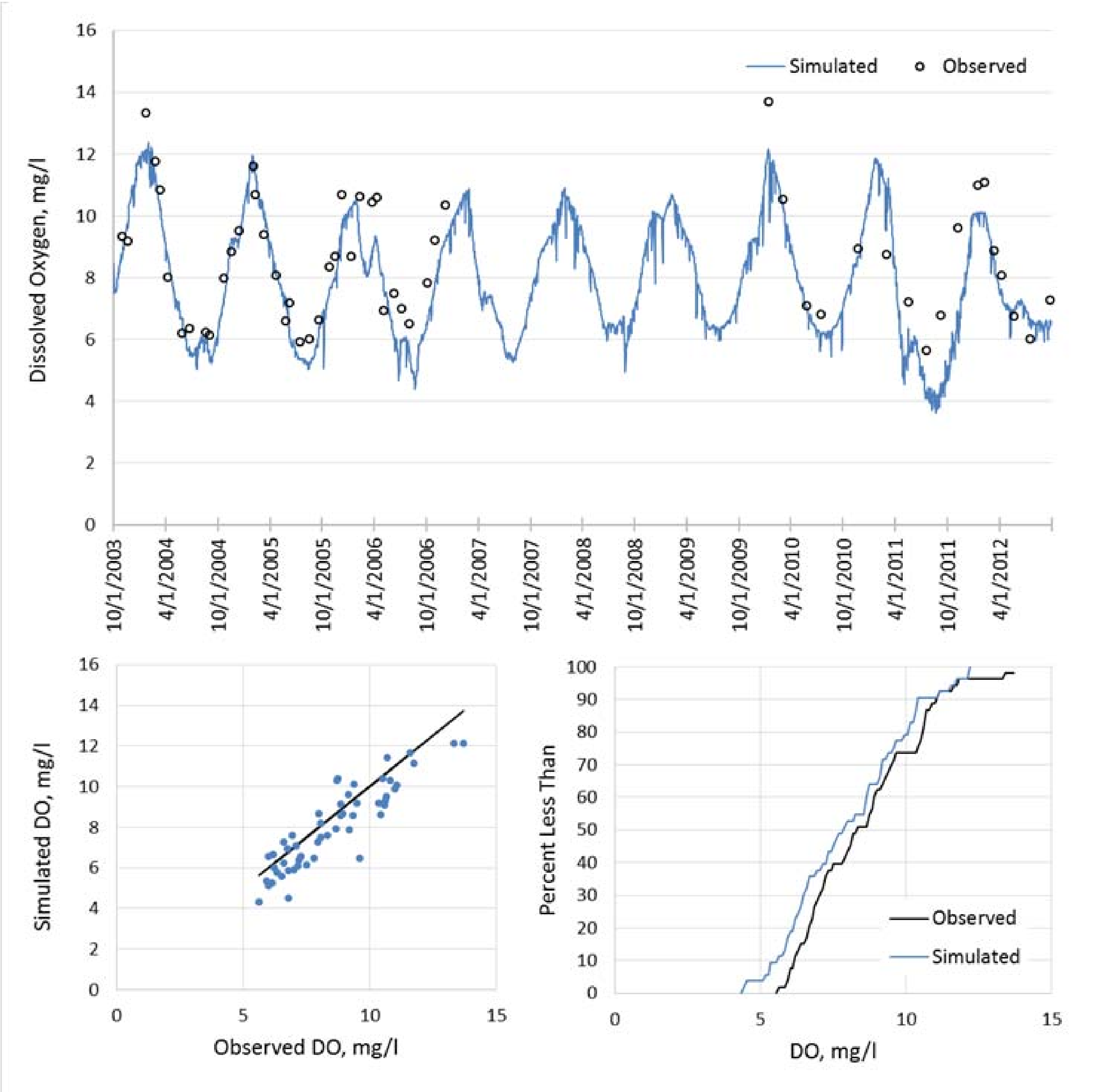

Figure 5-72 Dissolved oxygen simulation results, Catawba River at SC-5 (WARMF ID 69)

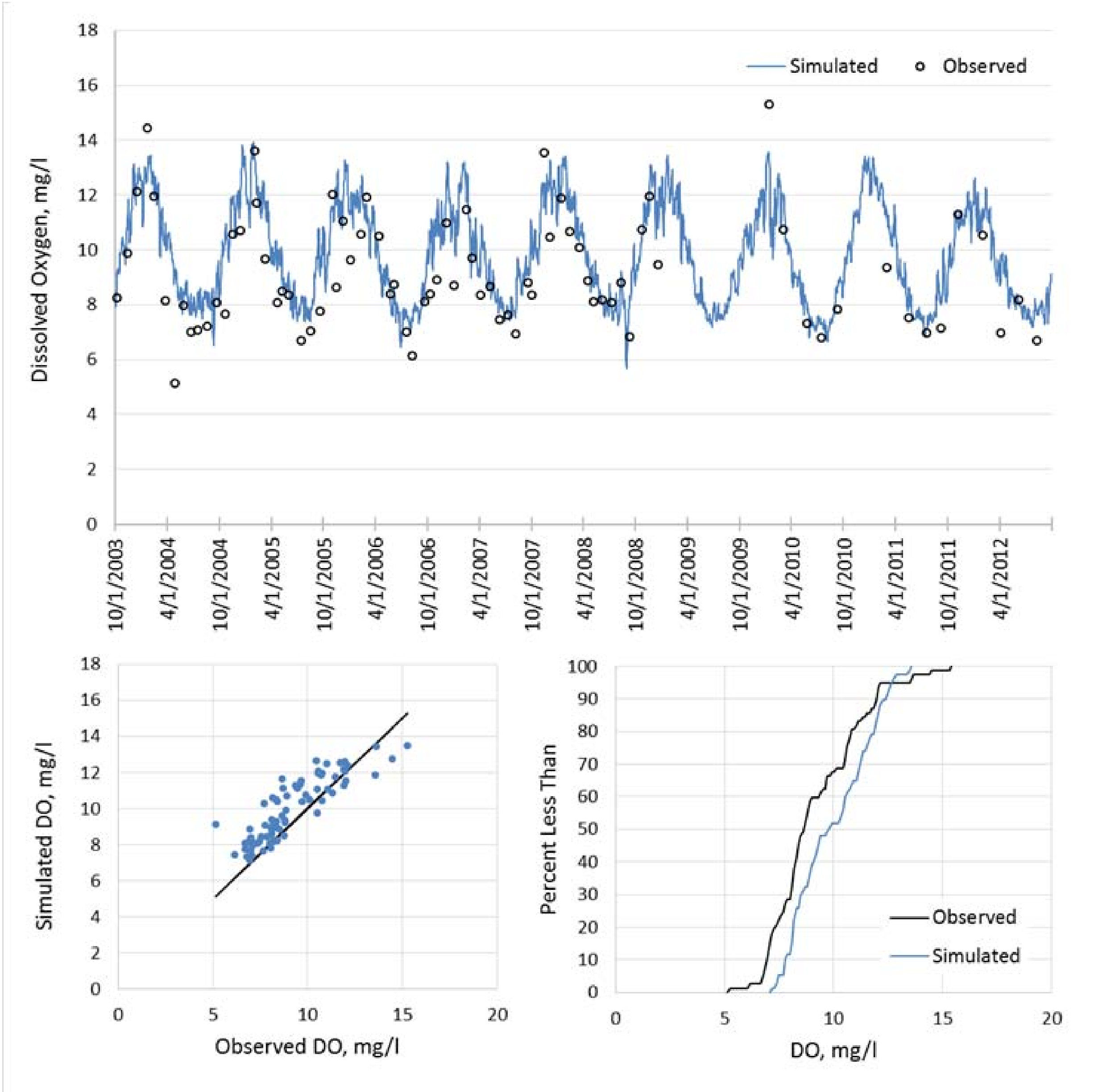

Figure 5-73 Dissolved oxygen simulation results, Fishing Creek near S-12-77 (WARMF ID 149)

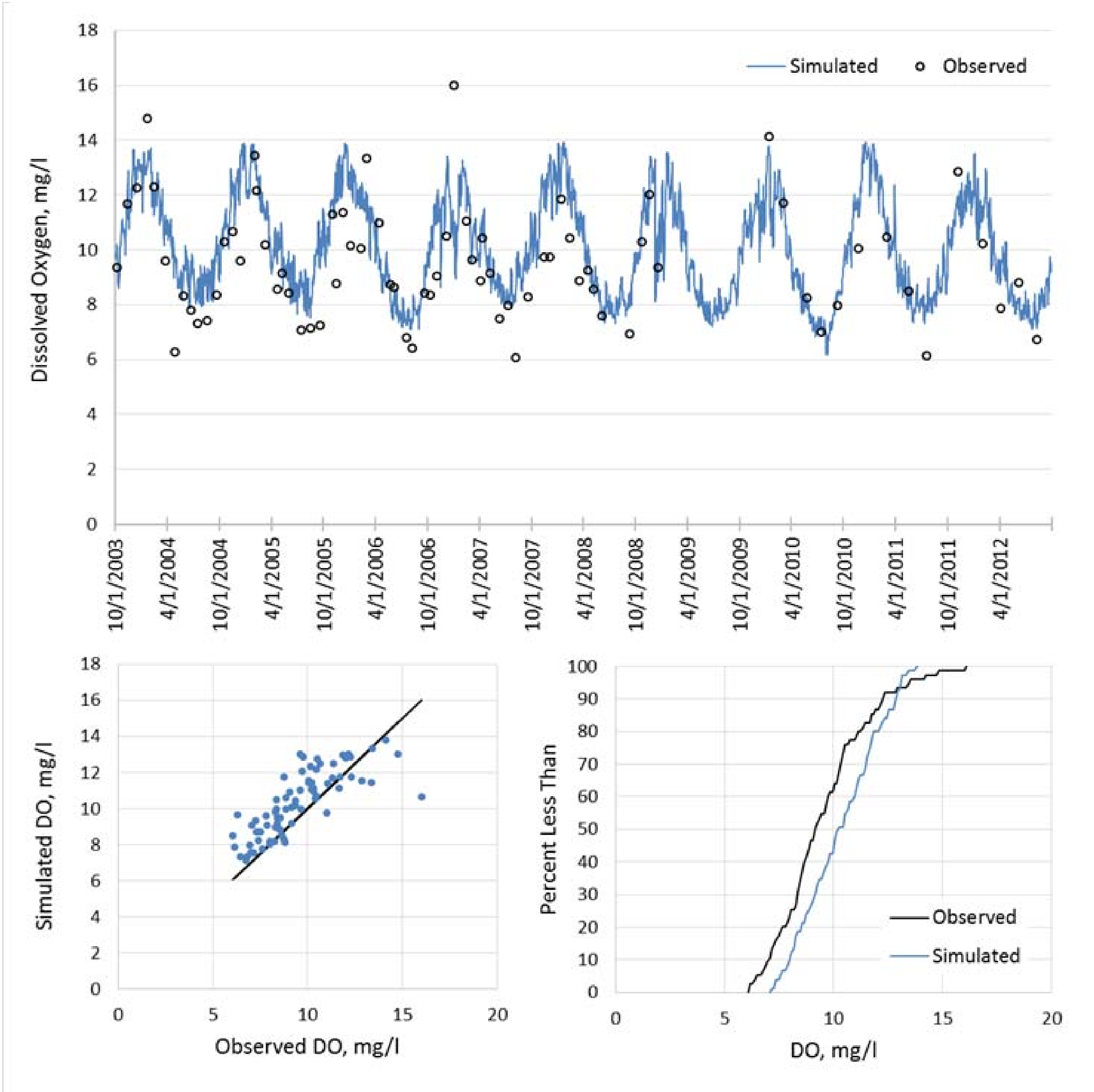

Figure 5-74 Dissolved oxygen simulation results, Lower Rocky Creek (WARMF ID 160)

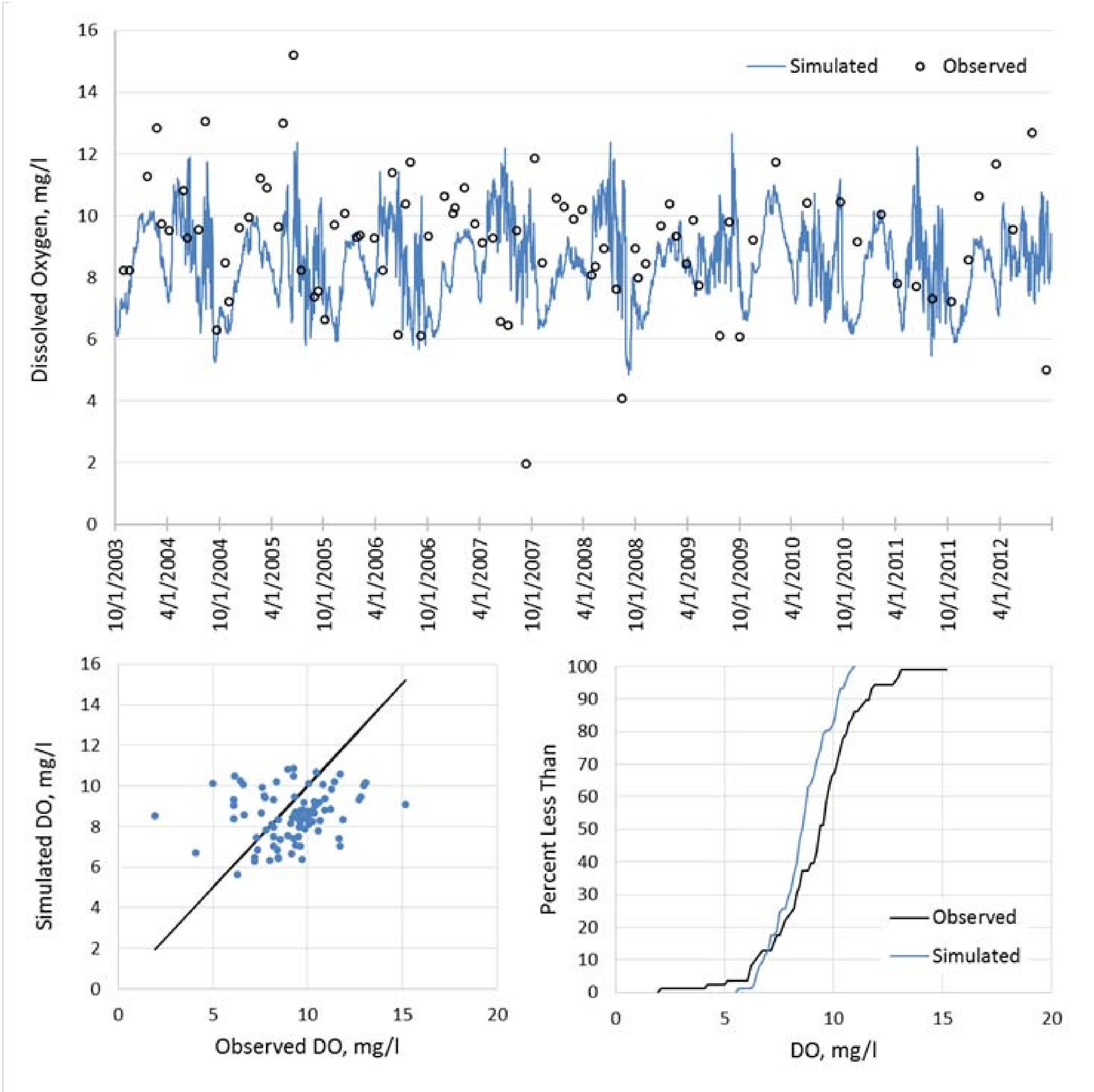

Figure 5-75 Dissolved oxygen simulation results, Fishing Creek Reservoir (WARMF ID 1562)

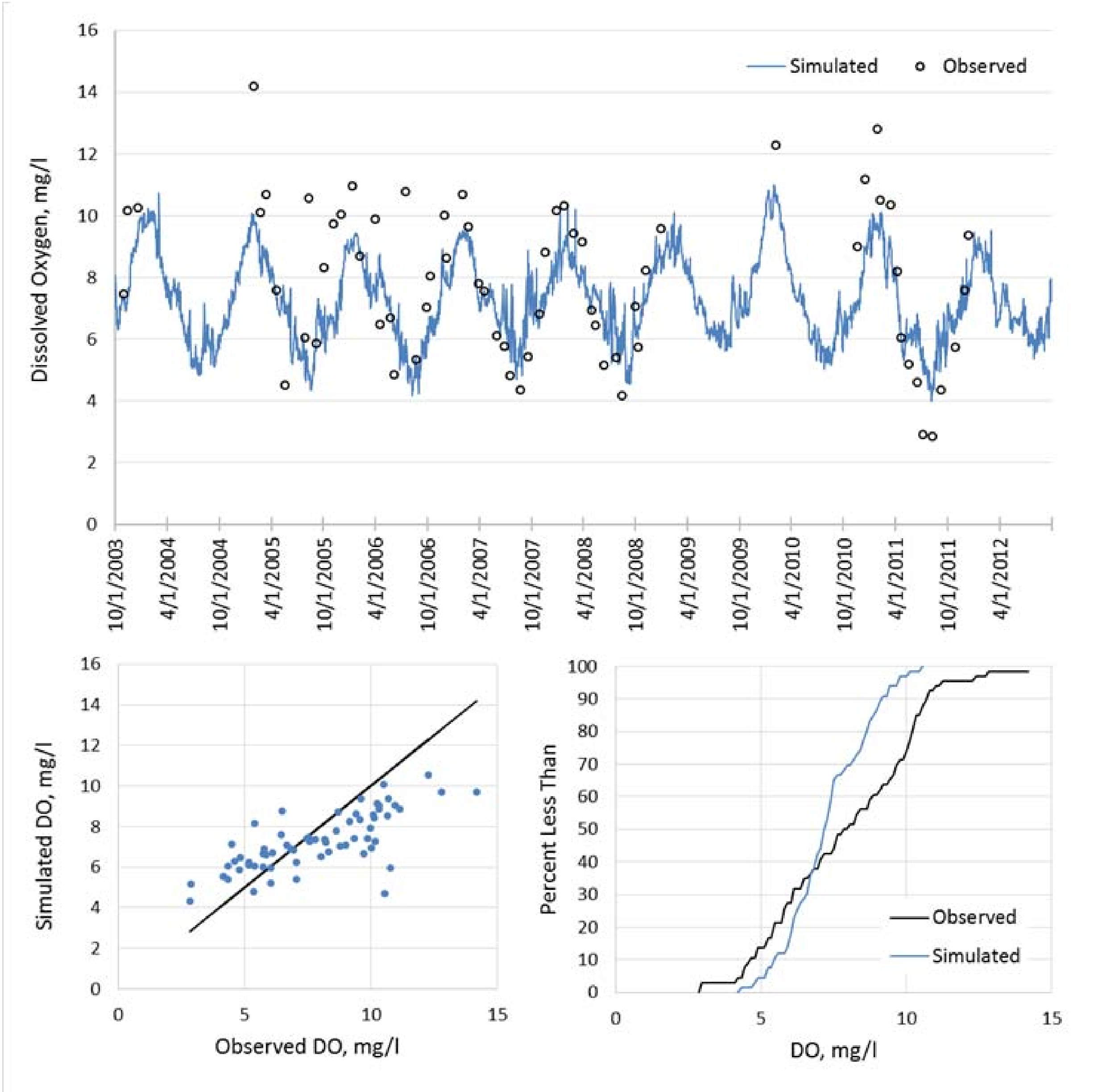

Figure 5-76 Dissolved oxygen simulation results, Great Falls Reservoir (WARMF ID 1563)

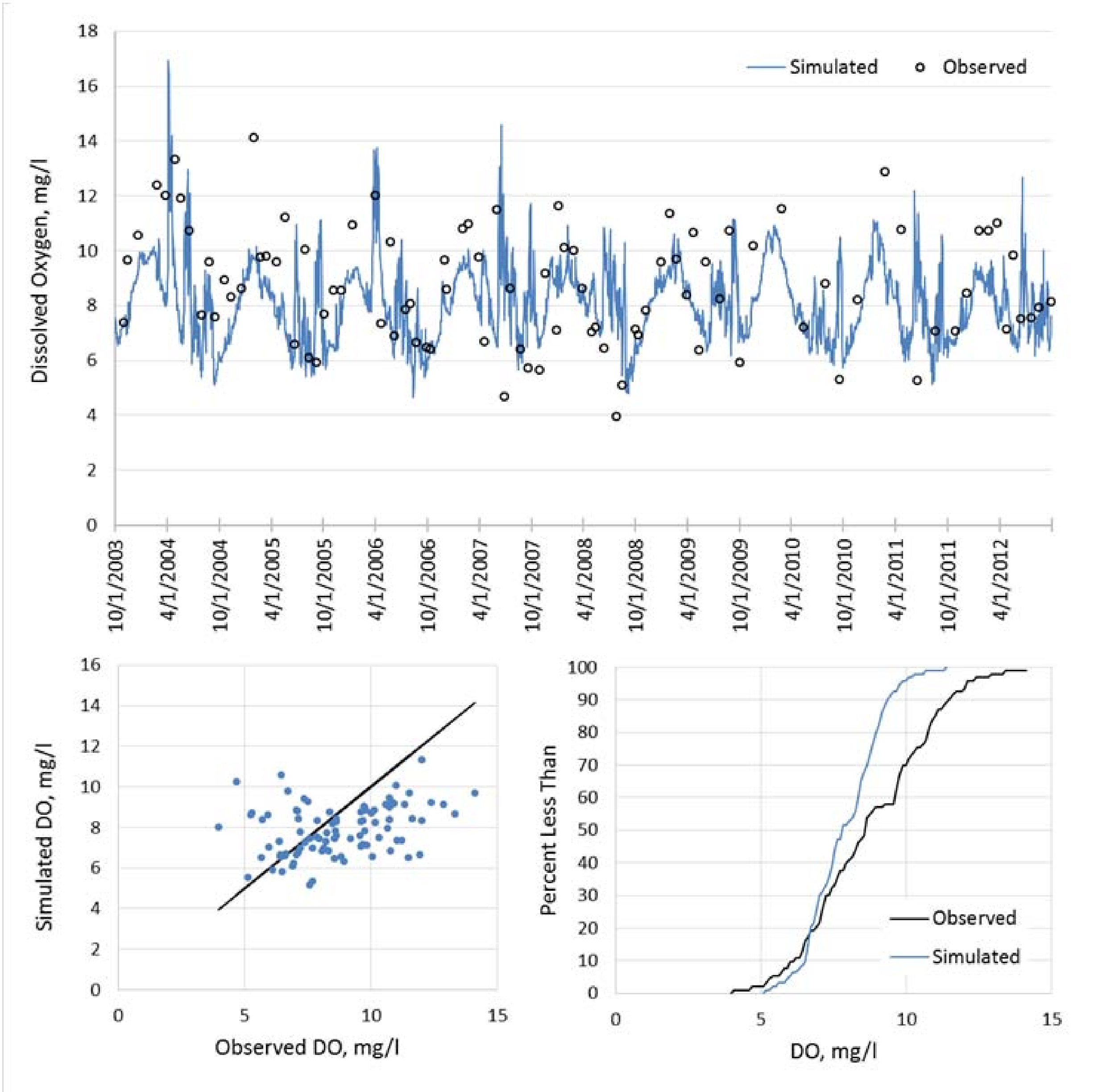

Figure 5-77 Dissolved oxygen simulation results, Cedar Creek Reservoir (WARMF ID 1567)

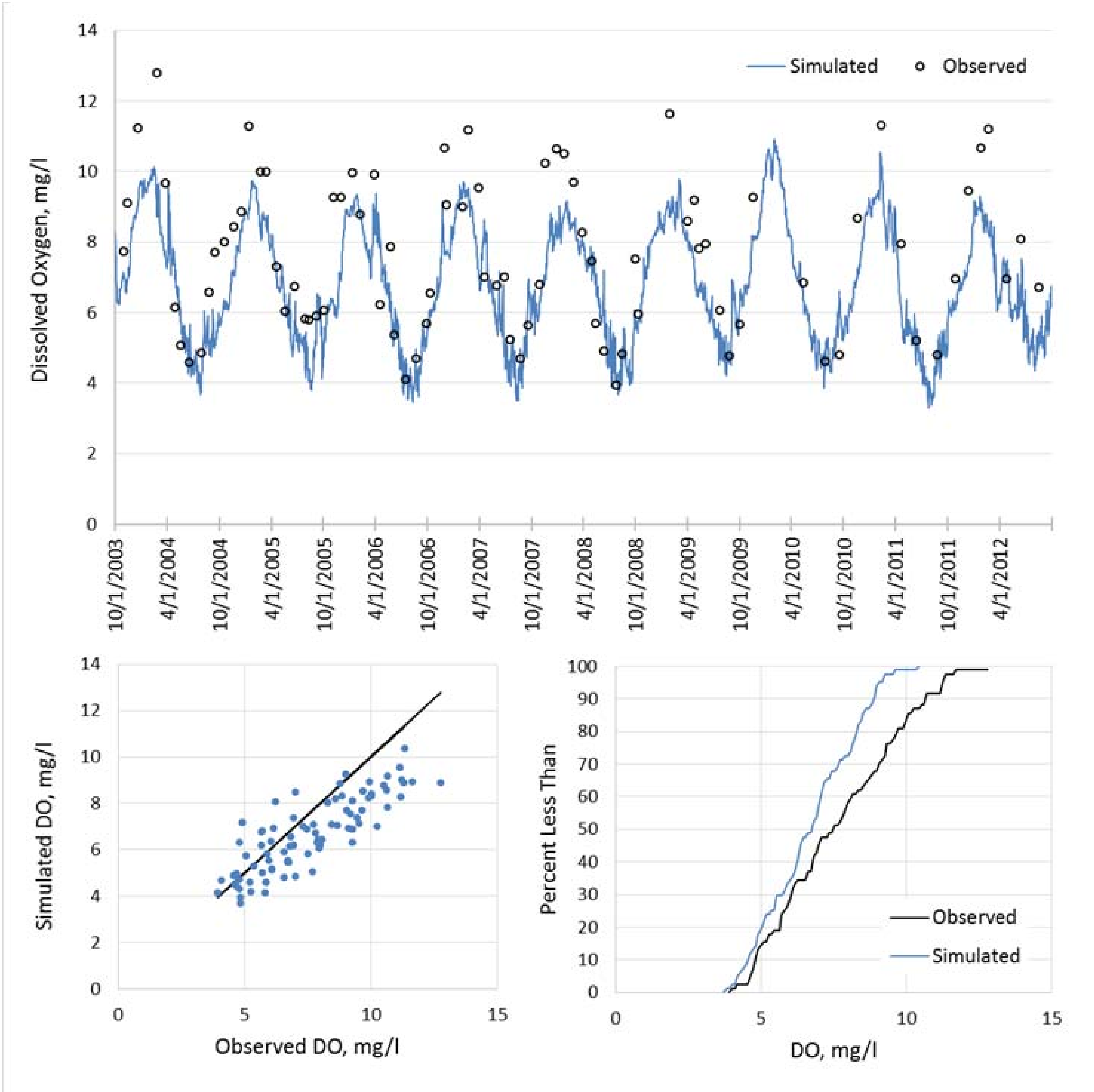

Figure 5-78 Dissolved oxygen simulation results, Catawba River below Cedar Creek (WARMF ID 624)

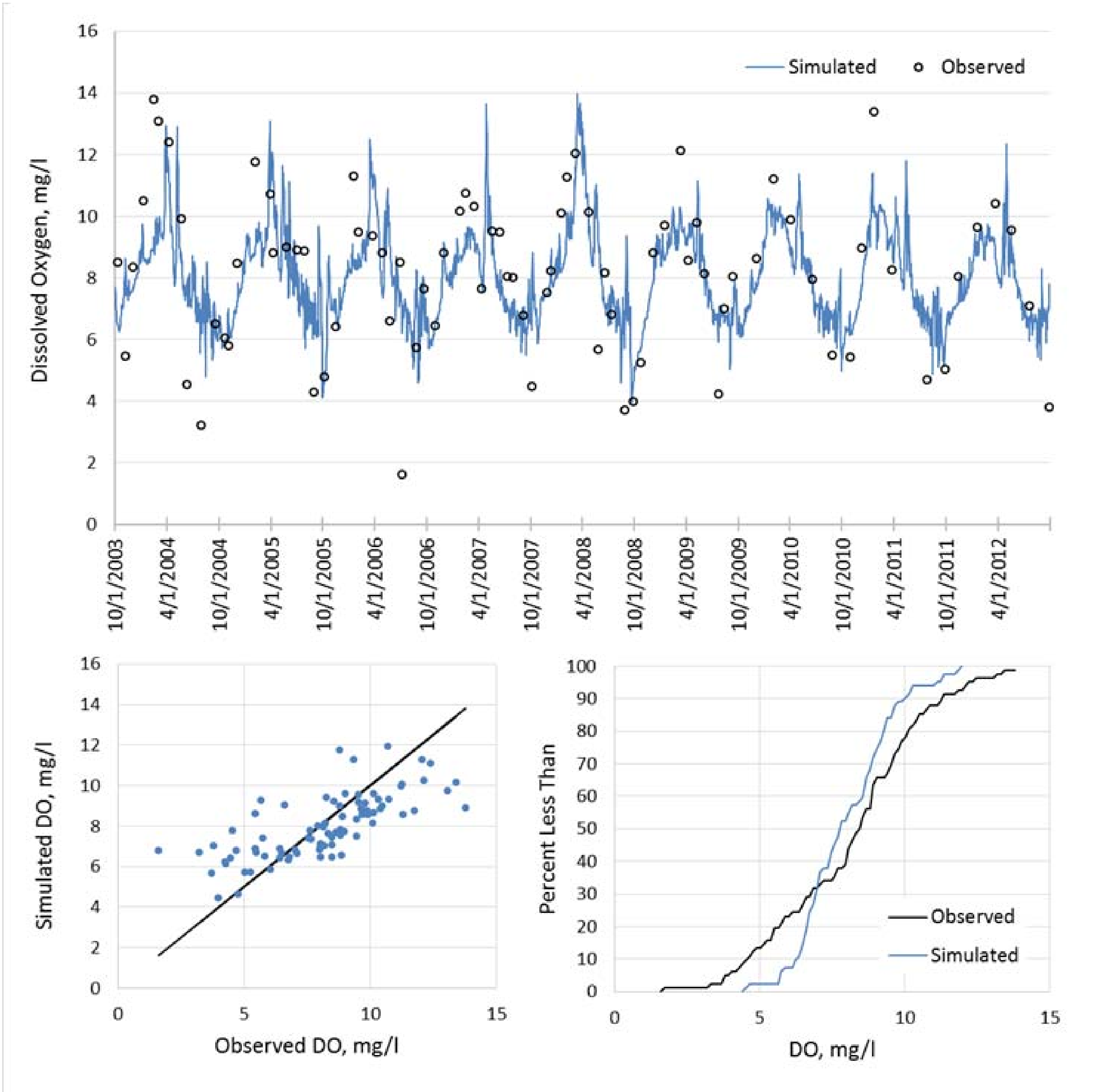

Figure 5-79 Dissolved oxygen simulation results, Lake Wateree Forebay (WARMF ID 2292)

Table 5-10 Dissolved oxygen simulation statistics

Location	Observed data (mg/l)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	2.00	13.08	8.20	1.00	0.1	0.05	-0.1%	1.0%	0.13	1.00
Sugar Creek at SC-160	4.40	11.20	7.87	0.60	6.1	0.63	-6.1%	8.3%	0.82	0.74
Catawba River at SC-5	5.63	13.70	8.55	0.72	6.3	0.53	-6.3%	10.2%	1.05	0.81
Fishing Creek at S-12-77	5.13	15.30	9.16	0.61	-8.7	0.63	8.7%	11.2%	1.28	0.76
Lower Rocky Creek	6.07	16.01	9.50	0.48	-8.3	0.72	8.3%	12.4%	1.50	0.63
Fishing Creek Reservoir	1.95	15.20	9.18	-0.22	7.0	1.10	-7.0%	20.1%	2.26	0.04
Great Falls Reservoir	2.85	14.20	7.90	0.45	7.8	0.74	-7.8%	18.5%	1.85	0.54
Cedar Creek Reservoir	3.97	14.14	8.73	-0.11	9.7	1.05	-9.7%	20.3%	2.22	0.11
Catawba River below Cedar Creek	3.95	12.79	7.63	0.50	12.4	0.71	-12.4%	16.7%	1.53	0.70
Lake Wateree Forebay	1.60	26.10	8.34	0.34	4.1	0.81	-4.1%	18.8%	2.59	0.37

5.10 pH

Measurements of pH have been made at a variety of locations throughout the watershed to enable evaluation of model performance. Figure 5-80 through Figure 5-89 illustrate the results of pH calibration efforts throughout the watershed, and **Error! Reference source not found.** provides the associated calibration statistics. In general, pH can be one of the most difficult water quality parameters to calibrate due to its dependence on so many in-stream processes and constituents. Without first fully calibrating all constituents that affect pH throughout the watershed, achieving a good pH calibration may not be possible in all locations. For this reason as well as some possible model limitations to be discussed, the results of pH calibrations for the Catawba watershed were mixed. For the Catawba River at SC-21, which is just downstream of a Lake Wylie defined boundary condition, the pH calibration is very good based on both plots and calculated statistics. Here, the pH is entirely dependent on the concentrations of total inorganic carbon and the relative concentrations of total cations and total anions (the alkalinity) defined at the boundary location. In Sugar Creek and in the Catawba River just below Sugar Creek (at SC-5), the simulated pH generally matches the magnitude and pattern of the observed data, leading to low relative and absolute error. The pH results in these two locations are also largely dependent on input concentrations of TIC and alkalinity (point source input concentrations in Sugar Creek and the Lake Wylie boundary inputs for Catawba at SC-5).

In locations where pH is dominated by catchment and/or in-stream (or lake) processes, plots and statistics show greater error in pH simulations. In the reservoirs, the pH is affected by many processes, including but not limited to algal dynamics, decay of organic carbon, and atmospheric reaeration of carbon dioxide. An important point for this application is that though algal dynamics can significantly alter pH in the lakes, error in the pH simulation does not necessarily indicate error in the algae simulation nor does the pH directly impact the algae concentration (i.e., though pH is a function of algae growth, algae growth is *not* a function of pH). The calibration of algae concentration was guided by the available observations of chlorophyll-a. Reducing the net production of algae reduced the error in pH simulations but also caused significant error in chlorophyll-a concentrations. Tests were performed to identify another possible cause of error in simulated pH. Increasing organic carbon decay also improved the pH simulation, but created large error in the ammonia and dissolved oxygen simulations. Another important process affecting pH in lakes is the atmospheric reaeration of carbon dioxide as algae grows and consumes inorganic carbon. Increasing atmospheric reaeration of carbon dioxide in the lakes reduced the pH error without causing greater error in another constituent. The formulation of the maximum carbon dioxide reaeration rate for reservoirs within WARMF is a fixed function of wind speed and temperature. A test run with increased carbon dioxide reaeration suggested that this rate may be insufficient during periods of significant algae growth. Figure 5-90 demonstrates the resulting decrease in pH during the algae growth season in Lake Wateree. However, a model coefficient is currently not available in WARMF to adjust the reaeration rate (test runs were performed by means of code change). The primary constituents of concern for this application (nutrients and algae) are not impacted by the change in pH resulting from adjusting carbon dioxide reaeration as shown in Figure 5-91 to Figure 5-93. Thus the pH error does not reduce the applicability of the Catawba River WARMF model as a tool for the development of nutrient and chlorophyll-a TMDLs. Redefining or altering the model formulation of reaeration would require significant research and investigation, in addition to model coding, and is beyond the scope of the current project.

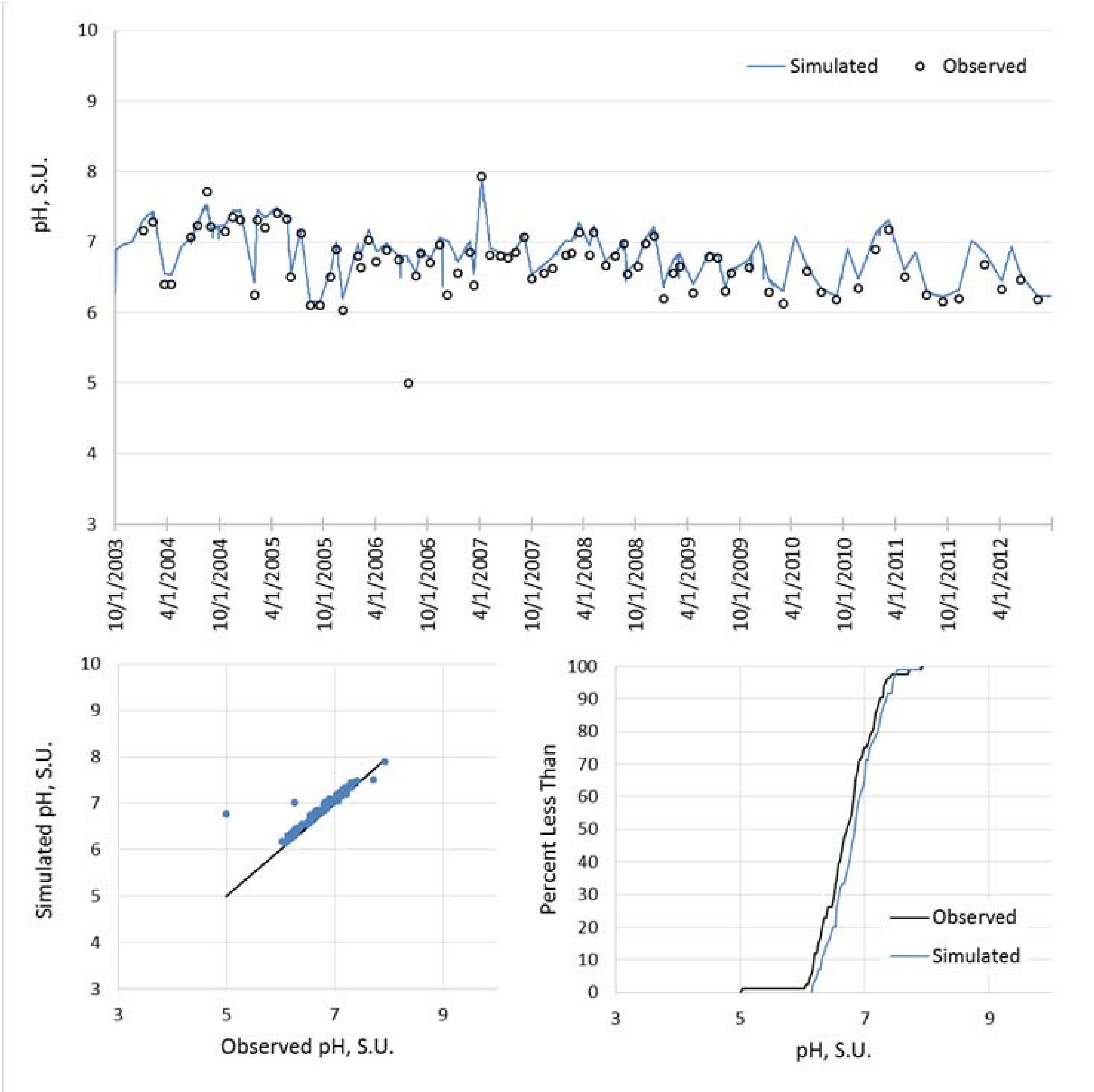

Figure 5-80 pH simulation results, Catawba River at SC-21 (WARMF ID 89)

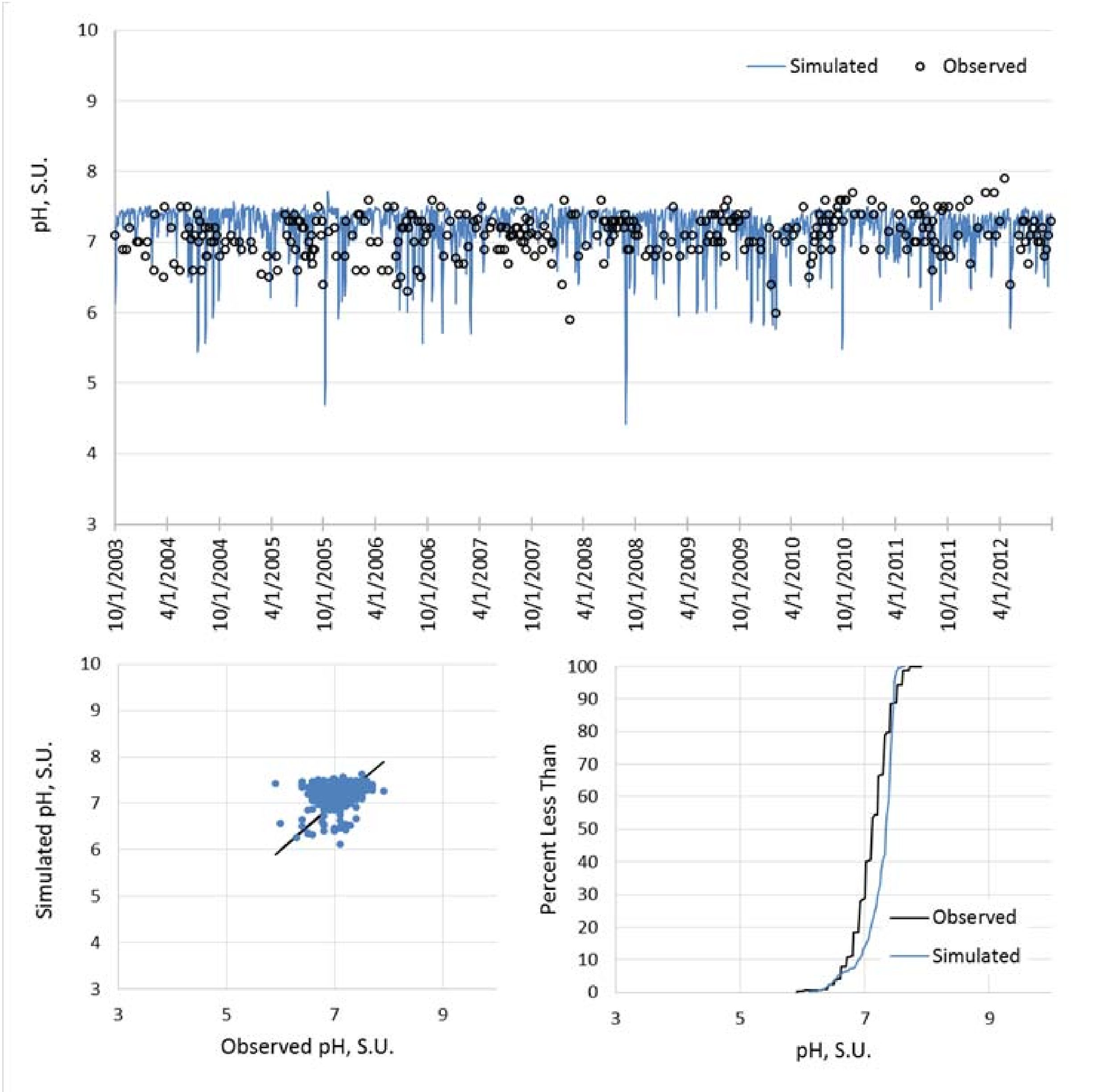

Figure 5-81 pH simulation results, Sugar Creek at SC-160 (WARMF ID 246)

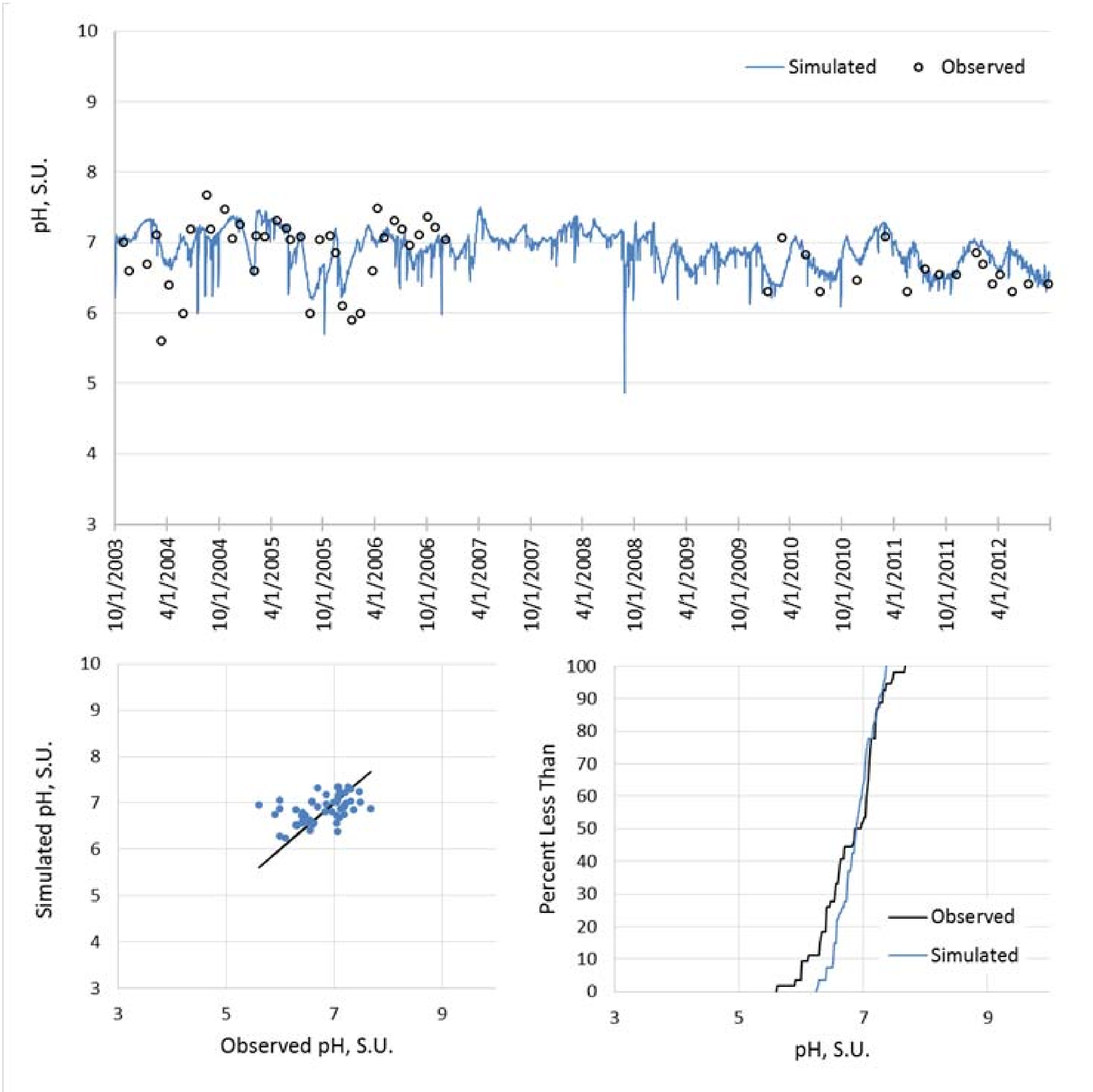

Figure 5-82 pH simulations results, Catawba River at SC-5 (WARMF ID 69)

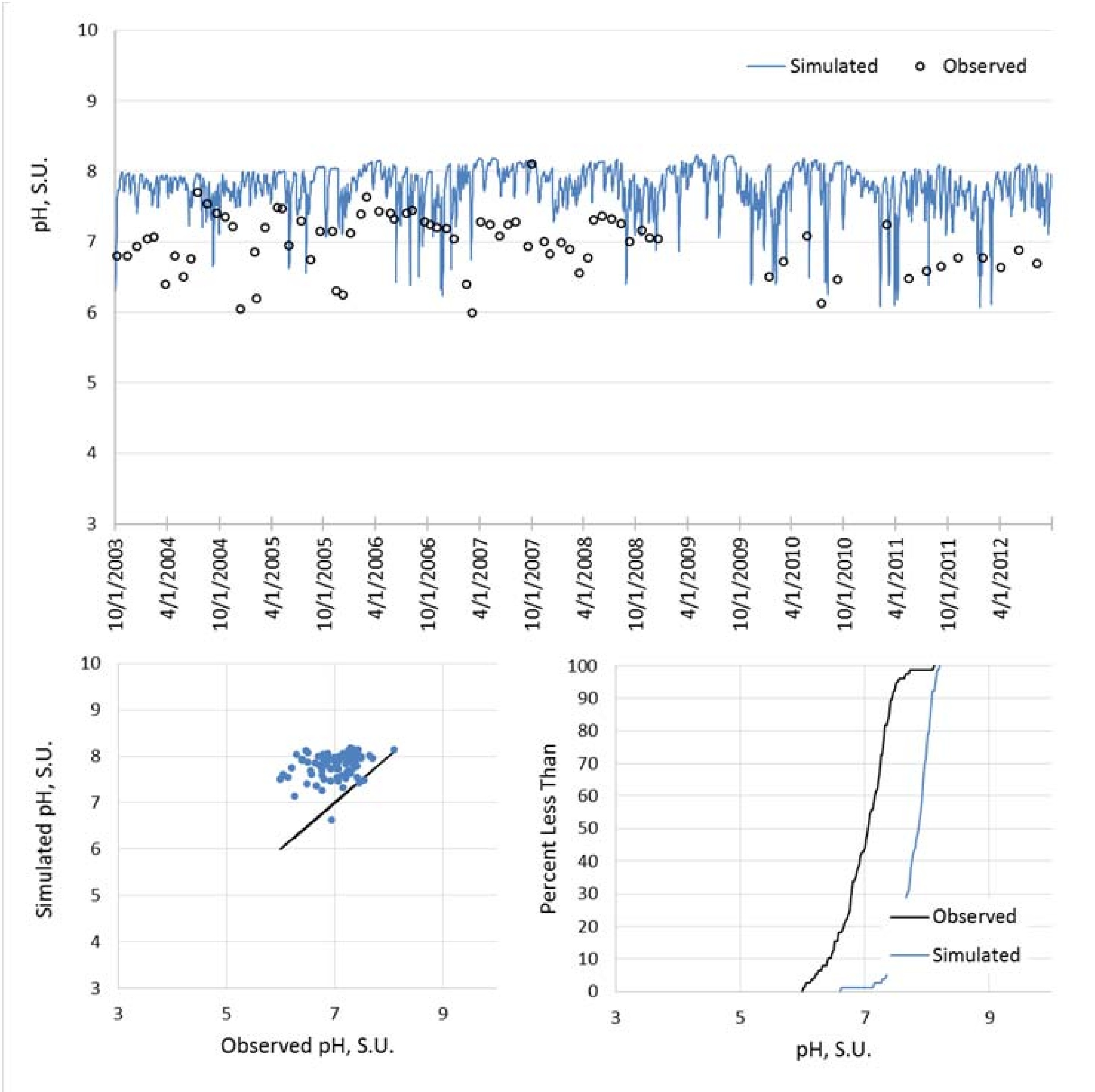

Figure 5-83 pH simulation results, Fishing Creek near S-12-77 (WARMF ID 149)

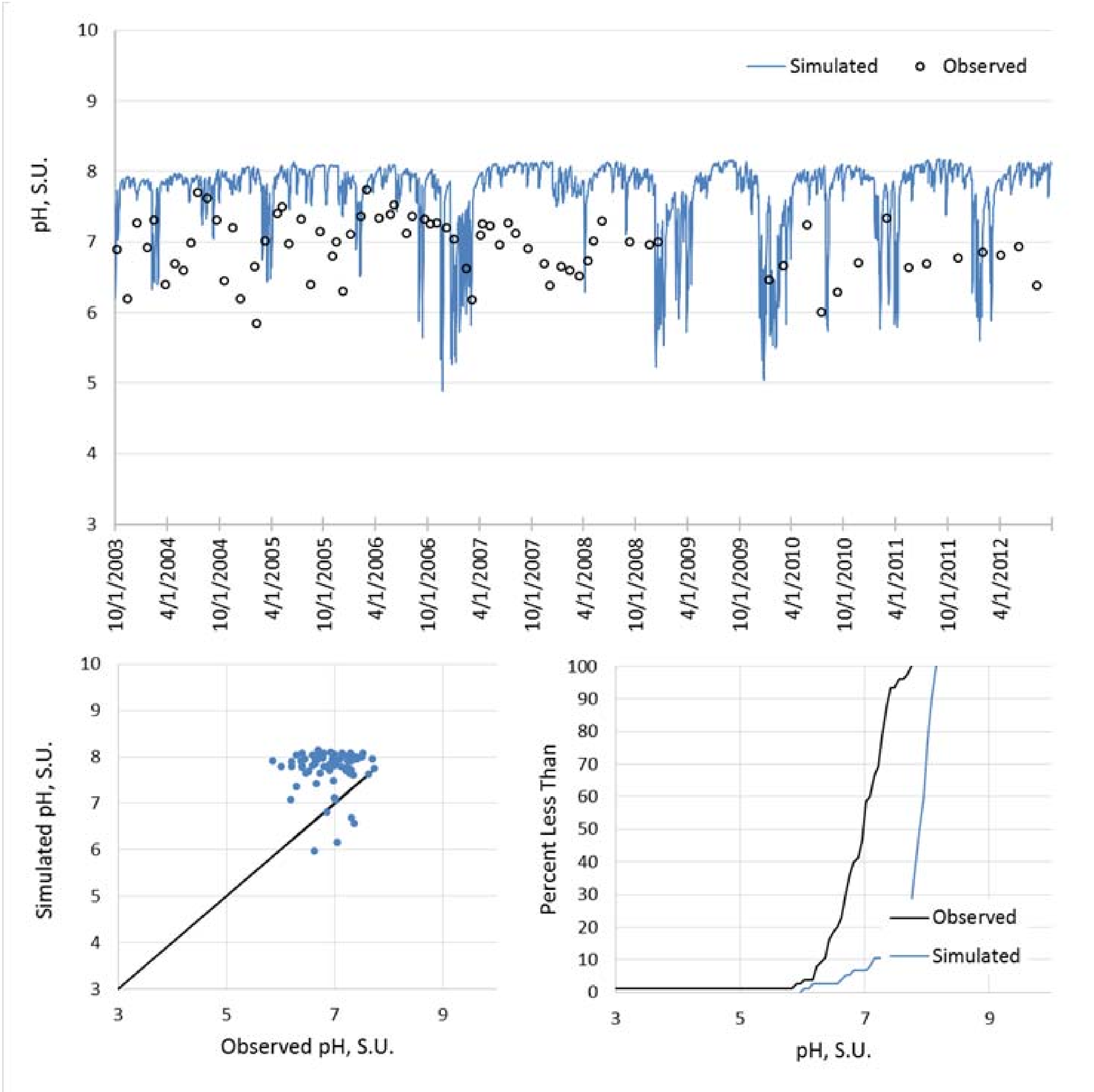

Figure 5-84 pH simulation results, Lower Rocky Creek (WARMF ID 160)

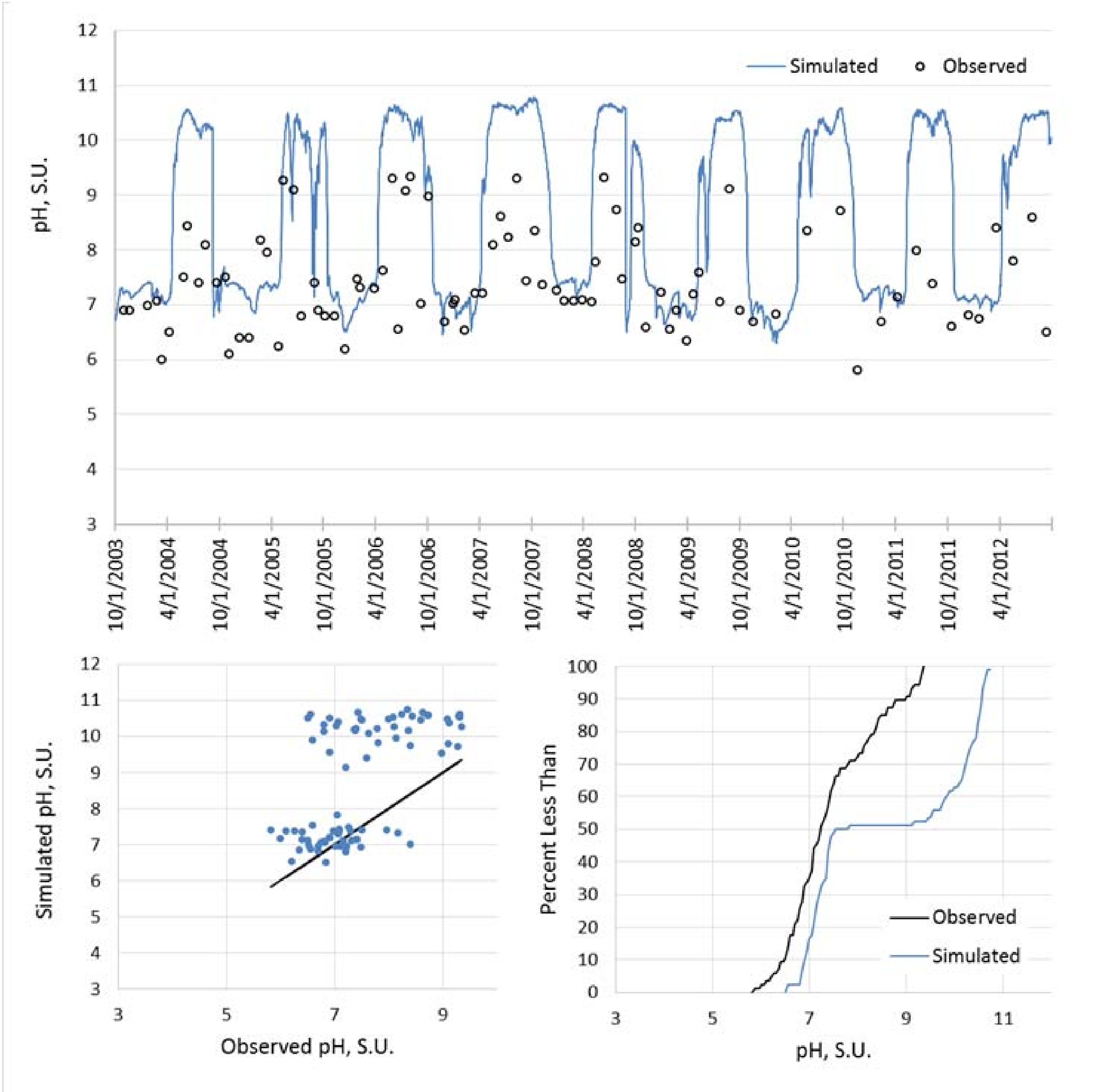

Figure 5-85 pH simulation results, Fishing Creek Reservoir (WARMF ID 1562)

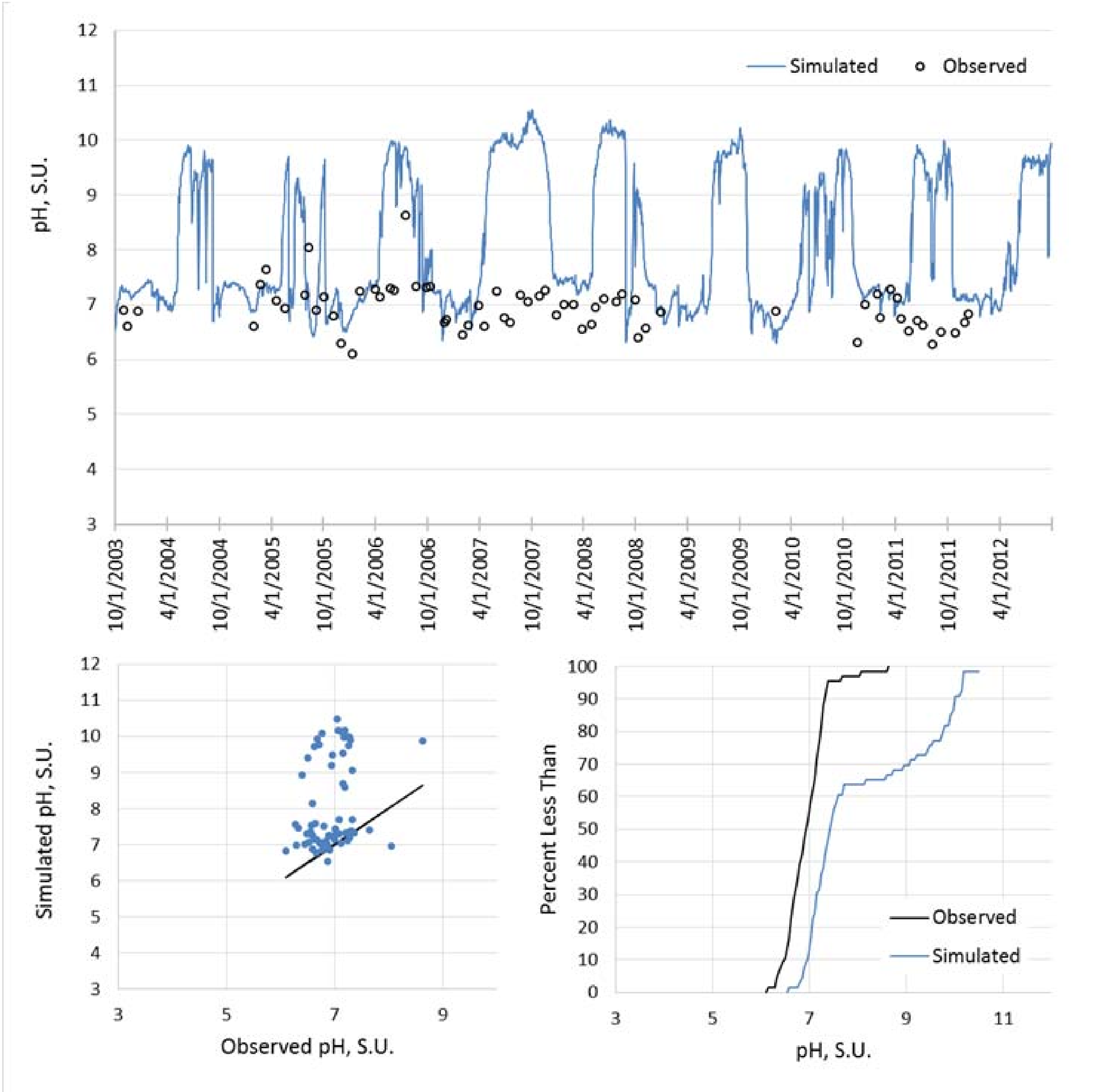

Figure 5-86 pH simulation results, Great Falls Reservoir (WARMF ID 1563)

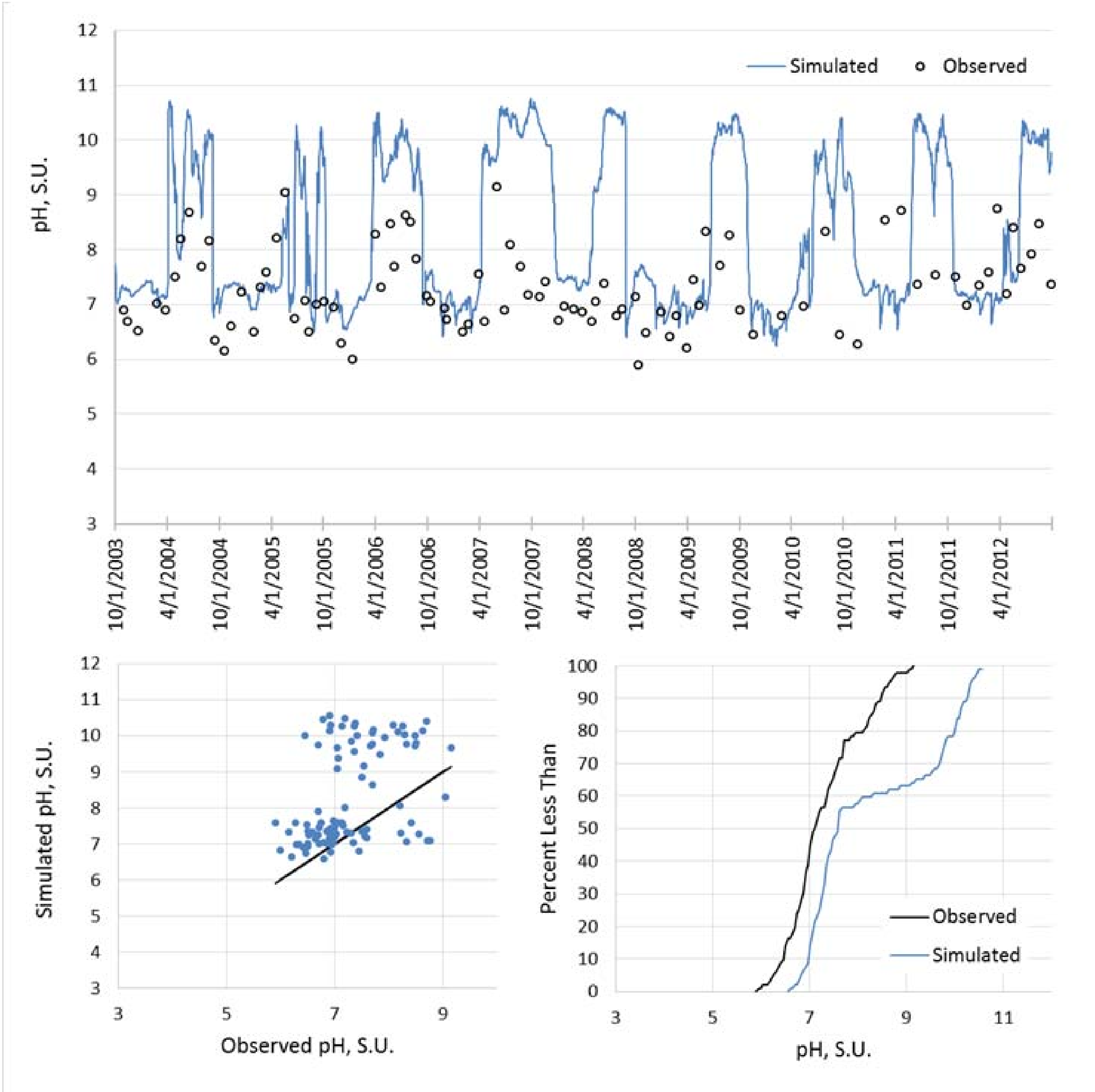

Figure 5-87 pH simulation results, Cedar Creek Reservoir (WARMF ID 1567)

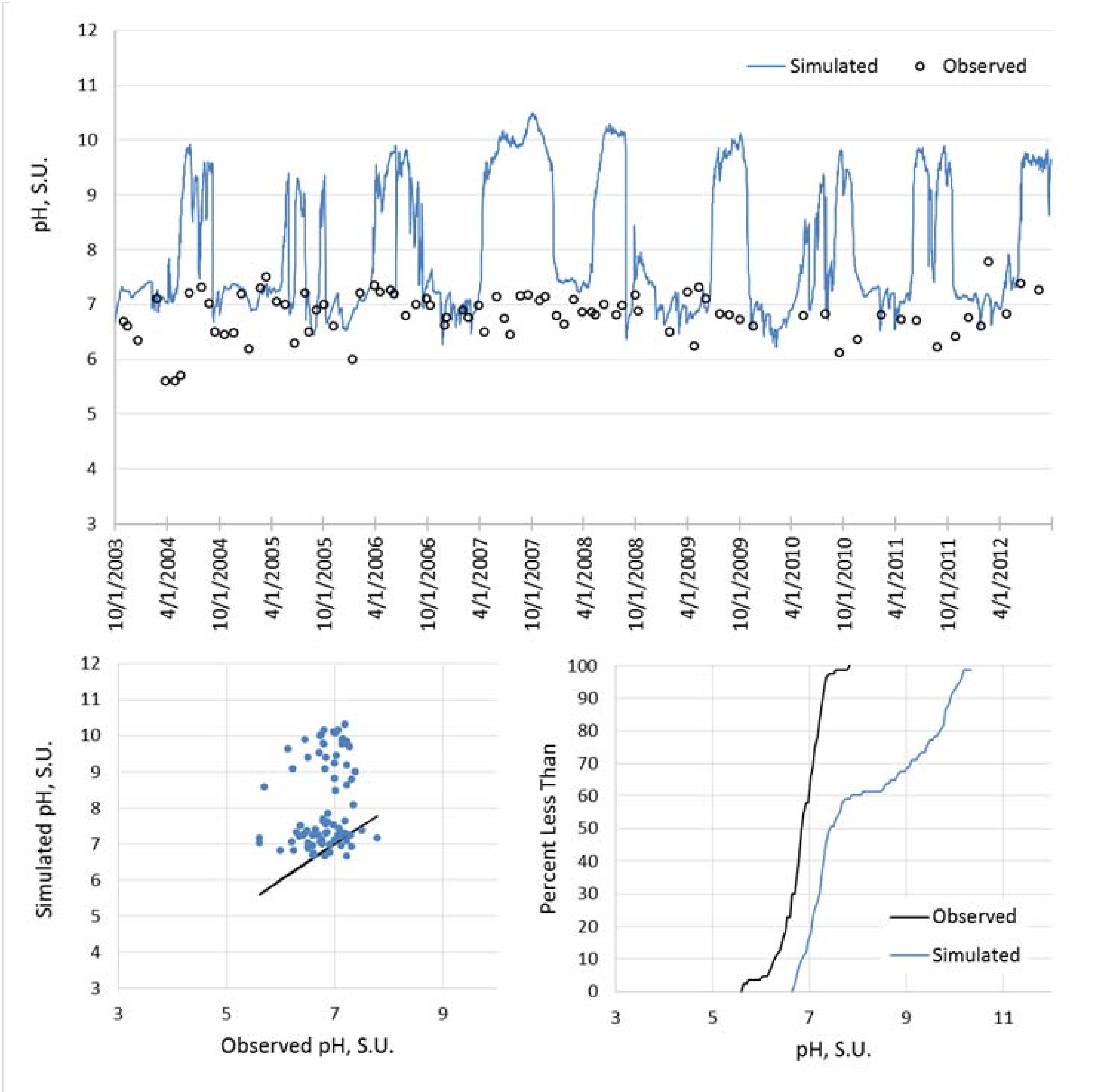

Figure 5-88 pH simulation results, Catawba River below Cedar Creek (WARMF ID 624)

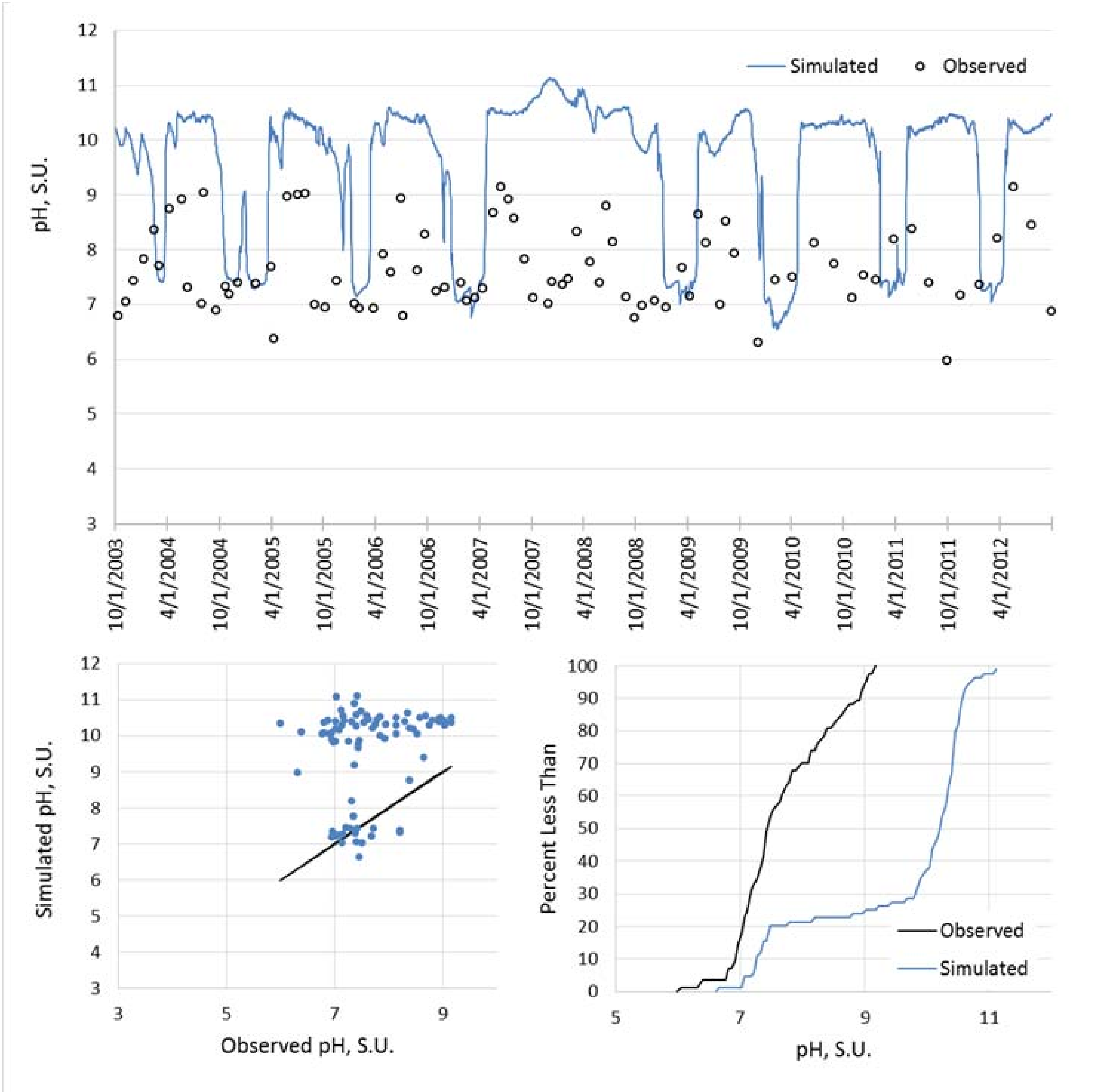

Figure 5-89 pH simulation results, Lake Wateree Forebay (WARMF ID 2292)

Table 5-11 pH calibration statistics

Location	Observed data (S.U.)			Simulation Statistics						
	Min	Max	Mean	NSE	PBIAS	RSR	E_R (%)	E_A (%)	RMSE	R^2
Catawba River at SC-21	6.03	7.93	6.73	0.9	-1.6	0.36	1.6%	1.6%	0.14	0.94
Sugar Creek at SC-160	5.90	7.90	7.10	-0.5	-2.0	1.21	2.0%	4.0%	0.36	0.10
Catawba River at SC-5	5.60	7.68	6.79	0.2	-1.2	0.89	1.2%	4.4%	0.41	0.25
Fishing Creek at S-12-77	5.99	8.11	6.99	-3.9	-11.4	2.22	11.4%	11.6%	0.91	0.07
Lower Rocky Creek	1.56	7.74	6.86	-1.8	-13.1	1.68	13.1%	14.3%	1.25	0.00
Fishing Creek Reservoir	5.82	9.34	7.45	-2.9	-16.3	1.98	16.3%	18.1%	1.76	0.36
Great Falls Reservoir	6.10	8.63	6.94	-15.5	-16.5	4.07	16.5%	17.4%	1.65	0.08
Cedar Creek Reservoir	5.90	9.15	7.29	-3.6	-13.8	2.14	13.8%	17.0%	1.59	0.17
Catawba River below Cedar Creek	5.60	7.78	6.82	-17.2	-18.8	4.27	18.8%	19.6%	1.75	0.05
Lake Wateree Forebay	5.99	9.15	7.66	-9.1	-25.1	3.18	25.1%	26.5%	2.34	0.05

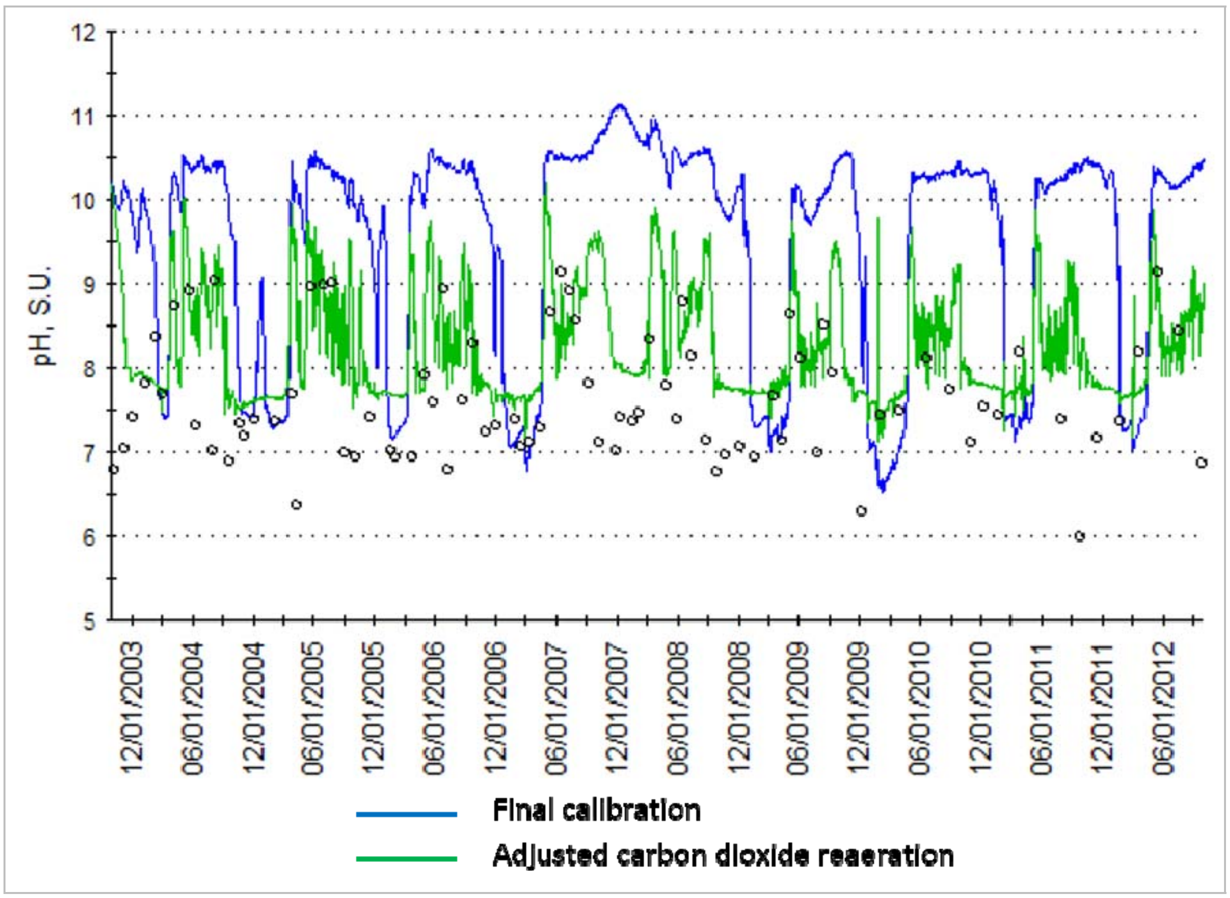

Figure 5-90 pH simulation results in Lake Wateree with original (blue) and increased (green) reaeration of carbon dioxide.

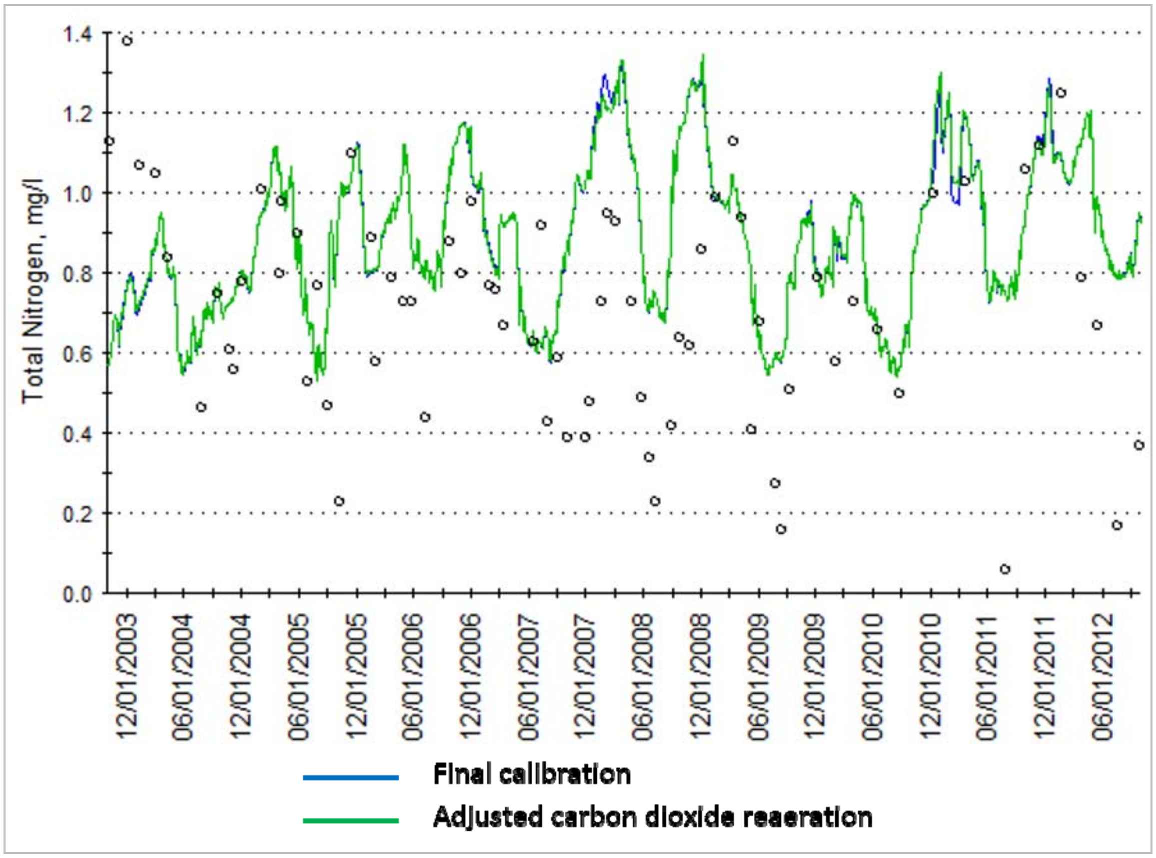

Figure 5-91 Total nitrogen simulation results in Lake Wateree with original (blue) and increased (green) reaeration of carbon dioxide.

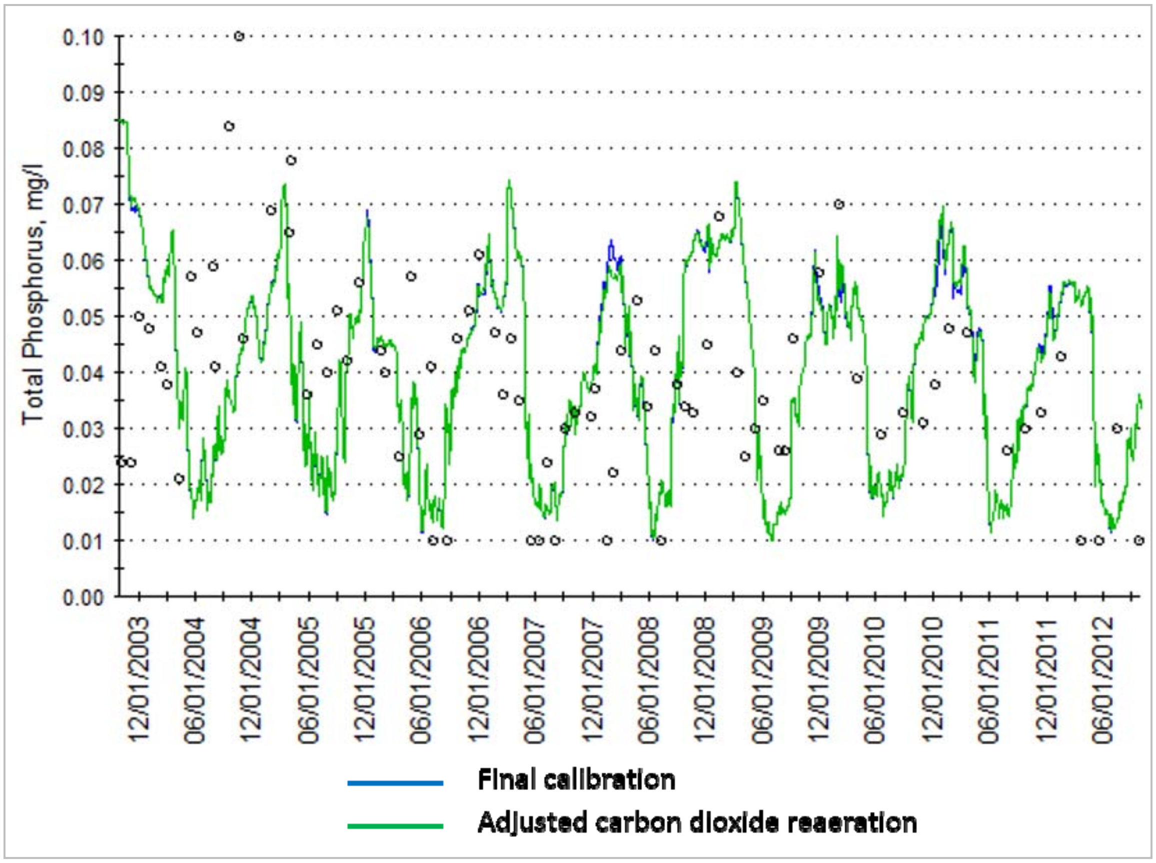

Figure 5-92 Total phosphorus simulation results in Lake Wateree with original (blue) and increased (green) reaeration of carbon dioxide.

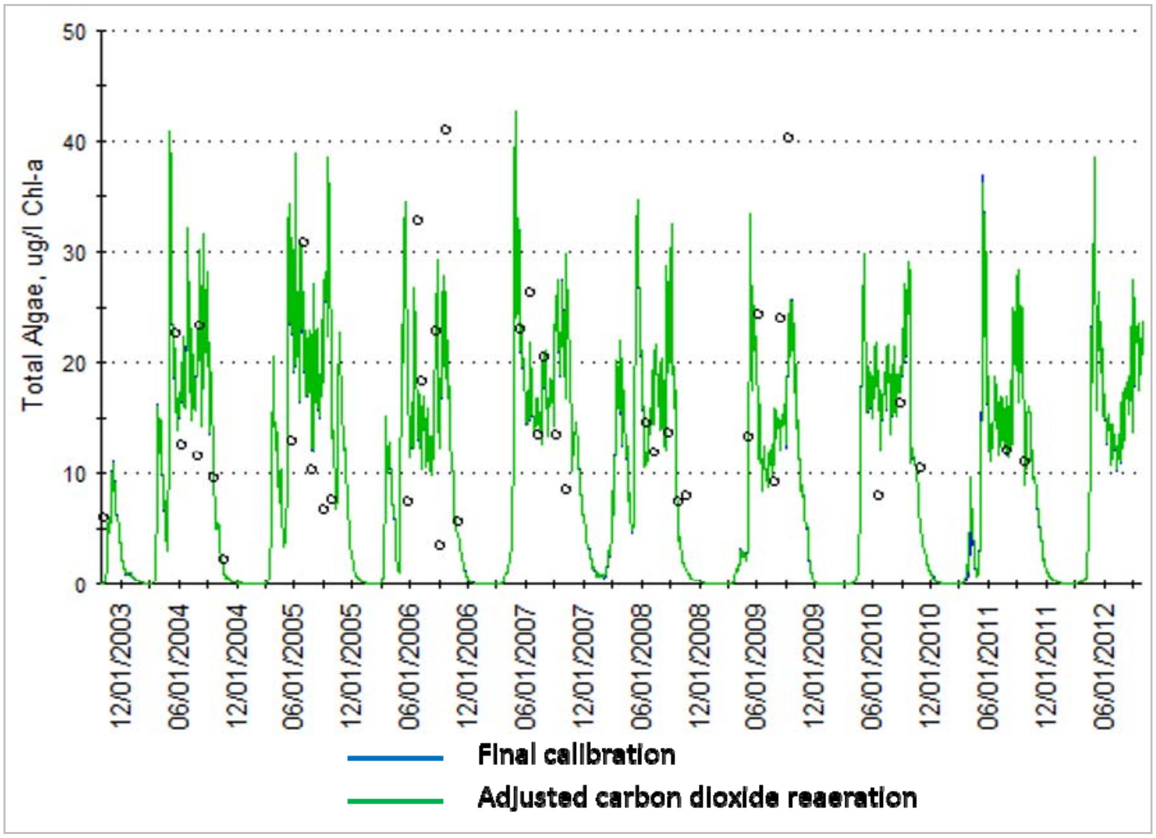

Figure 5-93 Total algae (chlorophyll-a) simulation results in Lake Wateree with original (blue) and increased (green) reaeration of carbon dioxide.

6 Conclusion

Systech assisted the South Carolina Department of Health and Environmental Control in updating and calibrating the Catawba River application of the Watershed Analysis Risk Management Framework (WARMF). Model updates included the subdivision of WARMF catchments for additional urbanized areas, updating the Lake Wylie boundary inflow input file, and testing the impact of periphyton on predicted nutrients concentrations. Periphyton was shown to have minimal impact on total nutrient concentrations in the mainstem of the Catawba River upstream of Fishing Creek Reservoir. Thus the additional complexity of including periphyton in the model is not warranted.

WARMF was calibrated at select locations for flow, temperature, sediment, nutrients, dissolved oxygen, and total algae. The primary objectives of the calibration were visually achieving the best fit possible between simulated and observed time series and, where the quantity of observed data supported statistical calculations, minimizing the relative and absolute error in simulations. The hydrology calibration yielded simulations of flow with less than 10% relative error in all calibration locations. The results for the main stem, which are dominated by releases from Lake Wylie, are better than results in tributaries, as expected. In addition to typical sources of error (e.g. measurement error, model conceptualization error), other possible sources of error for tributary flow simulations include precipitation variability on a smaller scale than the available meteorology station network (e.g. convective storms) and channel losses.

The water quality calibration followed a logical sequence, with conservative physical parameters including temperature and total suspended sediment calibrated first. The temperature calibration produced reasonable results in all locations, with a very close match between simulated and observed temperature in the reservoirs. The total suspended sediment calibration focused on matching the baseflow concentrations and a reasonable range of concentrations. The quantity of observed TSS data was very limited, making it infeasible to calibrate peak flow concentrations or statistically evaluate the results. After TSS, nutrients including ammonia, nitrate, total nitrogen, ortho-phosphate and total phosphorus were calibrated. Overall nutrient results demonstrated that the model is simulating the correct nutrient loads to the reservoir system over the simulation timeframe. The seasonal trends and net loss of nutrients in Lake Wateree is captured well by the model. Larger error in nutrient simulations occurred for the west side tributaries – Fishing Creek and Rocky Creek, however the error primarily occurred during low flow periods and was shown to have very minimal effect on concentrations in the reservoirs downstream. The calibration results for total algae (as chlorophyll-a) demonstrated that the model is correctly simulating the seasonal pattern and typical magnitude of algae in the reservoirs. However the small quantity of available data, as well as the nature of the observed data being point samples in space and time (whereas the model is a daily average value for the entire reservoir segment) needs to be considered when evaluating the calibration of total algae. The final two parameters presented – dissolved oxygen and pH – show mixed results. Dissolved oxygen simulations matched the observed well in most river locations. Algal dynamics in the reservoirs significantly increases the complexity and degrades the model performance for dissolved oxygen, particularly since the algae calibration is limited by the available data. Finally the calibration of pH yielded good results upstream of the reservoirs, while pH simulations in the reservoir include significant error. The model formulation for atmospheric reaeration of carbon dioxide during algae growth is suspected to be the main source of the pH error. Test runs demonstrated that adjusting carbon dioxide reaeration can improve the reservoir pH while leaving nutrient and algae simulations unchanged. Thus the error in pH does not limit the applicability of the model for simulating nutrient and algae in the Catawba River and reservoirs between Lake Wylie and Lake Wateree.

Addendum

The calibrated Catawba Model was used to estimate the contribution of sources of phosphorus and nitrogen for each of the Lower Catawba Reservoirs for 1/2007 – 9/2012 (Appendix B). The point source phosphorus load during this period has been consistent and follows improvements in treatment by some point sources and end of operation by others. The largest source of phosphorus and nitrogen to Fishing Creek Reservoir was point sources, followed by nonpoint sources and Lake Wylie (Figure B-1 and Figure B-5; Table B-1). The largest source of phosphorus and nitrogen by far to the three downstream reservoirs is the upstream reservoir (Figures B-2 to B-4, B-6 to B-8, and Table B-1). Direct point sources contributed less than 1 % of the phosphorus load each reservoir and nonpoint sources contributed no more 6 %.

At the time that this model update was carried out the most current land use data available was the NLCD 2006, which was used for the model land use. In 2014, the NLCD 2011 land use data became available. Land use data for the Lower Catawba Basin by 10-digit HUC for 2006, 2011, and change from 2006 to 2011 are presented in Tables C-1 through C-3 in Appendix C. These data show there has been a trend in conversion of undeveloped land to developed land. However, this trend is strongest in the Twelvemile and Fishing Creek watersheds and barely evident in the Cane Creek and Lake Wateree watersheds. While some of the percentages for changes in land use such as the increases in barren land use are quite large, the areas involved are small part of the total land so there is little effect on the model simulation results. Generally the change in land use from 2006 to 2011 was relatively small. Also this change occurred gradually over the this 5 year period.

7 References

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Appendix A – Additional Tables and Figures

Table A-1 Point Sources (PTS files) in the Lower Catawba Basin WARMF Model. Inactive point sources that continued to discharge after 1/1/1999 are included in model and are high-lighted in gray.

Point Source Name	NPDES Number	Out-fall ID	Design Flow (mgd)	Seg-ment	Receiving Stream	Date of Last Input Value or Inactive Date
Fishing Creek Reservoir						
CMU - Sugar Creek WWTP	NC0024937	001	20	455	Little Sugar Creek	10/31/2012
CMU - Irwin Creek WWTP	NC0024945	001	15	510	Irwin Creek	10/31/2012
CMU - McAlpine Creek WWTP	NC0024970	001	64	836	McAlpine Creek	10/31/2012
CWS - Forest Ridge	NC0029181	001		433	UT Irvins Creek	9/30/2012
Mint Hill Festival - Mid South	NC0063789	001		436	Irvins Creek	Limited data.
Union County - Twelvemile Creek WWTP	NC0085359	001	6	437	Twelvemile Creek	9/30/2012
Resolute Forest Products (Formerly Bowater)	SC0001015	001	29.7	61	Catawba River	10/31/2012
		003		61		Inactive 4/1/1999
		005		61		Inactive 4/1/1999
Fort Mill WWTP	SC0020371	001	3	87	Catawba River	9/30/2012
Rock Hill - Manchester Creek WWTP	SC0020443	001	20	87	Catawba River	12/31/2012
Foxwood SD WWTP	SC0027146	001	0.12	354	Sugar Creek	9/30/2012
Utililies SC - Shandon SD WWTP	SC0027189	001	0.014	69	Catawba River	9/30/2012
Lancaster County P&D Foster Plant	SC0027391	001		646	Catawba River	9/30/2012
Quail Meadow Park WWTP	SC0028622	001	0.025	87	Catawba River	10/31/2012
Lamplighter Village SD/CWS WWTP	SC0030112	001	0.63	358	McAlpine Creek	9/30/2012

Table A-1 Point Sources (PTS files) in the Lower Catawba Basin WARMF Model. (Continued.)

Point Source Name	NPDES Number	Out-fall ID	Design Flow (mgd)	Seg-ment	Receiving Stream	Date of Last Input Value or Inactive Date
Cedar Valley Mobile Home Park	SC0032417	001	0.03	61	Catawba River	10/31/2012
Nation Ford Chemical (R-M Industries)	SC0035360	001	1.24	87	Catawba River	9/30/2012
Util Services SC Carowoods SD	SC0038113	001	0.02	324	Jackson Br	9/30/2012
Rebound Behavorial Health	SC0041807	001	0.008	746	Waxhaw Crk	2/28/2006
City of Lancaster	SC0046892	001	7.5	Res 1562	Fishing Crk Res	9/30/2012
Lancaster County - Indianland	SC0047864	001	1.2/2.0	69	Catawba River	10/31/2012
P. Kaufman Inc	SC0022799	001		492	Sugar Creek	Inactive 8/1/2000
Pinecrest MHP	SC0031151	001		326	Steele Creek	Inactive 5/1/2001
Twin Lakes Mobile Home Estates	SC0031208	001	0.0625	492	Sugar Creek (Flint Hill Branch)	Inactive 8/1/2007
Indianland School	SC0035033	001		39	Sugar Creek	Inactive 8/1/2000
Faith Temple Bingo	SC0038563	001		497	McCollough Branch	Inactive 4/1/1999
Maco Commercial Park	SC0041483	001		324	Jackson Branch	Inactive 1/1/2002
Greens LLC (Formerly Celanese)	SC0001783	001		87	Catawba River	Inactive 1/1/2009
		002		87		Inactive 11/1/2008
		003		87		Inactive 8/1/2005
Springs - Grace	SC0003255	001		Res 1562	Catawba River	Inactive 6/1/2012
Republic Fasterners	SC0029572	001		Res 1562	Fishing Crk Res	Inactive 6/1/2006
South End LLC formerly McAteer Trailer Park	SC0027383	001	0.0055	496	Cane Creek	Inactive 5/1/2006
Piedmont Water Co - Woodforest SD	SC0035661	001	0.039	88	Big Dutchmans Crk	Inactive 11/1/2007

Table A-1 Point Sources (PTS files) in the Lower Catawba Basin WARMF Model. (Continued.)

Point Source Name	NPDES Number	Out-fall ID	Design Flow (mgd)	Seg-ment	Receiving Stream	Date of Last Input Value or Inactive Date
Great Falls Reservoir						
McAfee Trailer Park	SC0027111	001	0.018	390	Hope Branch	9/30/2012
City of York - Fishing Creek	SC0038156	001	3.0/4.0	383	Fishing Creek	9/30/2012
Adnah Hills Mobile Home Park	SC0041670	001	0.04	373	UT Tools Fork Crk	9/30/2012
Util Services SC Country Oaks SD	SC0039217	001	0.02	373	UT Tools Fork Crk	9/30/2012
Jack Nelson Enterprises	SC0027341	001	0.012	222	Neelys Creek	9/30/2012
Kentucky-Cumberland Coal Co.	SC0042129	001		336	Clinton Branch	9/30/2012
Chester - Lando/Manetta	SC0001741	001	0.8/1.0	266	Fishing Creek	9/30/2012
Carolawn, Inc NPL Site	SC0047538	001		167	Fishing Creek	9/30/2012
Plains LPG Services LP (formerly Suburban Propane)	SC0046248	001		395	Fishing Creek	8/31/2003
Neely's Creek Retirement Home	SC0041904	001	0.008	222	Neelys Creek	Inactive 10/1/2010
Cedar Creek Reservoir						
City of Chester - Rocky Creek	SC0036056	001	1.36	611	Rocky Creek	9/30/2012
Town of Great Falls	SC0021211	001	1.4	551	Catawba River	9/30/2012
Super Essex Communications	SC0040941	001		611	Rocky Creek	Inactive 10/1/2003
Lake Wateree						
White Oak Conf Center	SC0035980	001	0.0495	570	Gaydens Creek	9/30/2012
Carolinas Seventh Day Adventist - NOSOA	SC0033651	001	0.025	Res 2310	Lake Wateree	9/30/2012
USAF Wateree Recreation	SC0044440	001	0.007	Res 2292	Lake Wateree	7/31/2010
Jones & Frank Corp	SC0042048	001		Res 15	Lake Wateree	Inactive 2/1/1999

Point Sources in the Lower Catawba WARMF Model

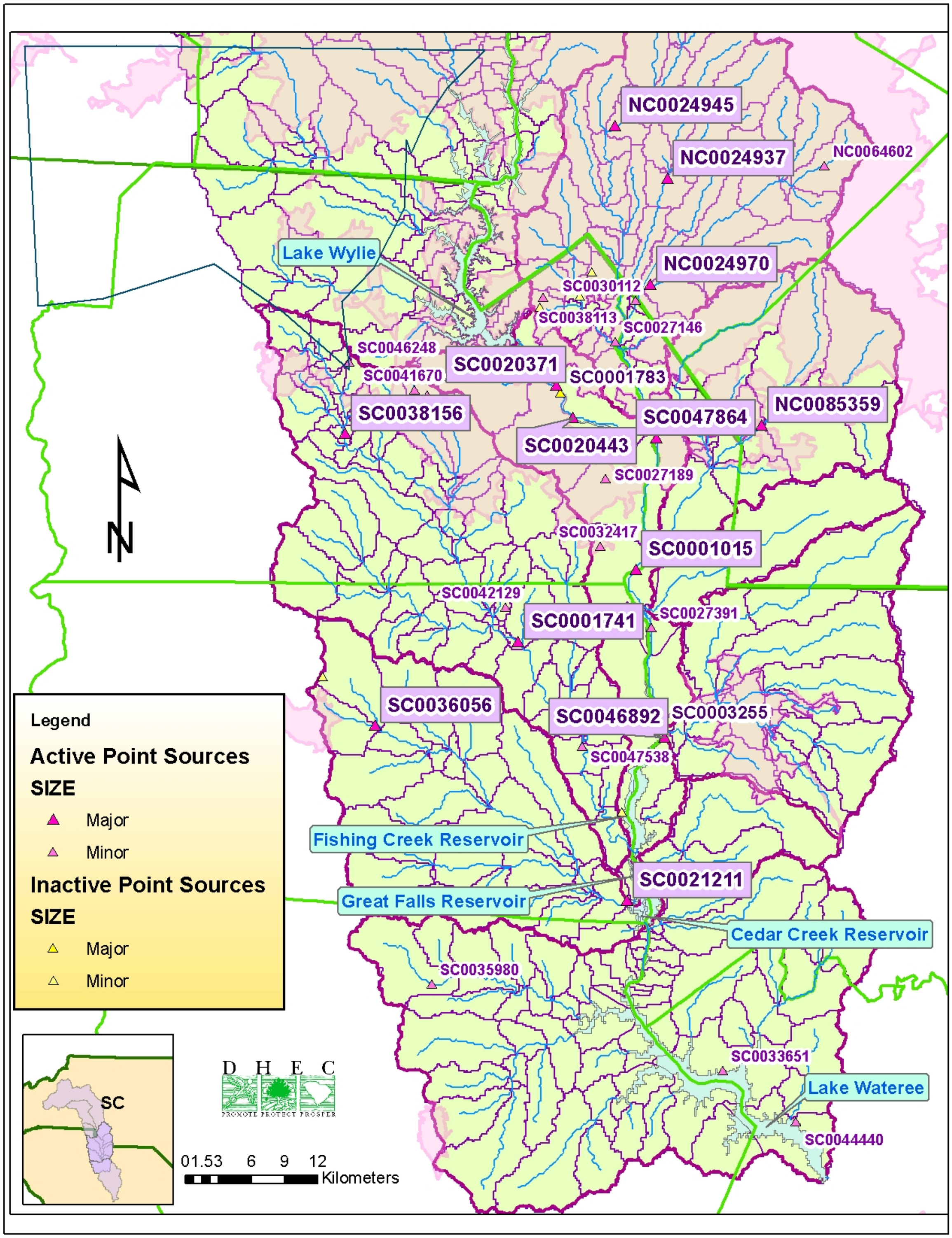


Figure A-1 Map of Lower Catawba showing locations of Point Sources in model.

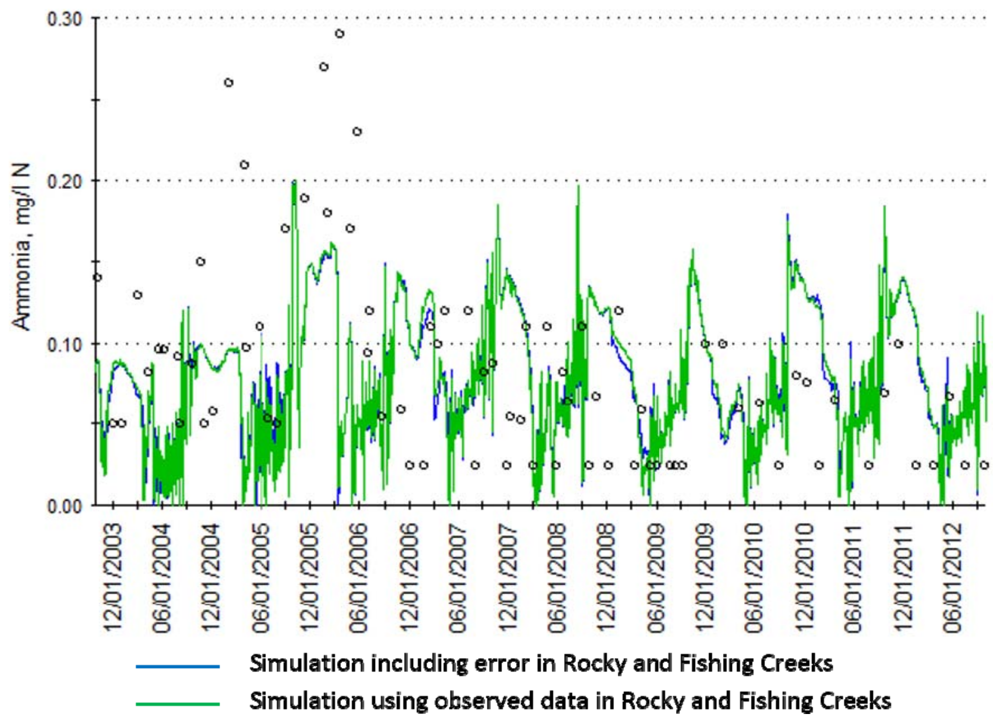


Figure A-1 Ammonia-nitrogen concentration in Lake Wateree with (blue) and without (green) simulation error in Rocky and Fishing Creeks

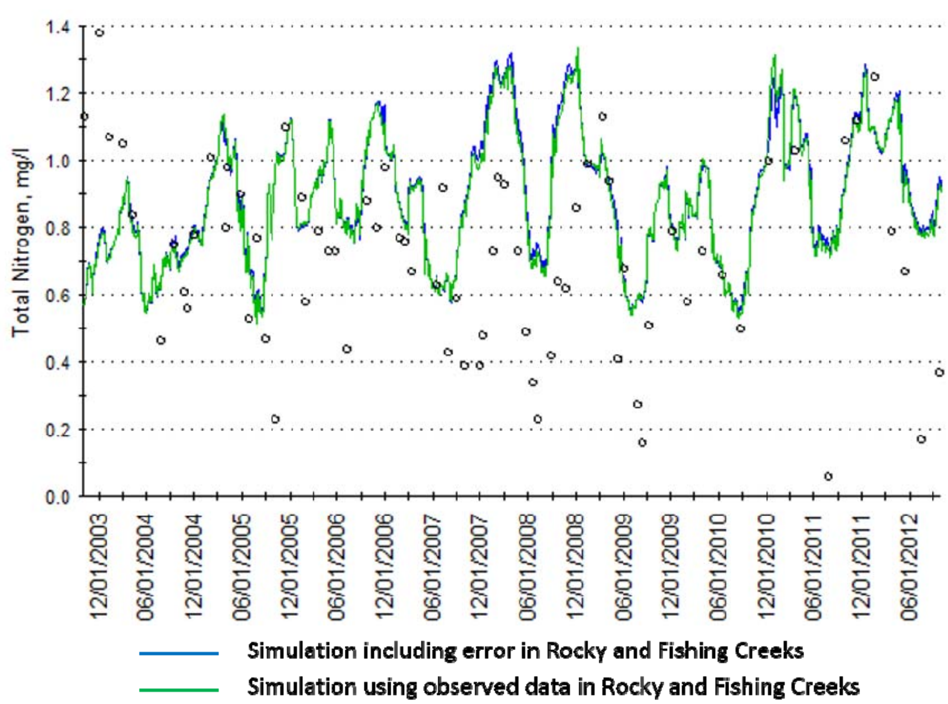


Figure A-2 Total nitrogen concentration in Lake Wateree with (blue) and without (green) simulation error in Rocky and Fishing Creeks

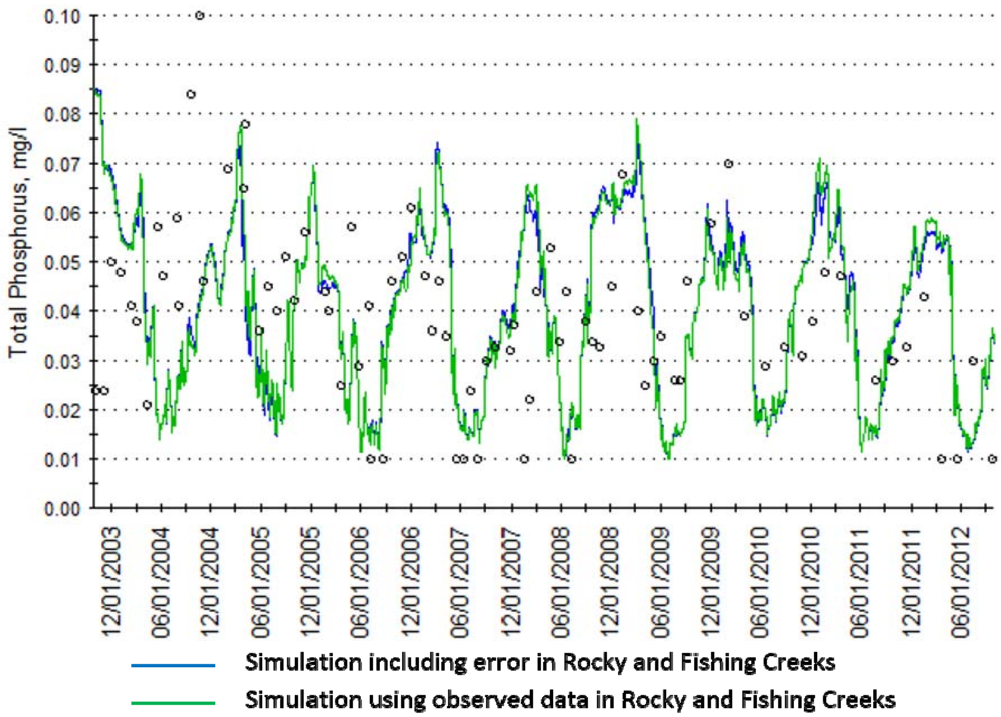


Figure A-3 Total phosphorus concentration in Lake Wateree with (blue) and without (green) simulation error in Rocky and Fishing Creeks

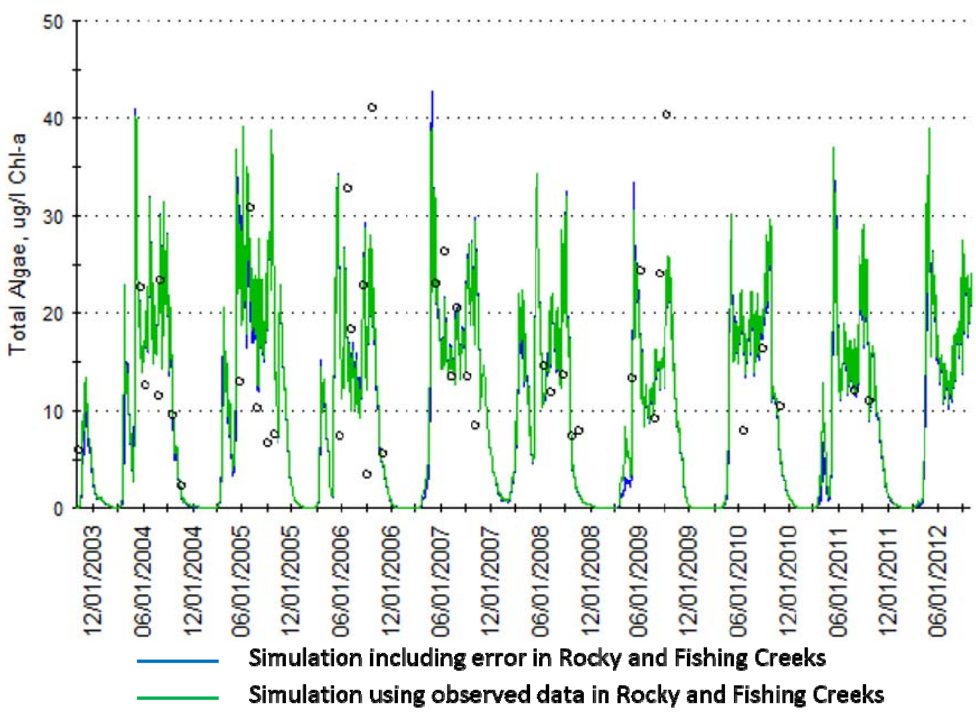


Figure A-4 Total algae (chlorophyll-a) concentration in Lake Wateree with (blue) and without (green) simulation error in Rocky and Fishing Creek

Appendix B – Source Contribution Tables and Figures

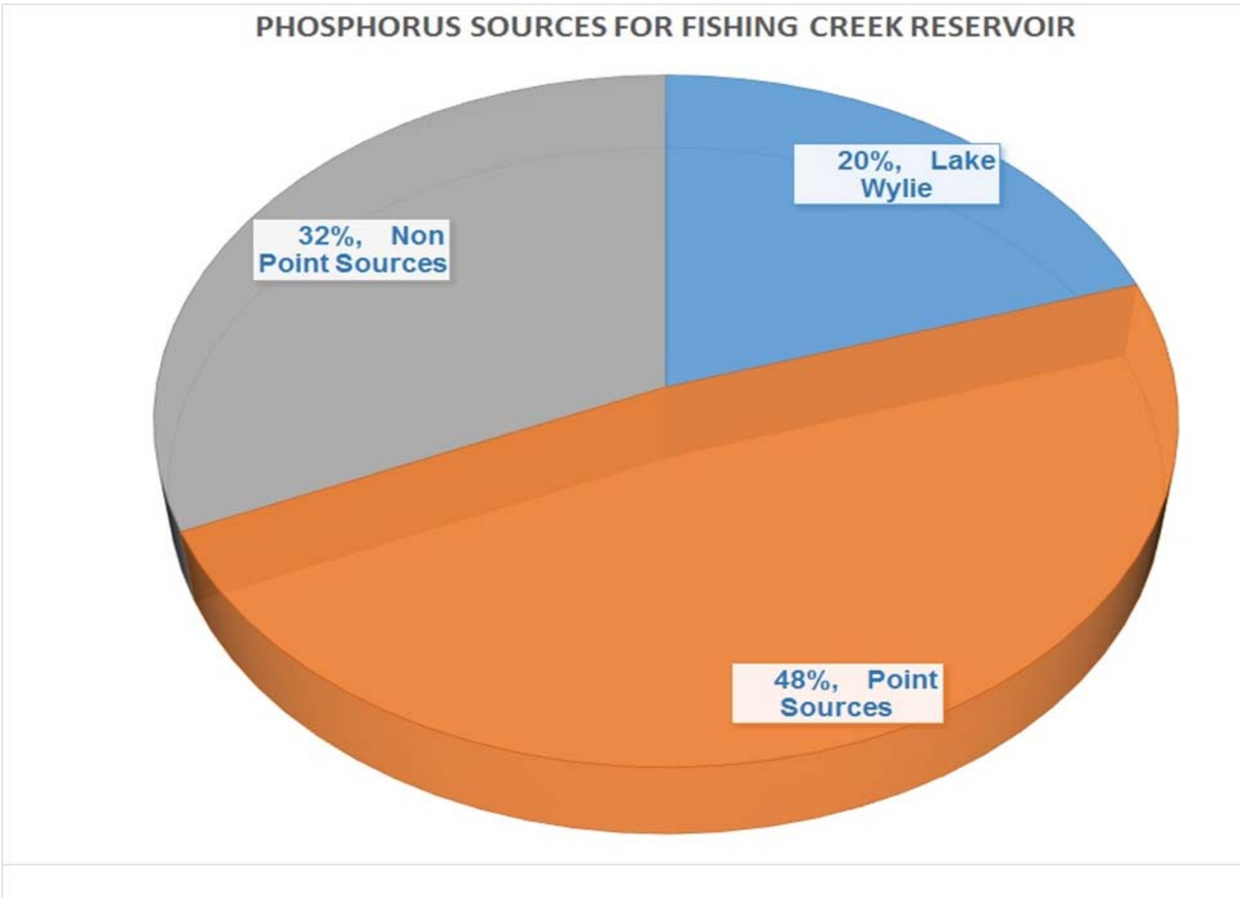


Figure B-1 Source contributions of phosphorus to Fishing Creek Reservoir for 1/2007-9/2012 based on calibrated Catawba Model.

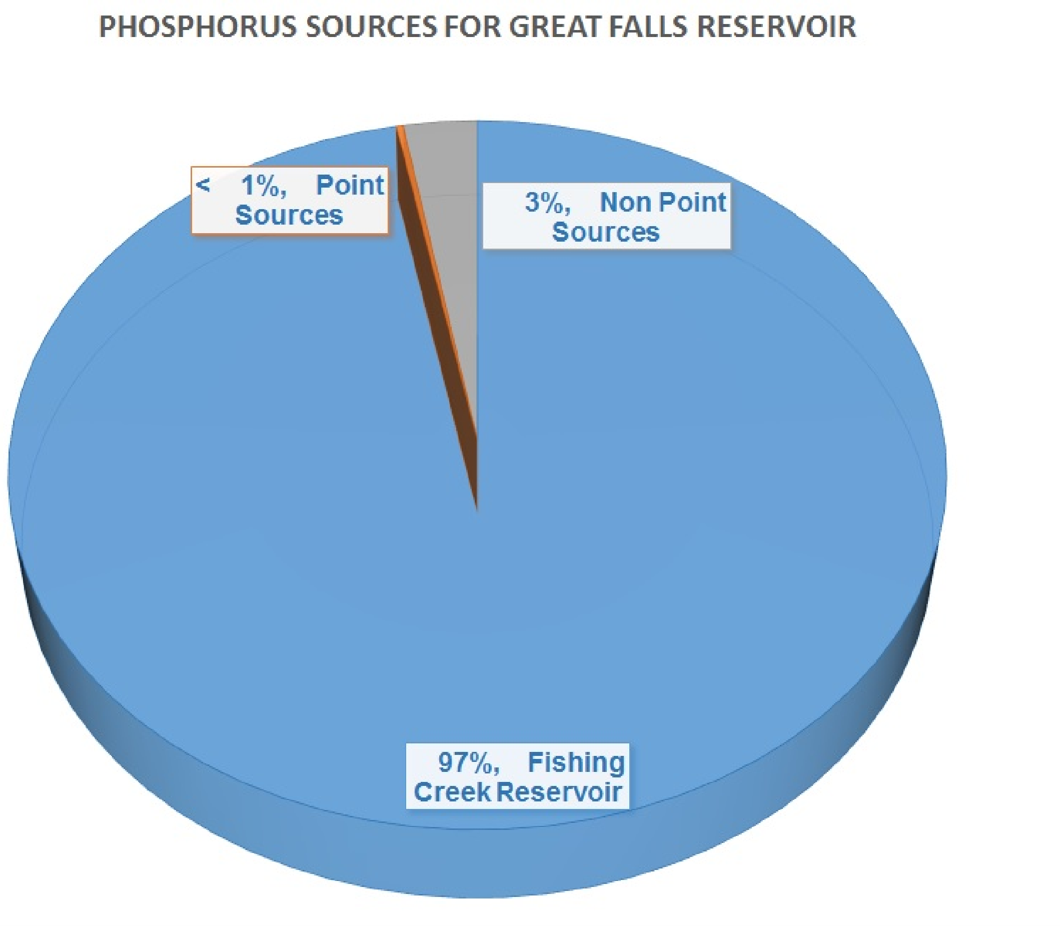


Figure B-2 Source contributions of phosphorus to Great Falls Reservoir for 1/2007-9/2012 based on calibrated Catawba Model.

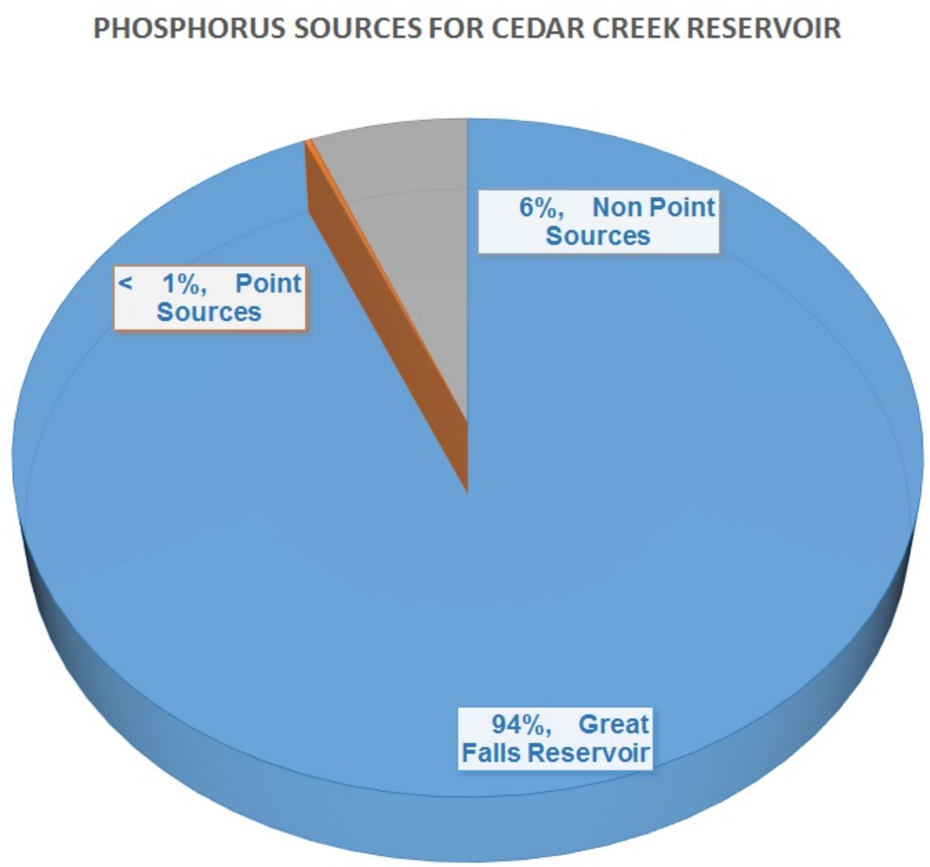


Figure B-3 Source contributions of phosphorus to Cedar Creek Reservoir for 1/2007-9/2012 based on calibrated Catawba Model.

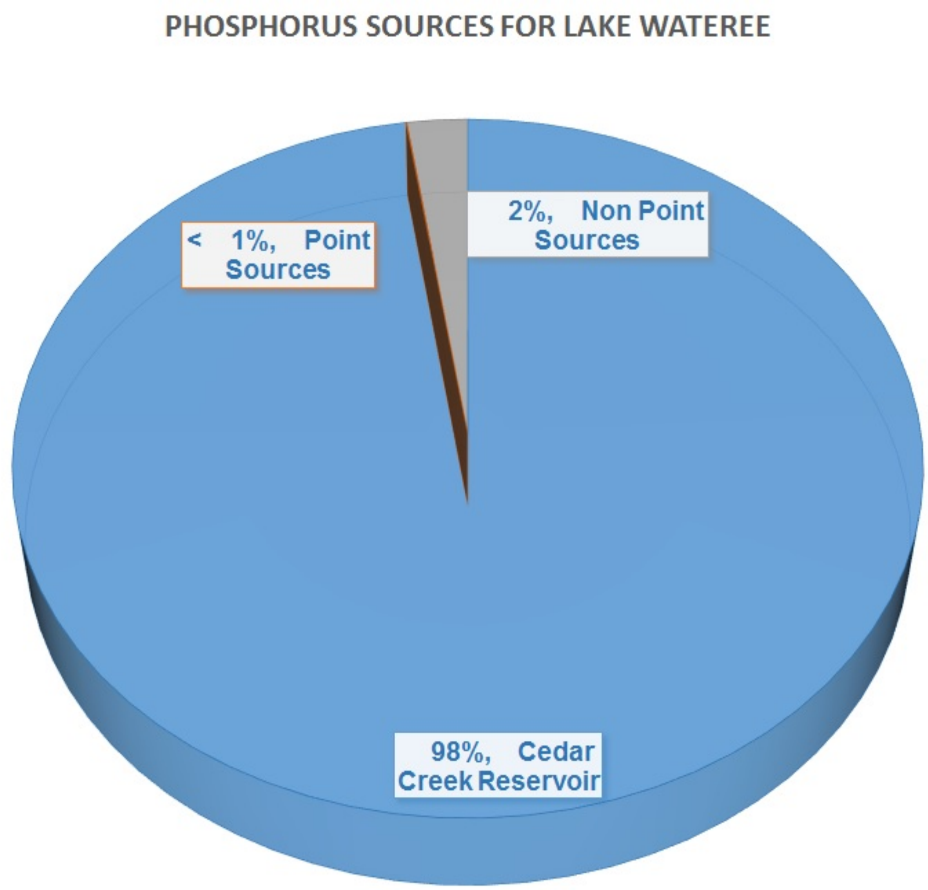


Figure B-4 Source contributions of phosphorus to Lake Wateree for 1/2007-9/2012 based on calibrated Catawba Model.

Table B-1 Source contributions of phosphorus to the Lower Catawba Reservoirs for 1/2007-9/2012 in kg/day based on calibrated Catawba Model.

Reservoir / Sources	Loads (kg/day)	Percen-tage
Fishing Creek Reservoir		
Lake Wylie	121	20%
Point Sources	292	48%
Non Point Sources	191	32%
Total	605	100 %
Great Falls Reservoir		
Fishing Creek Reservoir	559	97%
Point Sources	1.4	< 1%
Non Point Sources	16	3%
Total	576	100 %
Cedar Creek Reservoir		
Great Falls Reservoir	574	94%
Point Sources	1.6	< 1%
Non Point Sources	38	6%
Total	614	100 %
Lake Wateree		
Cedar Creek Reservoir	607	98%
Point Sources	0.2	< 1%
Non Point Sources	15	2%
Total	621	100 %

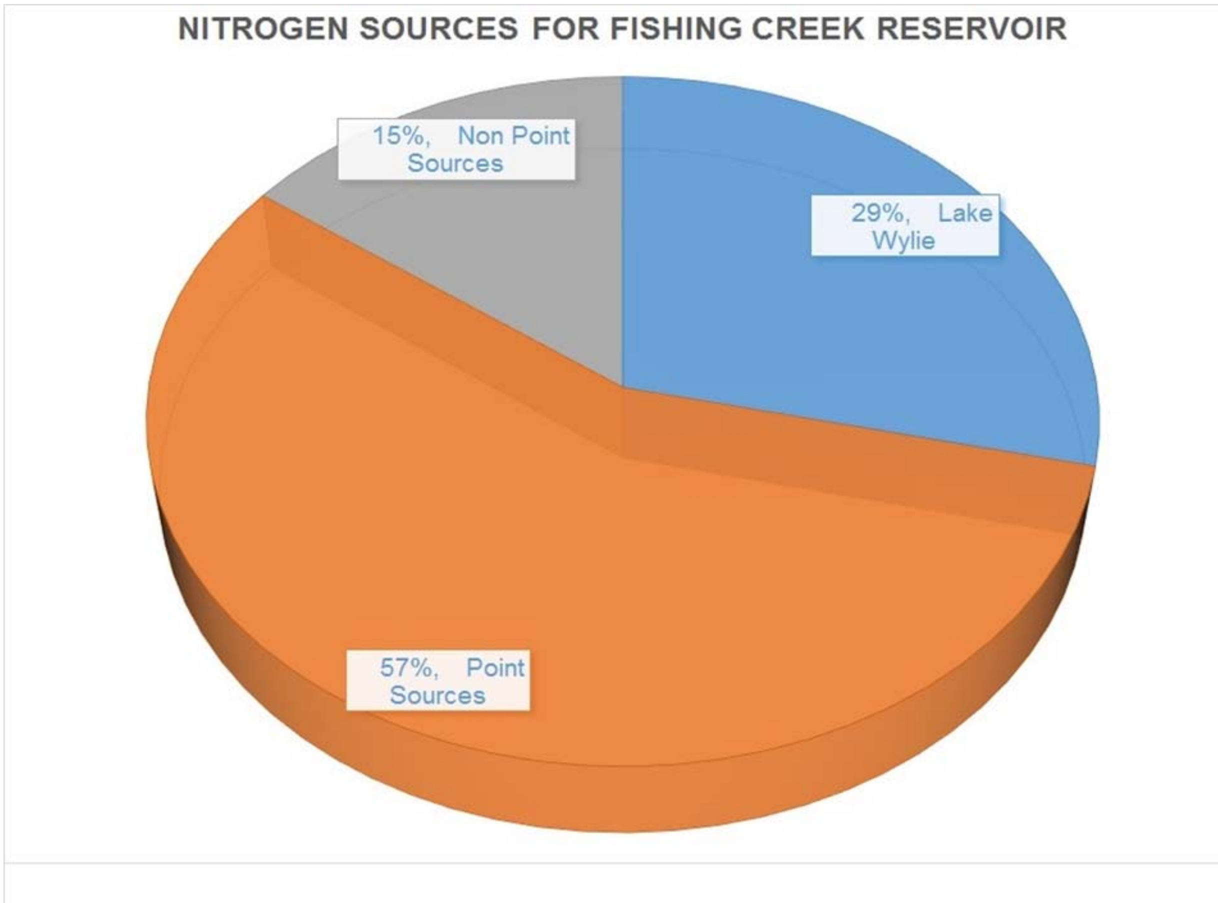


Figure B-5 Source contributions of nitrogen to Fishing Creek Reservoir for 1/2007-9/2012 based on calibrated Catawba Model.

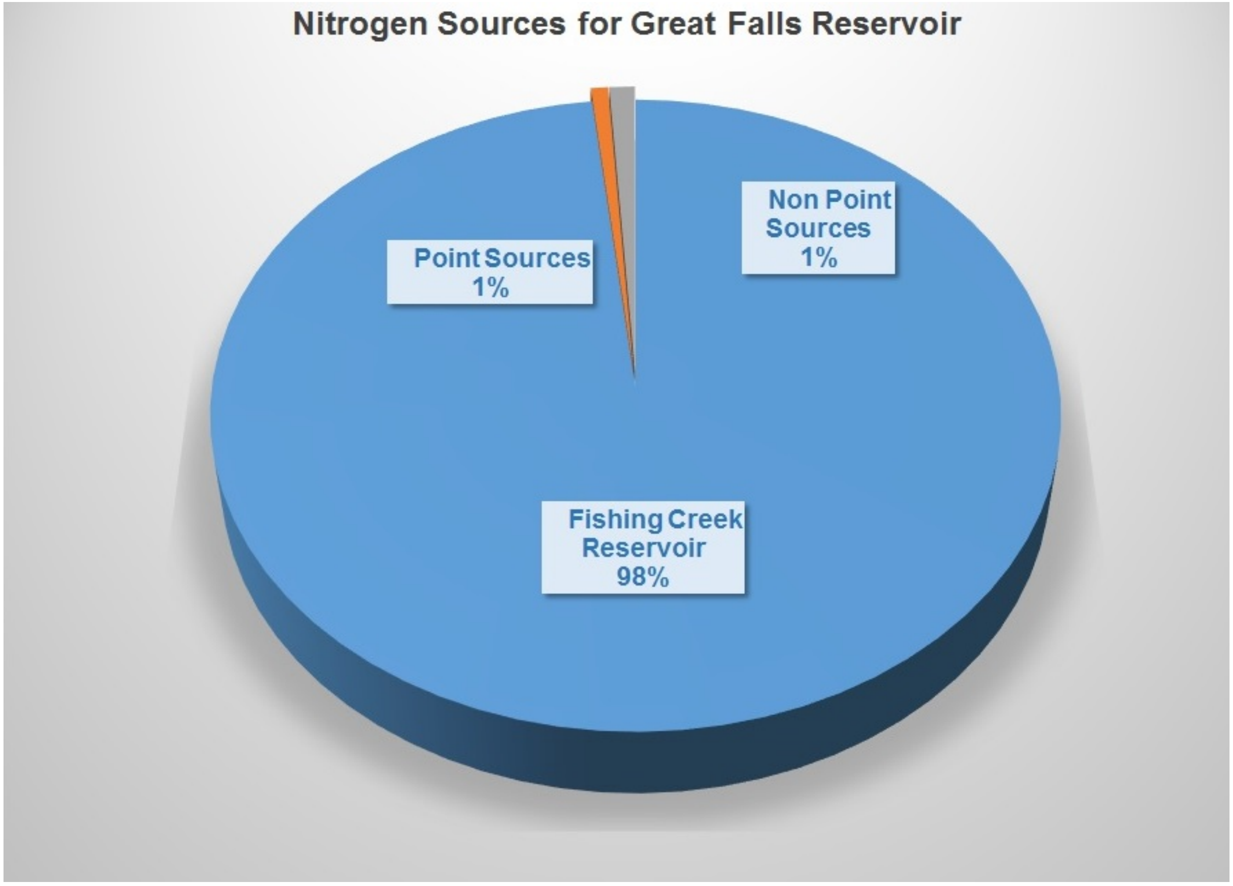


Figure B-6 Source contributions of nitrogen to Great Falls Reservoir for 1/2007-9/2012 based on calibrated Catawba Model.

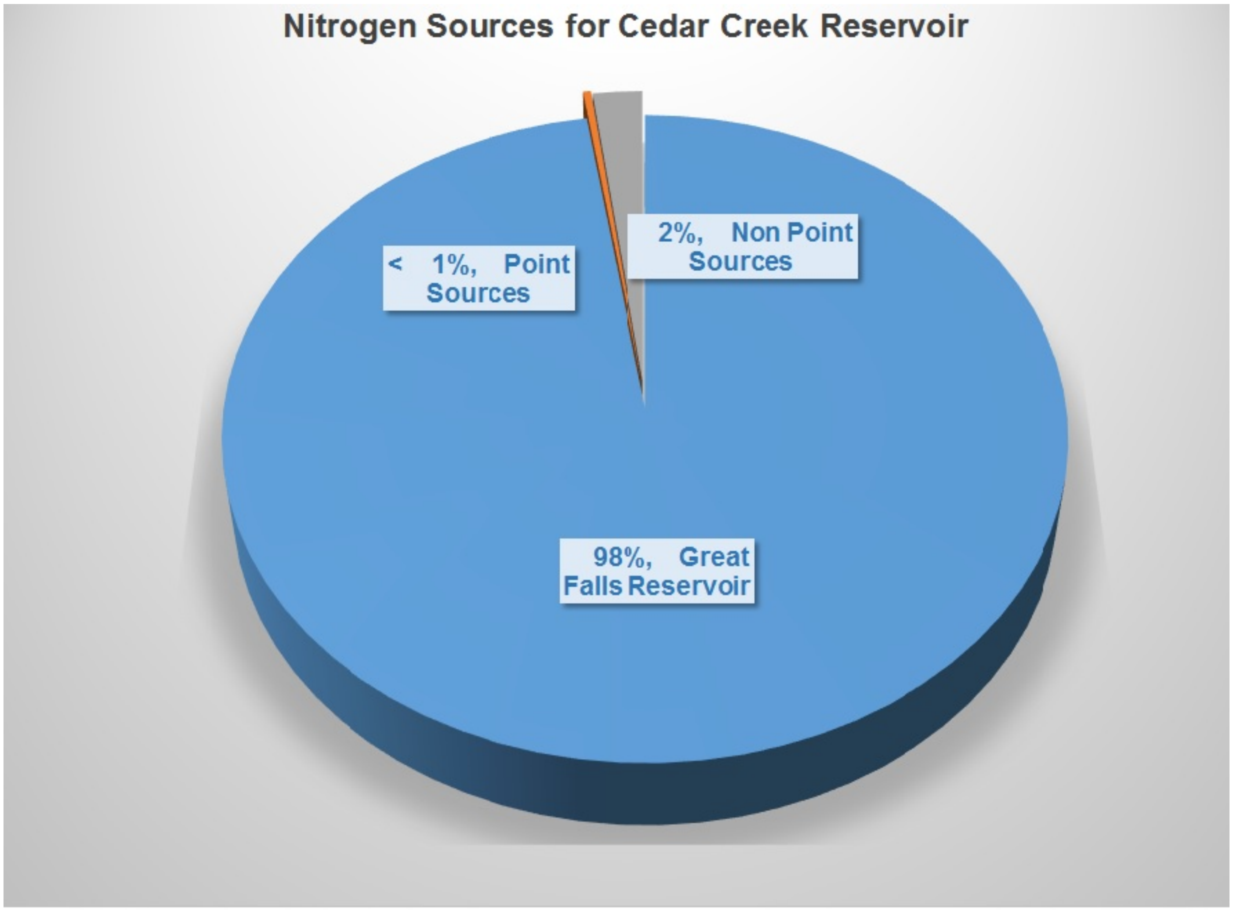


Figure B-7 Source contributions of nitrogen to Cedar Creek Reservoir for 1/2007-9/2012 based on calibrated Catawba Model.

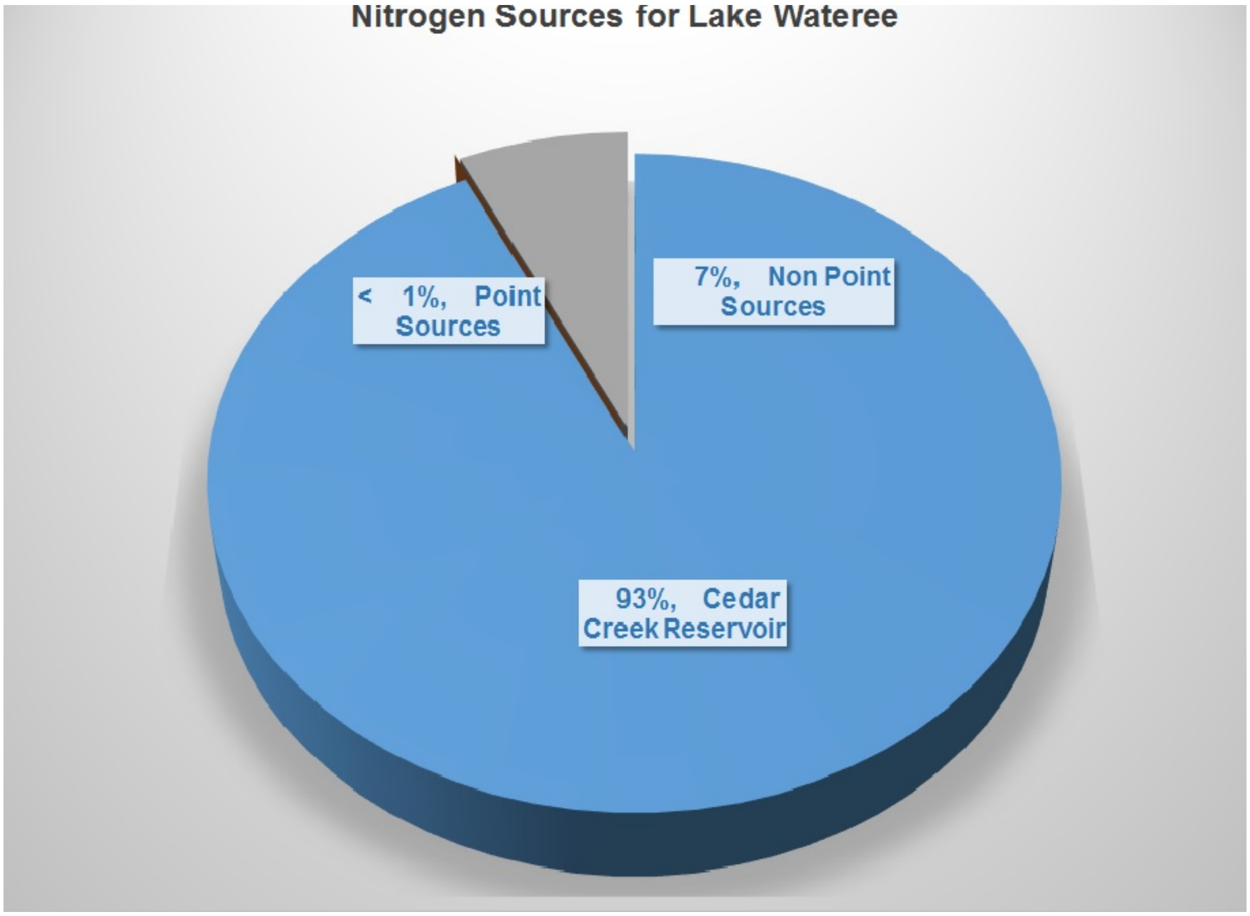


Figure B-8 Source contributions of nitrogen to Lake Wateree for 1/2007-9/2012 based on calibrated Catawba Model.

Table B-2 Source contributions of nitrogen to the Lower Catawba Reservoirs for 1/2007-9/2012 in kg/day based on calibrated Catawba Model.

Reservoir / Sources	**Loads (kg/day)**	**Percen-tage**
Fishing Creek Reservoir		
Lake Wylie	2726	29%
Point Sources	5382	57%
Non Point Sources	1416	15%
Total	9,523	

Great Falls Reservoir		
Fishing Creek Reservoir	9127	98%
Point Sources	66.7	< 1%
Non Point Sources	99	1%
Total	9,293	
Cedar Creek Reservoir		
Great Falls Reservoir	9,278	98%
Point Sources	31.1	< 1%
Non Point Sources	201	2%
Total	9,510	
Lake Wateree		
Cedar Creek Reservoir	9,468	93%
Point Sources	0.0	< 1%
Non Point Sources	720	7%
Total	10,188	

Appendix C – Changes in Land Use in Lower Catawba Basin Tables and Figures

Table C-1 Land Use in the Lower Catawba Basin in 2006 by 10-digit HUC

Land Use Class	Sugar Creek	Twelve-mile Creek	Cane Creek	Fishing Creek	Rocky Creek	Catawba Rvr & FCR & GFR & CCR	Lake Wateree
HUC 030501____ =>	**0301**	**0302**	**0303**	**0304**	**0305**	**0306**	**0401**
Area - hectares							
Forest/Shrub/Grass/Wetland	13,942	20,553	26,867	46,141	41,821	45,717	87,441
Water	159	149	405	376	239	2,564	5,107
Developed - Open Space	24,632	5,565	3,984	5,970	2,256	6,409	2,902
Developed - Urban	30,021	4,011	2,078	3,770	1,062	4,339	432
Agriculture	2,157	7,774	8,981	18,576	6,100	7,513	2,893
Barren	431	337	55	41	314	299	928
Totals	71,343	38,390	42,371	74,873	51,792	66,841	99,701
Percentages							
Forest/Shrub/Grass/Wetland	19.5%	53.5%	63.4%	61.6%	80.7%	68.4%	87.7%
Water	0.2%	0.4%	1.0%	0.5%	0.5%	3.8%	5.1%
Developed - Open Space	34.5%	14.5%	9.4%	8.0%	4.4%	9.6%	2.9%
Developed - Urban	42.1%	10.4%	4.9%	5.0%	2.1%	6.5%	0.4%
Agriculture	3.0%	20.3%	21.2%	24.8%	11.8%	11.2%	2.9%
Barren	0.6%	0.9%	0.1%	0.1%	0.6%	0.4%	0.9%
Totals	100%	100%	100%	100%	100%	100%	100%

Table C-2 Land Use in the Lower Catawba Basin in 2011 by 10-digit HUC

Land Use Class	Sugar Creek	Twelve-mile Creek	Cane Creek	Fishing Creek	Rocky Creek	Catawba Rvr & FCR & GFR & CCR	Lake Wateree
HUC 030501____ =>	**0301**	**0302**	**0303**	**0304**	**0305**	**0306**	**0401**
Area - hectares							
Forest/Shrub/Grass/Wetland	13,726	20,087	26,739	45,411	41,657	45,431	87,513
Water	165	144	407	378	241	2,586	5,110
Developed - Open Space	23,921	6,007	3,962	6,240	2,392	6,353	2,897
Developed - Urban	31,034	4,784	2,118	3,939	1,165	4,691	459
Agriculture	1,983	7,167	9,098	18,818	6,032	7,523	2,878
Barren	514	200	47	86	306	257	844
Totals	71,343	38,390	42,371	74,873	51,792	66,841	99,701
Percentages							
Forest/Shrub/Grass/Wetland	19.2%	52.3%	63.1%	60.7%	80.4%	68.0%	87.8%
Water	0.2%	0.4%	1.0%	0.5%	0.5%	3.9%	5.1%
Developed - Open Space	33.5%	15.6%	9.4%	8.3%	4.6%	9.5%	2.9%
Developed - Urban	43.5%	12.5%	5.0%	5.3%	2.2%	7.0%	0.5%
Agriculture	2.8%	18.7%	21.5%	25.1%	11.6%	11.3%	2.9%
Barren	0.7%	0.5%	0.1%	0.1%	0.6%	0.4%	0.8%
Totals	100%	100%	100%	100%	100%	100%	100%

Table C-3 Changes in Land Use in the Lower Catawba Basin from 2006 to 2011 by 10-digit HUC

Land Use Class	Sugar Creek	Twelve-mile Creek	Cane Creek	Fishing Creek	Rocky Creek	Catawba Rvr & FCR & GFR & CCR	Lake Wateree
HUC 030501____ =>	**0301**	**0302**	**0303**	**0304**	**0305**	**0306**	**0401**
Area - hectares							
Forest/Shrub/ Grass/ Wetland	-216	-467	-129	-730	-164	-287	72
Water	6	-5	2	3	2	23	3
Developed - Open Space	-712	443	-22	270	136	-56	-5
Developed - Urban	1,014	773	40	169	103	352	27
Agriculture	-175	-607	116	242	-68	11	-15
Barren	83	-137	-7	46	-8	-43	-83
Totals	ND	ND	ND	ND	ND	ND	ND
Percentages							
Forest/Shrub/ Grass/ Wetland	-1.6%	-2.3%	-0.5%	-1.6%	-0.4%	-0.6%	0.1%
Water	3.7%	-3.5%	0.5%	0.7%	0.9%	0.9%	0.1%
Developed - Open Space	-2.9%	8.0%	-0.6%	4.5%	6.0%	-0.9%	-0.2%
Developed - Urban	3.4%	19.3%	1.9%	4.5%	9.7%	8.1%	6.3%
Agriculture	-8.1%	-7.8%	1.3%	1.3%	-1.1%	0.1%	-0.5%
Barren	19.2%	-40.5%	-13.5%	112.4%	-2.6%	-14.2%	-9.0%
Overall	2%	-4%	-2%	20%	2%	-1%	-1%

Comments received from the following:
Charlotte-Mecklenburg Stormwater Services (CMSWS)
Charlotte-Mecklenburg Utilities Department (CMUD)
Mr. Dave Cole (Cole)
North Carolina North Carolina Division of Water Resources (NCDWR)
Resolute Forest Products (RFP)
City of Rock Hill (RH)
South Carolina Department of Transportation (SCDOT)
Dr. Dan Tufford, PhD (Tufford)
United States Environmental Protection Agency (USEPA)
United States Fish and Wildlife Service (USFWS)

Charlotte-Mecklenburg Storm Water Services

General Comments

CMSWS Comment 1:

"The hydrology calibration should balance the relative and absolute error rates due to the significant number of calibration points that are streams and not reservoirs.

The hydrology calibration should be improved with respect to the absolute error rate. Herr 2012, recommends; "A good absolute error is generally less than 20% for flow and conservative chemical constituents…" The relative error was the primary statistic used in the hydrologic calibration to account for reservoir water quality through the long-term pollutant load. However, as this model will be used to develop daily loading rates for pollutants in areas outside reservoirs, a more balanced approach to calibration in these areas will improve the simulation of pollutant loads."

CMSWS Response 1:

Absolute error recommendations are general and not necessarily appropriate for all applications since it is highly sensitive to small timing errors and outliers in the observed data. For applications such as this with 1) large area with comparatively sparse meteorology data, 2) few headwater locations with observed flow 3) time and budget not allowing for extremely detailed calibration and input data analysis, 4) a primary objective of characterizing long term pollutant loads, focusing on relative error is a more useful and necessary limitation for calibration.

CMSWS Comment 2:

"Revisit the total suspended sediment (TSS) calibration to improve R-squared values as well as error rates.

Improving the hydrology calibration statistics may help improve the TSS calibration as well. The NSE values are negative for several of the assessment points. According to Moriasi 2007 "…values ≤0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. We understand the difficulty with calibrating TSS in WQ models; however, could a surrogate such as turbidity be used as a substitute for TSS? There should be more turbidity data available as compared to TSS data. Improving the TSS calibration will further improve the calibration of adsorbed pollutants such as phosphorous."

CMSWS Response 2:

As emphasized by Moriasi regarding quality of the observed dataset: "…in situations when a complete measured time series does not exist, for instance when only a few grab samples per year are available, the data may not be sufficient for analysis using the recommended statistics.". The median NSE for daily

TSS simulations in Moriasi's literature review was -1.27. Statistical measures should not be used to evaluate TSS calibration without continuous datasets, particularly without co-located flow data (i.e., several of the locations with TSS did not have flow data for prior hydrology calibration). Calibration efforts focused on simulating the correct range of observed values, rather than the precise timing of peak concentrations. The current Catawba WARMF model application is unable to simulate turbidity. Our past calibration efforts relying on the relationship between turbidity and suspended sediment have not consistently been successful and have indicated that this relationship is highly variable in space and time. Recalibration of TSS would not improve results without substantially more data and is not within the budget constraints of this project.

CMSWS Comment 3:

"**Recalculate the fit statistics for ammonia-nitrogen based on post 2007 observed data to better represent the intention of the calibration procedure.**
We understand the difficulty resulting from sudden changes in observed data and the resulting statistics. Currently the calibration statistics do not meet recommended criteria from Herr 2012 ([absolute error] less than 30% for nutrients) nor Moriasi 2007 with regards to NSE. An additional table with the statistics calculated for data post 2007 would provide a better idea of how well the model is calibrated."

CMSWS Response 3:

The statistics were recalculated using only post-2007 data and table 5.5 was added to the report.

CMSWS Comment 4:

"Please expand on the comment regarding source assessment of ortho-phosphate.
We recommend more documentation regarding the following statement: "In the Sugar Creek watershed, majority of the phosphate that is exported from the watershed comes from upstream point sources. Thus coefficients that affect the amount of non-point source phosphorus that enters streams within the Sugar Creek subwatershed do not have a measurable impact on simulation results."

With the necessity of interstate coordination for TMDL implementation, it will benefit all parties to know the background behind these comments. The adsorption isotherm was the primary model coefficient used to calibrate ortho-phosphate but does sediment type or channel substrate have any effect on adsorption? A more robust TSS calibration may have effects on the ortho-phosphorus calibration as well."

CMSWS Response 4: An explanation of the Sugar Creek watershed ortho-phosphorus simulation has been updated in Section 5.6 of the report. In the model, adsorption varies only with the total suspended sediment. The relative percentages of different sediment classes does not have an effect on phosphorus adsorption. Error in the phosphate simulation stems mainly from days with higher concentrations which typically occur on days without rainfall events (and thus less dilution of point sources). On these days the TSS concentration is at the lower "base" concentration rather than peak concentrations (i.e, the concentrations occurring during high flow events from surface runoff and erosion). The "base" concentration of TSS is simulated very well in Sugar Creek, as compared to the low concentrations available in the limited TSS data set. Any efforts to improve TSS would focus on timing and high flow events and would not help to reduce Phosphate on low flow days when the error is highest.

CMSWS Comment 5:

"The quality of the Total Phosphorus (TP) calibration should be improved in areas other than Sugar Creek or the associated uncertainty should be accounted for during the allocation process.
Although TP simulation in Sugar Creek is much better than at other locations, improving the hydrology calibration in streams versus reservoirs and the TSS calibration may play an important role in simulating TP in the overall model. Because TP is driven by hydrology and TSS we recommend improving those calibrations before finalizing the model. If TP is accurate for Sugar Creek but not for the rest of the

model, then allocations should reflect the inaccuracy and be more conservative for the rest of the locations. The burden of TP reduction should not be placed only on Sugar Creek if the model cannot accurately quantify loading from other areas as well."

CMSWS Response 5:

TP calibration was done when/where observations were available. The results in Sugar Creek are better than other locations because there is sufficient hydrology and observed phosphorus data available. At other locations, data were limited and therefore the model could not be calibrated to the same extent. Also note that budget/resource constraints prevented were a consideration.

At this point in the nutrient TMDL development process, DHEC (or the Department) has not begun to develop wasteload (WLA) and load (LA) allocations using this tool. Instead, the Department is currently completing updates to the model application in order to begin developing allocation scenarios. There will be additional stakeholder involvement throughout the process, particularly as WLAs and LAs are proposed. The Department anticipates additional discussions with affected parties prior to finalizing TMDLs.

Charlotte-Mecklenburg Utilities Department

General Comments

CMU Comment 1:

"In regard to TP, SCDHEC and the NC Division of Water Resources have already implemented requirements to reduce TP from point sources in the watershed by approximately 70 to 80 percent through permit requirements implemented primarily prior to 2007. These prior reductions should be considered in developing an allocation approach for wasteload allocations (for point sources) and load allocations for nonpoint sources. Specifically, we do not believe an equal marginal percent reduction (EMPR) approach often used by States and EPA is appropriate unless the prior reductions are also considered."

CMU Response 1:

DHEC (or the Department) acknowledges the reductions in nutrient loading that have already been implemented in NPDES permits issued to traditional point sources. The Department also acknowledges that additional nutrient reductions will be necessary in the Catawba River watershed in order for the downstream reservoirs to demonstrate attainment of standards.

At this point in the nutrient TMDL development process, DHEC (or the Department) has not begun to develop wasteload (WLA) and load (LA) allocations using this tool. Instead, the Department is currently completing updates to the model application in order to begin developing allocation scenarios. There will be additional stakeholder involvement throughout the process, particularly as WLAs and LAs are proposed. The Department anticipates additional discussions with affected parties prior to finalizing TMDLs.

CMU Comment 2:

"TN allocation strategies need to be considered carefully for a number of reasons:

- TN impairments are not widespread in the reservoirs.
- The substantial over-prediction of nitrogen by the model may require more reductions than necessary to meet any allocations developed.

- Nitrogen reductions at wastewater treatment facilities can require substantial modifications to treatment approach at substantial cost; therefore, SCDHEC and stakeholders need to be satisfied with model predictions prior to proceeding with this allocation step."

CMU Response 2:

At this point in the nutrient TMDL development process, DHEC (or the Department) has not begun to develop wasteload (WLA) and load (LA) allocations using this tool. Instead, the Department is currently completing updates to the model application in order to begin developing allocation scenarios. There will be additional stakeholder involvement throughout the process, particularly as WLAs and LAs are proposed. Affected parties will have additional opportunity to review model scenarios prior to allocation.

Model Documentation

CMU Comment 3:

"**Model Coefficients Description**

In terms of model coefficients, Section 3.2 "Model Coefficients" listed (a) system coefficients, (b) catchment coefficients; (c) river coefficients and (d) reservoir coefficients. Tables 3-1 to 3-8 in this section have listed the final model calibration coefficients (e.g. either using model default values or calibrated values). We suggest adding one more data column in summary tables (i.e. Tables 3-1 to 3-8) to indicate whether model default values or calibrated values were used for any particular coefficient."

CMU Response 3:

Tables 3-1 and 3-2 were modified to make it more clear what the calibrated values are for each system coefficient (i.e., these apply to the entire watershed). Tables 3-3 to 3-5 list the coefficients that are typically calibrated for individual catchments. Tables 3-3 and 3-5 coefficients vary across the watershed. Since there are 314 catchments in the entire watershed, it is not feasible to list all of the calibrated coefficients for each catchment. Thus the ranges of calibrated values are listed in these tables. The captions, headings and text have been updated to make this clear. The same is true for river coefficients listed in tables 3-6 and 3-7.

CMU Comment 4:

" **Point Source Discharges**

In the January 2014 draft model calibration report, there was no description of point source discharges, except for listing a June 2013 technical memo as one of the references. This makes it difficult for the readers to locate the information on point source data by just looking at the January 2014 draft report alone. Therefore, there should be better cross-referencing between the January 2014 draft calibration report and the June 2013 technical memo on model updates.

In Table 3 of the point source section (on page 3 of June 2013 technical memo), only 12 point sources newly added to the model (among a total of 305 point sources) were listed. Furthermore, Appendix 1 of June 2013 technical memo only provided a summary list of "Updated Point Source Input Files", without descriptive information on each point source discharge (e.g. name of discharges). This made it difficult to track down specific point source information without spending additional search efforts. We would like to recommend such summary information on point sources to be included in the model calibration report so that a reviewer does not need to be looking at other reports or attempt to determine point source information from the model input files."

CMU Response 4:

Tables A-1 and A-2 from Appendix A of the June 2013 technical memo has been added to the calibration report. Adding further details to the tables is not considered high priority for a calibration report and is not within the scope of the contract. SCDHEC has added a table (Table A-1) in Appendix A that list all point sources in the Lower Catawba Basin that have discharged into the basin at any time since 1999. This table includes the discharger name, NPDES number, design or permitted flow (if known), and other information. A map of the Lower Catawba Basin showing all active and inactive point sources included in the model.

Additional details regarding points sources and existing permit limits included in the model application will also be included in a draft nutrient TMDL document. A draft TMDL document will also be made available for public comment, once additional discussions with affected parties has occurred.

CMU Comment 5:

“ **Land Use** To update land use information in the Catawba River WARMF application, gridded land cover data from the 2006 National Land Cover Database (NLCD) was downloaded. The land cover data were overlaid with the updated catchment boundaries and percentages of each land cover classification contained within each catchment were calculated.

Regarding land use coefficients, there are a number of model system coefficients which have values for each land use. These coefficients define how the different land uses receive anthropogenic model inputs such as irrigation and respond to natural model inputs such as atmospheric deposition. These land use coefficients were set based on literature values and agricultural practice. It appears that development of land use as model inputs followed the standard practice of model development.”

CMU Response 5:

Additionally, DHEC has added a table (Appendix A-3) showing changes in land use from the NLCD2006 to the NLCD2011. NLCD has recently been released to the public by 10-digit HUC but was not available at time of the model application updates. Generally the change in land use from 2006 to 2011 was relatively small.

CMU Comment 6:

“Nutrient Budget

Summary information on relative loading from point sources versus land use or upstream sources was not included in the model calibration report. Although this is not necessarily required for a calibration report, it does provide insight into issues related to model calibration. Ideally, this information would be available for subwatershed areas. For instance, the problems with the nitrate N calibration for a tributary such as Rocky Creek could be better understood if the reviewer knew the relative loading contributions (without having to dig them out of the model).”

CMU Response 6:

Pie charts have been added to the document (Appendix B) that breakdown the source contributions of Total Phosphorus and Total Nitrogen in Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, and Lake Wateree.

Adequacy of Hydrology and Water Quality Calibration

It appears that model calibration followed a logical sequence. Hydrological calibration was performed first. Then the calibrations for temperature and conservative substances were performed before the calibration of nutrients (phosphate, ammonia, and nitrate), algae and dissolved oxygen."

CMU Comment 7:

"Hydrologic Calibration

Hydrologic calibration is the process of adjusting the coefficients of the rainfall-runoff model so that the simulations of streamflow better match the observations as well as possible. There are three levels of hydrologic calibration: global, seasonal, and event.

The overall hydrologic calibration appears acceptable and in some cases matches well with observed streamflow. However, the hydrologic calibration for tributaries such as Sugar Creek (more urban land use type) and Rocky Creek (more rural land use type) appear to be significantly inferior to other sub-watersheds (see Figure 4-3 in January 2014 model calibration report). An explanation for possible reason should be provided in the draft report."

CMU Response 7:

The calibration for locations on the main-stem of the Catawba river upstream of Fishing Creek Reservoir is superior to tributary calibrations because the flow at those locations is dominated by the outflow of Lake Wylie, which is defined with observed data. The influence of meteorological data error, spatial heterogeneity in precipitation, runoff characterization error (ie, surface runoff versus interflow), and other model error is damped at the main-stem locations and more pronounced for tributary sub-watersheds.

CMU Comment 8:

"As an overall comment for Section 4 "Hydrology Calibration Report", the comparison plots for simulated flow versus observed flow (i.e. Figures 4-2 to 4-7) are difficult to see during the low flow ranges. A log-log scale should be considered to allow better visualization of the calibration results."

CMU Response 8:

For the purpose of assessing pollutant loading on an annual basis, low flow periods contribute a relatively minor portion of the total load and therefore were not the focus of this analysis. Producing additional plots is not feasible with the budgetary constraints of the project.

Water Quality Calibration

CMU Comment 9:

"**Temperature**

The temperature calibration appears quite good for both free-flowing portion of the Catawba River, tributaries such as Sugar Creek and Rocky Creek, and the lake stations. The temperature calibration statistics shows that the relative error is negative at nearly all sampling locations by comparing model simulation and observed data. This indicates a very slight systematic under-prediction of water temperature (within 1°C)."

CMU Response 9:

The temperature calibration adequately addressed both the Catawba mainstem and tributaries.

CMU Comment 10:

"pH

The pH calibration appears adequate to good for the free-flowing stations of the Catawba River and tributaries. The model significantly over-predicts pH for the reservoir sites with predicted values frequently exceeding a pH of 10 (see Figures 5-17 and 5-20 below which illustrate results for Fishing Creek Reservoir and Lake Wateree headwaters, respectively). The report discounts these over-predictions indicating that nutrient and algal simulations are not sensitive to pH. However, the nutrient and algal simulations should significantly influence pH and this substantial over-prediction (pH is a log scale) indicates that the model is likely predicting substantially more algal productivity than is occurring in the lakes. This will be discussed further under the discussion of chlorophyll *a* calibration."

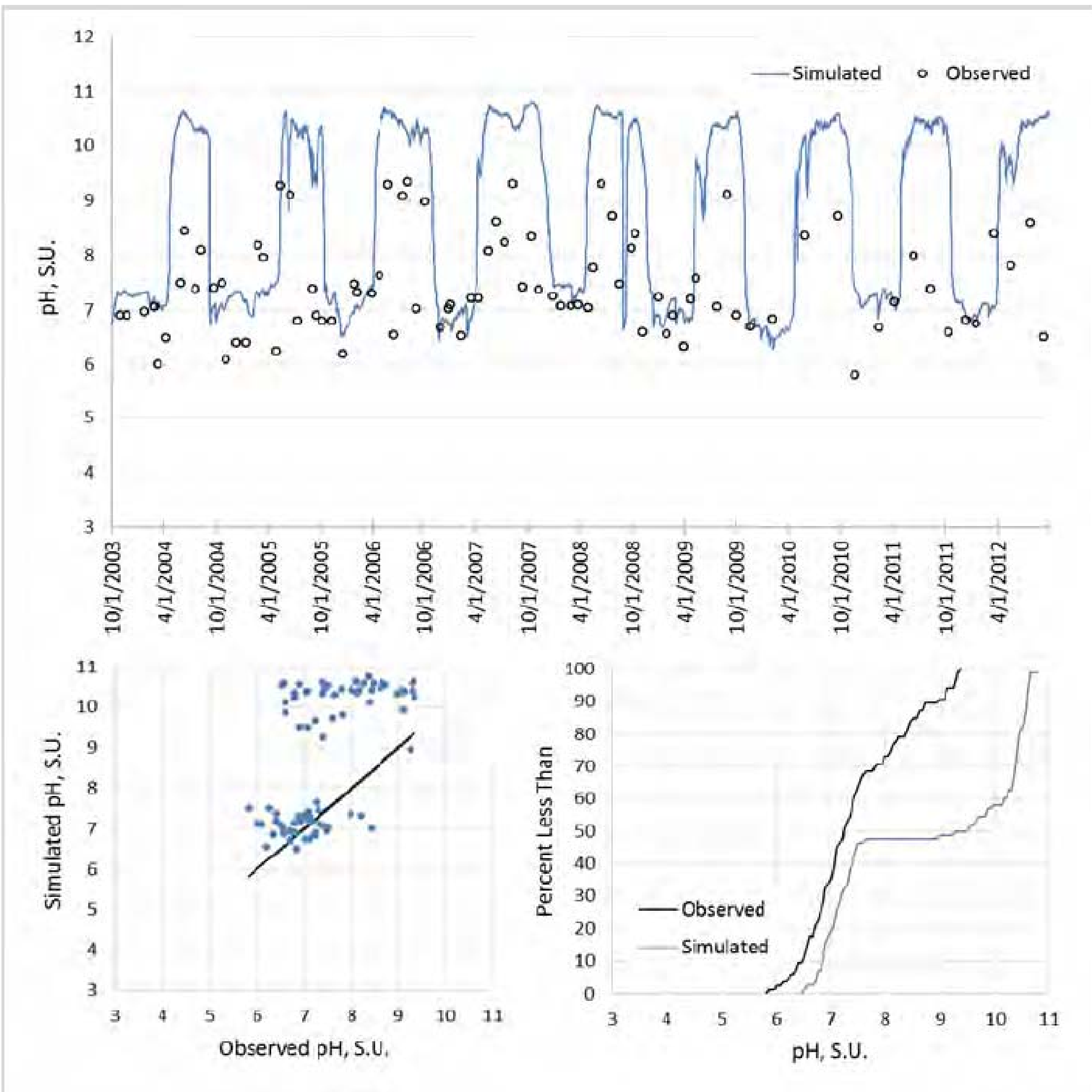


Figure 5-17 pH simulation results, Fishing Creek Reservoir (WARMF ID 1562)

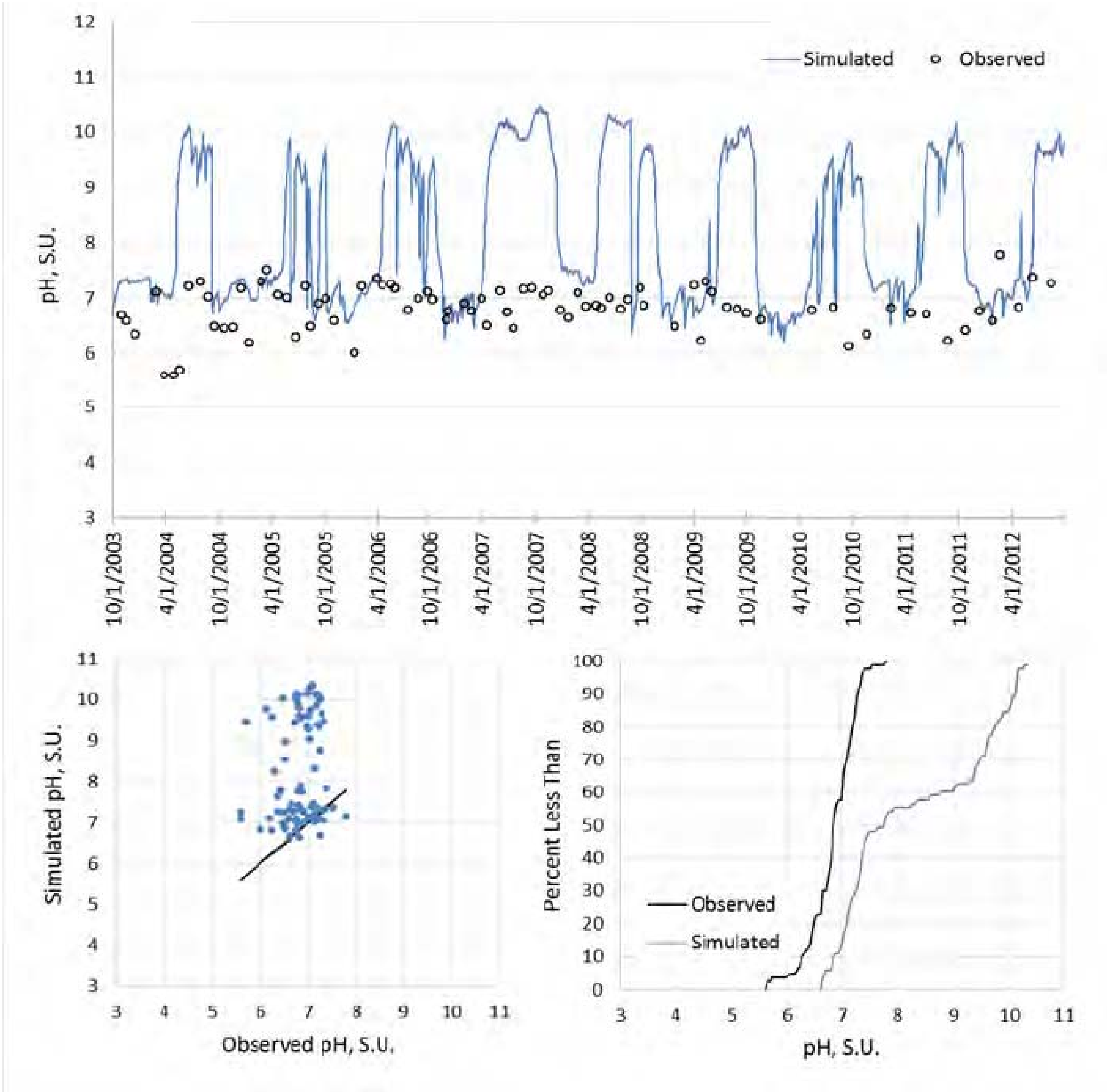
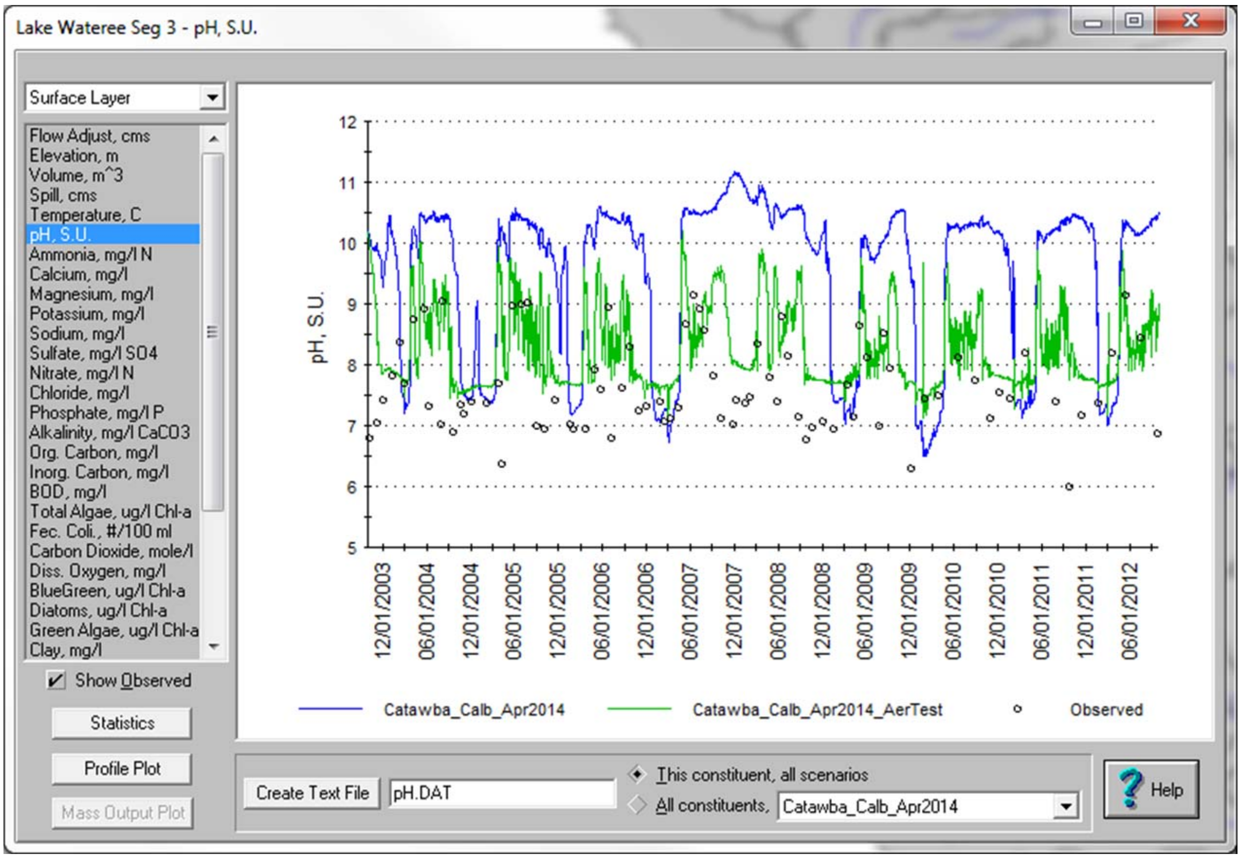
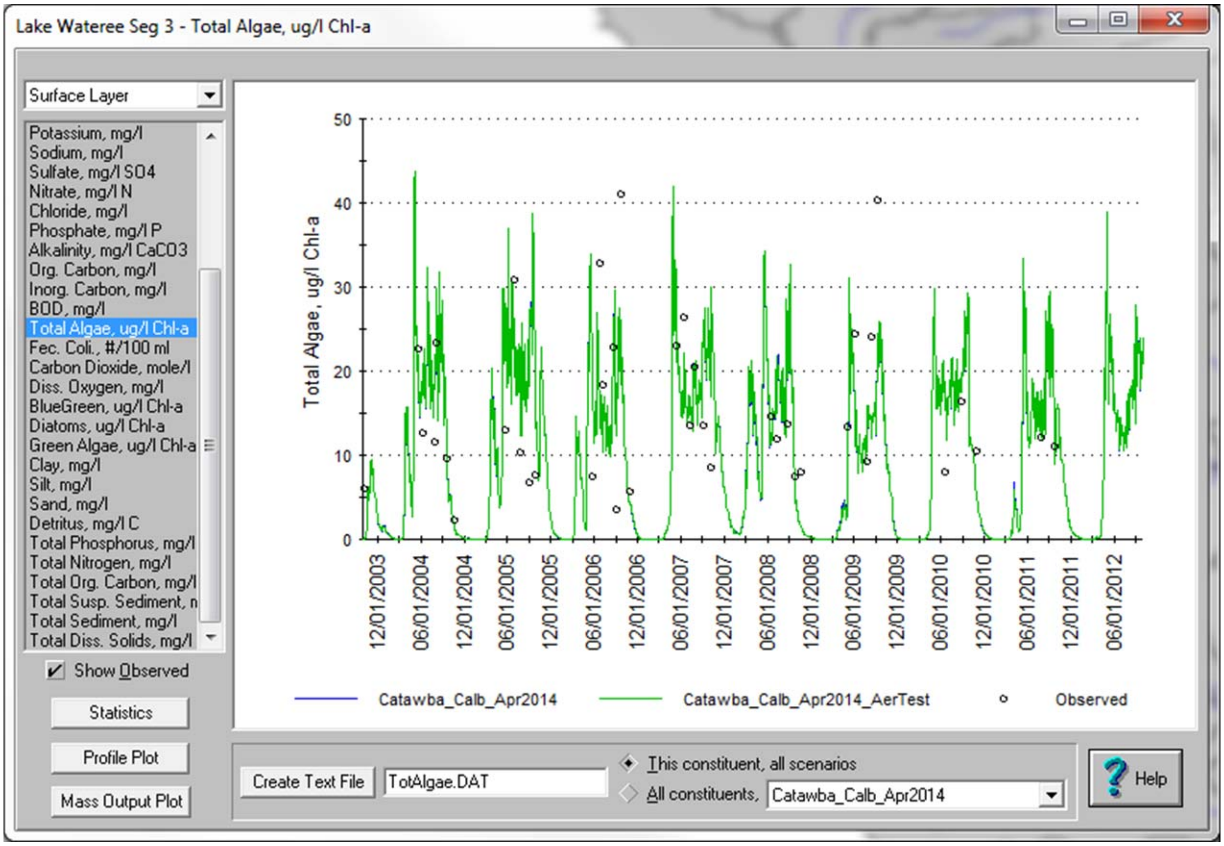


Figure 5-20 pH simulation results, Lake Wateree Headwaters (CW-231) (WARMF ID 624)

CMU Response 10:

Reducing the net growth of algae did lower pH simulations in the lakes during the summer, but also resulted in large negative error in chlorophyll-a concentrations and large positive error in nutrient concentrations. The point made in the report is that although pH is a function of algae (among many other processes), the converse is not true – nutrient and algae concentration are *not* a direct function of pH. The simulation of pH is affected by the many processes within the model that affect alkalinity and total inorganic carbon, in addition to algae growth. Of particular importance is the reaeration of CO_2 from the atmosphere as algae grows and consumes TIC. WARMF calculates the CO_2 reaeration rate in lakes as a fixed function of wind speed. A check of the resulting rate range and comparison with literature values suggests that the resulting values may be too low. The first figure below demonstrates the change in the pH simulation with an increase in the model reaeration rate at Lake Wateree (the change was made within the hard code, the model does not include coefficients to adjust reaeration in lakes). The results indicate that though reaeration may be occurring at a reasonable rate during the winter, reaeration of CO_2 during algae growth is likely not adequate. Nutrient results (figures following pH) demonstrate that algae and nutrient simulations are unaffected by this change. Since the primary constituents of concern for this application are not affected by the results, revisiting the model formulation of reaeration is not feasible within the current project constraints. Results of this test will be added to the final calibration report.




Lake Wateree Seg 3 - Total Algae, ug/l Chl-a
Surface Layer
Potassium, mg/l
Sodium, mg/l
Sulfate, mg/l SO4
Nitrate, mg/l N
Chloride, mg/l
Phosphate, mg/l P
Alkalinity, mg/l CaCO3
Org. Carbon, mg/l
Inorg. Carbon, mg/l
BOD, mg/l
Total Algae, ug/l Chl-a
Fec. Coli., #/100 ml
Carbon Dioxide, mole/l
Diss. Oxygen, mg/l
BlueGreen, ug/l Chl-a
Diatoms, ug/l Chl-a
Green Algae, ug/l Chl-a
Clay, mg/l
Silt, mg/l
Sand, mg/l
Detritus, mg/l C
Total Phosphorus, mg/l
Total Nitrogen, mg/l
Total Org. Carbon, mg/l
Total Susp. Sediment, n
Total Sediment, mg/l
Total Diss. Solids, mg/l
Show Observed
Statistics
Profile Plot
Mass Output Plot
Total Algae, ug/l Chl-a
50
40
30
20
10
0
12/01/2003
06/01/2004
12/01/2004
06/01/2005
12/01/2005
06/01/2006
12/01/2006
06/01/2007
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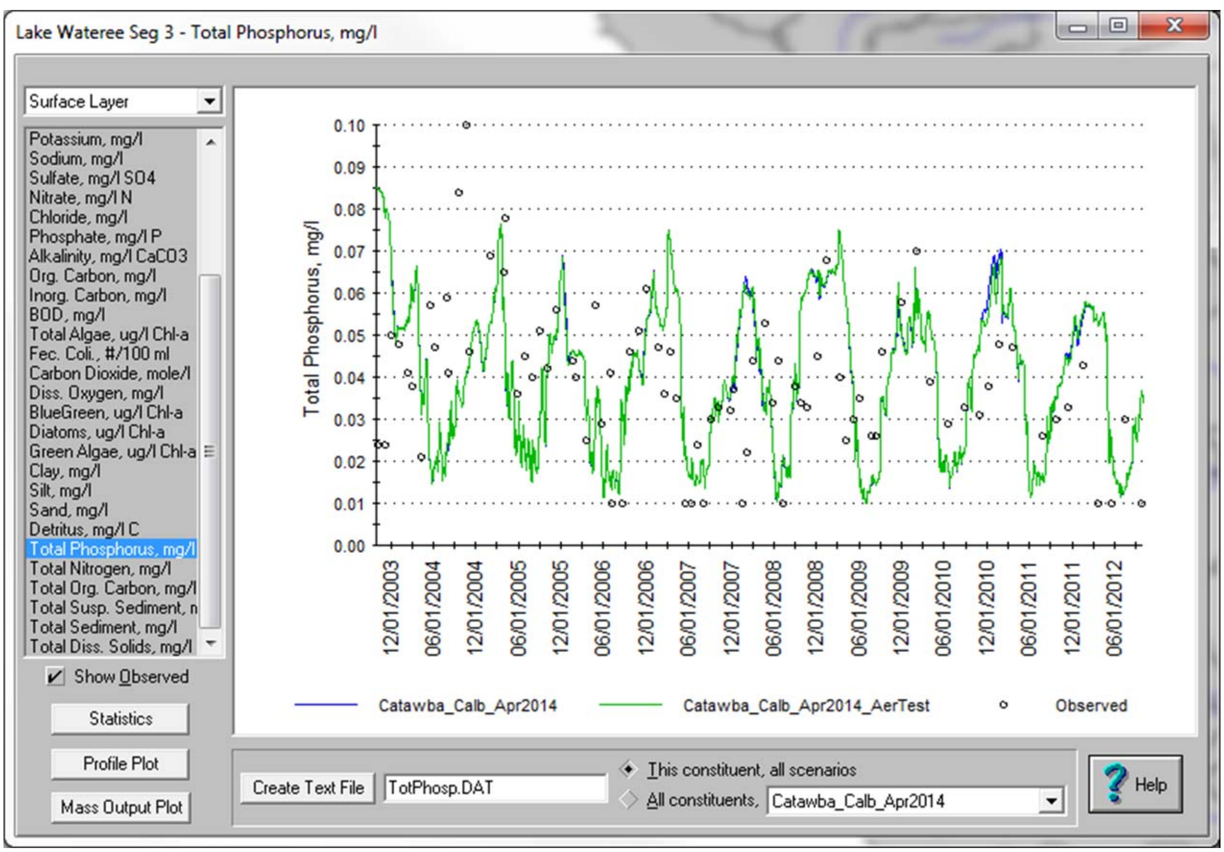
12/01/2008
06/01/2009
12/01/2009
06/01/2010
12/01/2010
06/01/2011
12/01/2011
06/01/2012
Catawba_Calb_Apr2014
Catawba_Calb_Apr2014_AerTest
Observed
Create Text File
TotAlgae.DAT
This constituent, all scenarios
All constituents,
Catawba_Calb_Apr2014
Help


Lake Wateree Seg 3 - Total Phosphorus, mg/l
Surface Layer
Potassium, mg/l
Sodium, mg/l
Sulfate, mg/l SO4
Nitrate, mg/l N
Chloride, mg/l
Phosphate, mg/l P
Alkalinity, mg/l CaCO3
Org. Carbon, mg/l
Inorg. Carbon, mg/l
BOD, mg/l
Total Algae, ug/l Chl-a
Fec. Coli., #/100 ml
Carbon Dioxide, mole/l
Diss. Oxygen, mg/l
BlueGreen, ug/l Chl-a
Diatoms, ug/l Chl-a
Green Algae, ug/l Chl-a
Clay, mg/l
Silt, mg/l
Sand, mg/l
Detritus, mg/l C
Total Phosphorus, mg/l
Total Nitrogen, mg/l
Total Org. Carbon, mg/l
Total Susp. Sediment, n
Total Sediment, mg/l
Total Diss. Solids, mg/l
Show Observed
Statistics
Profile Plot
Mass Output Plot
Total Phosphorus, mg/l
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
12/01/2003
06/01/2004
12/01/2004
06/01/2005
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06/01/2010
12/01/2010
06/01/2011
12/01/2011
06/01/2012
Catawba_Calb_Apr2014
Catawba_Calb_Apr2014_AerTest
Observed
Create Text File
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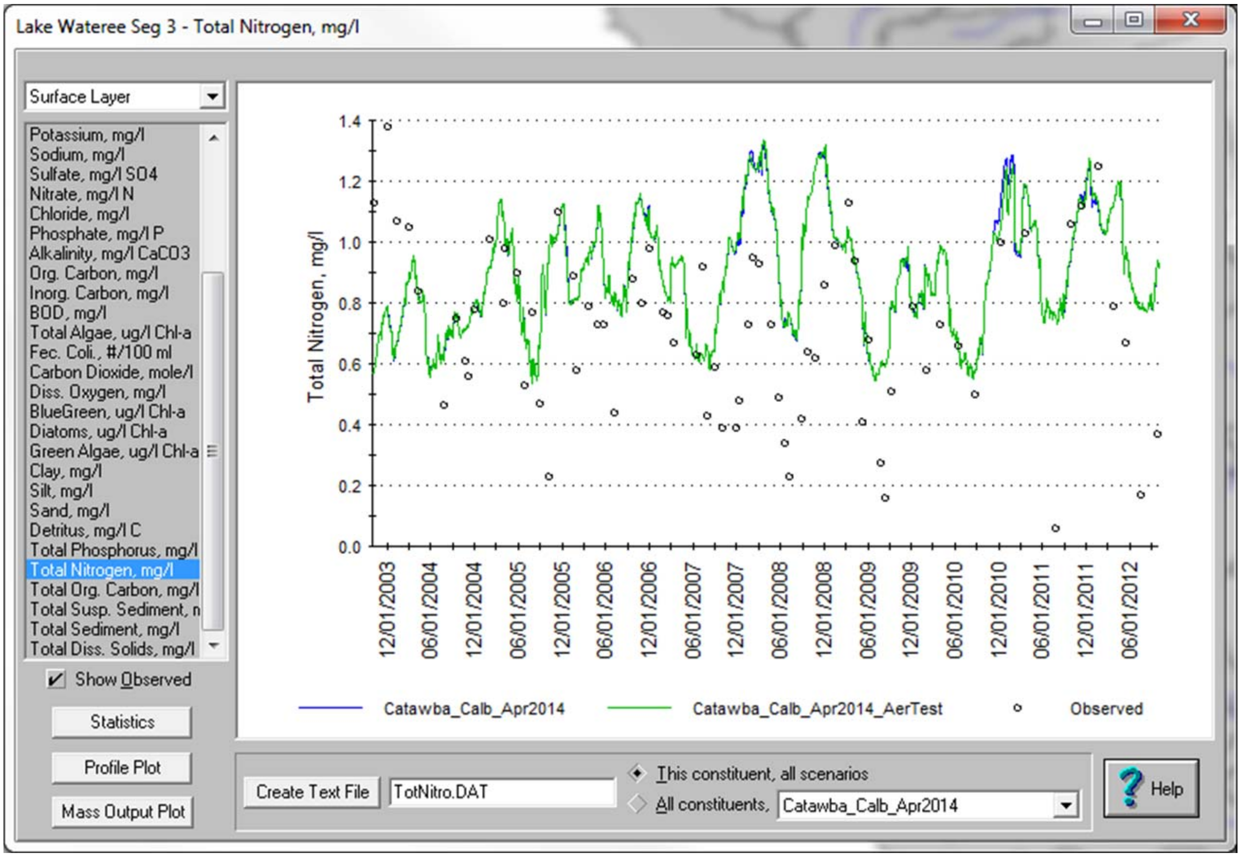
All constituents,
Catawba_Calb_Apr2014
Help



CMU Comment 11:

"Total Suspended Solids

As indicated in the calibration report, the calibration results for TSS are not very good and the model is generally under-predicting TSS. The report indicates the lack of TSS data and the effects of storms, soil erosion, and sediment transport. Compared with other water quality parameters, there is greater uncertainty in the model calibration for TSS. Adjustments of TSS calibration would have impacts on other parameters, particularly TP. "

CMU Response 11:

There are insufficient observed data to evaluate the TSS calibration, particularly high concentrations. The report has been updated in Sections 5.2 and 6.0 to clarify this point.

CMU Comment 12:

"Nitrate-Nitrogen

The calibration of nitrate-nitrogen appear to be adequate for the main stem of Catawba River downstream of Lake Wylie (e.g. at River ID 89) and certain tributaries (e.g. Sugar Creek). However, in several cases, simulated nitrate-nitrogen concentrations do not follow the observed values (e.g. Fishing Creek and Rocky Creek). For example, simulations of nitrate-nitrogen are significantly off in Rocky Creek (see Figure 5-32), where the model simulations of nitrate are higher than the observed (nitrate concentrations are all between 0 and 1 mg/l, while simulated concentrations are between 1 and 6 mg/L in the summer and fall of most years). The nitrate-N predictions for the reservoir locations typically follow the seasonal patterns (see Figure 5-31 for Fishing Creek Reservoir). However, in examining the simulated versus observed scatter plots for each of the reservoir sites (Figure 5-31 to 5-37) the model consistently over-predicts nitrate-N concentrations and these over-predictions increase as one moves downstream in the basin (i.e. Great Falls Reservoir calibration results are worse than Fishing Creek Reservoir, Cedar Creek Reservoir calibration results are worse than the downstream Great Falls reservoir, etc.)"

CMU Response 12:

Model updates have somewhat improved nitrate simulations in both the tributaries and reservoirs.

In Fishing and Rocky Creek, the most significant periods of nitrate over-simulation occur during periods of very low or near zero flow. During very low flows, error in concentration is amplified. Very slight changes in baseflow (<0.1 cms) resulted in a drastic changes in constituent concentrations. These changes did not result in any visible difference in nutrient concentrations in the reservoirs downstream.

Nitrate concentrations in reservoirs were improved through additional calibration of algae growth and timing as well as correction of errors in point source concentrations. A slight over-simulation is still apparent downstream of Fishing Creek Reservoir, however higher concentrations, which are the priority, are overall being simulated well.

CMU Comment 13:

"As mentioned in the January 2014 draft report, there are few mechanisms in the WARMF model to simulate a large removal of nitrate from the water column since it does not readily absorb to settling particles and denitrification occurs only in nearly anoxic conditions."

CMU Response 13:

This statement holds true. However since the highest error was occurring during low flow periods, slight improvement in the model simulation of baseflow in Rocky Creek resulted in an improvement in nitrate concentrations as well.

CMU Comment 14:

"Ammonia-Nitrogen

In all locations, the ammonia simulations are relatively good after year 2007. The pattern in observed ammonia data appears to change around the year 2007, with overall higher concentrations before 2007 and lower concentrations after 2007. The change in pattern in 2007 is not consistently found in the point source data nor in the hydrology, thus does not appear in the simulations.

Based on the January 2014 draft model calibration report, the calibration effort was focused on matching the ammonia concentrations after 2007. The higher concentrations in the observed data prior to 2007 cause a large negative relative error in most locations."

CMU Response 14:

An examination of ammonia concentrations over time in all South Carolina lake and stream samples shows that ammonia concentrations overall increased from 2003 through 2008, before falling back to about where they had been before 2003. The Catawba stations followed this pattern. The cause of this pattern is not clear, but may be related to climate variability. However ammonia is typically the least important of the forms of nitrogen in these waters averaging somewhat less than 10% of the total nitrogen. The model calibration is generally better for nitrate, which usually accounts for most of the nitrogen, and total nitrogen.

CMU Comment 15:

"Total Nitrogen

TN in WARMF is calculated as the sum of the dissolved and adsorbed concentrations of simulated nitrogen species (ammonia and nitrate), plus organic nitrogen, which is calculated as a proportion of organic carbon. Since Nitrate-N represents the largest component of TN, the simulation results are typically similar to those for Nitrate. Simulations were adequate for free-flowing portions of the Catawba River and Sugar Creek. TN is substantially over-predicted for Rocky Creek and Fishing Creek. For the reservoir stations, the TN pattern seems reasonable however the scatter plots show fairly consistent over-prediction particularly as you compare progressively downstream reservoirs, similar to nitrate-N results.

In summary, the nitrogen simulation results do not match and generally over-predict observed data in several circumstances. This issue needs to be addressed before the model can be used for allocation of TN in the TMDL process. This is particularly true since TN impairment is "patchy" and only occurs at a few locations within the basin based on the 2013 303(d) list."

CMU Response 15:

As previously mentioned, emphasis was placed on calibrating the mainstem Catawba River since proposed nutrient TMDLs will address impairments located in the reservoirs. In addition, most of the loading reaching all reservoirs comes from sources upstream of Fishing Creek Reservoir. Sensitivity tests on the effect of the model error in Fishing Creek and Rocky Creek showed the showed the error in the nitrogen prediction for these tributaries does not adversely affect the model in Lake Wateree (see Figure 5-28).

CMU Comment 16:

"Phosphorus

"In general, the WARMF model simulates the appropriate amount of TP over the simulation timeframe. However, the model performance statistics (see Table 5-8) indicate that the simulated values do not match the observations well when compared at the daily time step. In order to improve the daily simulation statistics, each tributary would have to be calibrated for hydrology, sediment transport, and TP concentrations. The free-flowing stations in the Catawba River and Sugar Creek simulations are quite good whereas Fishing Creek and Rocky Creek simulations are not as good. The scatter plots (see Figures 5-61 and 5-62) show pretty wide scatter with similar under and over-predictions. The reservoir predictions of TP are adequate, especially at Fishing Creek Reservoir, although the same pattern of over-prediction in each downstream reservoir is seen as observed with nitrate-N and TN."

CMU Response 16:

The model represents most of the TP data on Fishing Creek and Rocky Creek reasonably well but misses the higher values in the data. Both Fishing Creek and Rocky Creek data show an upward shift during 2010-2012 that is not represented by the model. The cause of the data shift is not known. Further calibration since the public comment period has improved TP simulation in the lakes. The model predicts TP levels in the lakes reasonably well.

CMU Comment 17:

"Generally, the TP simulations appear to be generally adequate, although the model calibration could probably be improved. It is likely that improved calibration for TSS would also result in improved calibration of TP."

CMU Response 17:

There are limited TSS data available for use in the model application. Recalibration of TSS would not improve results without substantially more data and is not within the budget constraints of this project. As noted above, further calibration since the public comment period has improved TP simulation in the lakes. The model predicts TP levels in the lakes reasonably well. The Department believes that the model calibration for TP is adequate to begin addressing the phosphorus impairments.

CMU Comment 18:

“A substantial number of ortho-phosphorus samples have been collected at Sugar Creek at SC-160 by Charlotte-Mecklenburg Utilities, which allows for comparison between the simulated and observed values. In general, the model simulates the trends in ortho-phosphorus concentration reasonably well at this location.”

CMU Response 18:

Comment noted.

CMU Comment 19:

“Algae - Chlorophyll *a*

The model was calibrated to measured algae concentrations (based on chlorophyll *a*) at five selected locations including Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir and two locations at Lake Wateree. The model is doing an acceptable job of simulating the annual pattern and magnitude of algae concentrations for Fishing Creek Reservoir. However, the model simulation of algae concentration for the downstream reservoirs is not as good and seems to over-predict chlorophyll *a* for the Great Falls and Lake Wateree (especially headwater) locations.”

CMU Response 19:

Both referenced locations are primarily dependent on levels of algae released from the upstream reservoir, which depends on the concentrations existing at the specified depth of the turbine intake. Though WARMF appears to be simulating a reasonable profile (seen in WARMF profile plots for a specified date), concentrations released are still higher than downstream observations. Further calibration efforts to reduce concentration at depth while maintaining the quality of simulations at the surface were not successful. Additional factors not included in the model may be affecting algae concentrations passing through the turbines to downstream segments.

CMU Comment 20:

“The report makes the point that the chlorophyll *a* data represents one point during the day whereas the model is simulating a daily average. We recognize there are a lot of complexities in calibrating the chlorophyll *a* portion of the model. Given the indication by the pH results that the model is predicting substantially more algal productivity than is occurring (because the increase in pH is reflective of uptake of various carbonate ions by algae), it would seem that the model is calibrated to match the peaks more than the mid-range concentrations. “

CMU Response 20:

See CMU Response 10 regarding pH simulations.

CMU Comment 21:

“Summary of Calibration Efforts

In summary, the overall approach for WARMF model calibration seems reasonable and consistent with standard practice used to develop nutrient TMDLs. Based on the 303(d) impaired water lists, TP impairments occur throughout the Lower Catawba River reservoirs. TN impairments are more “patchy,” occurring in Fishing Creek reservoir and one location downstream. In terms of draft model simulation results for nutrients, it appears that phosphorus simulation results are reasonably acceptable for further steps in the TMDL process (e.g. TMDL allocation); however, efforts to improve the TSS calibration would also impact TP predictions and would need to be considered before moving forward. Effort to refine the TSS calibration should precede acceptance of the TP calibration results. It would be interesting to see a sensitivity analysis regarding TSS and whether the impacts related to TP, algae (as chlorophyll a) and pH."

CMU Response 21:

Such a sensitivity analysis could be helpful in understanding the significance of TSS for the TP, algae and pH simulations; however, it is not feasible with the current project scope and budget constraints. Additional sensitivity analyses may be needed and conducted as the model is applied for TMDL development.

CMU Comment 22:

"There is a significant concern regarding whether current model calibration for nitrogen would be adequate before it can be used in the further steps of the overall TMDL process. Current calibrated model tends to over-predict nitrogen concentrations especially in some more rural tributaries and in the reservoirs. Further improvement for model calibration of nitrogen is necessary before moving forward with the TMDL process."

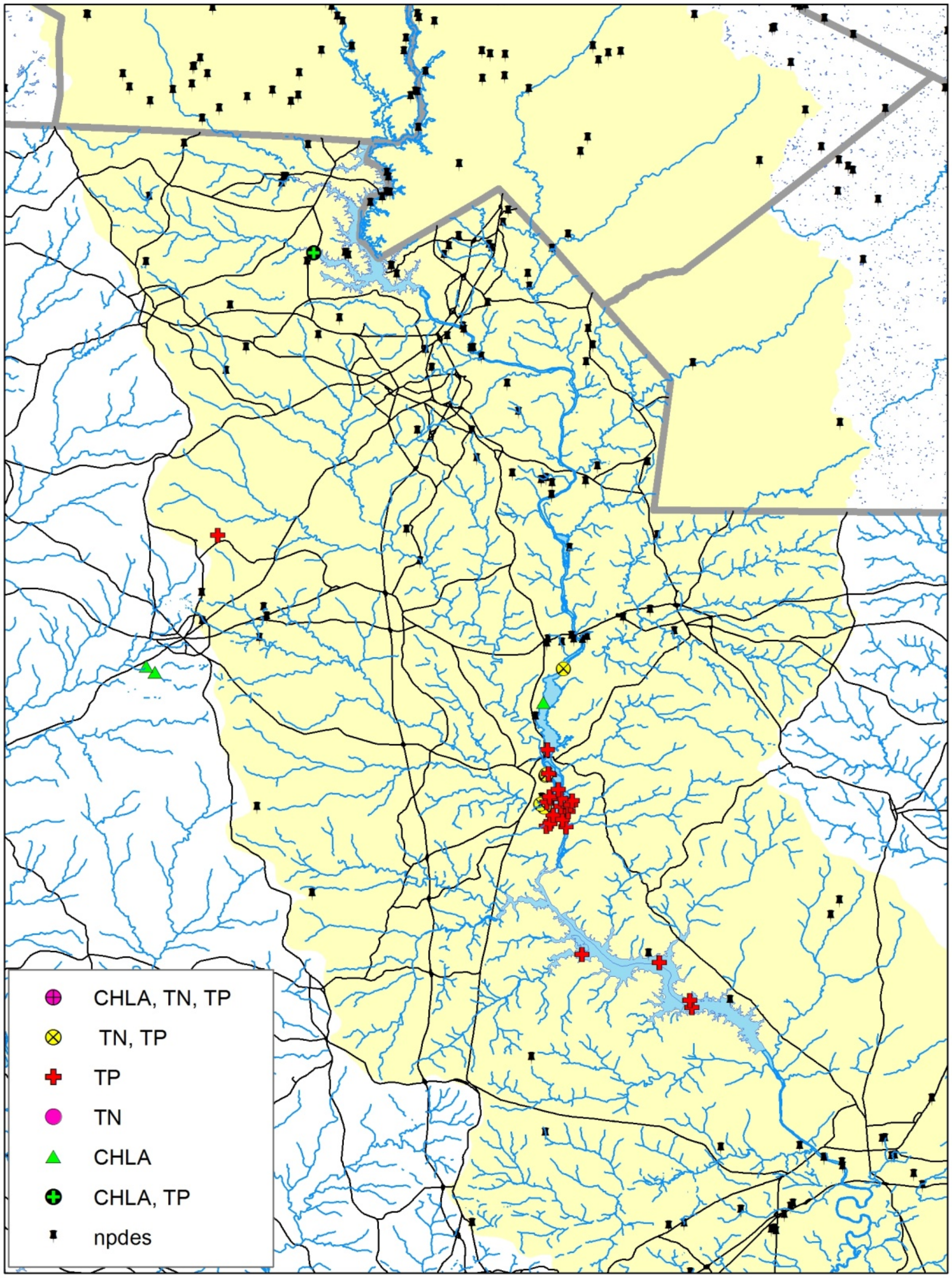
CMU Response 22:

Some improvements to nitrate simulations have been made in both tributaries and reservoirs. See CMU Response 12.

<u>Next Steps in the TMDL Development Process</u>

CMU Comment 23:

"The attached map indicates fairly widespread impairment of the TP water quality standard from Fishing Creek Reservoir through Lake Wateree. SCDHEC and the NC Division of Water Resources have already implemented requirements to reduce TP from point sources in the watershed by approximately 70 to 80 percent through permit requirements implemented primarily prior to 2007. These prior reductions should be considered in developing an allocation approach for wasteload allocations (for point sources) and load allocations for nonpoint sources. Specifically, we do not believe an equal marginal percent reduction (EMPR) approach often used by States and EPA is appropriate unless the prior reductions are also considered."



CMU Response 23:

See CMU Response 1.

CMU Comment 24:

"TN allocation strategies need to be considered carefully for a number of reasons:

- TN impairments are not widespread in throughout the reservoirs (see attached map)
- The substantial over-prediction of nitrogen by the model may require more reductions than necessary to meet any allocations developed
- Nitrogen reductions at wastewater treatment facilities can require substantial modifications to treatment approach at substantial cost; therefore, SCDHEC and stakeholders need to be satisfied with model predictions prior to proceeding with this allocation step."

CMU Response 24:

See CMU Response 2.

Mr. Dave Cole

(note: Mr. Cole's comments were submitted prior to the review period in emails dated Dec. 31, 2013, Jan. 7, 2014, and Jan. 15, 2014)

Cole Comment 1:

"I am formally writing you to specify and include lab analysis data from ND0080900 and SC0020443 in all calibrated WARMF models for the same model time period stream data is used and calibrated for this TMDL process. It is my opinion that it is a myth that "non-discharge" permits have no influence on surface water quality. Each of these reports should be on file with DHEC's Brenda Green, and must be contained in any model that leads to a scientifically sound representation of water quality in this basin. I have attached a few examples of what I am referring to (2010 SCDHEC Annual Report, City of Rock Hill, SC Residuals Land Application Program, Permit No. SC0020443). Please advise and clearly / scientifically document any and all reasons as to why DHEC Department of Water rejects this reasonable request."

Cole Response 1:

Field location, size, and land application records in the 2010 annual reports for permits ND0080900 and SC0020443 were used to determine that a total of 710 acres in Fishing Creek watershed received land applied biosolids in 2010, including 62,269 kg of phosphorus and 36,694 kg of nitrogen. These results were compared to the WARMF model inputs for all agriculture in Fishing Creek watershed (pasture plus row crops) for the same period. Results are summarized in the table below:

	Area (acres)	Phosphorus (kg/yr)	Nitrogen (kg/yr)
Total	185,014		
Pasture and Row Crops in WARMF Model	45,902	1,287,460	1,711,937
Biosolids Land Application Reported 2010	710	62,269	37,694

Biosolids land application occurred on 0.4 percent of the total area in Fishing Creek watershed and 2 percent of agricultural land. Total phosphorus and nitrogen introduced from land application of biosolids were 5 percent and 2 percent, respectively, of the total input already accounted for in the WARMF model.

Actual quantities of phosphorus and nitrogen introduced to the Fishing Creek watershed from land application of biosolids are relatively small compared to the phosphorus and nitrogen inputs used in the WARMF model to represent all agriculture combined. The acreage receiving biosolids is included in the WARMF model as part of the agricultural land use input. The phosphorus and nitrogen loads from biosolids are accounted for in the much larger loads from all agriculture. Based on this data, the current WARMF model application which aggregates all agricultural sources, including land application, by landuse (pasture or row crops) is considered appropriate.

Cole Comment 2:

"The WARMF model is deemed flawed if you do not include all data. Please be sure to also include Monitoring station data used from tetratech's study. This includes monitor stations CW-005, CW-007, CW-654, CW-695, and CW-697 I have attached and included one part of this study if you are unclear as to what I am referring to (draft TMDL Document, Fishing Creek Watershed, SCDHEC Monitoring Stations CW-005, CW-007, CW-654, CW-695, and CW-697, August 2011)."

Cole Response 2:

The referenced sites are benthic macroinvertebrate sampling sites in Fishing Creek or one of the tributaries. The macroinvertebrate population data collected at these sites are not relevant to the Catawba WARMF model which is being used to assess nutrient concentrations in the downstream lakes. One of the sites, CW-005 Fishing Creek at County Road S-46-347, is also a historical water quality monitoring site which is currently inactive. Water quality data at this location were not originally included but have been added in the revised version of the WARMF model.

Cole Comment 3:

"Again, DHEC has ignored land application data from sludge permit ND0080900 and SC0020443; annual reports are on file at SCDHEC Department of Water and this information MUST be included in any model / simulation. This is a SIGNIFICANT gap. All data - including so called "non-discharge" land application data, must be included in any simulation for this model for the simulation years covered to have any shred of credibility."

Cole Response 3:

Phosphorus and nitrogen inputs resulting from land application of biosolids are accounted in the overall agricultural inputs to the WARMF model, and because the loads from this specific agricultural source type are a small fraction of the total load from all agriculture, it is not necessary to disaggregate them in the model. See Cole Response 1.

Cole Comment 4:

"Again, SCDHEC has not included all water quality monitoring stations - Even SysTech , the creators of this WARMF model recommend to include more data, not less. Station data from CW-005, CW-007, CW-654, CW-695, and CW-697 were not included in updated model. This is a SIGNIFICANT gap. All data - even temporary monitor station data - must be included in any/all/every watershed model for this model even to have a shred of credibility. During the WARMF model meeting in November 2013, DHEC's Wade Cantrell suggested that all data, including the data from TetraTech's study WOULD be included in the updated model. Reading thru the report and looking at the dataset included in latest model concluded this was a false statement. Please include the data from these monitor stations, redo model, and advise when this has been completed. I've included the recording where Mr. Cantrell promised to include tetratech data: https://soundcloud.com/user924162303/dhec-warmf-meeting-recording#t=47:18"

Cole Response 4:

Relevant data from the Tetra Tech Fishing Creek study are included in the current Catawba WARMF model. The Tetra Tech Fishing Creek study lists 11 stream water quality monitoring sites in the Fishing Creek watershed. The sites are: CW-233, CW-234, CW-227, CW-008, CW-224, CW-096, CW-006, CW-212, CW-225, CW-005, and CW-029. Water quality data from all of these sites are included in the Catawba WARMF model. CW-005 and CW-212 were not originally included but have been added in response to comments. An additional water quality site not included in the Tetra Tech study, RS-11056, is also included in the Catawba WARMF model. As noted in the Response to Comment 2, macroinvertebrate population data from the benthic sampling sites CW-005, CW-007, CW-654, CW-695, and CW-697 were not included in the Catawba WARMF model because they are not relevant to the nutrient model application targeting the downstream lakes.

Cole Comment 5:

"This application is closed source, buggy and ancient. Is this really the best we can do to protect our natural resources? Program abends if user 1) Clicks file, open, navigate to catawba062013_fullshed.wsm, click open, click tmdl from select module "APPCRASH, warmf.exe, owl52f.dll, exeption code c00000005. No one (!) uses Borlands BDE to interface with a database anymore. The application is single threaded and simulations take entirely too long. DHEC must demand modern software from their chosen model contractor."

Cole Response 5:

The WARMF model is an EPA-approved tool for nutrient TMDL applications.

Cole Comment 6:

"DHEC appears to have "fudged" numbers re: Land application dataset for quadrants where DHEC has permitted sludge. DHEC *MUST* complete model for each historical and future land application site; DHEC has the data in their folders and this information *MUST* be entered into the land application model, pasture type land use, for this model to even have the slightest credibility. Pulling a value out of thin air when you actually have application data on hand is disingenuous as best."

Cole Response 6:

Biosolids land application data for Fishing Creek watershed were evaluated. Phosphorus and nitrogen loads from biosolids were compared to WARMF model phosphorus and nitrogen loads from all agricultural activity. Results demonstrated that phosphorus and nitrogen loads from biosolids are a small fraction of the total agricultural input in the WARMF model. The current WARMF model application which aggregates all agricultural sources, including land application, by landuse (pasture or row crops) is considered appropriate.See Cole Response 1.

Cole Comment 7:

"Sampling rates at some stations is collected daily vs hourly (resolution). This leads to gaps in incoming data; Attempt to use averages are a conversation non-starter. Recommend DHEC improve data collection quality and quantity efforts to fine tune model."

Cole Response 7:

Recommendation noted.

Cole Comment 8:

"I am unsure how this model simulates Metals."

Cole Response 8:

The current WARMF model application for the Lower Catawba River watershed does not simulate dissolved metals. Simulation of metals is out the scope of this TMDL effort.

Cole Comment 9:

“DHEC's own Dr. Glover recommended that input data is insufficient in previous TMDL efforts when modeling Fishing Creek proper in response to the conclusion presented by TetraTech. The assumption is no new stations have been added to basin - if one were to believe Dr. Glover in 2011 in regards to TetraTech's study, wouldnt one need to conclude the same is true today - that DHEC has insufficient data - without DHEC having added additional monitoring stations? What is DHEC's plans to address Dr. Glovers concerns? (attached) (Memorandum from James Glover to Heather Preston, dated 23 August 2011)”

Cole Response 9:

The Tetra Tech study related to macroinvertebrates in Fishing Creek, and it is true that macrovertebrate sampling in Fishing Creek has been limited or not available in recent years. As noted above, macroinvertebrate data, and any concerns about the Tetra Tech study, are not relevant to the current project targeting nutrient levels in the downstream lakes.

Cole Comment 10:

“WARMF does nothing to model dissolved oxygen (DO); how does DHEC plan to address this gap?”

Cole Response 10:

WARMF models DO. Refer to Section 5.9 in the calibration report.

Cole Comment 11:

“WARMF does nothing to model toxics; How does DHEC plan to address this gap?”

Cole Response 11:

Toxics are not relevant to the current nutrient application.

Cole Comment 12:

“WARMF does nothing to model temperature; How does DHEC plan to address this gap?”

Cole Response 12:

WARMF models temperature. Refer to Section 5.1 in the calibration report.

Cole Comment 13:

“Where is instream calibration to compare model to actuals?”

Cole Response 13:

Comparisions, both graphical and statistical, between the model and observed data are presented throughout the calibration report.

Cole Comment 14:

“Where is the formal error analysis of model?”

Cole Response 14:

Error statistics are included in the tables of calibration statistics throughout the calibration report.

Cole Comment 15:

"WARMF does not seem to simulate or take into consideration ground water movement or septic system use in a particular subcatchment; How does DHEC plan to address this gap?"

Cole Response 15:

Groundwater movement is simulated in the WARMF model. Septic systems are included as inputs in each catchment.

Cole Comment 16:

"Where is the QA check that source data is accurate?"

Cole Response 16:

The Catawba WARMF model includes data from a number of organizations each with their own QAQC protocols. DHEC data undergoes QAQC checks prior to publication and application in modeling projects in accordance with the Department's data quality policies.

NCDENR/DWR

Model Comments

NCDWR Comment 1:

"Hydrology labeling – For hydrology, it would help if the locations of the flow stations were labeled on Figure 4-1 and were consistent with the station names referred to in Figures 4-2 to 4-7 and in Table 4-1."

NCDWR Response 1:

The suggested changes have been made in the calibration report.

NCDWR Comment 2:

" Water quality labeling - For water quality, Figure 5-1 shows two stations named "Catawba River at US-21." Please check because it seems one of these is actually "Catawba River at SC 5." Also, please check that the locations provided in the water quality calibration tables (e.g. Table 5-1) are consistent with the labels included in Figure 5-1. For example, "Catawba River downstream of Shoals" is a station location in Table 5-1, but is not shown in Figure 5-1. "

NCDWR Response 2:

The suggested changes have been made in the calibration report.

NCDWR Comment 3:

"Flow – We recommend that the cumulative frequency graphs produced by WARMF be included in the report."

NCDWR Response 3:

The figures are already included in Section 4 of the report. The bottom right plot in each calibration figure is the cumulative frequency graph.

NCDWR Comment 4:

"Calibration performance targets – while statistics are provided for the calibration parameters, there is no discussion as to what targets were set for those statistical measures. In other words, what was used to determine that a calibration was good? Were there any targets set, such as for relative error?

DWR realizes that the figures and statistics provided in the report are readily produced by WARMF, but we encourage some additional post processing of the output to provide more information on the calibration. The following describes model performance targets that DWR has used for flow and water quality. These targets provide additional confidence in the ability of the model to represent seasonal trends. This is especially important when developing a TMDL (or any nutrient management strategy) where summer periods tend to be the most critical.

For flow, we recommend using the performance criteria provided in the USGS HSPEXP – Expert System for Calibration of HSPF (Lumb, et al., 1994); provided below in Table 1 below. These criteria can help during calibration as they provide insight into how well the model is performing under various flow conditions. For example, we prepared such a comparison for Rocky Creek in Chester County SC (Table 2). As Table 2 indicates, the model is performing well overall and in fall and winter, but the model seems to be under predicting flow in spring and summer.

Table 1. Flow performance criteria.

Prediction Error	Percent Difference Criteria
Error in total volume	±10%
Error in volume of 50% lowest flows	±10%
Error in volume of 10% highest flows	±15%
Seasonal volume error - Summer	±30%
Seasonal volume error - Fall	±30%
Seasonal volume error - Winter	±30%
Seasonal volume error - Spring	±30%

[1]Adopted from the USGS HSPEXP – Expert System for Calibration of HSPF (Lumb, et al., 1994).

Table 2. Evaluation of flow prediction in Rocky Creek:

Prediction Error	Model	Goal	Remarks
Error in total volume	-2.6%	10%	OK
Error in 50% lowest flows	-71.4%	10%	Check Calibration
Error in 10% highest flows	20.7%	15%	Check Calibration
Seasonal volume error - Summer	-42.0%	30%	Check Calibration
Seasonal volume error - Fall	-1.7%	30%	OK
Seasonal volume error - Winter	17.6%	30%	OK
Seasonal volume error - Spring	-168.6%	30%	Check Calibration

For water quality, it can be difficult to judge the quality of calibration when evaluating time series plots because water quality is not collected on a daily basis. For water quality parameters, we recommend seasonal box plots that compare the monthly median observation with the range of model predictions. For example, we prepared such a plot for total nitrogen for Sugar Creek at SC-

160, provided below in Figure 1. As shown in Figure 1, the model is predicting total nitrogen very well at this location.

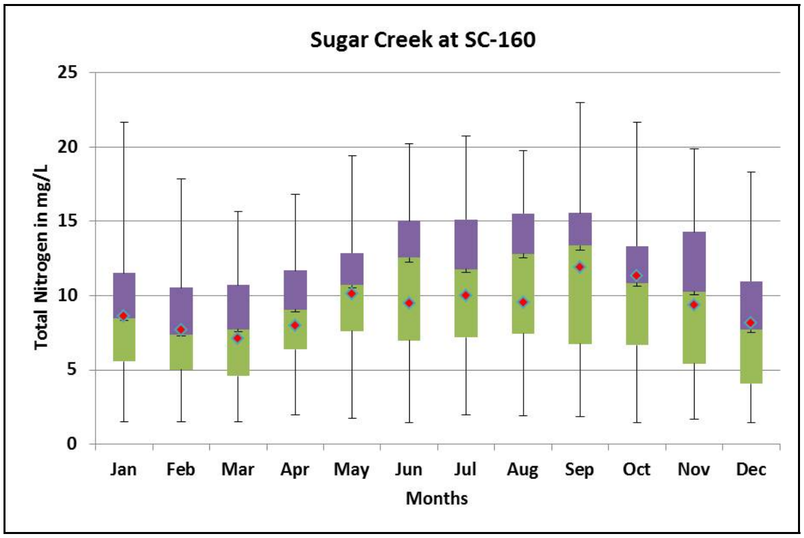


Figure 1. Total Nitrogen (mg/L), Sugar Creek at SC-160. The red dot is the median of observed data and the box plot is the range predicted by the model."

NCDWR Response 4:

The Department acknowledges that there are many approaches that can be taken to generate simulation statistics and evaluate model performance, and the example provided is an excellent choice. Unfortunately due to the number of locations and constituents included in the calibration, calculating additional performance measures external to WARMF is not possible given the limited budget of the project. Where possible, will modify the current report to state calibration targets for each of the statistical evaluation criteria that are presented.

A table listing the indicated hydrologic calibration performance results for the four stream segments where the model simulation of watershed hydrology can be evaluated has been added (Table 4-2).

Box & whisker plots of selected water quality constituents have also been included. Limitations in observed data for some constituents precludes providing these types of graphs. Plots comparing the median, quartiles, and 10% and 90% percentiles for simulations of TP, TN, and chlorophyll-*a* have been added (Figures 5-x,). The plot of TP indicates that the model simulates well the range of concentrations in the observed data in the Lower Catawba Basin.

NCDWR Comment 5:

"pH – On page 46, Section 5.2, the last line states that improving pH simulation results should not be considered a high priority because the nutrient and algae simulation is not particularly sensitive to simulated pH values. However, in keeping with stream chemistry, the decay of organic matter depletes DO and produces organic acids, thereby reducing the pH level. The depletion mechanism seems to be a limiting factor in the engineering module of the model, and as a result the simulated pH statistics provided in Table 5-2 appeared to be generally greater than the observed statistics at each station. The calibration of organic N is not considered; however, it is important for pH calibration and could be one of the reasons the pH calibration is not strong. Also, deposition from the air is not included as an input in the model. It is important for pH calibration. Addressing these issues would be a significant undertaking. Therefore, unless pH is a specific target for TMDL development or critical for some other target, we would recommend not including pH in the report. Actually air deposition of nitrogen is an input into the model. Air deposition data is from the EPA Castnet database. Data for the Catawba Basin is from the Cranberry station in the North Carolina mountains."

NCDWR Response 5:

During calibration, organic decay rates were adjusted to test the effect on pH and nutrient simulations. Increasing decay of organic matter from the current calibrated values caused the DO simulation to be far too low and ammonia concentrations to be far too high. The pH did improve with more decay however since other constituents of degraded this was determined not to be the correct mechanism for pH adjustment. Tests of reaeration rates indicate that model wind-based values of CO2 reaeration may be too low (see CMU Response #10). SCDHEC agrees that pH should not be of high concern since the error in pH simulation (or correcting such error) does not directly affect simulations of nutrients and algae. Organic nitrogen is including in the model as a portion of organic carbon. How large or small is that portion (ie, the ratio of OrgN/OrgC) is a fixed value in WARMF system coefficients. In reality that ratio is variable in space and time, likely introducing some error into WARMF TN simulations.

NCDWR Comment 6:

"TSS – On page 57, Section 5.3, the second paragraph states that data for TSS is more limited than other parameters, so calibration for this parameter is more difficult, and there is greater uncertainty in the results. It seems that the uncertainty is further increased due to constant soil coefficients, such as percentage of sand, silt, and clay, and soil erosion factor, for entire sub watersheds and streams. These coefficients should be input into the model with respect to actual physical soil types and land cover in order to simulate existing sediment erosion and transport processes in the model. This is probably a significant source of uncertainty with regards to the TSS calibration and should be addressed. This should help improve the phosphorus calibration as well."

NCDWR Response 6:

Updating the model with STATSGO or SSURGO data on particle size distribution and erosivity information could improve sediment transport modeling results. However these soil characteristics are highly spatially variable. The data would need to be aggregated to the catchment scale resulting in average soil characteristics over a large area. How representative the average characteristic is for highly variable and nonlinear catchment processes is debatable and the subject of many ongoing modeling studies. We acknowledge that with such limited data for calibration using a spatial average of soil data may have provided a better starting point than regional values. However, budget restrictions made the latter approach necessary.

NCDWR Comment 7:

"Section 5.5 ammonia nitrogen – The difference in ammonia data prior to and after 2007 is discussed, but is there any information available to explain why there is a pattern shift after 2007? Did lab procedures change? Is this pattern evident in both states? If there are any known reasons why this pattern changed, a brief discussion would be appropriate."

NCDWR Response 7:

An examination of ammonia concentrations over time in all South Carolina lake and stream samples shows that ammonia concentrations overall increased from 2003 through 2008, before falling back to about where they had been before 2003. The Catawba stations followed this pattern. The cause of this pattern is not clear, but may be related to climate variability. However, ammonia is typically the least important of the forms of nitrogen in these waters averaging somewhat less than 10% of the total nitrogen. The model calibration is generally better for nitrate, which usually accounts for most of the nitrogen, and total nitrogen.

NCDWR Comment 8:

"Section 5.10 dissolved oxygen – Are there any thoughts as to why the calibration of dissolved oxygen at Fishing Creek Reservoir is not as good as at other locations? Potential sources of error should be included."

NCDWR Response 8:

The overall calibration of dissolved oxygen in all of the reservoirs (Fishing Creek is actually better than other reservoirs) is not as good as the in-stream sites. Algae population dynamics and reservoir reaeration add complexity to reservoir simulations and are likely the sources of greater error.

NCDWR Comment 9:

"Conclusion – It would be helpful if there was a conclusion included in the document that summarizes where the model is performing well and where it is not, including a discussion of the key assumptions and uncertainties."

NCDWR Response 9:

An overall conclusion (Section 6) was added to the final calibration report. References became Section 7.

Resolute Forest Products

<u>General Comments</u>

RFP Comment 1:

"Resolute Forest Products (Resolute) and its consultants, Shield Engineering, Inc. (Shield) are of the opinion that most of the Catawba River TMDL Coalition (CRTC) comments previously presented in 2002 are still appropriate for this modeling effort. Some of these are reiterated for emphasis and to indicate that these are still important comments that do not appear to have been taken into consideration by either Systech or SCDHEC. Before discussing the specific comments several general comments concerning the modeling principles do need to be re-iterated as follows:

> "*The level of effort used to develop a model should reflect the significance of the regulatory consequences that will flow from its application*." (CRTC, 2002). This statement still rings true today, as much as it did 12 years ago. The follow-on from this statement in 2002 was the recommendation for SCDEHEC to develop a Quality Assurance Project Plan for this work. Since this recommendation was initially made, the Environmental Protection Agency (EPA) has issued ***Guidance for Quality Assurance Project Plans for Modeling*** (EPA QA/G-5M, December 2002). We are not aware of the development of a QAPP for this modeling effort. The Systech report describing the 2014 modeling effort does not discuss quality assurance within the document provided to the reviewers.
>
> The development of the QAPP would require the modelers and SCDHEC to initially review the defensibility of the selected model for use in this river basin and whether the model requires specific attributes of the basin to be adjusted or changed within the model to reflect evolving characteristics (see Comment #3) of that specific river basin. Many aspects of the modeling

effort should be identified upfront in the QAPP and one of the more important of these includes the performance criteria for the model. No known calibration criteria were defined prior to the execution of the modeling effort. Hence our understanding of what is acceptable in terms of calibration criteria and Systech's degree of acceptability for calibration criteria may be different. However, these discrepancies should be resolved upfront through a cooperative review (i.e., industries, municipalities, SCDHEC, modelers) of the QAPP for this modeling effort **prior to the execution of the modeling**.

Calibration of a model is an iterative process. The Systech report describing the 2014 modeling effort does not detail the iterative process used during the calibration. What changes or decisions were made during the modeling process to improve the model calibration? Can those changes or decisions be justified? Did such changes improve the model calibration, and if not why not? Why was one type of simulation process (e.g., single segment vs. multiple segments vs. CE-QUAL-W2) used for simulating the water bodies and not one of the other simulation processes? The model calibration process is a tool that will provide an understanding of the peculiarities and site specific aspects of a river basin. As a reader of the Systech report describing the 2014 modeling effort none of this process is evident.

Since there are no previously established (i.e., presented within a site-specific QAPP prior to the execution of the modeling effort) acceptance criteria for the application of a model to simulate the water quality of the Lower Catawba River, it is difficult to evaluate the acceptability of this model for the intended purposes."

RFP Response 1:

WARMF is an EPA-approved tool for nutrient TMDL projects such as the Catawba project. The Catawba WARMF model is a historical model that has been developed and documented over time for the purpose of evaluating nutrient scenarios in the Catawba Lakes. For the current project, the historical Catawba WARMF model was updated to present day using all available data. Development of a QAPP for the model update was beyond the scope of the current project and was not considered necessary since the purpose was to update the existing model. Based on the calibration results for the target waterbodies, the Department considers the current Catawba WARMF model suitable for the intended application to develop nutrient reduction scenarios for the Catawba system.

RFP Comment 2:

"The Systech report describing the 2014 modeling effort does not present results of any sensitivity analyses from which the reader could better understand which attributes of the river basin are sensitive and which attributes are insensitive. An understanding of these sensitivities is critical for those industries with discharge permits along the river course between Lakes Wylie and Wateree. These sensitivities are particularly important for their potential impact upon those water quality parameters that may ultimately be provided a TMDL (e.g., total phosphorus). Knowing which model input parameters are sensitive on the constituent concentrations (particularly those for which a TMDL is being considered) in the river provides a basis for SCDHEC to focus on those users of the Catawba River that have the greatest impact on those model parameters – for example; land use; flows from North Carolina; etc. (see Comments #3 and #11).
Discussion was presented within the report concerning sensitive input parameters, however no sensitivity analyses were presented to the reader for evaluating which model input parameters are critical to the users of the Catawba River. "

RFP Response 2:

The sensitivity analysis was not included in the current scope of work. Additional sensitivity analyses may be needed and conducted as the model is applied for TMDL development.

RFP Comment 3:

"A concern with a water quality model such as WARMF is the land use characteristics for the river basin. The categorization of land uses across the river basin used within this particular version of the model is based on 2006 land use data. The Systech report describing the 2014 modeling effort does state "*The model is sensitive to the* 'land use' *coefficients shown in Table 3-2*." In accepting this statement at face value, as no sensitivity analyses data were presented, that would suggest that as increased development occurs throughout the northern part of the river basin (i.e., both York and Mecklenburg County areas) land use patterns keep changing as formerly rural land is enveloped into these growing metropolitan areas. These land use changes are likely to impact the non-point source contributions and hence make it more difficult for any water quality model to simulate dynamic conditions using steady-state data. The dynamics of a river basin such as the Catawba River are likely difficult to simulate under the best of circumstances due to the multiplicity of variables, but such a simulation is only made more difficult using steady state data to reflect a dynamic system. This dilemma would have been assessed and resolved, if it was found to need resolution, if the processes outlined within a project QAPP were to be followed by the modelers.

This water quality model is a dynamic tool capable of replicating changes in numerous input parameters, however based on the stated sensitivity of land use data (which was not quantified), the ability of this model to reflect a dynamic system utilizing steady-state data raises questions as to the appropriateness of this model for simulating the Catawba River basin. "

RFP Response 3:

The statement about sensitivity in the January 2014 draft calibration report referred to sensitivity of land use coefficients, not the percentage of a particular landuse (e.g. developed) within the catchments. The latter being the model inputs that would change due to the urban development described above. The land use coefficients listed in Table 3-2 are sensitive because they apply to all area of the corresponding land use over the entire watershed. Changes to these coefficients typically have a larger impact on resulting simulations at downstream points than other land use related coefficients in the model. However this does not imply that the model would be sensitive to changes to the relative fraction of land use covering each sub-catchment area. The level of increase in developed (and corresponding decrease in ag/rural) land use associated with urbanization in local areas during the simulation period is unlikely to have a measurable effect on simulations at the outlet of a watershed of this scale. Tests of this could be performed by the user by altering a given catchments assigned landuse percentages. Furthermore, virtually all watershed models utilize static land use information to simulate runoff and water quality processes over the simulation timeframe. Land use data is extremely difficult to accurately obtain, and therefore data sets are typically available on approximately ten-year intervals.

RFP Comment 4:

"A review of the 2003 model results indicate that though the current 2014 model provides a better fit to the observed data it is evident and the modelers suggest that additional model calibration is needed for select parameters. In addition, it is disconcerting that select parameters (periphytes, pH) are not considered "high priority". The fit (simulated vs observed) of the pH results are relatively good for the upstream boundary and Sugar Creek, but are woefully inaccurate for all other stations. The results for all modeled parameters provide confidence to the regulated community that the kinetics of the modeled segment is understood and properly characterized."

RFP Response 4:

The effect of including periphyton on nutrient and algae simulations was demonstrated to be minimal with simulation examples in Section 2 of the calibration report. The error is pH simulation was found to be most likely due to atmospheric reaeration of CO2 during algae growth. Figures are included in the final report demonstrating the effect of reaeration on the pH simulation and resulting insignificance for nutrient and algae simulations. For practical purposes, priority constituents must be identified for any model of this size and scope. In this case, pH is not the constituent of concern, nor does reduction of error in pH simulations affect the primary constituents of concern.

RFP Comment 5:

"The WARMF model, as constructed, provides the ability to settle particulate matter, but does not allow for their resuspension. Since phosphorus has the potential to adsorb to solids and is a building block of algae, once the solids settle or the algae die and settle, the phosphorus is no longer available to phytoplankton in the model. In reality, after settling, the phosphorus and to a lesser extent nitrogen, can be released from the sediment into the overlying water column. This availability is the result of resuspension from shallow waters and the benthic release from the sediment. The benthic release of nutrients is a recognized phenomena in lake modeling and under select conditions, has been shown to be a significant phosphorus source in lake modeling studies.[1,2,3,4] We are aware of studies conducted by US EPA that measure lake nutrient flux in southeastern reservoirs. The referenced Nutrient in Lakes and Reservoirs study reaffirms this fact: "Internal loading of nutrients, a process whereby phosphorus is released from sediment under conditions of low oxygen, can be significant in reservoirs." [4]

The WARMF model uses a simplistic modeling process for nutrients that involves routing external loads from watersheds and point sources through downstream reaches, including rivers and reservoirs. This modeling process ignores the internal loading processes (resuspension and benthic release) that have been proven to be a potentially significant source of nutrients in reservoirs. As a result, to calibrate a model the external loading must be increased to compensate for the lack of internal loading. It is our opinion that internal loads be included in the model. "

RFP Response 5:

WARMF model does in fact account for settling and resuspension of particulate matter in each stream and lake segment. The magnitude of settling and resuspension within each stream segment is dependent on the hydraulic geometry of the stream segment. In lakes, WARMF simulates diffusion of constituents from the lake bed sediments back into the water column (See Section 3-42 of WARMF Technical Documentation, October 2001).

RFP Comment 6:

"Several of the upstream wastewater treatment facilities (WWTF) were upgraded in 2006-07 to incorporate nutrient removal. As a result there is a noticeable difference in the 2003-2006 and the 2006-2012 observed data. It is our opinion that focus of the calibration (specifically calibration statistics) should center around that time period."

RFP Response 6:

The model calibration period began in 2003 because this incorporates some of the previous model calibration period. Including this longer period in the calibration also incorporates more of the limited observed data necessary for calibration. However, going forward the focus of modeling will be the period after the significant changes in phosphorus that occurred in 2005 and 2006.

RFP Comment 7:

"Total nitrogen - as stated in the Calibration Report (pg. 86) Total Nitrogen (TN) mimics the ammonia and nitrate results and where there are issues with ammonia or nitrate there will be issues with TN. As can be seen in several of the figures (5-48 to 5-57), the simulation results for two (2) stations could be considered to represent the in-situ kinetics while the results at six (6) stations are greater than the observed data and one (1) under predicts. It was noted that the TN results at many stations had a better fit to higher concentrations than to the lower concentrations. Since the model had difficulty in reproducing TN concentrations less than 1 mg/l, the model when used for regulatory purposes will have a bias to predict higher concentrations. The over prediction should be reconciled."

RFP Response 7:

Some improvements have been made to TN simulations in both tributaries and reservoirs. Concentrations just above and in Fishing Creek Reservoir are the primary indication of the model's representation of upstream nutrient load. Load coming from Rocky and Fishing Creek are comparatively small (even while over-simulated) and have a minimal effect on reservoir concentrations. Test simulations using Fishing and Rocky Creek as boundary conditions (i.e., adjusting simulated to the observed concentrations) indicate that simulation error in those two tributary simulations has no visible/measurable impact on the reservoir simulations. Variation in concentration within the reservoirs (downstream of the inflow point to Fishing Creek Reservoir) is primarily a reflection of internal dynamics rather than external loading. During model calibration, the intended application always guides the focus of calibration. If high concentrations are the concern, calibration focuses on high concentrations.

The model predicts total nitrogen in Fishing Creek and Great Falls Reservoirs reasonably well. As shown in Figure B-6, the major sources of total nitrogen are upstream of Fishing Creek Reservoir. The Department considers the model suitable to evaluate total nitrogen scenarios for the sources to Fishing Creek Reservoir.

RFP Comment 8:

"Total phosphorus –The observed total phosphorus (TP) is exhibiting a pattern of trending lower in 8 of the 10 calibration stations. This pattern is more than likely the result of the regulations enacted in North Carolina limiting the TP that can be discharged from WWTFs. The downstream reservoirs act as sinks for the phosphorus and as previously mentioned, result in a future internal nutrient source. These significant changes in upstream loading rates can take significant periods of time to work their way out of downstream reservoirs.

The model results for TP are mixed. As stated in the report (pg 100) "indicating that the simulated values do not match the observations particularly well when compared at the daily time step." Since phosphorus could be the limiting factor for algal growth, the simulation of the fate of phosphorus is paramount when evaluating compliance with established criteria. The recommendation to provide a better correlation between flow and phosphorus adsorption, may be needed, but it is our opinion that the first step would be to incorporate within the model internal loading from the reservoir sediments."

RFP Response 8:

See Response #5 - The WARMF model does currently include internal loading from the reservoir sediments via diffusion.

RFP Comment 9:

"Chlorophyll a - though we agree with the report statement (pg 111) that the simulations "follow the correct seasonal trends and approximate magnitude of the observations" , it is our opinion that the model is generally over predicting algal concentrations, particularly in the important post 2006 period. It is not difficult for a model to be seasonally correct (abundant light, warm temperatures and ample nutrients). It is more difficult to calibrate to the observed value when the available data are scant.

It is difficult to have any confidence in the "calibration" results shown on Figures 5-69 to 5-73. Reservoirs, even shallow reservoirs, have thermoclines with the top layers warmer during the spring, summer and fall seasons. These warm top layers are where the algal population thrives and where water quality samples for algae are collected. In addition, algal concentrations vary over the course of a day, with the highest concentrations normally in the mid to late afternoon and lowest concentrations during the night. Since the reservoirs were modeled as homogeneous systems (not layered) and the simulation results are daily averages, it is near impossible to evaluate the acceptability of the "calibration" results. Incorporating lake/reservoir segments into the model would provide the capability to simulate kinetics in individual layers and provide a more direct comparison to the observed data. "

RFP Response 9:

WARMF does simulate lake layers, and the changing algae concentration with depth of the lake can be seen in the profile plots of the WARMF output. The plots of simulated versus observed algae (Chlorophyll a) included in the report are showing the simulated concentration in the surface layer of the lake as compared to observations.

<u>Note that the Department only collects profile data for a limited number of parameters and at a few reservoir locations statewide. The calibration effort compared simulated versus observed surface values during the September 2003 - September 2012 time-frame.</u>

<u>Comments on Future Use of WARMTH Model</u>

RFP Comment 10:

"As CRTC (2002) outlined in their fourth comment "*to date most of the work associated with the TMDL development process has focused on the relationship between point source phosphorus loadings and ambient phosphorus and chlorophyll a levels*." We would like to take this opportunity to reiterate that SCDHEC should consider non-point sources reduction options for these constituents. A recent Government Accountability Office (GAO) report ***Changes Needed If Key EPA Program Is to Help Fulfill the Nation's Water Quality Goals*** (December 2013) indicated that "*In response to GAO's survey, state officials reported that long-established TMDLs generally do not exhibit factors most helpful for attaining water quality standards, particularly for nonpoint source pollution (e.g., farms and storm water runoff). The officials reported that landowner participation and adequate funding—factors they viewed as among the most helpful in implementing TMDLs—were not present in the implementation activities of at least two-thirds of long-established TMDLs, particularly those of nonpoint source TMDLs. Because the Clean Water Act addresses nonpoint source pollution largely through voluntary means, EPA does not have direct authority to compel landowners to take prescribed actions to reduce such pollution. In GAO's survey, state officials knowledgeable about TMDLs reported that 83 percent of TMDLs have achieved their targets for point source pollution (e.g., factories) through permits but that 20 percent achieved their targets for nonpoint source pollution. In 1987, when the act was amended to cover such pollution, some Members of Congress indicated that this provision was a starting point, to be changed if reliance on voluntary approaches did not significantly improve water quality. More than 40 years after Congress passed the Clean Water Act, however, EPA reported that many of the nation's waters are still impaired, and the goals of the act are not being met. Without changes to the act's approach to nonpoint source* *pollution, the act's goals are likely to remain unfulfilled.*" This conclusion by GAO does indicate that non-point source pollution should be given consideration by the regulators. A properly calibrated and "confirmed" model would be a useful tool to assess the optimal direction for SCDHEC to move (i.e., point sources or non-point sources) in terms of improving the water quality of the rivers in South Carolina.

A water quality model meeting predetermined acceptance criteria and subsequently confirmed as being capable of simulating the water quality of the lower Catawba River basin would better provide SCDHEC the optimal direction for focusing future goals (point sources vs. non-point sources) to improve the water quality of the rivers in South Carolina. "

RFP Response 10:

SCDHEC recognizes that improving water quality in these reservoirs to meet the nutrient standards cannot be accomplished by reductions in traditional point sources alone. Reductions in loading will also need to come from regulated stormwater MS4s, unregulated stormwater MS4s, agriculture, septic systems, and other anthropogenic controllable source that is determined to be contributing to the impairments. SCDHEC and NCDENR have limited regulatory authority over nonpoint sources, which will have to be targeted with incentive programs such as 319 grants. The TMDLs will include recommended reductions from all sources. Only by targeting the recommended reductions from all sources (both the wasteload allocation and load allocation) will the water quality standards for nutrients be achieved.

RFP Comment 11:

"To emphasize the latter portion of the CRTC (2002) fourth comment "*is for SCDHEC to give adequate consideration to the substantial non-point source component originating from North Carolina*." The significant reduction in the total phosphorus loading in Sugar Creek especially around 2006 and 2007 was largely due to the construction of the biological nutrient removal systems at the three WWTP that discharge into Sugar Creek (i.e., Irwin Creek, Sugar Creek, and McAlpine Creek WWTPs). This creek is tributary to the Catawba River upstream from the Resolute Forest Products NPDES discharge point. Discharges entering into North Carolina waters should not be considered irreducible, "*SCDHEC should coordinate with DENR to explore opportunities for achieving basin-wide reductions*", utilizing joint initiatives and programs with the goal of reducing specific constituent concentrations.

Recommend more cooperative efforts between SCDHEC and DENR through joint initiatives and programs to reduce specific constituent concentrations throughout the river basin. "

RFP Response 11:

SCDHEC has been working with NCDENR and will continue to collaborate regarding this TMDL effort. As stated in the previous response, achieving the reductions necessary to eliminate the nutrient impairments will necessarily include the sources in North Carolina, both regulated and nonpoint sources. The targeted watersheds include the North Carolina parts of Sugar, Twelvemile, Waxhaw, and Cane Creeks.

The City of Rock Hill

General Comments

RH Comment 1:

"In regard to TP, SCDHEC and the NC Division of Water Resources have already implemented requirements to reduce TP from point sources in the watershed by approximately 70 to 80 percent through permit requirements implemented primarily prior to 2007. These prior reductions should be considered in developing an allocation approach for wasteload allocations (for point sources) and load allocations for nonpoint sources. Specifically, we do not believe an equal marginal percent reduction (EMPR) approach often used by States and EPA is appropriate unless the prior reductions are also considered."

RH Response 1:

See CMU Response 1.

RH Comment 2:

"TN allocation strategies need to be considered carefully for a number of reasons:

TN impairments are not widespread in the reservoirs.

The substantial over-prediction of nitrogen by the model may require more reductions than necessary to meet any allocations developed.

Nitrogen reductions at wastewater treatment facilities can require substantial modifications to treatment approach at substantial cost; therefore, SCDHEC and stakeholders need to be satisfied with model predictions prior to proceeding with this allocation step."

RH Response 2:

See CMU Response 2.

Model Documentation

RH Comment 3:

"**Model Coefficients Description**

In terms of model coefficients, Section 3.2 "Model Coefficients" listed (a) system coefficients, (b) catchment coefficients; (c) river coefficients and (d) reservoir coefficients. Tables 3-1 to 3-8 in this section have listed the final model calibration coefficients (e.g. either using model default values or calibrated values). We suggest adding one more data column in summary tables (i.e. Tables 3-1 to 3-8) to indicate whether model default values or calibrated values were used for any particular coefficient."

RH Response 3:

See CMU Response 3.

RH Comment 4:

" **Point Source Discharges**

In the January 2014 draft model calibration report, there was no description of point source discharges, except for listing a June 2013 technical memo as one of the references. This makes it difficult for the readers to locate the information on point source data by just looking at the January 2014 draft report alone. Therefore, there should be better cross-referencing between the January 2014 draft calibration report and the June 2013 technical memo on model updates.

In Table 3 of the point source section (on page 3 of June 2013 technical memo), only 12 point sources newly added to the model (among a total of 305 point sources) were listed. Furthermore, Appendix 1 of June 2013 technical memo only provided a summary list of "Updated Point Source Input Files", without descriptive information on each point source discharge (e.g. name of discharges). This made it difficult to track down specific point source information without spending additional search efforts. We would like to recommend such summary information on point sources to be included in the model calibration report so that a reviewer does not need to be looking at other reports or attempt to determine pint source information from the model input files."

RH Response 4:

See CMU Response 4.

RH Comment 5:

" Land Use

To update land use information in the Catawba River WARMF application, gridded land cover data from the 2006 National Land Cover Database (NLCD) was downloaded. The land cover data were overlaid with the updated catchment boundaries and percentages of each land cover classification contained within each catchment were calculated.

Regarding land use coefficients, there are a number of model system coefficients which have values for each land use. These coefficients define how the different land uses receive anthropogenic model inputs such as irrigation and respond to natural model inputs such as atmospheric deposition. These land use coefficients were set based on literature values and agricultural practice. It appears that development of land use as model inputs followed the standard practice of model development."

RH Response 5:

See CMU Response 5.

RH Comment 6:

"Nutrient Budget

Summary information on relative loading from point sources versus land use or upstream sources was not included in the model calibration report. Although this is not necessarily required for a calibration report, it does provide insight into issues related to model calibration. Ideally, this information would be available for subwatershed areas. For instance, the problems with the nitrate N calibration for a tributary such as Rocky Creek could be better understood if the reviewer knew the relative loading contributions (without having to dig them out of the model)."

RH Response 6:

See CMU Response 6.

<u>Adequacy of Hydrology and Water Quality Calibration</u>

RH Comment 7:

"Hydrologic Calibration

Hydrologic calibration is the process of adjusting the coefficients of the rainfall-runoff model so that the simulations of streamflow better match the observations as well as possible. There are three levels of hydrologic calibration: global, seasonal, and event.

The overall hydrologic calibration appears acceptable and in some cases matches well with observed streamflow. However, the hydrologic calibration for tributaries such as Sugar Creek (more urban land use type) and Rocky Creek (more rural land use type) appear to be significantly inferior to other sub-watersheds (see Figure 4-3 in January 2014 model calibration report). An explanation for possible reason should be provided in the draft report."

RH Response 7:

See CMU Response 7.

RH Comment 8:

"As an overall comment for Section 4 "Hydrology Calibration Report", the comparison plots for simulated flow versus observed flow (i.e. Figures 4-2 to 4-7) are difficult to see during the low flow ranges. A log-log scale should be considered to allow better visualization of the calibration results."

RH Response 8:

See CMU Response 8.

Water Quality Calibration

RH Comment 9:

"**Temperature**

The temperature calibration appears quite good for both free-flowing portion of the Catawba River, tributaries such as Sugar Creek and Rocky Creek, and the lake stations. The temperature calibration statistics shows that the relative error is negative at nearly all sampling locations by comparing model simulation and observed data. This indicates a very slight systematic under-prediction of water temperature (within 1°C)."

RH Response 9:

See CMU Response 9.

RH Comment 10:

"pH

The pH calibration appears adequate to good for the free-flowing stations of the Catawba River and tributaries. The model significantly over-predicts pH for the reservoir sites with predicted values frequently exceeding a pH of 10 (see Figures 5-17 and 5-20 below which illustrate results for Fishing Creek Reservoir and Lake Wateree headwaters, respectively). The report discounts these over-predictions indicating that nutrient and algal simulations are not sensitive to pH. However, the nutrient and algal simulations should significantly influence pH and this substantial over-prediction (pH is a log scale) indicates that the model is likely predicting substantially more algal productivity than is occurring in the lakes. This will be discussed further under the discussion of chlorophyll *a* calibration."

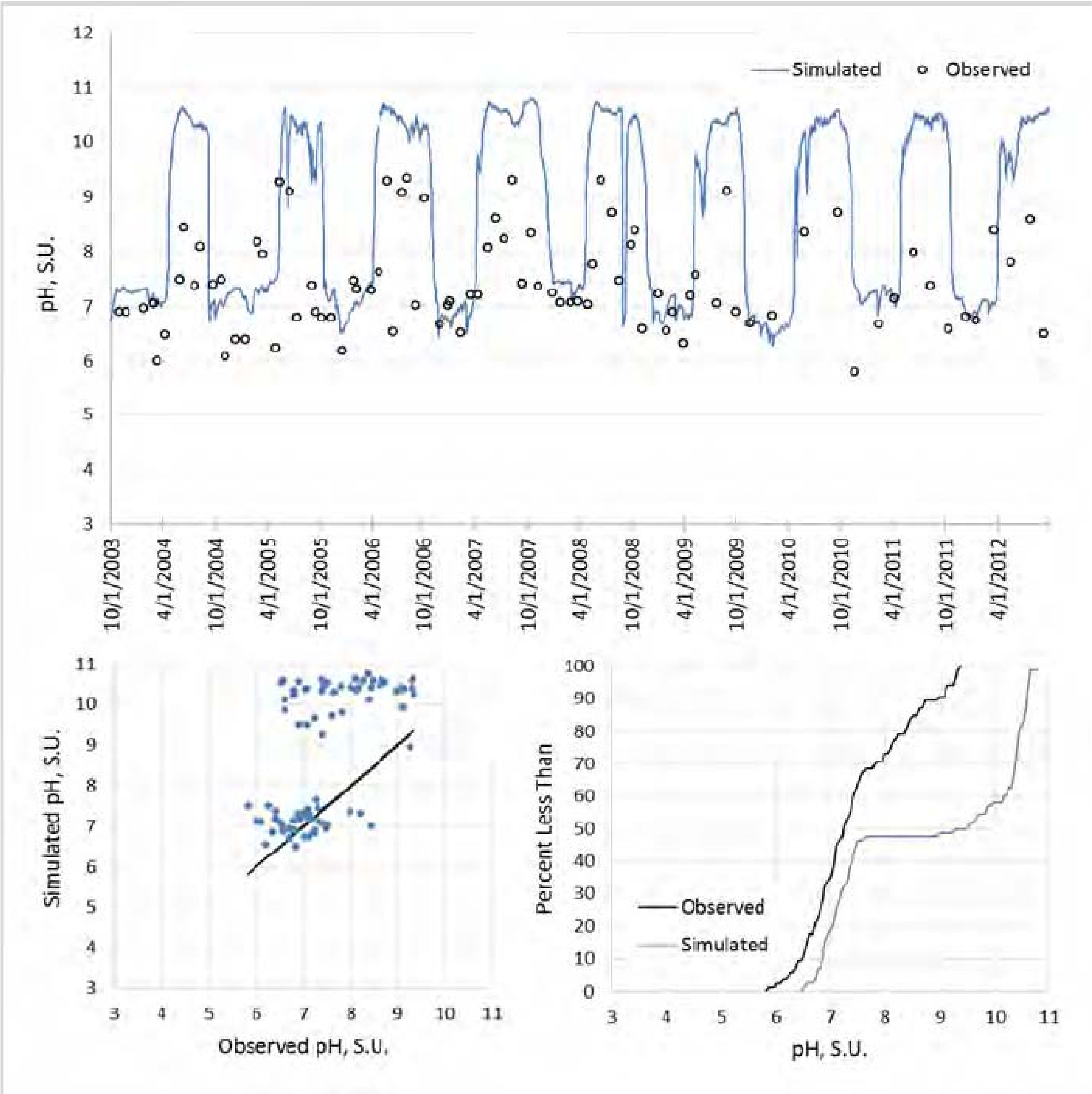


Figure 5-17 pH simulation results, Fishing Creek Reservoir (WARMF ID 1562)

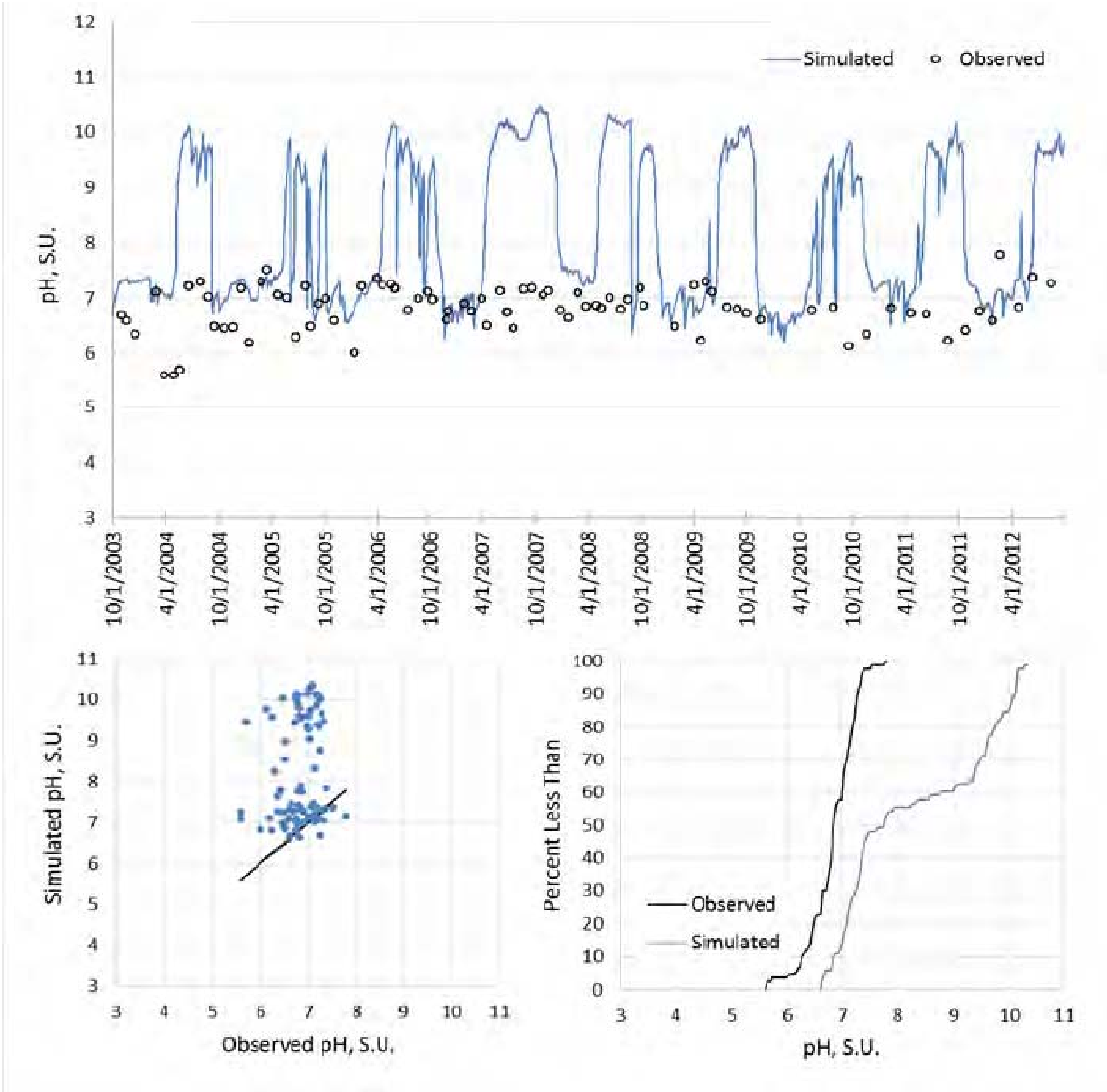


Figure 5-20 pH simulation results, Lake Wateree Headwaters (CW-231) (WARMF ID 624)

RH Response 10:

See CMU Response 10.

RH Comment 11:

"Total Suspended Solids

As indicated in the calibration report, the calibration results for TSS are not very good and the model is generally under-predicting TSS. The report indicates the lack of TSS data and the effects of storms, soil erosion, and sediment transport. Compared with other water quality parameters, there is greater uncertainty in the model calibration for TSS. Adjustments of TSS calibration would have impacts on other parameters, particularly TP. "

RH Response 11:

See CMU Response 11.

RH Comment 12:

"Nitrate-Nitrogen

The calibration of nitrate-nitrogen appear to be adequate for the main stem of Catawba River downstream of Lake Wylie (e.g. at River ID 89) and certain tributaries (e.g. Sugar Creek). However, in several cases, simulated nitrate-nitrogen concentrations do not follow the observed values (e.g. Fishing Creek and Rocky Creek). For example, simulations of nitrate-nitrogen are significantly off in Rocky Creek (see Figure 5-32), where the model simulations of nitrate are higher than the observed (nitrate concentrations are all between 0 and 1 mg/l, while simulated concentrations are between 1 and 6 mg/L in the summer and fall of most years). The nitrate-N predictions for the reservoir locations typically follow the seasonal patterns (see Figure 5-31 for Fishing Creek Reservoir). However, in examining the simulated versus observed scatter plots for each of the reservoir sites (Figure 5-31 to 5-37) the model consistently over-predicts nitrate-N concentrations and these over-predictions increase as one moves downstream in the basin (i.e. Great Falls Reservoir calibration results are worse than Fishing Creek Reservoir, Cedar Creek Reservoir calibration results are worse than the downstream Great Falls reservoir, etc.) "

RH Response 12:

See CMU Response 12.

RH Comment 13:

"As mentioned in the January 2014 draft report, there are few mechanisms in the WARMF model to simulate a large removal of nitrate from the water column since it does not readily absorb to settling particles and denitrification occurs only in nearly anoxic conditions."

RH Response 13:

See CMU Response 13.

RH Comment 14:

"Ammonia-Nitrogen

In all locations, the ammonia simulations are relatively good after year 2007. The pattern in observed ammonia data appears to change around the year 2007, with overall higher concentrations before 2007 and lower concentrations after 2007. The change in pattern in 2007 is not consistently found in the point source data nor in the hydrology, thus does not appear in the simulations.

Based on the January 2014 draft model calibration report, the calibration effort was focused on matching the ammonia concentrations after 2007. The higher concentrations in the observed data prior to 2007 cause a large negative relative error in most locations."

RH Response 14:

See CMU Response 14.

RH Comment 15:

"Total Nitrogen

TN in WARMF is calculated as the sum of the dissolved and adsorbed concentrations of simulated nitrogen species (ammonia and nitrate), plus organic nitrogen, which is calculated as a proportion of organic carbon. Since Nitrate-N represents the largest component of TN, the simulation results are typically similar to those for Nitrate. Simulations were adequate for free-flowing portions of the Catawba River and Sugar Creek. TN is substantially over-predicted for Rocky Creek and Fishing Creek. For the reservoir stations, the TN pattern seems reasonable however the scatter plots show fairly consistent over-prediction particularly as you compare progressively downstream reservoirs, similar to nitrate-N results.

In summary, the nitrogen simulation results do not match and generally over-predict observed data in several circumstances. This issue needs to be addressed before the model can be used for allocation of TN in the TMDL process. This is particularly true since TN impairment is "patchy" and only occurs at a few locations within the basin based on the 2013 303(d) list."

RH Response 15:

See CMU Response 15.

RH Comment 16:

"Phosphorus

In general, the WARMF model simulates the appropriate amount of TP over the simulation timeframe. However, the model performance statistics (see Table 5-8) indicate that the simulated values do not match the observations well when compared at the daily time step. In order to improve the daily simulation statistics, each tributary would have to be calibrated for hydrology, sediment transport, and TP concentrations. The free-flowing stations in the Catawba River and Sugar Creek simulations are quite good whereas Fishing Creek and Rocky Creek simulations are not as good. The scatter plots (see Figures 5-61 and 5-62) show pretty wide scatter with similar under and over-predictions. The reservoir predictions of TP are adequate, especially at Fishing Creek Reservoir, although the same pattern of over-prediction in each downstream reservoir is seen as observed with nitrate-N and TN."

RH Response 16:

See CMU Response 16.

RH Comment 17:

"Generally, the TP simulations appear to be generally adequate, although the model calibration could probably be improved. It is likely that improved calibration for TSS would also result in improved calibration of TP. "

RH Response 17:

See CMU Response 17.

RH Comment 18:

"A substantial number of ortho-phosphorus samples have been collected at Sugar Creek at SC-160 by Charlotte-Mecklenburg Utilities, which allows for comparison between the simulated and observed values. In general, the model simulates the trends in ortho-phosphorus concentration reasonably well at this location."

RH Response 18:

See CMU Response 18.

RH Comment 19:

"Algae - Chlorophyll *a*

The model was calibrated to measured algae concentrations (based on chlorophyll *a*) at five selected locations including Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir and two locations at Lake Wateree. The model is doing an acceptable job of simulating the annual pattern and magnitude of algae concentrations for Fishing Creek Reservoir. However, the model simulation of algae concentration for the downstream reservoirs is not as good and seems to over-predict chlorophyll *a* for the Great Falls and Lake Wateree (especially headwater) locations."

RH Response 19:

See CMU Response 19.

RH Comment 20:

"The report makes the point that the chlorophyll *a* data represents one point during the day whereas the model is simulating a daily average. We recognize there are a lot of complexities in calibrating the chlorophyll *a* portion of the model. Given the indication by the pH results that the model is predicting substantially more algal productivity than is occurring (because the increase in pH is reflective of uptake of various carbonate ions by algae), it would seem that the model is calibrated to match the peaks more than the mid-range concentrations. "

RH Response 20:

See CMU Response 20.

RH Comment 21:

"Summary of Calibration Efforts

In summary, the overall approach for WARMF model calibration seems reasonable and consistent with standard practice used to develop nutrient TMDLs. Based on the 303(d) impaired water lists, TP impairments occur throughout the Lower Catawba River reservoirs. TN impairments are more "patchy," occurring in Fishing Creek reservoir and one location downstream. In terms of draft model simulation results for nutrients, it appears that phosphorus simulation results are reasonably acceptable for further steps in the TMDL process (e.g. TMDL allocation); however, efforts to improve the TSS calibration would also impact TP predictions and would need to be considered before moving forward. Effort to refine the TSS calibration should precede acceptance of the TP calibration results. It would be interesting to see a sensitivity analysis regarding TSS and whether the impacts related to TP, algae (as chlorophyll a) and pH."

RH Response 21:

See CMU Response 21.

RH Comment 22:

"There is a significant concern regarding whether current model calibration for nitrogen would be adequate before it can be used in the further steps of the overall TMDL process. Current calibrated model tends to over-predict nitrogen concentrations especially in some more rural tributaries and in the reservoirs. Further improvement for model calibration of nitrogen is necessary before moving forward with the TMDL process."

RH Response 22:

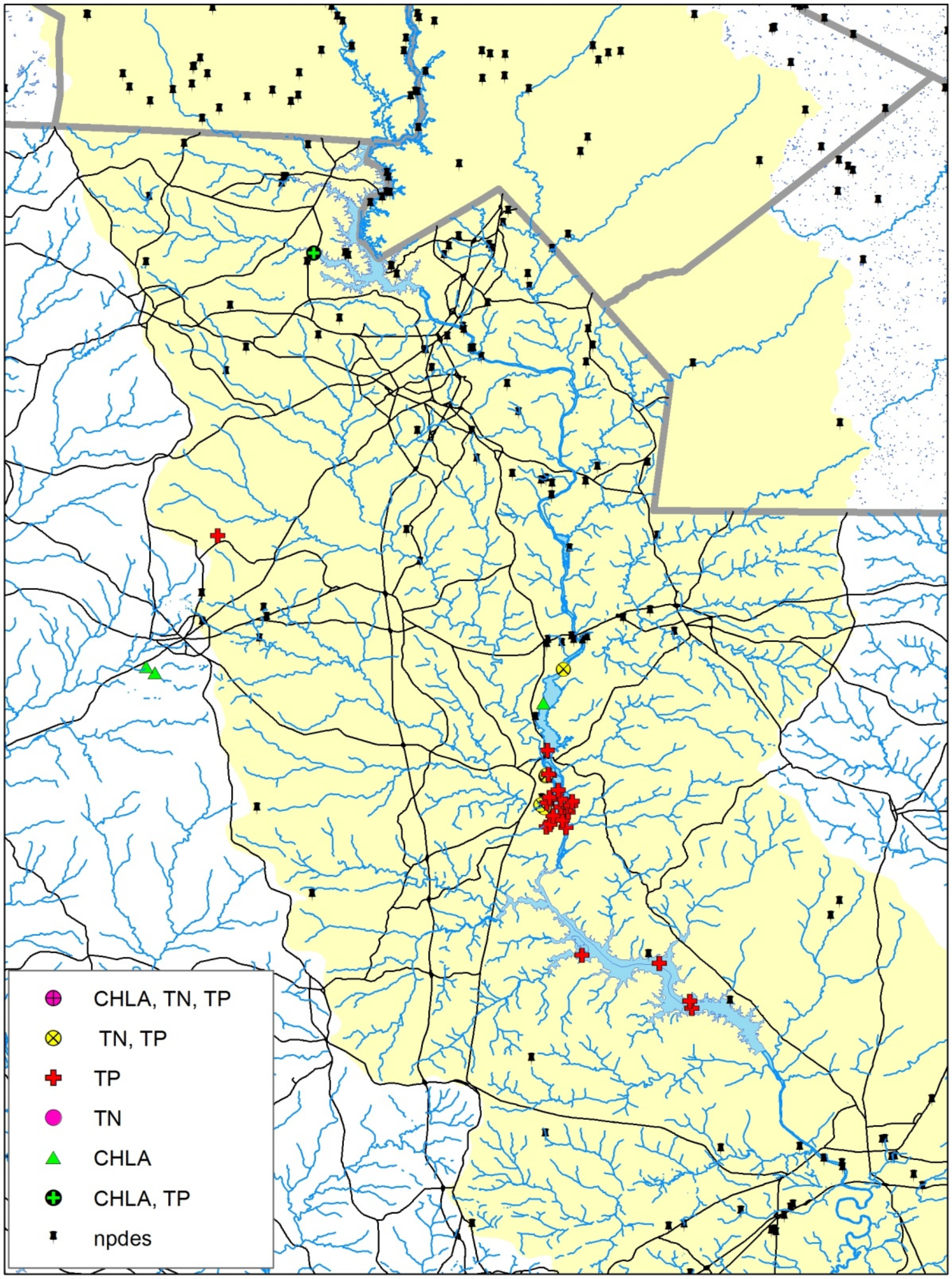
See CMU Response 22.

<u>Next Steps in the TMDL Development Process</u>

RH Comment 23:

"The attached map indicates fairly widespread impairment of the TP water quality standard from Fishing Creek Reservoir through Lake Wateree. SCDHEC and the NC Division of Water Resources have already implemented requirements to reduce TP from point sources in the watershed by approximately 70 to 80 percent through permit requirements implemented primarily prior to 2007. These prior reductions should be considered in developing an allocation approach for wasteload allocations (for point sources) and load allocations for nonpoint sources. Specifically, we do not believe an equal marginal percent reduction

(EMPR) approach often used by States and EPA is appropriate unless the prior reductions are also considered."



Map showing impairments in Lower Catawba River basin Lakes based on SC 2012 303 (d) list

RH Response 23:

See CMU Responses 1 & 23.

RH Comment 24:

"TN allocation strategies need to be considered carefully for a number of reasons:

TN impairments are not widespread in throughout the reservoirs (see attached map)

The substantial over-prediction of nitrogen by the model may require more reductions than necessary to meet any allocations developed

Nitrogen reductions at wastewater treatment facilities can require substantial modifications to treatment approach at substantial cost; therefore, SCDHEC and stakeholders need to be satisfied with model predictions prior to proceeding with this allocation step."

RH Response 24:

See CMU Response 24.

The South Carolina Department of Transportation (SCDOT)

General Comments

SCDOT Comment 1:

"WARMF (Watershed Analysis Risk Management Framework) is a base model developed by the EPA to facilitate TMDL development. Although WARMF uses state of the art hydrologic and water quality process equations, it performs simulations in daily time-step increments only. At this time scale, impacts from stormwater runoff are often muted. Extrapolating the pollutant loading results from the current model to assess the impacts of MS4s from storm events on water quality will yield inaccurate estimates. The results will be further aggravated since the water quality portion of the model has not been well calibrated, and furthermore, the model calibration has not been tested through model validation."

SCDOT Response 1:
The WARMF model is capable of simulating hydrology and water quality on a sub-daily time step. The process requires sub-daily meteorology information, which is not available from the publicly available data sources. Additional calibration was performed resulting in some improvement to nutrient simulations. The project budget, combined with limited record of observed data for some constituents, did not support reserving several years of data as necessary for a model validation. The process of validation, though desirable in theory and academic studies, for practical purposes does not result in a better calibration. After reviewing model results for a validation period, if any large errors exist, the calibration would be adjusted to optimize results over the full period of record. For calibrating large watersheds with limited budget, a validation analysis adds time and cost without adding value to the calibration.

SCDOT Comment 2:

"Watershed models have numerous parameters that represent physical processes and are adjusted during model calibration based on their sensitivity. There is no documentation of a parameter sensitivity analysis provided with the model report. This model will have a high degree of uncertainty when implemented.

The current model can be used as a tool for watershed planning and prioritizing, but a sensitivity analysis should be included in the model documentation."

SCDOT Response 2:

SCDHEC (the Department) agrees a sensitivity analysis would provide useful information for understanding the model, however under the current project and scope of work a sensitivity analysis was not feasible. Additional sensitivity analyses may be needed and conducted as the model is applied for TMDL development.

SCDOT Comment 3:

"There is no background or source information provided in the report to support the event mean concentration (EMC) values associated with each different landuse category. EMC values are used to predict pollutant loads from hydrologic model outputs. Without sound EMC values, the model will not predict accurate pollutant loadings."

SCDOT Response 3:

The WARMF model uses buildup and wash off of constituents based on land use categories rather than event mean concentrations. These rates are determined from literature, any available data, and calibration. That is, the rates are initially set based on literature and available data, but then adjusted through calibration.

SCDOT Comment 4:

"For most of the water quality constituents, test statistics suggested a poor calibration. A more extensive dataset, such as a continuous water quality dataset, should be collected and incorporated into the model to assess trends and processes before the model is used to promulgate TMDLs. Currently, the model is based upon data from collected grab samples, which can only give an instantaneous picture of water quality parameters. This limited water quality dataset is then applied to the daily time-step outputs from the hydrologic portion of the model. The report does not contain information on the methods used to align these two datasets, which have different time scales. This step of the modeling process likely leads to inaccuracies."

SCDOT Response 4:

Both the hydrology and water quality simulations are performed at a daily time step within the model, thus there is no alignment necessary. Observed datasets of water quality (i.e. the above mentioned grab samples) in streams and lakes are used as a means of comparison to model simulations. In its current state, the WARMF model was calibrated using the best dataset that could be assembled from available sources, under the constraints of the project budget and scope.

<u>Specific Comments</u>

SCDOT Comment 5:

(Report, Page 2) "For this task, WARMF catchments overlaying additional specified urbanized areas were subdivided and generally include areas west of the Catawba River that contribute to watershed area below Lake Wylie, as well as Charlotte and Rock Hill. Urbanized areas delineated for Phase II are listed in Table 2-1.Urbanized areas east of the river within South Carolina were subdivided as part of Phase I of the project (Figure 2-1)."

“There is no information provided to indicate how SCDOT’s right of ways and facilities are incorporated into land use classifications. It is unclear how the load requirements will be disaggregated in order to assign a load specifically to SCDOT.”

SCDOT Response 5:
The Department does not anticipate that SCDOT will be assigned a WLA based on the urbanized land delineation. SCDHEC expects that the nutrient matrix established between SCDOT and SCDHEC will determine any requirements that SCDOT would be required to meet as a result of nutrient TMDLS for the Lower Catawba reservoirs.

SCDOT Comment 6:
(Report, Page 9) “Sensitivity results indicate that periphyton primarily effects dissolved oxygen and nitrogen species, as shown in Figure 2-5 through Figure 2-10 for the Catawba River at SC-9. The variation in dissolved oxygen becomes larger, with higher peaks and lower troughs due to the growth (DO release) and decay (DO consumption) of the periphyton. Periphyton consumes both ammonia and nitrate during growth, but only releases ammonia during decay. Thus simulations of ammonia are higher with periphyton, while simulations of nitrate are lower, resulting in a slight net reduction in total nitrogen. Periphyton also causes a small net reduction in total phosphorus. The impact on nutrient levels (TN and TP) and algae in Fishing Creek Reservoir are minimal as shown in Figure 2-11 through Figure 2-13. Thus periphyton does not significantly contribute to total net nutrient levels in the Catawba River and downstream reservoirs. For this reason, and because the periphyton had a negative effect on the DO calibration, periphyton were turned off in WARMF.”

“The full process for conducting the periphyton sensitivity analysis is not explained in this report. It appears as though a local sensitivity analysis was performed. Given that periphyton influence and are influenced by multiple parameters, a global sensitivity analysis would be more appropriate than a local sensitivity analysis. The impact of periphyton growth, mortality and settling on TN, TP, and DO concentrations appears to be non-linear. A probabilistic approach with a range of values should be used instead of a single value to validate the statement: “Periphyton does not significantly contribute to total net nutrients levels in the Catawba River and downstream reservoirs.”

SCDOT Response 6:

The test of the effect of periphyton on nutrients and DO was performed by setting the periphyton growth rate equal to a value we have used in other watersheds. Based on the resulting effect on DO, the growth rate was on the high end of values that might be tested for the Catawba watershed. A global sensitivity analysis of periphyton was not feasible within the project constraints.

SCDOT Comment 7:
(Report, Page 15) “Given the available meteorological and operational data, the Catawba River Model simulated stream flow and water quality at various river segments. At locations where monitoring data were collected, the model predictions should match the measured stream flow and water quality. Initially, some model coefficients such as physical properties of the watershed are known. Other coefficients are left at default or typical literature values. The initial predictions made did not necessarily match the observed values very well. Model calibration was performed by adjusting model coefficients within acceptable ranges to improve the match between model predictions and observed data.”

“The model calibration is not accompanied by the model validation.”

“Typically, model calibration is based on parameter sensitivity. There is no mention here about the sensitivity of various parameters.”

“The report does not specify how “acceptable ranges” were determined.”

SCDOT Response 7:
Validation requires that a subset of observed data be reserved for this purpose and not used for calibration. The quantity of data available is quite small, making calibration difficult in the majority of the Catawba tributaries. Further reducing the quantity of data available for calibration was not considered due to the limitations of the dataset, additional cost with added value (see Response #1).

Conducting a sensitivity analysis was beyond the scope of this project. The parameters used for calibration were selected based on Systech's experience calibrating the WARMF model for other watersheds. Additional sensitivity analyses may be needed and conducted as the model is applied for TMDL development.

Acceptable ranges for each parameter were determined from literature values and previous calibration experience.

SCDOT Comment 8:
(Report, Page 21) “Physical data for river segments, including upstream and downstream elevations and lengths, are derived from digital elevation model data. Default stage-width curves and roughness coefficients (i.e. Manning's n) were used for each river segment since no data were available to calculate these values. An initial value for the Manning's n coefficient of 0.04 was used as recommended by Rosgen (1996). The Manning's n value was increased for the majority of river segments because it improved the simulation results when compared with observed data.”

“Manning’s n values were not verified and aerial photographs or field visits were not conducted to derive appropriate Manning’s n values. Instead an initial value based on Rosgen, 1996 was used. The Manning’s values and accurate information are very important, especially since increased Manning’s n values improved the simulation results.”

SCDOT Response 8:
Field visits and aerial photograpic analysis were beyond the scope of this project. In addition, as with any watershed model of this scale, channel characteristics such as roughness and shape within the model must be an aggregated value representing the entire length of the model segment. Thus point measurements and observations are not directly applicable and would still require calibration. It’s true the Manning’s n values in the model were found to be important for the hydrology calibration, however this does not necessarily indicate that using field-collected values as starting points would have resulted in a different calibration.

SCDOT Comment 9:
(Report, Page 24) “Event calibration is the process of matching the simulated peak flows to the observed peaks during precipitation events. There are 22 streamflow gaging stations on rivers and streams located

within the Catawba River Watershed between Lake Wylie and Lake Wateree (Figure 4-1). Simulated flow was compared to observed data at each of these locations."

"In the current modeling efforts, statistics (such as NS coefficient, RMSE, R2 etc.) are calculated at each station. Calculating these statistics for the output overall would be helpful in evaluating the model performance."

SCDOT Response 9
SCDHEC is not certain of what is being proposed by the commentor.

SCDOT Comment 10:
(Report, Page 32, Table 4-1) "NSE statistics are below 0.5 at Rocky Creek and Waxhaw Creek. Based on scientific literature, these values should be greater than 0.5 for a good calibration."

SCDOT Response 10:
Though generalized targets for statistical measures are often reported in scientific literature, these values are not applicable for all watersheds and models. Several considerations must be taken into account that affect the achievable model performance with respect to statistical criteria. In Moriasi et al (2007) (which remains the most comprehensive review of watershed model calibration evaluation measures) the recommended value of 0.5 for a "good" calibration is applicable for models run on a monthly time step only. The "good" values for a daily time step model would be lower. The Catawba WARMF model is run on a daily time step. As stated by Moriasi regarding his recommended ranges:

"The performance ratings presented in table 4 for RSR and NSE statistics are for a monthly time step; therefore, they need to be modified appropriately. Generally, as the evaluation time step increases, a stricter performance rating is warranted."

And regarding NSE in general:

"NSE ranges between $-\infty$ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance".

The NSE for both Rocky and Waxhaw Creeks are both greater than 0 thus would be considered "acceptable". Additional calibration efforts for Rocky Creek was performed and still did not yield improved results with respect to NSE. Sub-model element scale of variability in meterological inputs, as well as watershed processes not well captured in the model can reduce the maximum achievable performance. Without further analysis, it is unclear why a better calibration was not attainable for Rocky and Waxhaw Creek. If further calibration in these areas is performed internally, we recommend performing a detailed comparison of magnitude and timing of forcing variables as compared to hydrologic response (flow). A brief statistical comparison of precipitation and flow in Rocky Creek indicated poor correlation.

SCDOT Comment 11:
(Report, Page 57, Table 5-2) "Based on NSE statistics and R^2 values, the model calibration is very poor. Other than downstream of Lake Wylie, the NSE statistics do not indicate a good calibration. The R^2 statistics suggest that the model did not simulate pH trends well at any sites with the exception of downstream of Lake Wylie."

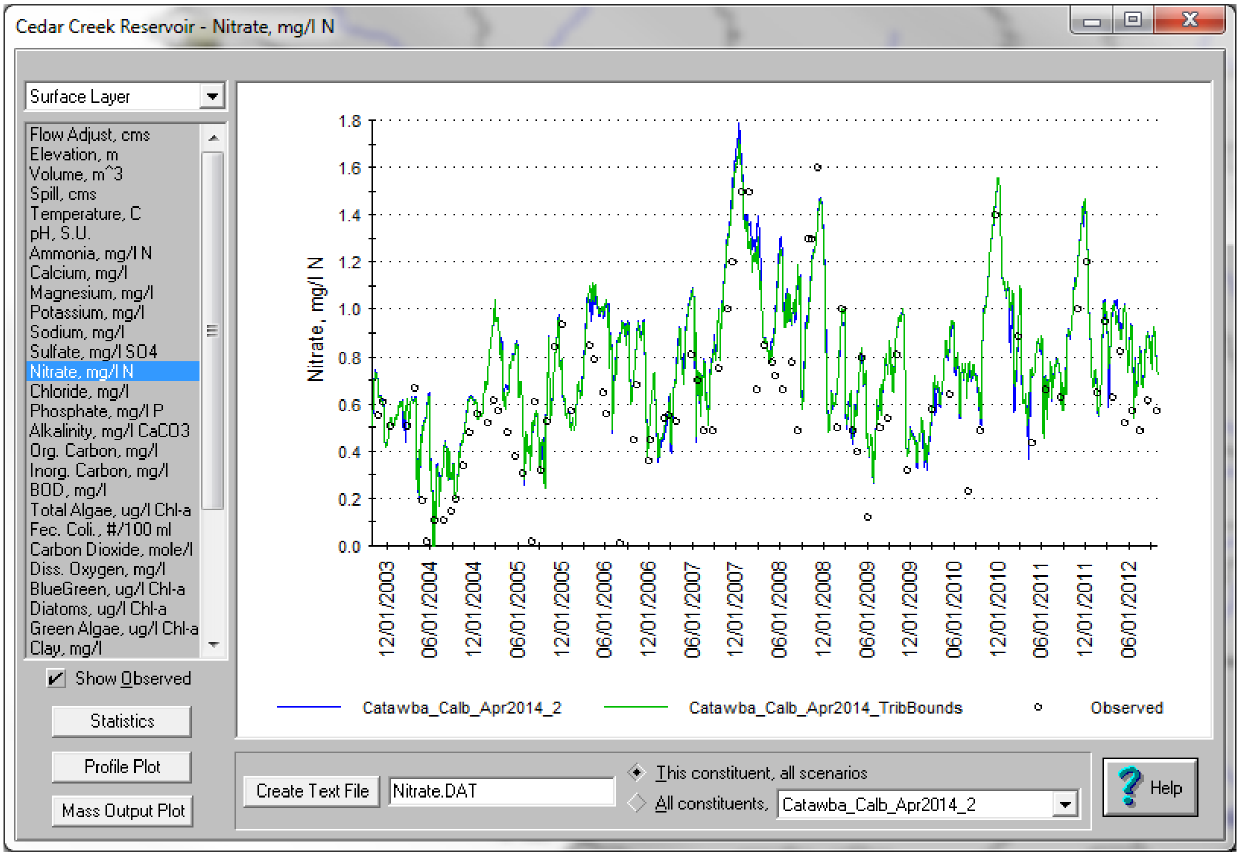
SCDOT Response 11:
The error is pH simulation in reservoirs was found to be most likely due to insufficient atmospheric reaeration of CO2 during algae growth. Figures are included in the final report demonstrating the effect of reaeration on the pH simulation and resulting insignificance for nutrient and algae simulations. In general due to the very large number of process affecting pH, it is one of the most difficult parameters to simulate well in natural aquatic systems. If not all parameters that affect pH are fully calibrated (which is rarely feasible in practical applications on a limited budget), pH simulations would be expected to include greater error than other constituents. Also, due to it's significant oversensitivity to extreme values and outliers (from experience and supported by Moriasi, 2007), R^2 is not a good indication of overall model performance and was not used to guide the calibration process. Results were included in the report by request and for completeness only. Guidelines for statistical measures reported for other constituents (flow, nutrients, sediment) are not applicable for pH.

SCDOT Comment 12:
(Report, Page 64, Table 5-3) "Very few data points are included to compare the TSS results. NSE statistics suggested a poor calibration. Additionally, no stormflow comparison has been conducted, which is very critical for allocating appropriate loads to the MS4s. The R^2 values advised poor model performance in capturing the water quality trends."

SCDOT Response 12:
The TSS analysis is data limited. There is not a single continuous-monitoring station within the study area. Without stormflow TSS sampling it is impossible to know how sediment transport in these watersheds is affected by storm events. The lack of storm sampling also makes it difficult to evaluate the quality of the calibration. The calibration statistics are based on grab sample data that appear to be collected during low to moderate flow conditions. Without information on high flow sediment transport, calibration of high sediment concentration days is not possible. However despite this known limitation, the Catawba TSS calibration results (NSE values) are actually within the range reported by Moriasi et al as a result of literature review (-2.5 to 0.23).

SCDOT Comment 13:
(Report, Page 75, Table 5-4) "Based on NSE and R^2 values, the model performs very poorly for nitrate-nitrogen."

SCDOT Response 13:
Some improvement has been made to simulations of Nitrate-N in the reservoirs (Wateree in particular), as well as Fishing and Rocky Creeks. A negative bias remains for the latter two locations, however test runs indicated that nutrient simulations in the reservoirs are not sensitive to error in these tributary simulations, as shown below. Blue line is the final calibration including bias in Fishing and Rocky Creek simulations, green line is using observed concentrations in Fishing Creek and Rocky Creek, as well as observed flow in Rocky Creek.

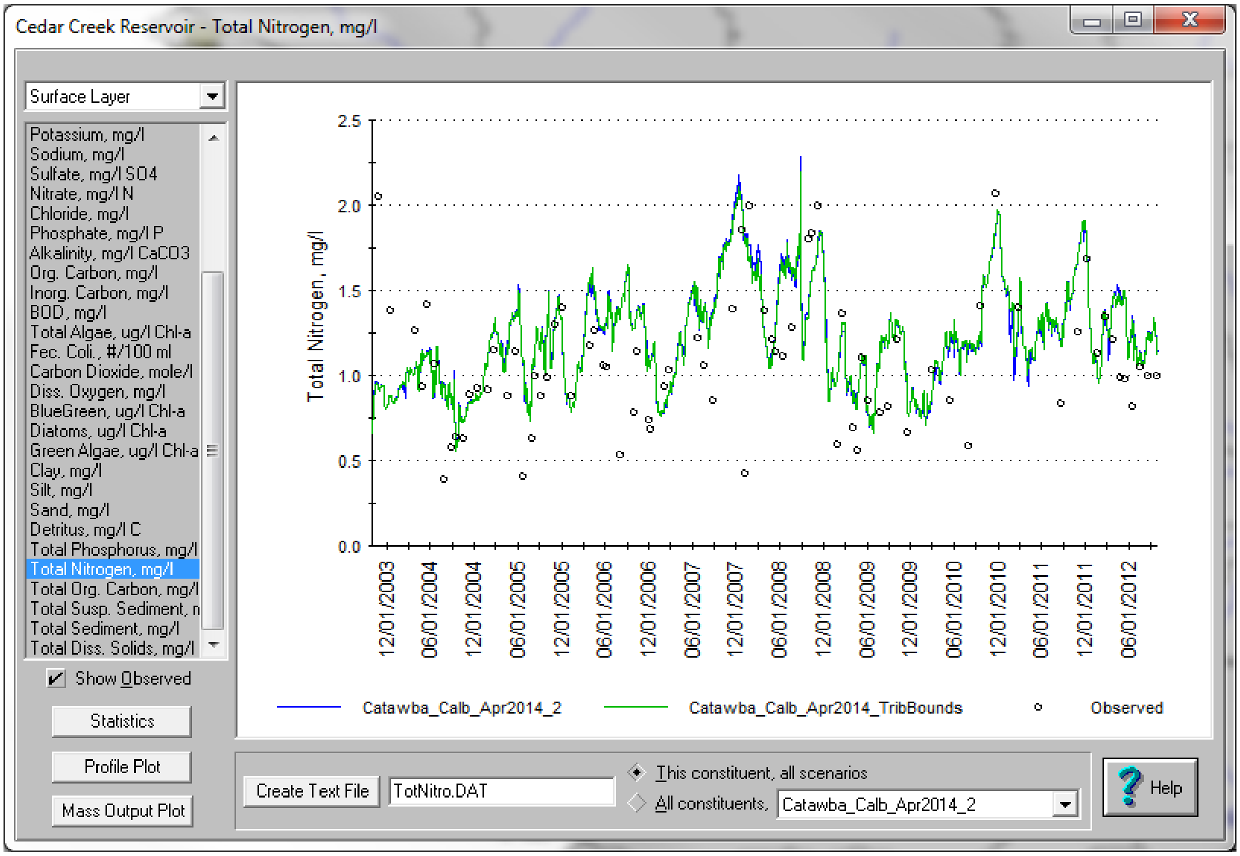


SCDOT Comment 14:
(Report, Page 86, Table 5-5) “Based on NSE and R^2 values, the model performs very poorly for ammonia-nitrogen.”

SCDOT Response 14:
A clear shift in the trend of ammonia concentrations in the observed data occurred around 2006, which degrades the model statistics. In addition, in many locations the observed data is too sparse to warranted evaluations with calculated statistics and calibration focused on visual inspection of simulated versus observed plots.

SCDOT Comment 15:
(Report, Page 98, Table 5-6) “Based on NSE and R^2 values, the model performs very poorly for total-nitrogen.”

SCDOT Response 15:
See Response #13 and figure below for TN.

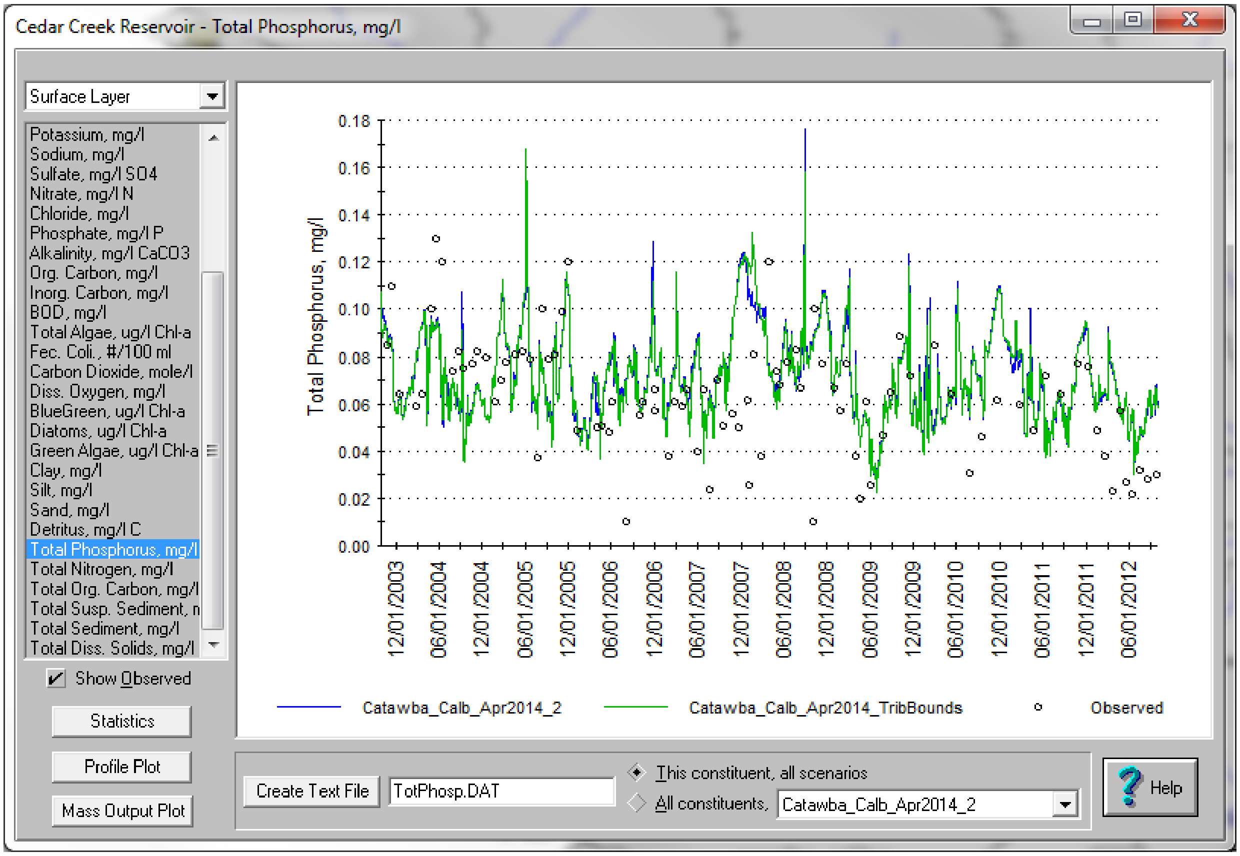


SCDOT Comment 16:
(Report, Page 99, Table 5-7) "These model statistics, with some exceptions, are slightly more robust. Ortho-P is the bioavailable phosphorus. More Ortho-P data is needed to calibrate the model."

SCDOT Response 16:
There were little orthophosphorus data available for inclusion of this model application. The available orthophosphorus data were used. In addition, additional data collection was out of the scope of this project.

SCDOT Comment 17:
(Report, Page 111, Table 5-8) "Again, very poor NSE and R^2 values across all the sites."

SCDOT Response 17:
Simulations of total phosphorus have been improved in the reservoirs. As for nitrogen, error in Rocky and Fishing Creek simulations was demonstrated to have very little effect on reservoir simulations, shown below. Blue line is the final calibration including bias in Fishing and Rocky Creek simulations, green line is using observed concentrations in Fishing Creek and Rocky Creek, as well as observed flow in Rocky Creek.



SCDOT Comment 18:
(Report, Page 117, Table 5-9) "Again, very poor NSE and R^2 values across all the sites."

SCDOT Response 18:
Chl-a data are collected only during the growing season, May-October of each year. Observations of Chl-a are too sparse to warrant evaluation with calculated statistics. Calibration focused on visual inspection of time series plots.

SCDOT Comment 19:
(Report, Page 128, Table 5-10) "These statistics show stronger DO predictions at some sites."

SCDOT Response 19:
The Department believes that the model calibration for DO was acceptable at most sites.

Dr. Dan Tufford, PhD.

General Comments

Tufford Comment 1:

" I am a little concerned about the comments relating to pH on p.46. The pH calibration is quite poor and the report minimizes the importance of further work because nutrients and algae are not sensitive to pH. In most freshwater systems algal dynamics are one cause, often the dominant cause, of variability in pH. I did not look into the WARMF model to see how it simulates pH but the poor performance suggests it is either not correctly coupled with phytoplankton dynamics or more work is needed to improve the calibration. There is direct relevance to the TMDLs in those waterbodies because at one time, if not currently, some locations (watersheds) were on the 303(d) list due to pH noncompliance."

Tufford Response 1:

Given that pH is dependent on many factors and constituents, it is one of the most difficult water quality parameters to calibrate. In practical application, budget and time constraints rarely allow for full calibration of all constituents that affect pH. The very limited budget available for this model calibration required prioritizing constituents that will be focus of current TMDL analysis for the calibration process.

However, though pH is not the primary constituent of concern, tests were performed to attempt to identify the cause of the high simulated values in lakes. Simulations of pH in the lakes are affected by several processes in addition to algae dynamics, most notably organic carbon decay and atmospheric reaeration of CO_2. Increasing organic carbon decay improved pH but significantly degraded dissolved oxygen and nutrient (NH_4) calibrations. Tests indicated that simulated reaeration of CO_2 may be insufficient during the algal growth. Adjusting the internal reaeration rate (possibly by code change only) significantly improved pH in the reservoirs during the growth season. Simulations of nutrients and chlorophyll-a were unchanged by this adjustment. Since the primary constituents of concern are not impacted, revisiting the formulation of CO_2 reaeration in the model is not feasible within the current project budget constraints.

Tufford Comment 2:

"A related issue is the somewhat poor calibration of nutrients and to a lesser extent CHLa. The report correctly observes that the seasonal dynamics appear to be pretty good. For SCDHEC purposes that may not be good enough. You need to use the model to forecast the effects of altering nutrient loads. In the absence of acceptable calibration results it may be difficult to have confidence in the loading simulations. I am well aware of how difficult these calibrations are and am not expecting great things, but I am concerned about these results."

Tufford Response 2:

Nutrient calibrations have been somewhat improved, particularly for Lake Wateree. However the lack of a complete record of data – i.e., more frequent and year round samples (nutrient data indicates algae growth prior to start of seasonal data in Lake Wateree) in a consistent location inhibits the Chl-a calibration.

Tufford Comment 3:

"Also related to #2 is the absence of any documented validation/verification work. Normal modeling protocol includes this step. It would seem to be particularly important for SCDHEC because of your future uses of the model."

Tufford Response 3:

The project budget, combined with limited record of observed data for some constituents, did not support reserving several years of data as necessary for a model validation/verification. The process of validation, though desirable in theory and academic studies, for practical purposes does not result in a better calibration. After reviewing model results for a validation period, if any large errors exist, the calibration would be adjusted to optimize results over the full period of record. For calibrating large watersheds with limited budget, a validation analysis adds time and cost without adding value to the calibration.

Tufford Comment 4:

I am also curious about the apparent change in ammonia concentrations around 2007. Ammonia can be particularly important in water quality dynamics so understanding why that might have occurred may be relevant. It is clear in the report that some investigative work was done. Is SCDHEC satisfied with that?

Tufford Response 4:

As in the response to previous comments about ammonia, an examination of ammonia concentrations over time in all South Carolina lake and stream samples shows that ammonia concentrations overall increased from 2003 through 2008, before falling back to about where they had been before 2003. The Catawba stations followed this pattern. The cause of this pattern is not clear, but may be related to climate variability. However ammonia is typically the least important of the forms of nitrogen in these waters averaging somewhat less than 10% of the total nitrogen. The model calibration is generally better for nitrate, which usually accounts for most of the nitrogen, and total nitrogen.

United States Environmental Protection Agency

USEPA's comments were submitted after the review period had ended in an email dated March 31, 2014.

USEPA Comment 1:

"Relative error and absolute error were used primarily as metrics for comparison of simulated and observed data. Other measures used are Nash-Sutcliffe Efficiency (NSE), percent bias, ratio of RMSE to standard deviation of measured data. The other statistics were presented '*but were not used to inform the calibration process'*. The other measures should also be used to quantify the performance of the calibrated model. These other metrics particularly NSE and RMSE are indicator measures of uncertainty in model predictions. Was there any performance goal *set a-priori* for the hydrology calibration process (i.e. what was the target relative error, absolute error, etc for the calibration to be evaluated as reasonable calibration)?"

USEPA Response 1:

The additional statistics mentioned are not included within the WARMF model statistical calculations and output. The calibration was performed on a very limited budget for the size of watershed and number of constituents and calibration points included. Thus we were limited to using the tools readily available within the model for the calibration process. The target relative and absolute error are typically 10% and 20%, respectively. These are used as guides, while the calibration process was performed until parameter adjustments were no longer resulting in improvements to the simulation. As the result of comments received, SCDHEC has included Table 4-2 comparing the hydrologic simulation of the model to several performance measures for the four tributary stream segments which are the function of precipitation.

USEPA Comment 2:

"In a few cases where it is evident that the total volume of rainfall was consistently too high or too low, the meteorology coefficients were further adjusted during the calibration process. What are these coefficients? Hydrology forcing functions are normally not adjusted in the calibration process as a standard modeling practice. They are estimated independent of the calibration process."

USEPA Response 2:
Point measurements of hydrological model forcing such as precipitation must always be aggregated or adjusted by some means to produce values that are representative for the spatial scale and location of the model elements, i.e. the subcatchments. In WARMF, the nearest meteorology station to each subcatchment centroid is identified and assigned to the catchment. Precipitation and temperature multipliers are then calculated based on climatic trends across the available station network to account for climatic variability within the extent of the network. This is an alternative approach to calculating mean areal precipitation from point values to use as forcing. Using either approach, how representative the forcing is for entire subcatchment area is highly uncertain particularly if the available station network is sparse, characterized by large climatic variability, or a given catchment is located at the outer edge of the network. Bias in the meteorological forcing can lead to significant error in simulated hydrologic response. The precipitation and temperature multipliers in WARMF are calculated within the model prior to simulations and held static throughout a simulation. However if it becomes evident during the calibration process that a meteorological bias exists, it may be necessary to adjust the multipliers to improve the water balance. This is analogous to adjusting station weights in mean areal precipitation calculations if a particular station is known to be more or less representative for a given catchment area.

USEPA Comment 3:
"Twenty-two calibration stations for flow were used. The model report indicated comparisons to observe data were made at these stations. However, Table 4.1 and Figures 4-2 through 4-7 only showed a summary for six stations. In an appendix, please present the results for all stations used in the calibration process."

USEPA Response 3:
Section 4 *Hydrology Calibration Resul*ts has been adjusted in the report. The six stations presented are the primary stations used for the calibration process. The others were used for additional comparison only. There are more than 30 flow gages in the Lower Catawba Basin. However, most are on small streams, many of which are not in model or are not useful at the scale of this model.

USEPA Comment 4:
"For Figures comparing simulated flows, please indicate the USGS gage identification number for easy reference. Also, it would be helpful to the readers if in Figure 4-1, the USGS gages used in the calibration are labeled. What USGS gage was used as upstream boundary condition of the model?"

USEPA Response 4:
USGS IDs will be included in the figure captions and map of calibration locations. Lake Wylie total downstream releases provided by Duke Energy was used as the upstream boundary condition. Days with errors evident from this source were replaced with data from USGS gage 2146000.

USEPA Comment 5:
"Flow in the Catawba River is dominated by releases from Lake Wylie which have been incorporated into the simulation, while flow in the tributaries is simulated from meteorology data and watershed runoff characteristics, both of which have considerable associated uncertainty. The hydrologic calibration should focus on having a reasonable model calibration at the tributary gages. It is at these gages where model performance is critical since it would indicate how well the model describes watershed runoff characteristics. Statistics shown in Table 4-1 indicates that tributaries are simulated with larger errors, lower NSE and higher ratios of RMSE to observed mean than the main stem. (Table 4-1). Please provide additional discussion on the relevance of the calculated NSE, RSR, and RMSE. These are metrics that indicate some measures of uncertainty of the predictions of the model. For the purposes of this modeling exercise, what are the acceptable limits of NSE, RSR and RMSE?"

USEPA Response 5:
Hydrologic model calibration did focus on tributaries, very little parameter adjustment was warranted for main-stem locations. Much larger error is to be expected in the tributaries versus the main stem, which is dominated by measured releases from Lake Wylie. The model developers were limited to using the statistical tools available within WARMF for the calibration process, which do not include NSE and RSR. Identification of "acceptable limits" depends on the specific circumstances such as model type, time step, data quality/quantity, and other factors. The process to identify such limits is a very involved analysis in and of itself (see Moriasi 2007). Setting a limit for this calibration alone would be without supporting basis. Our standard practical calibration procedure aims to minimize error as much as possible in each calibration location given the project constraints (budget) and intended model application. The objectives conveyed were to minimize error in long term trends as the priority for a TMDL application, thus minimizing relative error was the main focus of calibration. SCDHEC has added Table 4-2 that provides the hydrologic calibration performance of the model for the four tributaries compared to several performance measures for total volume, low and high flows, and seasonal flows.

USEPA Comment 6:
"Was there any performance goal set *a-priori* to evaluate the goodness-of-fit of the water quality calibration? What was the target relative error, absolute error, etc for the model performance to be evaluated as reasonable calibration?"

USEPA Response 6:
The general goal for the calibration of conservative substances is 10% relative error, however the attainability of this goal is highly influenced by the quality, quantity and representativeness of observed data, all of which are often much lower for water quality parameters as compared to flow. Thus the practical goal for water quality calibration is to reduce error as much as possible given the constraints of the dataset. Like hydrology calibration, parameter adjustments were made until simulations could no longer be improved.

USEPA Comment 7:
"Similar to the hydrologic calibration, water temperature calibration for the tributaries have larger errors, lower NSE and higher RMSE. For pH, seven out of ten stations have errors larger than 10% and NSE less than zero which indicate that the mean of the observed data is a better predictor than the model."

USEPA Response 7:
As for all constituents, simulations of temperature are expected to have more error in tributaries than the main stem because the main stem simulations are dominated by the Lake Wylie boundary condition. For pH simulations, tests were performed to better understand the source and effects of the error in pH simulations in the reservoirs. The error in pH was found to not affect the priority constituents – nutrients and Chl-a. Demonstration and explanation of this was added to Section 5.10 of the report.

USEPA Comment 8:
"If TSS prediction proves to be a critical part of the TMDL allocation process, the model needs improvement on the calibration for TSS. Four out of six calibration stations have relative errors greater than +/- 35% with NSE's less than zero."

USEPA Response 8:
Due to the very limited dataset of TSS observations, statistical measures of the TSS calibration are significantly effected by errors in timing, and outliers or bias in the observed data (e.g., lack of high flow TSS sampling). In general, the quantity of TSS data does not support model evaluation with calculated statistics (Moriasi 2007), particularly without co-located flow data (i.e., several of the locations with TSS

did not have flow data for hydrology calibration). Thus calibration of TSS for watersheds with limited data focuses on simulating concentrations within the range of the observed data points, not on matching individual observations. Statistics were included for consistency in the report but were not used to inform the calibration process.

USEPA Comment 9:
"In section 5.8, the report stated that ' *to improve the daily simulation statistics (NSE, RSR, R2) each tributary would have to be calibrated for hydrology, sediment transport, and phosphorus concentrations. Currently the amount of observed hydrology and water quality data available does not support a more intensive calibration effort to improve the daily simulation statistics*.' There are USGS gages in the tributaries with periods of record that is adequate for intensive calibration."

USEPA Response 9:
This referenced statement has been reworded in Section 5.8 to clarify. At the six locations with complete USGS records of flow, intensive hydrology calibration was performed. However this constitutes only a portion of the total watershed and only 2 of the 6 main tributaries to the Catawba below Lake Wylie. The intended point is that to calibrate daily variation in any water quality constituents, complete observations at a daily time scale are necessary. Thus statistics which emphasize error in daily variation of concentration are less meaningful when complete daily observations are not available.

USEPA Comment 10:
"Calibration for five out of 10 water quality stations for TN shows relative errors greater than or less than 25%. The errors are particularly high for the tributaries. All ten stations have NSE less than 0.5. If critical to TMDL allocation scenarios, calibration should be improved for TN."

USEPA Response 10:
Some improvement has been made in TN simulations, particularly in Lake Wateree but also in Fishing and Rocky Creeks. In addition, error in tributary simulations (Fishing and Rocky Creek) was found to have very minimal effect on concentrations in the reservoirs downstream.

USEPA Comment 11:
"Calibration for four out of 10 water quality stations for TP shows relative errors greater than or less than 25%. Similar to TN calibration, the errors are particularly high for the tributaries. All ten stations have NSE less than 0.5 or RSR > 0.7. If critical to TMDL allocation scenarios, calibration should be improved for TP.'

USEPA Response 11:
Some improvement has been made in TP simulations in Lake Wateree. Error in tributary simulations (Fishing and Rocky Creek) was found to have very minimal effect on concentrations in the reservoirs downstream.

The United States Fish and Wildlife Service (USFWS)

USFWS Comment 1:

"Compared to other aquatic species, freshwater mussels are extremely sensitive to water quality degradation, including high nutrient levels and increases in suspended sediments. Therefore, the Service is particularly interested in the water quality calibration results presented in the 2014 draft report. As stated in the report, SCDHEC's objective is to develop a watershed model capable of simulating temperature, dissolved oxygen, total suspended sediment, nutrients and algae in the Catawba River Watershed between Lake Wylie and Lake Wateree. Water quality data used to calibrate the model was taken from 85 locations between Lake Wylie and Lake Wateree. However, the majority of these data collection points are located in areas lower in the watershed (nearer the reservoirs), and outside of habitat for protected species. Therefore, the Service is concerned that the largest cause of water quality degradation in the upper reaches of the watershed, non-point source pollution, is not being fully accounted for in the model. In their 2013 technical memorandum, Systech Water Resources, Inc. states that Phosphorus is significantly over predicted by the model in Fishing Creek (e.g., segment 10 149) throughout both run periods. They go on to say that loading plots indicate that non-point sources, particularly from pasture land use but from other land uses as well, are the main sources of total phosphorus in Fishing Creek. Systech recommends that recalibration efforts in Fishing Creek should focus on model inputs that affect non-point sources of total phosphorus such as land application and livestock exclusion. The Service agrees and strongly encourages SCDHEC to investigate non-point sources as primary causes of impairment throughout the LCB."

USFWS Response 1:

The Department acknowledges USFWS concern regarding headwater habitats for protected species. The Catawba Nutrient TMDL effort and the WARMF model used to develop the TMDL include and will address nonpoint sources to the extent that they contribute to nutrient impairments in the Catawba lakes. Additional WARMF model calibration has been performed by Systech, as documented in the July, 2014 WARMF model calibration report. As a result, phosphorus simulation for Fishing Creek and Rocky Creek has improved. Nitrogen simulation in these areas, however, is poor. Based on the sensitivity work by Systech documented in Section 5.3 of the calibration report, error in the nitrogen simulation in the tributaries is not likely to adversely affect model results in the downstream lakes which is the focus of the TMDL effort.

While nonpoint sources may be the main source of impairment in some areas, model runs indicate the major source of nutrient impairment in the Catawba lakes, where this TMDL will be applied, are point sources as shown in Figures B-1 through B-8. However, as noted above, all sources contributing to nutrient impairments in the lakes will be addressed by the TMDL.

USFWS Comment 2:

"Nutrient and sediment contributions from non-point sources, particularly land application of biosolids and pasture land use, have continued to impact Carolina heelsplitter populations and aquatic habitat in small streams throughout the LCB. In some portions of the LCB, there are virtually no permitted point source discharges, yet streams are still listed on the 303(d) list as impaired, indicating the large role non-point sources are playing in nutrient and sediment issues, and use impairments. For example, South Fork Fishing Creek is impaired for aquatic life use (station# CW-0007) even though there are no permitted point-source discharges into the stream. The same is true for Gills Creek in Lancaster County (station # RS-07043). Both streams contain occupied habitat for the Carolina heelsplitter, and both have experienced declines in population numbers."

USFWS Response 2:

The Department acknowledges USFWS concerns regarding nonpoint sources and potential impacts to Carolina heelsplitter populations and aquatic habitat in small streams in the basin. As discussed above, the focus of this nutrient TMDL is attainment of water quality standards in the Catawba lakes.

USFWS Comment 3:

"The Service welcomes the opportunity to work with SCDHEC to ensure that endangered species concerns are addressed through water quality monitoring efforts, as well as TMDL development and implementation. It will be especially important to ensure that proposed TMDL Wasteload and Load Allocations reflect the habitat and water quality requirements of the Carolina heelsplitter, as well as other sensitive aquatic species in the LCB.
Please note that obligations under the ESA must be reconsidered if: (1) new information reveals impacts of this identified action may affect any listed species or critical habitat in a manner not previously considered; (2) *this* action is subsequently modified in a manner, which was not

considered in this assessment; or (3) a new species is listed or critical habitat is designated that may be affected by the identified action."

USFWS Response 3:

Federally-endangered species, such as the carolina heelsplitter, are considered as the 303 (d) list of impaired waters is developed and sites impaired for aquatic life are prioritized for future TMDL development. The WARMF model application will be used to develop TMDLs that address nutrient impairments in the downstream reservoirs. Reductions in nutrients should result in attainment of the aquatic life use for those pollutants in the target waterbodies. TMDLs may be revised at any time and at the discretion of the Department.

Additional Amendments

The following additional amendments were made by the Department to the draft *Catawba River WARMF Model Calibration Report* after the 30-day public comment period. These amendments were not made as a result of written comments received but may have been result of an error in or a clarification of descriptive information.

Amendment 1:

See Addendum as well as Appendices B and C.