Falls Lake Watershed Analysis Risk Management Framework (WARMF) Development

FINAL REPORT

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PURPOSE

This report provides documentation on the development of a watershed model for Falls Lake in North Carolina. The report follows the standard format used for modeling documentation and includes information on model inputs, assumptions, calibration and validation results, and nutrient loading from various watershed sources. The watershed model provides only one line of evidence to aid in the development of a nutrient management strategy. **The results presented in this report are not meant to serve as the sole framework for a management strategy.**

ACKNOWLEDGEMENTS

The Falls Lake watershed model was developed under the guidance of the Falls Lake Technical Advisory Committee (TAC). The NC Division of Water Quality appreciates the data provided by the TAC for model development as well as the helpful advice and recommendations regarding model selection, calibration locations, and performance criteria. We also appreciate the TAC's review of the initial draft model and draft report. Finally, we greatly appreciate the technical assistance provided by the watershed model developers, Systech, Inc, throughout this process.

TAC members included representatives from the Neuse Riverkeeper Foundation, City of Durham, City of Raleigh, Wake County, NC Division Soil and Water Conservation, NC Department of Transportation, URS Corporation (representing the NC Department of Transportation), Triangle J. Council of Governments, South Granville Water and Sewer Authority, Durham County, and NC Division of Water Quality.

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List of Acronyms

AE	Average Error
ANSWERS	Areal Non point Source Watershed Environment Response Simulation
BASINS	Better Assessment Science Integrating Point and No point Sources
BMP	Best Management Practice
BOD	Biological Oxygen Demand
CASTNET	Clean Air Status and Trends Network
CE	Coefficient of Efficiency
CGIA	North Carolina Center for Geographic Information and Analysis
CMS	Cubic Meters per Second
CSTR	Continuously Stirred Tank Reactor
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DSWC	North Carolina Division of Soil and Water Conservation
DWQ	NC Division of Water Quality
EMC	Environmental Management Commission
EPA	United States Environmental Protection Agency
GIS	Geographic Information System
GPD	Gallons Per Day
HSPEXP	Expert System for Calibration of HSPF
HSPF	Hydrological Simulation Program--Fortran
ILWAS	Integrated Lake-Watershed Acidification Study
LA	Load Allocation
MRLC	Multi-Resolution Land Characteristics Consortium
NADP	National Atmospheric Deposition Program
NCDOT	NC Department of Transportation
NH4	Ammonium
NLCD	National Land Cover Data
NO3	Nitrate
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
pBias	Percent Bias
R2	R-square
RE	Relative Error
RMSE	Root Mean Square of Error
RMSE/SDobs	Ratio of Root Mean Square Error and Standard Dev. For Obs. Data
SCS	Soil Conservation Service
SDobs	Standard Deviation For Observational Data

SSO	Sanitary Sewer Overflow
SWMM	Storm Water Management Model
TAC	Technical Advisory Committee
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Sediment
UNRBA	Upper Neuse River Basin Association
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WARMF	Watershed Analysis Risk Management Framework
WASP	Water Quality Analysis Simulation Program
WDT	Watershed Deposition Tool
WLA	Waste Load Allocation
WRF	Water Reclamation Facility
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

1.0 Introduction

In 2005, the North Carolina General Assembly passed Session Law 2005-190 (also referred to as Senate Bill 981), which directed the Environmental Management Commission (EMC) to study drinking supply reservoirs and develop and implement a nutrient management strategy for reservoirs that were listed as impaired or that will be impaired by 2010. Falls Lake was listed on North Carolina's Draft 2008 303(d) list as impaired for chlorophyll-*a*. The portion of the lake west of I-85 was also listed for turbidity.

This report provides information on the development, calibration, and validation of the Watershed Analysis Risk Management Framework (WARMF) in the Falls Lake Watershed. The purpose of this watershed model, although not required by Senate Bill 981, is to aid in the development of a nutrient management strategy for Falls Lake.

1.1 Project Background

The 770 square-mile Neuse River Subbasin (03-04-01), also referred to as the Falls Lake Watershed or Upper Neuse Basin, is located in the northeastern Piedmont of North Carolina and makes up the northern portion of the Neuse River Basin. The watershed spans portions of six counties including parts of Durham and Raleigh. Over 90,000 people reside in the watershed with the population projected to double by the year 2025. The Raleigh-Cary area was the fastest growing metro area in the country between years 2007 and 2008 with a 4.3 percent population increase (U.S. Census, 2009). Nine water supply reservoirs in the watershed, including Falls Lake, serve 500,000 people (NC DWQ, 2008). Land cover in the watershed is approximately 58 percent forest, 18 percent agriculture, and 11 percent developed.

The Flat, Little, and Eno Rivers make up the three major headwaters on the western portion of the watershed. The confluence of the Flat and Little Rivers form the beginning of Falls Lake and the Neuse River, which then stretches approximately 28 stream miles east to the Falls Lake Dam. Other major tributaries in the watershed are Ellerbe Creek, Knap of Reeds Creek, Ledge Creek, Lick Creek, Little Lick Creek, and Beaverdam Creek (Figure 1).

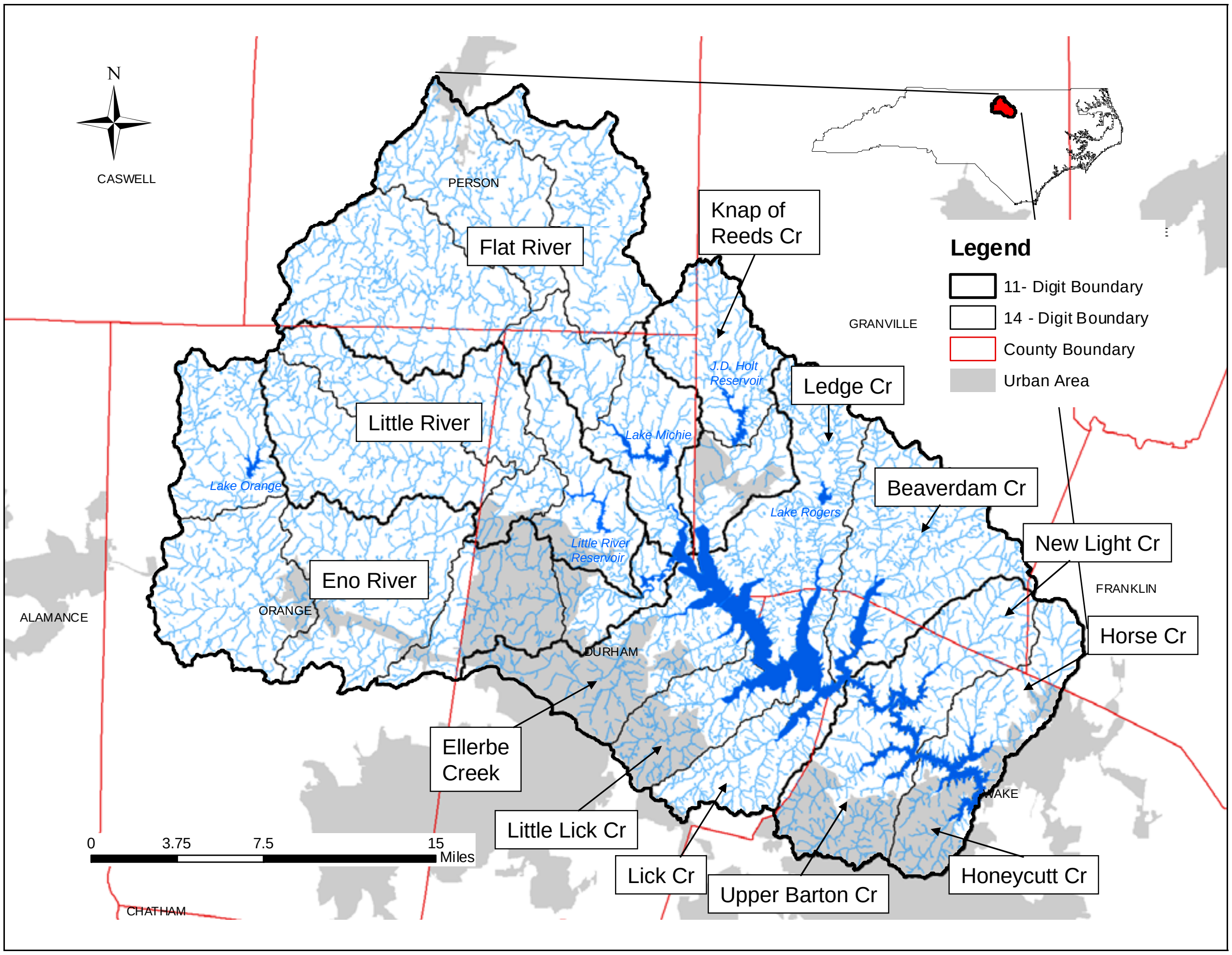

Figure 1. Location of the Falls Lake Watershed

Falls Lake was originally constructed for the purposes of flood protection, water supply, water quality control, and recreation in the Neuse Basin (Army Corps of Engineers, 1974). Construction of the Falls Lake Reservoir was completed in 1981 and the gates on the dam were closed in January 1983.

Water quality in the lake was subsequently monitored from the summer of 1983, when the lake reached normal pool level, through 1987. Water quality study reports indicate that the chlorophyll-*a* standard of 40 µg/l was exceeded in years 1983-1987 by 29, 58, 53, and 24 percent, respectively (Water and Air Research, Inc, 1988). Monitoring in later years indicated continuing chlorophyll-*a* standard exceedances in the lake.

In July 2003, the Upper Neuse River Basin Association (UNRBA), in collaboration with Tetra Tech, Inc., developed the Upper Neuse Watershed Management Plan. The report includes a 25-year projected assessment of water quality conditions at various build densities under the current regulations. The plan also provided management strategies and recommended municipality ordinance changes to protect water quality. The document is available online at http://www.unrba.org/downloads.htm#techreps. The DWQ Neuse River Basinwide Water

Quality Plans provide additional information on the current and historical conditions of the Falls Lake watershed and are available online at http://h2o.enr.state.nc.us/basinwide/.

1.2 Technical Advisory Committee

DWQ convened a technical advisory committee (TAC) in July 2005 to assist with development of mathematical tools for the management of nutrients in Falls Lake. The TAC is a subgroup of the Falls Lake stakeholders and is primarily comprised of members of state and local governments and the Upper Neuse Riverkeeper.

The TAC met monthly from July 2005 until February 2006 and provided recommendations for monitoring, model development, and performance criteria. The TAC then met periodically, about every six months, to receive updates and provide input on model development.

The TAC has helped shape many aspects of the watershed modeling process including:

- Providing data used to drive the watershed model, including: sand filter information, NCDOT (Department of Transportation) land application rates and system coefficients, agriculture land application rates, Doppler radar precipitation estimates, atmospheric deposition of nitrogen, watershed reservoir information, and sanitary sewer overflow data.
- Providing input on the watershed model selection criteria including daily output, simulating BMPs, and simulating atmospheric deposition.
- Providing input on calibration locations and model performance criteria.

After DWQ developed, calibrated, and validated the initial draft watershed model, TAC members were offered the opportunity to review the model calibration and provide comments and suggestions on possible ways to improve the calibration. A summary of the comments is provided in Appendix A.

2.0 Modeling Approach

2.1 Watershed Model Selection

The Watershed Analysis Risk Management Framework (WARMF) was selected for this study because of its capability to assess the impact of point and nonpoint sources in a large watershed with varying land cover and management conditions. It is incorporated with a decision support system designed to support the watershed approach and Total Maximum Daily Load (TMDL) calculations. It has the potential to educate stakeholders on how meteorological factors impact hydrology and nonpoint loads; how land use affects nonpoint loads; how point and nonpoint loads are spatially distributed; how point and nonpoint loads translate to water quality in rivers and lakes; and whether the water quality is suitable for a particular intended use. In addition, the WARMF user interface is much more user-friendly than most other watershed models with a similarly comprehensive formulation.

One of the important processes of WARMF is that it is designed to assess on-site wastewater systems separately, which is missing in most watershed models. WARMF allows liquid septic tank effluents to be released to the sub-surface with a specified flow rate and nutrient composition. Most other watershed models require simulating the septic inputs as applied with irrigation or as fertilizer. Once set up, it is a stand-alone tool that can be easily distributed to stakeholders who may not have access to ArcView.

Overall, WARMF is the most suitable watershed model to meet the criteria recommended by the TAC. However, a few weaknesses exist. Like most watershed models, WARMF does not thoroughly simulate ground-water processes. It models up to the shallow ground water zone for the exchange between the surface water and the unsaturated zone. It does not model deep groundwater aquifers.

2.2 Model Description

WARMF is organized into five linked modules (WARMF, 2001):

1. The Engineering module simulates the hydrology and water quality for the landscape of a river basin.
2. The Data module provides time series input data (meteorology, air quality, precipitation quality, point source discharge, and reservoir flow release data) and calibration data.
3. The Knowledge module is a utility to store important documents for the watershed.
4. The Consensus module follows the guidelines of the watershed approach issued by the US Environmental Protection Agency (EPA).
5. The TMDL module estimates TMDLs for nonpoint source loads (LA) under different control levels of point source loads (WLA) and vice versa.

The last two modules are roadmaps to provide guidance for stakeholders during the decision-making process.

WARMF contains several embedded models adapted from the ILWAS, ANSWERS, SWMM, and WASP models. The model simulates hydrology and water quality for different landscapes of a river basin. It divides a river basin into a network of land catchments (including canopy and soil layers), stream segments, and lake layers for hydrologic and water quality simulations. Land surface is characterized by land use / land cover and precipitation is deposited on the land catchments to calculate snow and soil hydrology and the resulting surface runoff and groundwater accretion to river segments. Water is then routed from one river segment to the next, from river segments to reservoirs, and then from reservoir to river segments, until the watershed terminus is reached. Instead of using export coefficients, a complete mass balance is performed starting with atmospheric deposition and land application as boundary conditions. Pollutants are routed with water in throughfall, infiltration, soil adsorption, exfiltration, and overland flow. The sources of point and nonpoint loads are routed through the system with the mass so that the source of nonpoint loading can be tracked back to land use and location.

For simulating a landscape, WARMF uses a dynamic water balance based on the physical processes of snow, soils, and surface hydrology rather than empirical methods such as the Soil Conservation Service runoff method. It uses physically based algorithms that track the mass balance and geochemistry through the soil layers rather than using specified soil concentrations. It divides a watershed into land catchments, river segments, and reservoirs and uses the continuously stirred tank reactor (CSTR) model for flow routing and mass balance within a given soil layer or river segment. All the assumptions related to CSTR formulation apply to the model. Simulated parameters include flow, temperature, water depth and velocity, and water quality constituents such as nutrients (nitrogen and phosphorus species), total suspended sediment (TSS), biological oxygen demand (BOD), dissolved oxygen (DO), fecal coliform bacteria, and chlorophyll-*a*.

For simulating a stratified reservoir, WARMF divides the reservoir into about 30-layers to simulate hydrology and water quality simultaneously. Each layer is assumed to be horizontally mixed. Bathymetric data in the form of stage-area, stage-flow, and inflow-outflow relationships are the required model inputs.

2.3 Model Setup

The automatic watershed delineation tool provided in the EPA BASINS 3.1 framework was utilized to delineate the Falls Lake watershed using the stream coverage reach file and digital elevation model (DEM) maps. The reach file was initially digitized from the USGS 1:24000 topographic maps and then was masked with the reservoir layer in ARC/INFO format. The DEMs in grid format for the watershed were obtained from the BASINS database. Resolution of the DEM used for this study was 30 by 30 meters. A total of 114 catchments, 74 river segments, and 6 reservoirs were delineated to estimate geometric and geographic information of each catchment and stream. Major tributaries included were Knap of Reeds Creek, Flat River, Little River, Eno River, and Ellerbe Creek; as well as smaller tributaries in the middle and lower watershed. In addition to Falls Lake there were five reservoirs included: Lake Michie, J.D. Holt Reservoir (Lake Butner), Lake Rogers, Lake Orange, and Little River. The watershed includes parts of Orange, Person, Granville, Durham, Wake, and Franklin counties in North Carolina. The watershed constitutes approximately 770 square miles.

After generating the BASINS 3.1 delineation files, the shape files of catchments, river/streams (including reservoirs), and land cover were exported into WARMF (Figure 2). WARMF assigns a hydrologic coefficient to each catchment layer, river/stream layer, and land cover layer in each sub-watershed after importing the files to estimate hydrologic responses and nutrient pools. The watershed delineation and data management processes are well documented (Systech, 2005).

In February 2007, DWQ entered into a contract with Systech Engineering, Inc. (Systech) to further update WARMF to link the sub-watersheds together into a seamless system so that flow paths were correctly connected to river and reservoir segments and directed from upstream to downstream. A report from Systech is attached in Appendix B.

WARMF was then populated with measured data for 2004 through 2007 for meteorology, rain chemistry, air quality, major point source discharge, onsite discharge, gage flow, and water quality to calibrate and validate the model.

Calibration and validation of the model was limited to the five major subwatersheds, located in the upper part of the Falls Lake watershed, and include Knap of Reeds Creek, Flat River, Little River, Eno River, and Ellerbe Creek. While the model was set-up for the entire Falls Lake watershed, it was not calibrated for the smaller subwatersheds in the lower part of the watershed. This is primarily due to limited available flow and water quality data and the time constraints of this study. There is also substantial uncertainty associated with transferring the calibrated parameters to the lower subwatersheds due to differences in land cover, hydrology, topography, and soil properties.

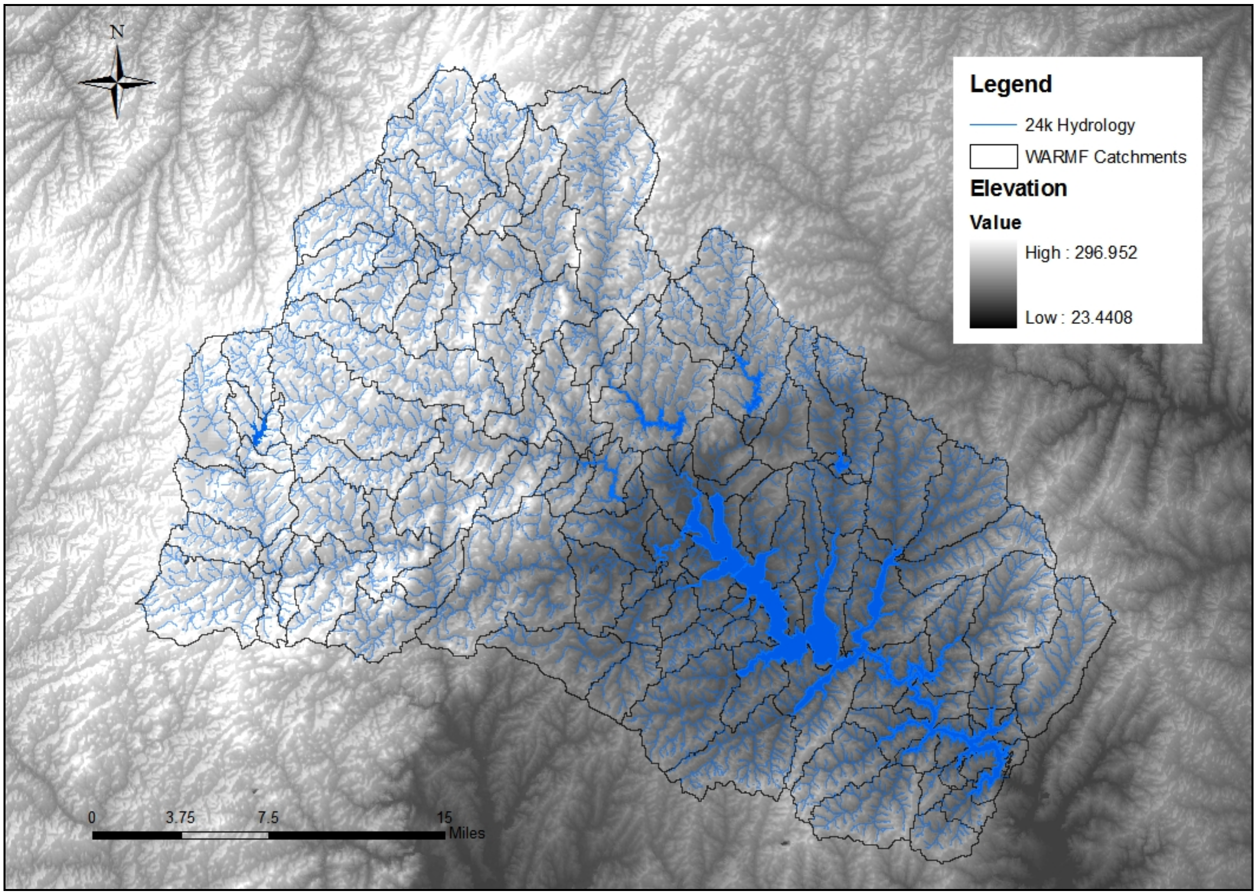

Figure 2. Model Catchments as delineated by BASINS

3.0 Model Input

3.1 Land Cover

The 2001 National Land Cover Data (NLCD) was used to provide land cover data (Figure 3). The City of Durham also provided higher resolution local land use data for the Ellerbe Creek and lower Eno River watersheds. However, the land use classifications were inconsistent with the NLCD classification system used in the remainder of the watershed. NLCD was produced by the Multi-Resolution Land Characteristics Consortium (MRLC), made up of nine government agencies, and uses the same 30-meter grid system from the previous 1992 NLCD. Improvements in classification algorithms and other improvements in image processing have increased accuracy for 2001. Due to these changes and slight differences in land categories pixel-to-pixel comparison between the two NLCD years is not recommended (US EPA, 2007). The NCDOT also integrated the road network right-of-way with the 2001 NLCD as an additional land class. Methodology used for this integration is included in Appendix B.

The land cover shapefile was imported into WARMF and converted into percentages of land cover type for each model catchment. Land coverage in the watershed is shown in Figures 4 and 5. Distribution of land coverage by 14-digit hydrologic unit is shown in Table 1.

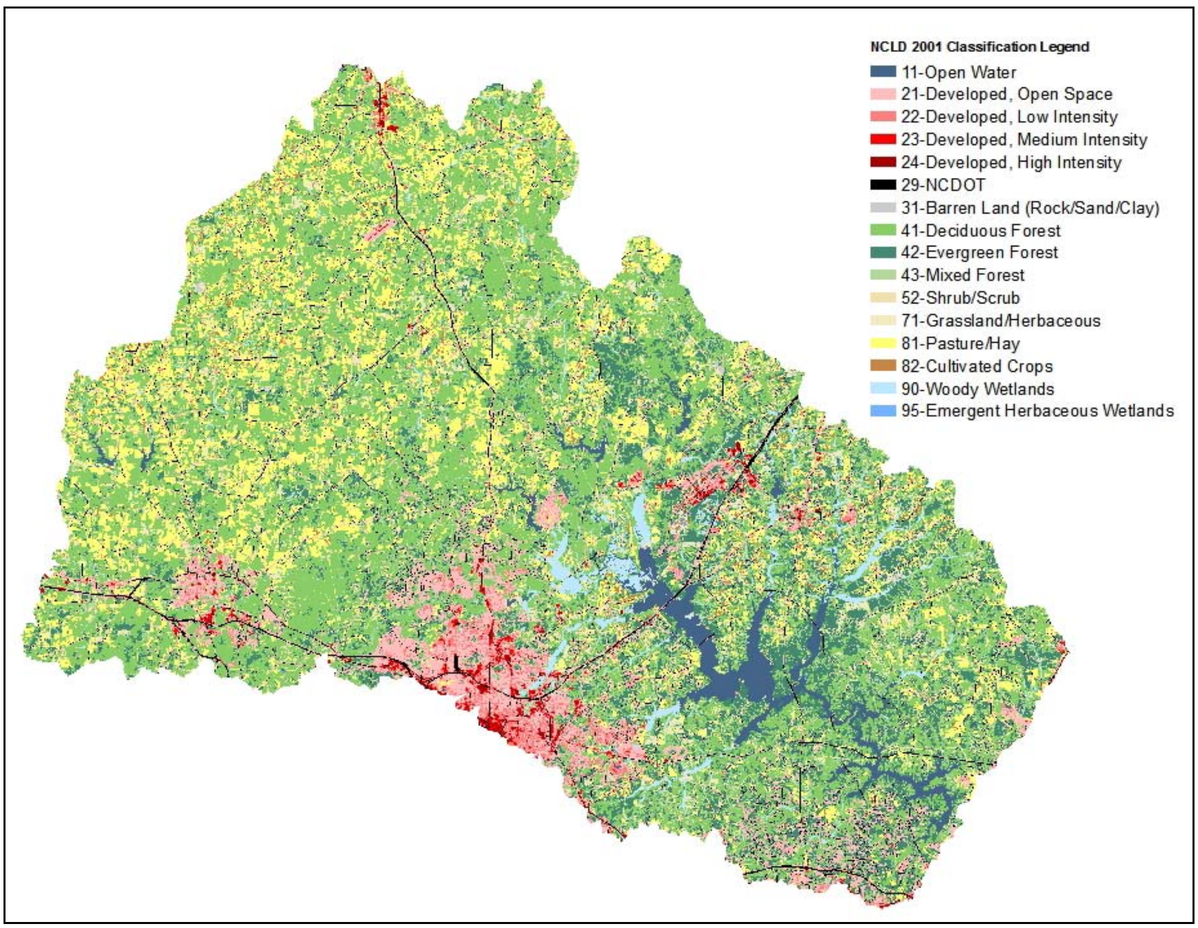

Figure 3. 2001 NLCD of the Falls Lake Watershed.

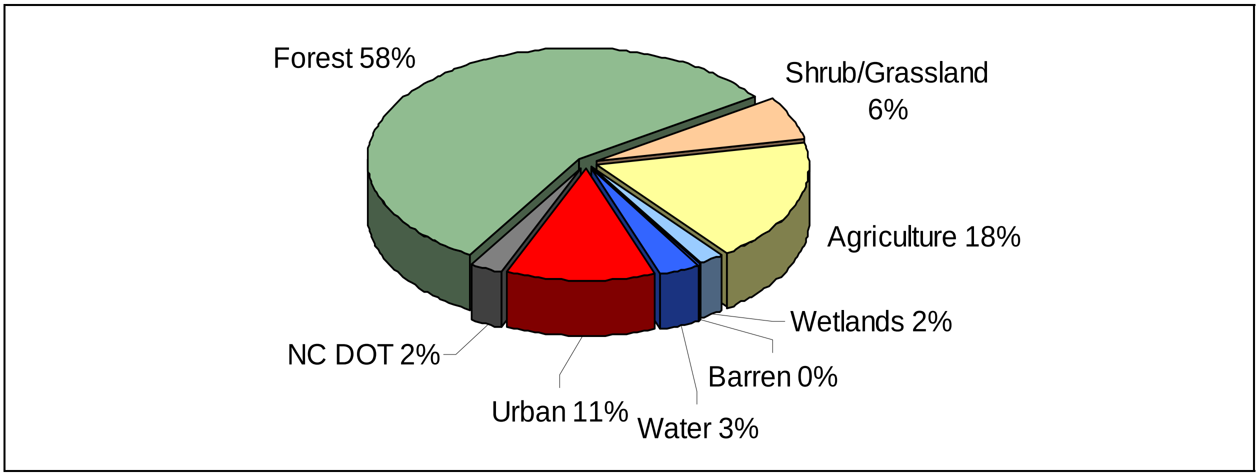

Figure 4. Consolidated Land Cover Distribution in the Falls Lake Watershed.

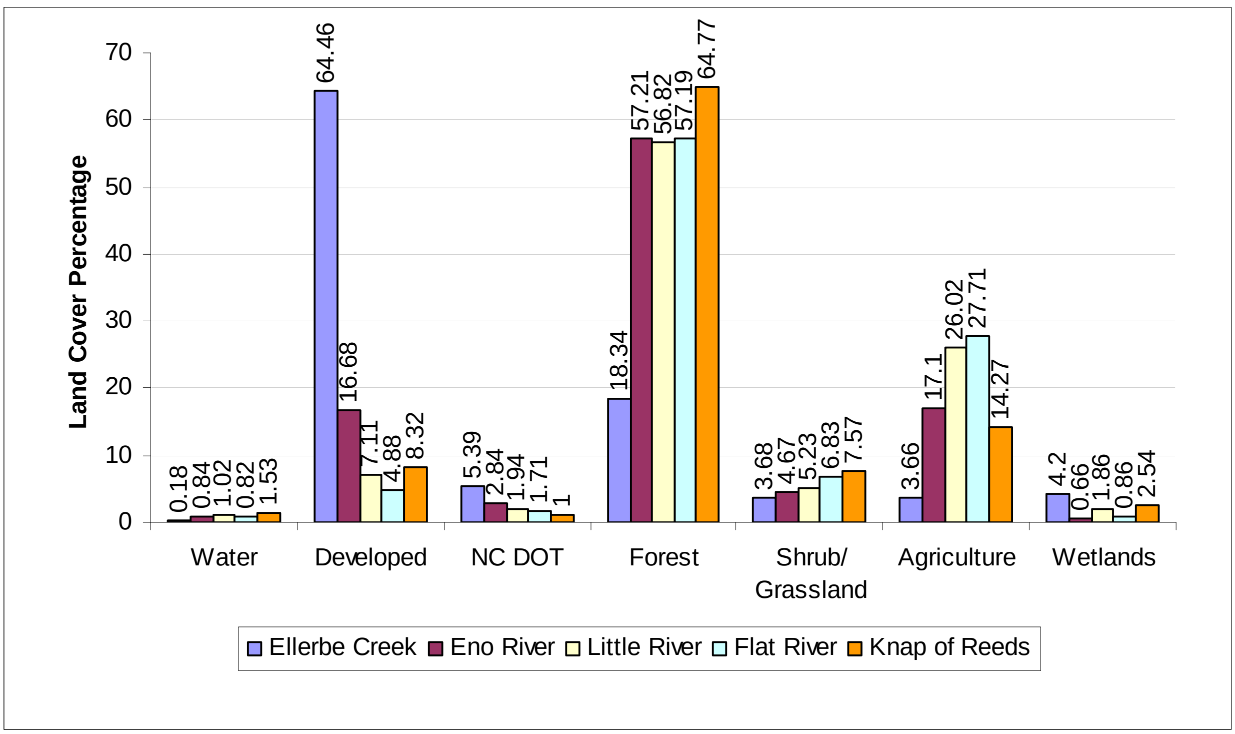

Figure 5. Consolidated Land Cover Distribution for Calibrated Watersheds.

Table 1. 2001 NLCD Land Cover Distribution (acres) by 14 digit HUC

HUC 0302020-	Open Water	Developed Open Space	Developed, Low Intensity	Developed, Medium Intensity	Developed, High Intensity	NC Department of Transportation	Barren Land	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub/Scrub	Grassland/Herbaceous	Pasture/Hay	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands	Total
1010010	88	1,006	387	210	139	545	25	11,013	924	668	467	1,129	7,026	421	179	7	24,234
1010020	155	1,266	215	31	6	615	86	16,461	1,608	1,221	688	1,500	10,413	1,007	101	8	35,380
1010030	57	359	47	2	0	179	15	4,366	1,296	449	146	428	2,111	124	98	4	9,681
1010040	61	596	53	2	1	230	27	10,280	1,141	919	537	1,007	3,795	314	278	3	19,245
1010050	566	683	86	10	0	163	20	7,095	2,594	768	403	890	2,853	175	508	33	16,849
1020010	105	966	116	9	14	316	3	9,563	1,630	928	378	836	5,612	360	283	0	21,120
1020020	98	1,084	87	11	1	382	22	11,312	2,175	877	452	814	7,225	271	185	2	24,997
1020030	18	383	29	4	0	131	2	2,901	577	279	53	172	729	14	25	0	5,316
1020040	455	1,746	186	25	1	465	15	6,037	1,267	625	144	652	3,262	105	699	0	15,684
1030010	423	700	115	3	0	202	10	6,878	749	330	350	382	4,876	341	116	2	15,475
1030020	109	2,281	583	211	69	738	21	10,984	2,021	772	487	747	4,508	100	139	6	23,776
1030030	100	2,407	426	166	50	897	5	16,165	2,197	1,117	510	883	4,490	124	97	8	29,642
1030040	71	4,741	1,091	233	54	638	15	5,479	2,144	1,016	89	319	807	25	68	2	16,792
1030050	107	1,395	487	240	90	206	20	2,455	953	363	197	430	450	109	819	8	8,327
1040010	404	377	27	2	0	124	62	7,961	3,178	900	398	1,029	2,517	175	176	2	17,335
1040020	98	1,158	493	217	96	163	62	3,070	2,768	586	125	574	1,211	79	766	11	11,476
1050010	369	5,660	2,924	1,253	480	976	24	3,817	2,539	790	303	930	1,342	315	1,372	36	23,130
1050020	139	2,551	1,162	152	12	394	56	3,236	2,600	770	201	810	1,182	123	479	8	13,873
1050030	96	636	97	47	9	260	24	5,654	3,467	1,143	233	912	858	64	476	4	13,982
1050040	3,133	9	2	0	0	28	1	38	43	4	0	17	1	1	8	7	3,292
1060010	760	1,845	653	199	80	915	82	7,737	6,907	2,006	525	2,113	3,822	781	1,174	60	29,658
1060020	474	1,111	267	68	14	442	62	8,300	8,498	3,026	489	2,416	3,780	754	1,456	20	31,178

HUC 0302020-	Open Water	Developed Open Space	Developed, Low Intensity	Developed, Medium Intensity	Developed, High Intensity	NC Department of Transportation	Barren Land	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub/Scrub	Grassland/Herbaceous	Pasture/Hay	Cultivated Crops	Woody Wetlands	Emergent Herbaceous Wetlands	Total
1060030	3,581	6	2	0	0	19	3	25	26	3	1	46	0	0	11	9	3,734
1065010	196	537	42	1	0	224	11	6,728	4,095	2,029	283	754	2,050	68	260	1	17,280
1065020	128	1,079	145	29	4	473	7	4,764	3,613	1,387	173	583	2,121	60	127	3	14,697
1065030	221	3,026	258	44	2	1,065	17	6,525	4,356	1,374	52	497	1,214	34	277	9	18,970
1065040	124	1,630	186	39	2	547	2	2,121	2,642	423	21	192	466	7	20	0	8,423
1065050	2,454	4	0	0	0	15	0	85	94	11	1	10	1	0	1	1	2,678
Total	14,589	39,242	10,165	3,208	1,124	11,353	697	181,050	66,105	24,785	7,708	21,073	78,723	5,953	10,197	255	476,225

Note: 1 acre = 0.404685642 hectares

3.2 Climate

The hydrologic model in WARMF uses daily precipitation, minimum and maximum temperatures, and daily-averaged cloud cover, dew point temperature, air pressure, and wind speed. Data from seven weather stations in or near the watershed were used for model input, and ten Doppler-estimate locations were chosen to provide additional precipitation coverage (Figure 6). All data originated from the NC State Climate Office. Missing data or parameters for some weather stations and all Doppler-estimate stations were filled in with available data from the nearest station. For example, dewpoint, air pressure, and windspeed data from the Raleigh/Durham Int. Airport (KRDU) were transferred to the Falls Lake station (312993) that does not measure these parameters. Each catchment in the model is manually assigned data from the most proximate site. A summary of monthly versus average rainfall totals is shown in Figure 7.

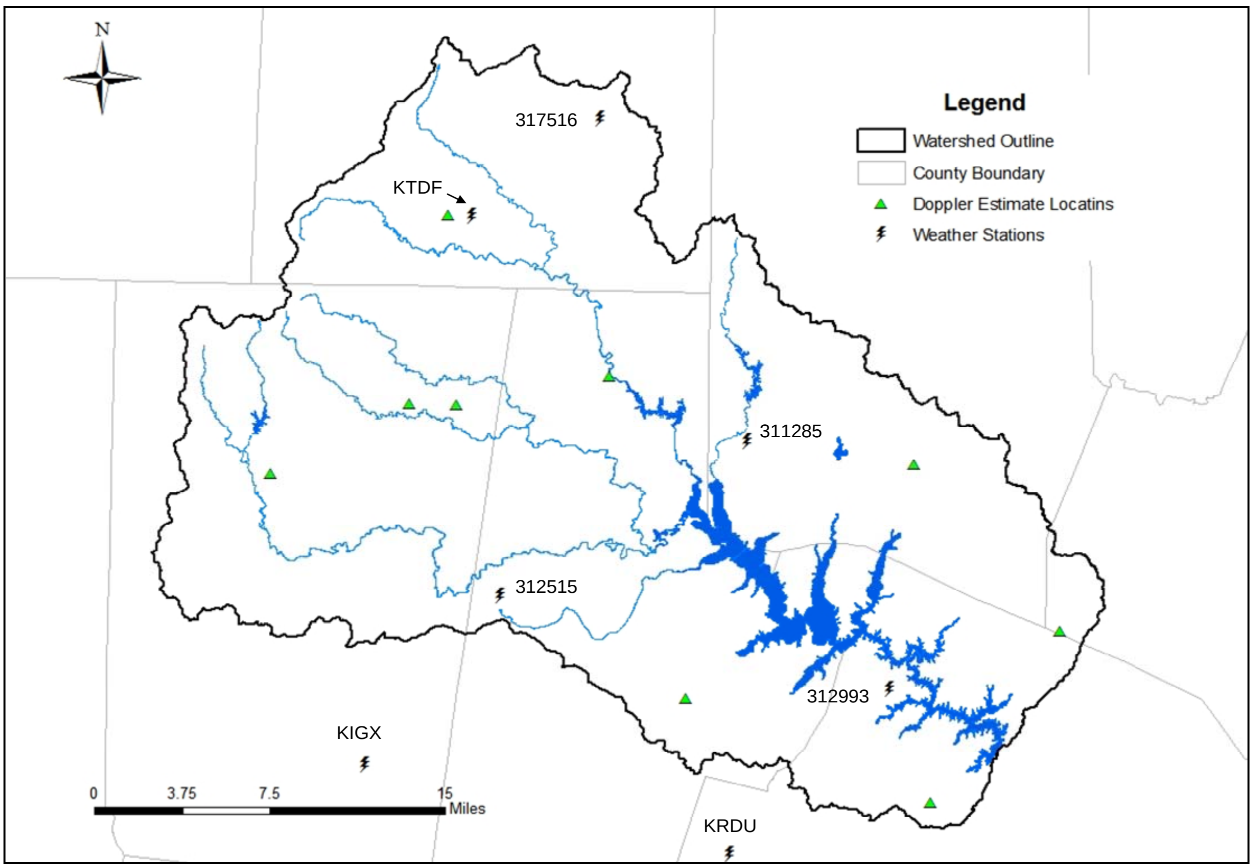

Figure 6. Meteorological stations used in the Falls Lake Watershed model

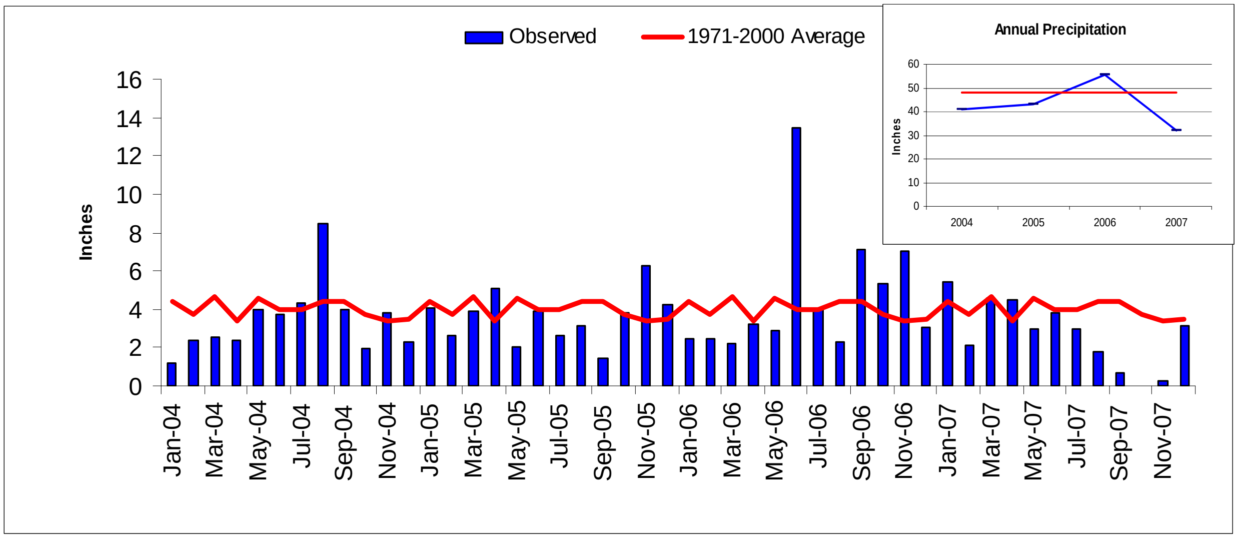

Figure 7. Durham Station 312515 Observed vs. Average Monthly Precipitation

3.3 Soil Coefficients and Sediment

WARMF uses catchment specific soil coefficients to represent hydrologic parameters, initial concentrations, initial adsorption saturation, mineral composition, and inorganic carbon.

The soil coefficients for hydrology parameters were determined by using layer depth and physical and engineering properties from the ten most common soil types in each catchment. This involved obtaining soil survey spatial coverage for the watershed and soil type properties from the USDA-NRCS Soil Data Mart. ArcGIS was used to extract soil type coverage from model catchments and exported to an Excel spreadsheet to be analyzed. The resulting model input included a weighted average (based on percent coverage) of soil layer depth, initial moisture, field capacity, saturated moisture, vertical conductivity, and bulk density. The horizontal hydraulic conductivity coefficient was originally assumed to equal vertical conductivity, and then altered to improve flow calibration.

Sediment and erosion were simulated by providing surface particle distributions for clay, silt, and sand; and transport coefficients for erosion and sediment. Fractions of clay, silt, and sand were determined by using the given soil texture for each soil type paired with the corresponding particle distribution based on the soil textural triangle. The erosivity factor was adjusted as needed to improve total suspended sediment calibration.

3.4 Stream Flow and Water Quality Calibration Stations

Daily stream flow data was included in the watershed model from eight USGS stream gages within the watershed; however, stations 02086849 (Ellerbe Creek) and 02086624 (Knap of Reeds Creek) were not operational until 2006. Water quality data collected by DWQ at six ambient monitoring sites and data from two USGS gages were used to calibrate nutrients (Table 2). In support of the modeling study, DWQ increased the sampling frequency of the ambient water quality stations to twice per month from March 2005 through September 2007. The locations of the flow and water quality stations are shown in Figure 8.

Table 2. Falls Lake Watershed WARMF Model Flow and Water Quality Stations

Watershed	Gage Station	Water Quality Station	Flow	Water Quality
			Project Years (2004-2007) Data Availability	
Knap of Reeds Creek	USGS 02086624	J1210000	2006-2007	2005-2007
Flat River	USGS 02085500	USGS 02085500	2004-2007	2004-2007
Flat River below Lake Michie	USGS 02086500	J110000	2004-2007	2004-2007
Little River above LR Reservoir	USGS 0208521324	J0820000	2004-2007	March 2005-2007
Little River below LR Reservoir	USGS 0208524975	USGS 0208524975	2004-2007	2004-2007
Eno River near Hillsborough	USGS 02085000	-	2004-2007	NA
Eno River at SR 501 near Durham	USGS 02085070	J0770000	2004-2007	March 2005-2007
Eno River at SR 1004 near Durham	-	J0810000	NA	2005-2007
Ellerbe Creek	USGS 02086849	J1330000	2006-2007	2004-2007

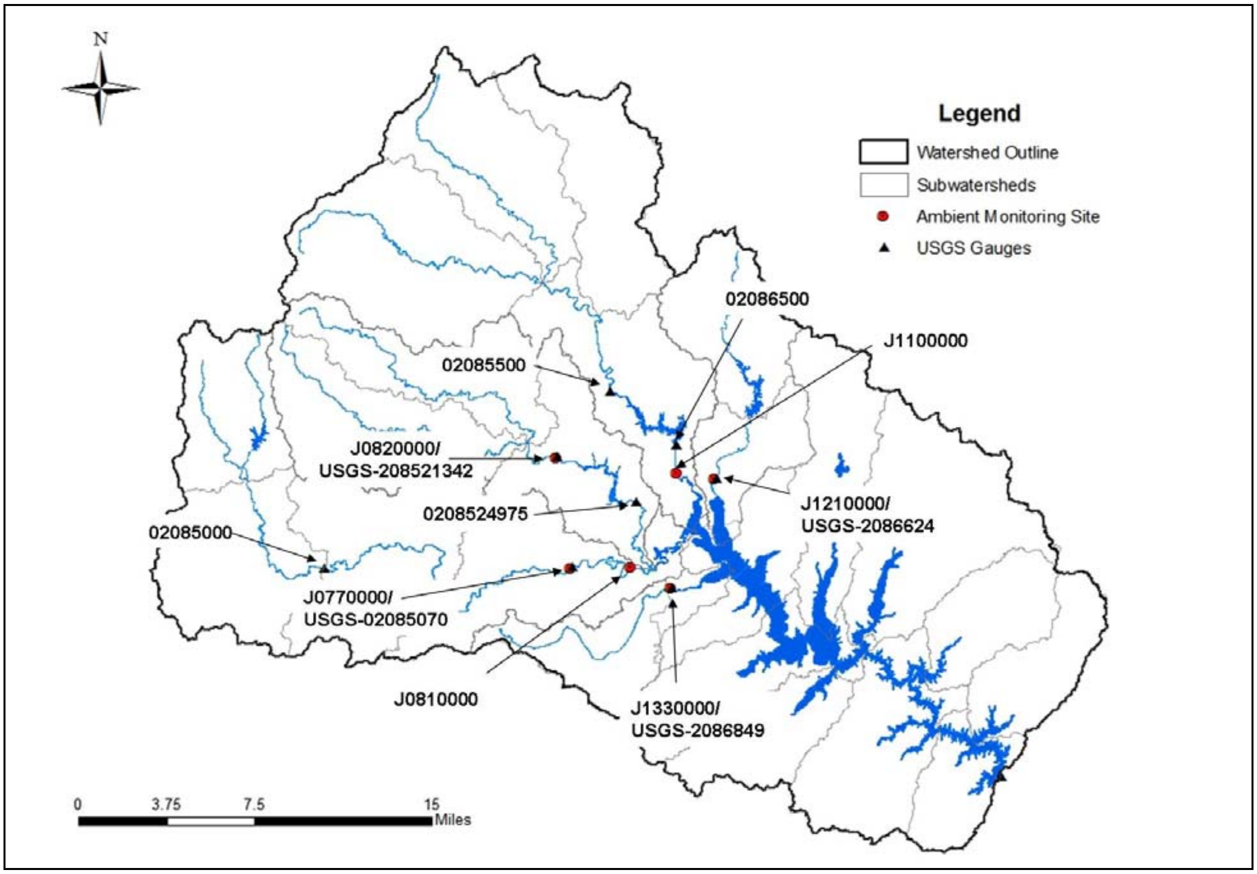

Figure 8. Falls Lake Watershed WARMF Model Calibration Stations

3.5 Watershed Reservoirs and Surface Water Intakes

There are nine reservoirs in the Falls Lake watershed. Those included in the model are shown in Figure 1. While the focus of this effort was not to model water quality within these reservoirs, the daily flow coming out of these reservoirs was needed to maintain the water balance and improve the flow calibration. In addition, most of the catchments have surface water intakes to withdraw water. Daily withdrawal data was also needed for the flow calibration.

Dam releases from reservoirs and withdrawals by surface water intakes are both included in the watershed model as managed flow. Managed flow can refer to dam releases from reservoirs (an input of flow to the system) or withdrawals by intakes (a diversion of flow out of the system).

3.5.1 Knap of Reeds Creek Watershed

There is one reservoir in the Knap of Reeds Watershed, J.D. Holt Reservoir (also called Butner Lake). There is no required minimum release for J.D. Holt Reservoir. Daily release and daily elevation were not available for the modeled time-period. There is a USGS gage (02086624) downstream of J.D. Holt Reservoir; however, this gage is also capturing flow from the Picture Creek subwatershed drainage and discharges from the Town of Butner Waste Water Treatment

Plant (WWTP) and the John Umstead Water Treatment Plant (WTP). Daily release was therefore estimated as the gage flow minus the WWTP and WTP discharges multiplied by a scaling factor to account for other inflows.

Flow from the USGS gage on Knap of Reeds Creek, 02086624, was not available until January 13, 2006. As a result, estimated release is not available before this date.

There is an intake in J.D. Holt Reservoir, however daily withdrawal data was not available for the modeled time-period. Withdrawals from J.D. Holt Reservoir were therefore assumed to be the sum of the discharges from the WWTP and WTP.

3.5.2 Eno River Watershed

Flow is managed in the Eno River through the Eno River Voluntary Water Management Plan, which is administered by the North Carolina Division of Water Resources. The voluntary management plan provides for the allocation of available water supply between the primary withdrawers and includes six stages of water withdrawal restrictions that become progressively more limiting as storage capacity in Lake Orange declines.

Four reservoirs are located in the Eno River Watershed: West Fork Eno Reservoir, Lake Orange, Corporation Lake, and Lake Ben Johnston. However, only Lake Orange is explicitly represented in the watershed model.

The West Fork Eno Reservoir was not included in the hydrography used to develop the watershed model, most likely because it is a relatively new reservoir. To account for flows from the West Fork Eno Reservoir, the West Fork Eno was represented as a point source in the model. The Town of Hillsborough provided release data, which is measured once a week. Missing values were estimated to be the same as the previous reported value until the next entry.

Daily release data is not available for Lake Orange. The release was therefore estimated from the nearest downstream USGS gage (02085000) minus the release from the West Fork Eno Reservoir and point source discharges.

Corporation Lake and Lake Ben Johnston are smaller run of the river impoundments. Orange-Alamance Water System, Inc. withdraws water from Corporation Lake to provide water supply to rural areas of Orange and Alamance counties. The Town of Hillsborough withdraws water from Lake Ben Johnston. Withdrawal data was available from the Division of Water Resources for both of these intakes.

Piedmont Minerals also withdraws water from the Eno River below Lake Ben Johnston. Withdrawal data was available from the Division of Water Resources.

3.5.3 Flat River Watershed

Lake Michie is the only reservoir in the Flat River Watershed. There is no required minimum release for Lake Michie. There is withdrawal by a surface water intake in this reservoir. The City of Durham's Brown WTP provided both estimated daily release and withdrawal data.

3.5.4 Little River Watershed

The Little River Reservoir is the only reservoir in the Little River Watershed. There is a minimum release requirement for the Little River Reservoir. There is withdrawal by a surface water intake in this reservoir. The City of Durham's Brown WTP provided both estimated daily release and withdrawal data.

3.5.5 Ellerbe Creek Watershed

There are no reservoirs or surface water intakes in the Ellerbe Creek Watershed.

3.6 NPDES Permit Dischargers

Effluent data from discharge monitoring reports for the 14 dischargers holding NPDES permits were included in the model for years 2004-2007 (Table 3). The Days Inn WWTP discharge, although included, was operational for only two months during the study. Missing data in monitoring reports were completed with monthly averages for that month and non-detect entries were replaced with values at half the laboratory detection limit.

Table 3. NPDES Dischargers in the Falls Lake Watershed

Discharger	Permit Number	Watershed	Permitted Flow (gpd)
North Durham WRF	NC0023841	Ellerbe Creek	20,000,000
Orange-Alamance WTP	NC0082759	Eno River	300,000
Arbor Hills Mobil Home Park WWTP	NC0037869	Eno River	6,000
Grand Oak Subdivision WWTP	NC0056731	Eno River	6,800
Hillsborough WWTP	NC0026433	Eno River	3,000,000
Eaton Corporation	NC0003379	Flat River	22,000
SGWASA WWTP	NC0026824	Knap of Reeds	5,500,000
SGWASA WTP	NC0058416	Knap of Reeds	200,000
Lake Ridge Aero Park WWTP	NC0059099	Panther Creek	16,000
Creedmoor WTP	NC0007625	Ledge Creek	12,000
Hawthorne Subdivision WWTP	NC0049662	Barton Creek	250,000
Wildwood Green WWTP	NC0063614	Barton Creek	100,000
Waterfall Plantations WTP	NC0085863	Horse Creek	5,000
Days Inn WWTP	NC0024520	Ellerbe Creek	18,000

3.7 Atmospheric Deposition

The NCDOT Highway Stormwater program provided wet and dry nitrogen deposition data for the watershed model. WARMF's data module includes monthly average data input for dry chemical constituents (µg/m^3) and wet chemical constituents (mg/l).

The National Atmospheric Deposition Program (NADP) station NC41 (Finley Farms, Wake County) was the most appropriate source for weekly wet chemistry data. The Clean Air Status and Trends Network (CASTNET) station PED108 located 65 miles north of the watershed in Price Edward, Virginia was the best source for weekly dry chemistry data (Figures 9 and 10). Data from these programs are accessed through the internet. In addition, NCDOT used the USEPA's Watershed Deposition Tool (WDT) to evaluate seasonal and annual deposition in the watershed. A complete summary of the NCDOT analysis is provided in Appendix B.

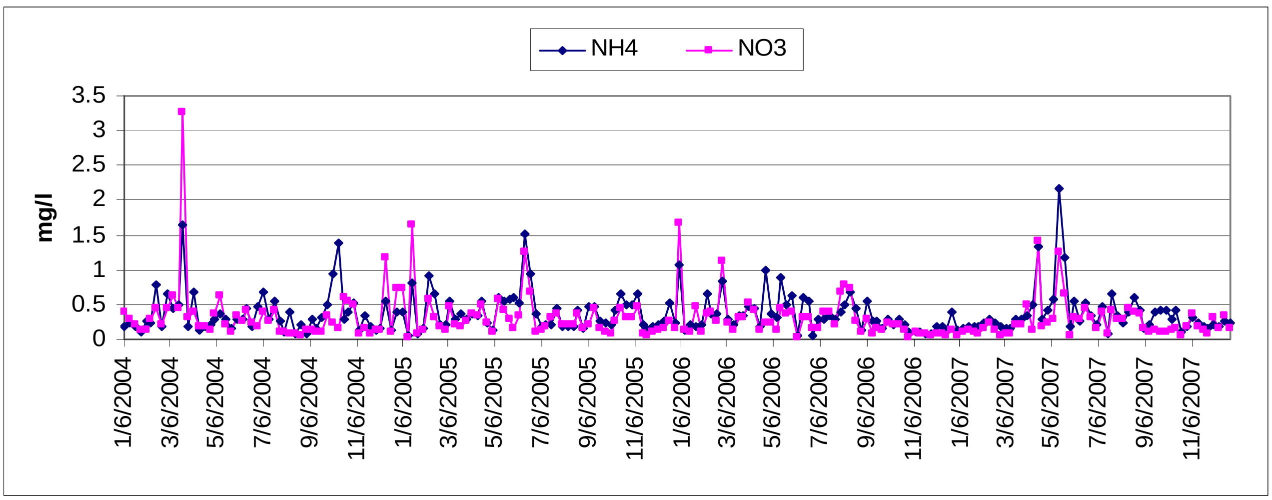

Figure 9. Wet NH4 and NO3 Deposition Model Input

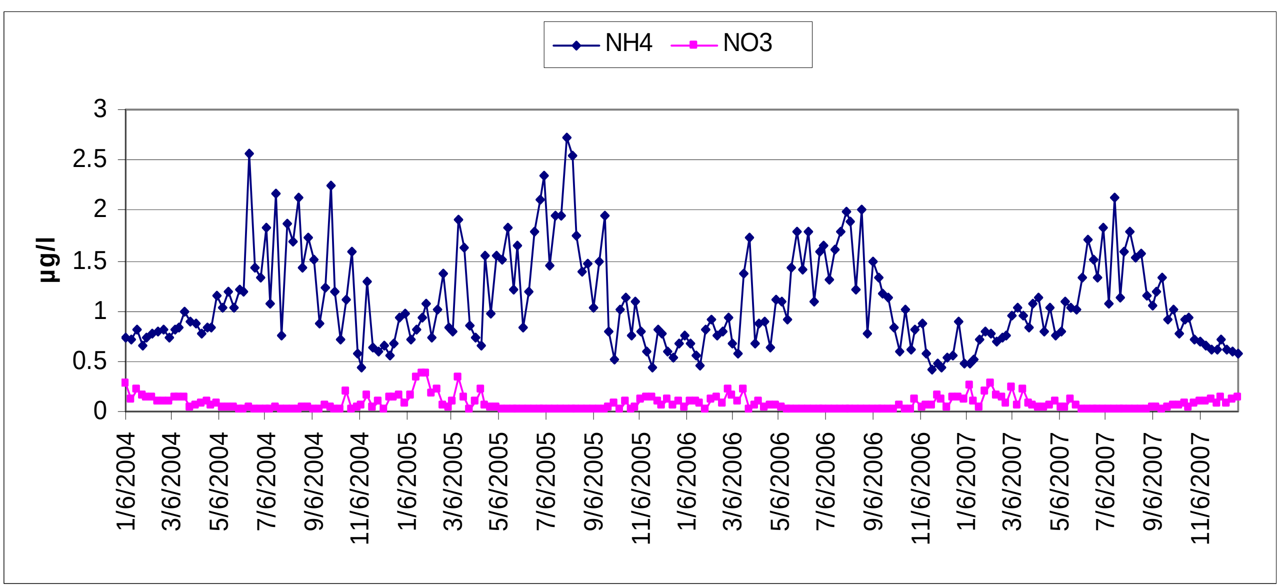

Figure 10. Dry NH4 and NO3 Deposition Model Input

3.8 Land Application

Nutrient inputs for WARMF are specific to each land cover type within each catchment and are included by month as kg/ha. Nutrient inputs were included for the cultivated crops, pasture/hay, and NCDOT, and developed land covers. Nutrient sources include fertilizer application for crop, pasture, hay, developed, and NCDOT land as well as manure from grazing for pastureland. Nutrients are applied in the model as monthly loading rate upon the land surface. The loading builds up on a daily basis until a rainfall event or until the maximum user-specified accumulation time is reached. At this point, the loading is distributed through surface-runoff and infiltration processes.

The North Carolina Division of Soil and Water Conservation (DSWC) provided annual fertilizer application per crop and percentage of application by month on an 11 digit HUC scale. This data were derived from a survey of cooperative extension, farmers in the watersheds, NRCS, and Soil and Water District staff. The nitrogen application loading was split between a ratio of 90 percent nitrate and 10 percent ammonium based on DSWC communications with agricultural suppliers in the watershed of the most common fertilizers being purchased. In order to apply multiple monthly crop applications into one land cover, the loading rate for a particular crop was weighted by its respective percentage out of all crops grown for that county; this data was also provided by DSWC.

Review of the NLCD distribution of pasture/hay and cultivated cropland in the watershed by the DSWC revealed that the NLCD pasture/hay acreage was much higher, and the cultivated crop acreage was lower than what was reported in the 2002 Agricultural Census. The NLCD acreages by county were compared to the crop, hay, and pasture acreages by county from the 2002 Agricultural Census and confirmed the observations of DSWC. Therefore, the nutrient inputs for the cultivated crop and pasture/hay land covers have been adjusted (as further discussed below) to reflect the acreages of the 2002 Agriculture Census while still being applied to the NLCD acreage used in the model.

3.8.1 Fertilizer Application Rates for the Cultivated Crop Land Cover

Fertilizer applied to the cultivated cropland cover represent the barley, corn, oats, sorghum, tobacco, and wheat crops. The application rates were calculated using the following equation:

$$A_{nm} = \frac{1.12085116\left(Q \bullet F \bullet P_q \bullet P_c\right) \bullet CensusAcres}{NLCDAcres} \quad \textbf{(1)}$$

Where:

A_{nm} = Application rate for n species of nutrient for *m* month
1.12085116 = Conversion factor from lbs/acre to kg/ha
Q = lbs/acre/year/crop application rate for Nitrogen or Phosphorus
F = Fraction of nitrate (0.9) or ammonium (0.1) from *Q (not used for Phosphorus)*

P_q = Percent of Q used during m month (typically 2 or 3 applications during the year)
P_c = Percent of c crop from all crops grown in 10 digit HUC
Census Acres = Acres of cropland (by county) as specified in the 2002 Agricultural Census (Table 4)
NLCD Acres = Acres of cultivated crop land (by county) from the NLCD (Table 4)

Table 4. 2002 Ag Census Vs. NLCD Crop Acres

	2002 Agriculture Census (acres)										NLCD
County	Corn for Grain	Wheat for grain	Barley	Oats	Rye	Tobacco	Soybeans	Potatoes	Sweet Potatoes	**Census Crop Total**	**Cultivated Crop Acres**
Person	1,900	5,285		174		3,232	5,275	1		15,867	4,685
Durham	34	505			60	820	303			1,722	1,398
Orange	725	1,416	280	65	15	859	1,639	3	23	5,025	2,396
Granville	760	2,636		128		4,656	2,286			10,466	6,120
Wake	No crops grown in the Wake County portion of the watershed										

As shown in equation 1, the cultivated crop application rate was multiplied by the census crop Total column and then divided by the NLCD cultivated crop Acres in Table 4. Because there was more crop acreage reported in the census, the calculation increased the application rate applied to the lower NLCD acreage in order to reflect the higher census acreage.

3.8.2 Application for the Pasture/Hay Land Cover

Nutrient input for the pasture/hay land cover include the Bermuda grass, fescue, and pasture fertilizer rates provided by DSWC and manure from grazing for pastureland. The Bermuda grass, fescue, and pasture application rates account for “hay” and were calculated using the following equation:

$$A_{nm} = 1.12085116\left(Q \bullet F \bullet P_q \bullet P_c\right) \bullet R \qquad \textbf{(2)}$$

Where:

A_{nm} = Application rate for n species of nutrient for m month
1.12085116 = Conversion factor from lbs/acre to kg/ha
Q = lbs/acre/year/crop application rate for Nitrogen or Phosphorus
F = Fraction of nitrate (0.9) or ammonium (0.1) from Q *(not used for Phosphorus)*
P_q = Percent of Q used during m month (typically 2 or 3 applications during the year)
P_c = Percent of c crop from all crops grown in 11 digit HUC
R = Application reduction fraction used for hay and pasture based on respective reduction fraction shown in Table 5.

Table 5. Pasture, Hay and Manure Reduction Fractions

	2002 Ag Census Acreage			NLCD	*R* (Loading Reduction Fractions)		
County	Pasture Land all Types	Pasture Land and Rangeland Fertilized	All Hay Harvested	Pasture/Hay Acres	**Manure from grazing**	**Fertilized Pasture**	**Fertilized Hay (Bermuda grass and fescue)**
Person	19,700	5,618	8,708	56,452	0.35	0.10	0.15
Durham	7,001	2,712	2,566	17,295	0.40	0.16	0.15
Orange	22,016	7,480	13,506	53,761	0.41	0.14	0.25
Granville	35,317	7,993	9,824	57,888	0.61	0.14	0.17
Wake	21,111	4,688	5,571	61,563	0.34	0.08	0.09

The manure from grazing, fertilized pasture, and fertilized hay loading reduction fractions are calculated by dividing the respective pasture land all types, pasture land and rangeland fertilized, and all hay harvested columns by the NLCD pasture/hay column, as shown in Table 5. Contrary to the cultivated crop application, these reduction fractions lower the application rate to fit the lower pasture/hay acreage from the 2002 Agricultural Census acreage.

3.8.3 Manure from Grazing Loading Rates

Manure loading from grazing on pastureland was distributed over 12 months and was included in the application rates for the pasture/hay land use. The manure loading from grazing was calculated using the following equation:

$$A_{nm} = \frac{\left(\frac{Q_c \bullet W}{1000}\right)\left(\frac{365 \bullet T \bullet N \bullet C_n}{12}\right)}{P} \bullet R \bullet H \qquad \textbf{(3)}$$

Where:

A_{nm} = Application rate for *n* species of nutrient for *m* month
Q_c = Number of animals for *c* county (USDA, 2004)
W = Average animal weight (BCME, 1996)
1000 = 1000 pounds (animal unit)
N = Nutrient in 1bs/day per animal unit (USDA, 1999)
C_n = Fraction of nitrate (0.5) or ammonium (0.5) from *N (not used for Phosphorus)*
T = Percent of time animal spend in pasture (White, et. al. 2001)
365 = Days in year
12 = Months in year
P = Acres of pasture land all types (USDA, 2004)
R = Application reduction fraction for manure based on manure reduction fractions shown in Table 5
H= Conversion factor from lbs/acre to kg/ha

3.8.4 Fertilizer Application Rates for NCDOT

The North Carolina Department of Transportation provided the application rates for the NCDOT land use in the watershed model. The steps used to determine the NCDOT land application rates are located in Appendix B.

3.8.5 Developed Land Turf Application

The developed land application rates used in the model were largely derived from a turf practices study by Deanna Osmond and David Hardy (2004) of five North Carolina communities. The report shows the mean annual nitrogen fertilizer rates for Cary, Kinston, New Bern, and Greenville as 151, 29, 54, and 73 kg/ha, respectively. Based on the results of the survey, 70 percent of the turf in the study areas was fertilized and assumes an average N use of 111 kg/ha/year based on the range of N use in their study. The combined monthly application data in the report for fescue and warm season grasses by homeowners and lawn care services was used to determine the fertilizer distribution by month. The nitrogen fertilizer loading rates used in the model are 30, 111, 29, 20, and 76 (kg/ha/year) for the Knap of Reeds, Flat River, Little River, Eno River, and Ellerbe Creek watersheds, respectively. The variation in these rates was based on similarities between the communities in the study and the watershed.

Most turf fertilizers use a coated urea (slow release), which hydrolyses into ammonia. Therefore a ratio of 70-30 for ammonium (NH_4) and nitrate (NO_3), respectively, was chosen for model input given that some fertilizers may have more NO_3 than others. In addition, the application rates were reduced by the fraction of impervious surface described in the NLCD for each developed land intensity. Application rates were calculated using the following equation:

$$A = 0.7 \bullet L \bullet P \bullet N_f \bullet M_a \quad \textbf{(4)}$$

Where:

A = Application rate (kg/ha/month/developed land use intensity)
L = Annual nitrogen fertilizer loading
P = Fraction of pervious cover by land use (90, 65, 35, and 10 percent pervious for developed open, low, medium, and high land covers, respectively*)*
0.7 = Percent of pervious land fertilized
N_f = Fraction of NH_4 or NO_3 (70 and 30 percent respectively)
M_a = Monthly distribution of annual load

Owing to lack of any phosphorus application data for developed land uses, the default value of 0.01 kg/ha was used in the model. Most developed lawns need significantly less phosphorus fertilizer than nitrogen, which may explain the lack of data.

3.9 On-Site Waste Water Treatment

WARMF simulates septic system input based on per capita loading for up to three treatment types. Nutrient and flow input are assumed constant throughout the watershed while population served is specific to each catchment.

WARMF accepts septic tank effluent discharged to a user-specified soil layer. Individual septic systems within a catchment are lumped and evenly distributed in the subsurface of the catchment. Loading from septic systems is added to the specified layer of each catchment as a function of the concentration, population, and flow. Once this load is added, the uptake, decay, nitrification, adsorption, and transport of pollutants in soil layers are simulated by the existing algorithms of WARMF.

For this model, septic systems are grouped into two treatment types: type one represents a properly functioning system and type two represents a poorly functioning system, with an 85 and 15 percent distribution, respectively, based on the EPA Onsite Wastewater Treatment Systems Manual (U.S. EPA, 2002). Flow is rated at 260 L/person/day. Nutrient concentrations for the septic system effluent are shown in Table 6 (McCray *et. al.,* 2005). WARMF does not directly simulate septic tank effluent overland flow that may occur in reality with poorly functioning systems. All septic tank effluent loading is added to the user-specified soil layer. Therefore, to simulate poorly functioning septic systems within WARMF, higher concentrations are assumed.

Table 6. Septic System Model Coefficients

Nutrient	**Concentration (mg/l)**	
	Type 1	**Type 2**
Ammonium	58	178
Nitrate	0.2	1.94
Phosphate	9.0	21.8
Organic Nitrogen	14	15

Source: McCray *et. al.*, 2005. (Working system values taken from median concentration column, and poorly functioning system concentrations from highest value on range column on Table 1, p. 630)

The 2000 census did not include information on septic system usage, as did the 1990 census. Therefore, the method used to determine the population served by septic systems was to use the model catchment GIS layer overlaid with a 2004-sewer coverage area layer (Figure 12) compiled by the NC Center for Geographic Information and Analysis (CGIA). In addition, the City of Durham provided locations within Durham County that used sand filters for wastewater treatment. Based on field observations, the sandfilter designs were split between sub-surface and land discharges (M. Woolfolk, personal communication, 2008). Half of the sandfilters were subsequently assigned a population per household and added to the population served by septic systems while the other half were combined and included as a single point source within the catchment.

The population served by septic or sandfilter was determined using the following equation:

$$T = (P_c \bullet A - P_s) + \left(3 \bullet \frac{S}{2}\right) \quad \textbf{(5)}$$

Where:

T = Population served by septic or sand filter systems
P_c = Population per square mile from sum of population and area in census blocks within catchment
A = Square miles of catchment
P_s = Population of sewered area in catchment (if present)
3 = Average person per household (2.4 person per household in 2000 Census)
S = Number of sand filter locations in catchment
2 = Half of sand filter locations designed as a sub-surface discharge, the other half are designed as point source surface discharge (advised by City of Durham)

3.10 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) were included in the model with flow and nutrient concentration values. A total of 138 incidents from 2004-2007 were extracted from the DWQ Basinwide Information Management System (BIMS). The estimated volume (gallons) of wastewater released from each event was converted to the WARMF format of cubic meters per second (cms) and assigned calculated nutrient loading values based on typical domestic wastewater characteristics shown in Table 7.

Table 7. Assigned WARMF SSO Loading Values.

Parameter	Concentration mg/l
Suspended Solids	220
5-Day BOD	220
Ammonia	25
Total Phosphorus	8

Source: Metcalf, and Eddy. Wastewater Engineering. 3rd ed. New York: McGraw-Hill, 1991

Much of the location information only provided road intersections or pump station numbers and coordinates had to be assigned using Google Earth loaded with a 24k hydrology .kml file for reference. Once each SSO was assigned coordinates, GIS was used to overlay the SSOs over the model catchments and SSO point sources were accordingly made in WARMF (Figure 12). Multiple SSOs in a single catchment were combined into one point source. There are six total SSOs included that did not reach a stream. These incidents were treated as land discharge point sources and not connected to the stream segment.

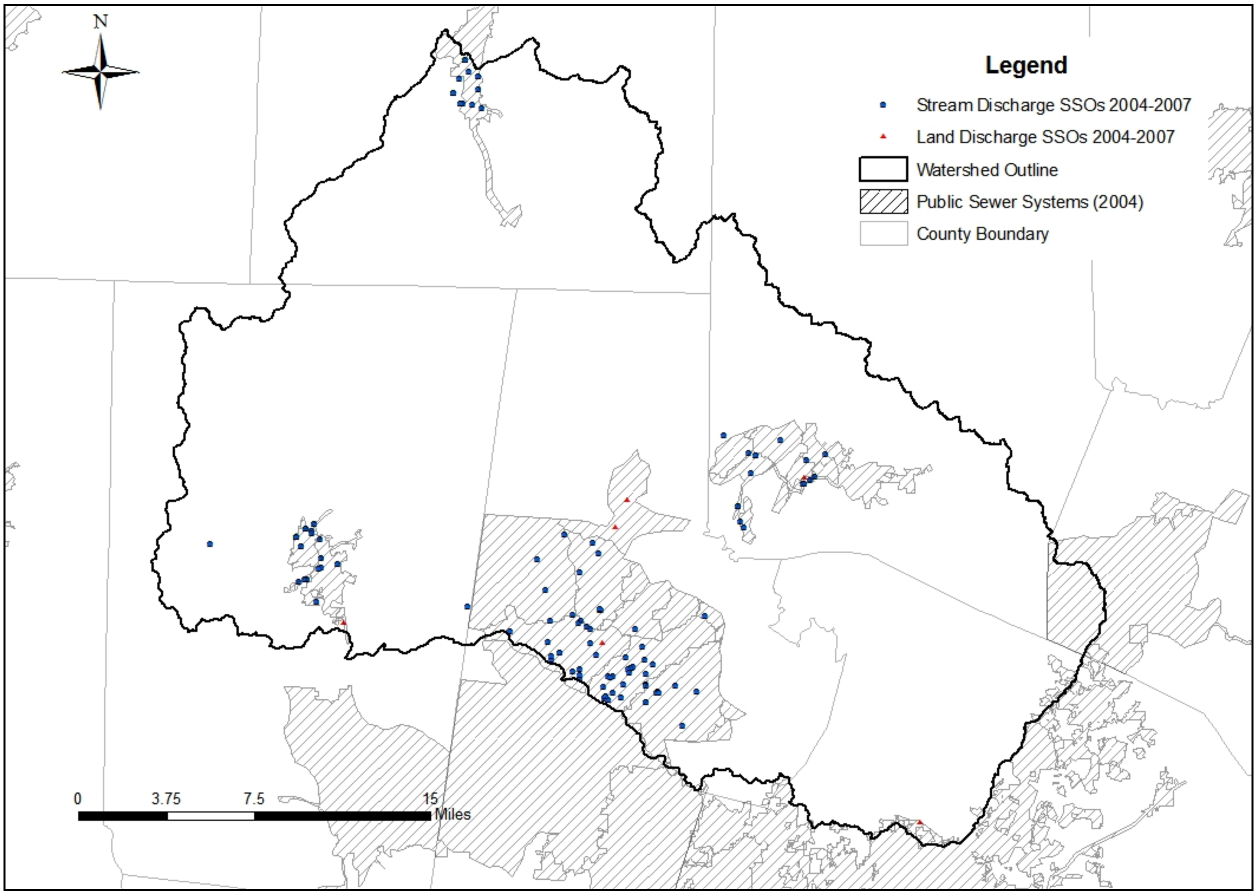

Figure 11. 2004-2007 SSOs in the Falls Lake Watershed.

4.0 Model Calibration and Validation

Model calibration and validation are essential and critical steps in watershed modeling. For most watershed models, calibration is a process in which model parameter estimations and adjustments are made by comparing model predictions to observed data. During the calibration step, model parameters are evaluated and refined as a result of comparing simulated and observed values. Model validation is essentially an extension of the calibration process. One purpose of validation is to demonstrate the ability to predict field observations for periods separate from the calibration effort (Donigian, 2002). The goal of the model calibration phase is to obtain an optimal agreement between the model calculations and the observed monitoring data.

Once calibrated, the model was validated by comparing predictions against a new set of observed data not used during calibration. During the validation phase, the hydrologic and water quality parameters remain fixed at the values set during the calibration process and the forcing parameters, such as the meteorological data, are changed to reflect the new conditions. Table 8 outlines the calibration and validation periods used for the Falls Lake watershed modeling study. The calibration period for each watershed varies depending on the availability of USGS flow gage data. The validation year for all watersheds was 2007.

<u>Hydrologic Calibration</u>
During the hydrologic calibration process, simulated stream flows were compared to the observed stream flow at the USGS continuous recording station (see Figure 8 for a map of the station locations). Hydrologic parameters that were adjusted in the model calibration included soil layer thickness, porosity and soil moisture content, hydraulic conductivity, detention storage, Manning's coefficient, precipitation weight, temperature lags, and evaporation parameters (skewness and magnitude). The initial values of these parameters were set from site-specific soil and climate data when available (as described in Section 3.3). These values were adjusted to obtain optimal agreement between simulated and observed flow. These adjustments were made within the ranges of literature values applicable to local conditions.

<u>Water Quality Calibration</u>
After the hydrologic calibration was completed, the model was calibrated for total suspended sediment and water quality (nutrients) by adjusting sediment and water quality model parameters within appropriate limits until a reasonable agreement between observed and simulated data was achieved.

Initial sediment parameters were estimated from Natural Resource Conservation Service (NRCS) data and minimal adjustment was made to these parameters. Soil coefficients for sediment transport equations include soil particle distribution (sand, silt, and clay), cropping factors, turbulent detachment factors, and riverbank erosion factors. Beasley and Huggins (1991) and Beasley et al. (1990) provide ranges of values for these parameters. Sediment parameters adjusted during calibration include soil erosivity, bank stability factor, and detachment factors. It should be noted that, while the WARMF User's Manual suggests a soil erosivity range of 0.1 to 0.4, a USDA handbook provides a range of 0.03-0.69 (Wischmeier and Smith, 1979). Therefore, in some subwatersheds, the soil erosivity factor of less than 0.1 was used to achieve optimum TSS calibration.

Nutrient (TN - ammonium, organic nitrogen, and nitrate, and TP) parameters adjusted during calibration include initial concentration, adsorption isotherms, and decay rates.

Table 8. Model calibration and validation periods.

Calibration Station	Gage Station	Water Quality Station	Flow		Water Quality	
			Calibration Year	Validation Year	Calibration Year	Validation Year
Knap of Reeds at WWTP outfall near Butner	USGS 02086624	J1210000	2006	2007	2006	2007
Flat River above Lake Michie	USGS 02085500	USGS 02085500	2004-2006	2007	2004-2006	2007
Flat River at SR 1004 near Willardsville	USGS 02086500	J110000	2004-2006	2007	2004-2006	2007
Little River at SR 1461 near Orange Factory	USGS 0208521324	J0820000	2004-2006	2007	2005-2006	2007
Little River below LR trib. at Fairntosh	USGS 0208524975	USGS 0208524975	2004-2006	2007	2004-2006	2007
Eno River near Hillsborough	USGS 02085000	-	2004-2006	2007	NA	NA
Eno River at US 501 near Durham	USGS 02085070	J0770000	2004-2006	2007	2005-2006	2007
Eno River at SR 1004 nr. Durham	-	J0810000	NA	2007	2004-2006	2007
Ellerbe Creek at SR 1636 near Durham	USGS 02086849	J1330000	2006	2007	2004- 2006	2007

4.1 Calibration Criteria and Performance Measures

In the Falls Lake Watershed modeling study, model performance and calibration/validation are evaluated through qualitative and quantitative measures, involving both graphical and statistical comparisons. For flow simulations where continuous records are available for the calibration stations, both the qualitative and the quantitative techniques were employed during both the calibration and validation processes. For water quality constituents, model calibration and validation were conducted based primarily on visual and graphical presentations, as the frequency of observed data is inadequate for accurate statistical comparisons.

Although the importance of calibration and validation criteria have been emphasized in the past (ASCE, 1993), uniform model calibration and validation criteria have not been established, but statistical performance measures have been proposed for model evaluation where there is sufficient observed data for such comparisons (Donigian, 2002; Lumb, et al., 1994; and Moriasi et al., 2007). For Falls Lake watershed model flow calibration and validation, the criteria recommended in the USGS HSPEXP – Expert System for Calibration of HSPF given in Table 9 was adopted (Lumb, et al., 1994). In addition, selected statistical error measures including relative error, coefficient of efficiency, percent bias, coefficient of determination (R^2), Root Mean Square of Error (RMSE), and percent seasonal differences along with the visual and graphical comparison were employed for hydrology calibration and validation. Pearson's correlation coefficient (r) and coefficient of determination (R^2) are commonly used for model evaluation, but questions have been raised as to whether these statistics are appropriate performance measures (Legates and McCabe, 1999). The statistical performance measures used to assess model performance are listed in Table 10.

Table 9. Flow calibration criteria[1]

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 10. Model Evaluation Statistics

Relative Error (RE)	$RE = \frac{\sum(Pred - Obs)}{\sum Obs}$
Average Error (AE)	$AE = \frac{\sum(Pred - Obs)}{n}$
Standard deviation for observational data (SD_{obs})	$SD_{obs} = \sqrt{\frac{\sum(Obs - \overline{Obs})^2}{n-1}}$
R-square (R^2) -	$R^2 = \left(\frac{\sum_{i=1}^{n}(Obs_i - \overline{Obs})(Pred_i - \overline{Pred})}{\sqrt{\sum_{i=1}^{n}(Obs_i - \overline{Obs})^2}\sqrt{\sum_{i=1}^{n}(Pred_i - \overline{Pred})^2}}\right)^2$

Root Mean Square Error (RMSE)	$RMSE = \sqrt{\frac{\sum (Pred - Obs)^2}{n-1}}$
Ratio of RMSE and SD_{obs} ($RMSE/SD_{obs}$)	$RMSE / SD_{obs} = \frac{RMSE}{SD_{obs}}$
Coefficient of Efficiency (CE)	$CE = 1 - \frac{\sum (Pred - Obs)^2}{\sum (Obs - \overline{Obs})^2}$
Percent Bias (pBias)	$pBias = \frac{\sum (Pred - Obs)}{\sum Obs} * 100$

Additional statistics provided by the WARMF during model runs can be used during the calibration step for preliminary evaluation of model performance. The WARMF user's manual presents various statistics for the user to evaluate the reliability of the model predictions. The user must bear in mind that there is no single statistical measure for the goodness of fit between two time series. For example, if the simulated time series match the observed time series in magnitude, but are off by one day, the errors can still appear be very large. The calculation of error terms is based on the assumption that the measured values are 100% correct. This assumption may not necessarily be correct (Herr, 2001). For water quality constituents where there are infrequent data, using statistical measures to evaluate model performance will not give accurate and reasonable results. Therefore, for water quality constituents only visual and graphical comparisons are employed.

5.0 Watershed Model Results – Knap of Reeds Creek

5.1 Hydrologic Calibration

For the hydrologic calibration, simulated stream flows were compared to the observed stream flow at the Knap of Reeds Creek USGS gage (USGS 02086624), which is downstream of J.D. Holt Reservoir (shown in Figure 8).

Daily lake releases from J.D. Holt Reservoir were not available for the modeled time period; therefore daily lake releases were estimated using the flow at the USGS gage, as described in Section 3.5. Because the USGS gage did not become operational until January 13, 2006, the calibration period for Knap of Reeds Creek was 2006.

Figure KOR-1 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at the Knap of Reeds USGS gage. WARMF simulates the magnitude and trend of flow well in this watershed, although there is some slight underestimation of higher peaks. This could be the result of the method used to estimate daily release from J.D. Holt Reservoir. Figure KOR-2 is a scatter plot of observed and simulated flow at the same station. Linear regression resulted in an R^2 value of 0.93, indicating a very good match between observed and model predicted flows.

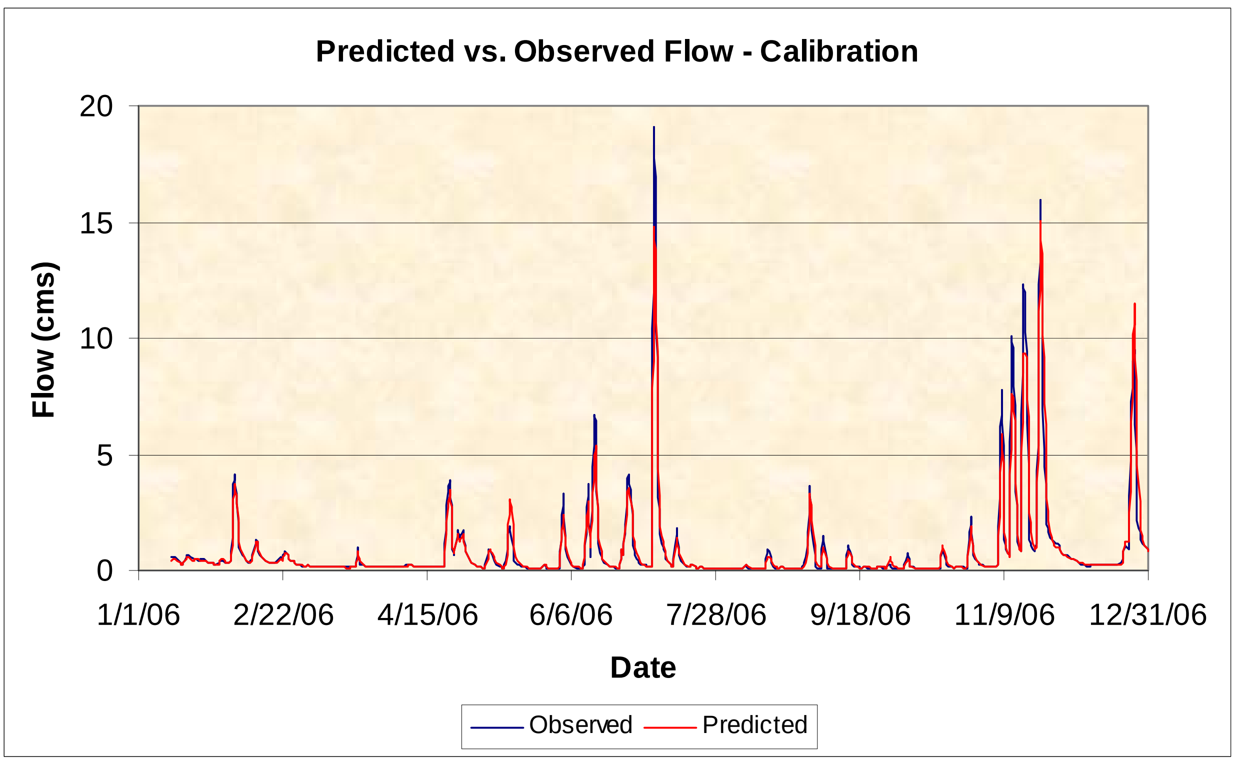

Figure KOR- 1. Calibration - Time series of predicted and observed flow for Knap of Reeds Creek.

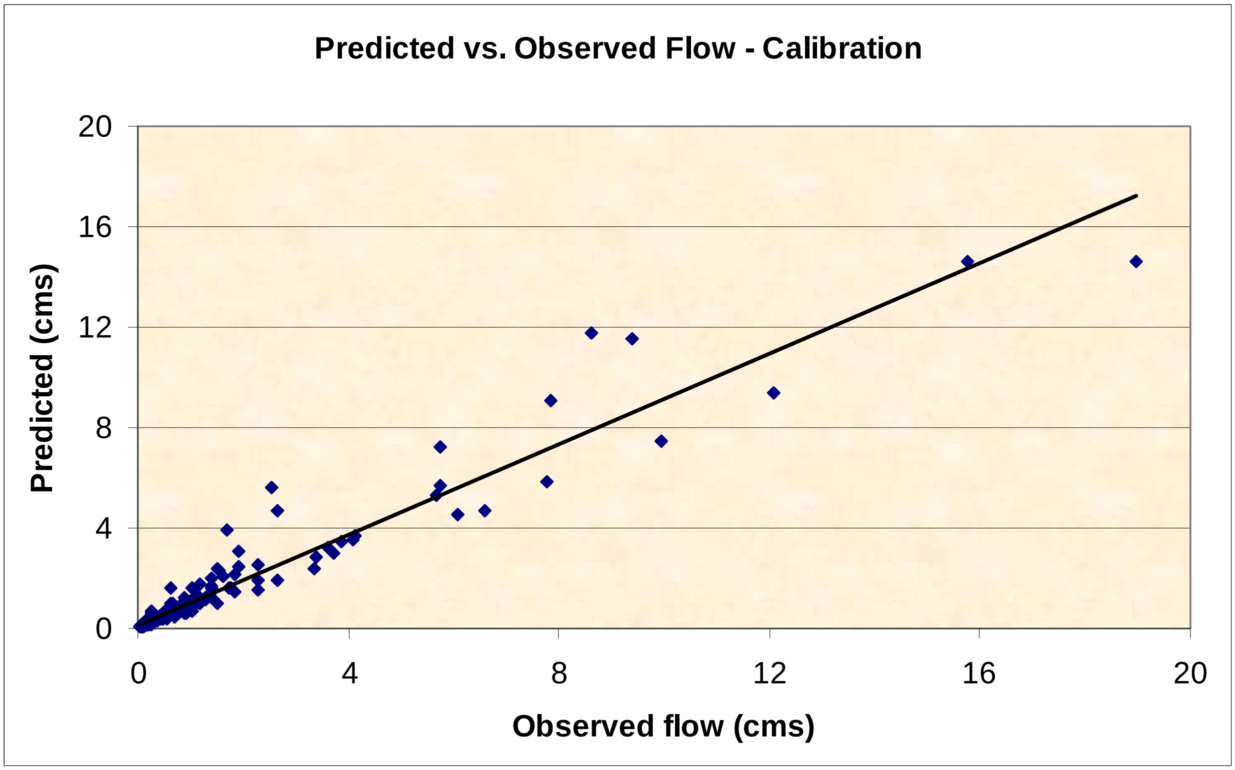

Figure KOR- 2. Calibration - Predicted versus observed flow for Knap of Reeds Creek.

Table KOR-1 provides the error statistics for total and seasonal flow volume. The total volume and seasonal volume errors more than satisfy the calibration criteria set during the calibration process, except for a slight exceedance of the criteria for total volume of 50 percent lowest flows. The total volume stream flow error was only 1.3 percent. The model slightly underpredicted high flows and overpredicted low flows. In general, while not exceeding any of the recommended error criteria, WARMF slightly overestimated flow during fall months and slightly underestimated flow during winter, spring, and summer months.

Table KOR- 1. Predicted flow volume statistics for the calibration period at USGS Station 02086624 in Knap of Reeds Creek.

	Predicted (m^3)	Observed (m^3)	% Diff[1]	Recommended Criteria
Total predicted in-stream flow volume	24,492,064	24,167,268	1.3%	10%
Total volume of highest 10% flows	11,191,561	11,752,206	-4.8%	15%
Total volume of lowest 50% flows	2,091,911	1,856,913	12.7%	10%
Total summer flow volume (months 7-9)	4,335,214	4,426,348	-2.1%	30%
Total fall flow volume (months 10-12)	11,802,866	11,130,951	6.0%	30%
Total winter flow volume (months 1-3)	2,895,461	3,043,879	-4.9%	30%
Total spring flow volume (months 4-6)	5,458,523	5,566,090	-1.9%	30%

% Diff refers to percent difference and is calculated by (predicted – observed)/observed.

Table KOR-2 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flows are very close to the observed mean. The percent bias, relative error, and average error are all very small, indicating a very close match between observed and predicted flow.

Table KOR- 2. Additional daily flow statistics for predicted versus observed data for the calibration period at USGS Station 02086624 in Knap of Reeds Creek.

	Flow Statistics
Relative Error	0.01
Average Error	0.01
Root Mean Square of Error (m^3/s)	0.51
Standard deviation (SD_{obs}) (m^3/s)	1.94
$RMSE/SD_{obs}$	0.26
R^2	0.93
Coefficient of Efficiency	0.93
Percent Bias	1.3%
Observed Mean Flow (m^3/s)	0.79
Predicted Mean Flow (m^3/s)	0.80

5.2 Water Quality Calibration

In the water quality simulation, WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to the DWQ ambient monitoring data from the Knap of Reeds Creek DWQ ambient monitoring station, J1210000, shown in Figure 8.

Total Suspended Sediment (TSS)

Figure KOR-3 illustrates the time series plot of the observed and WARMF predicted TSS concentrations at the Knap of Reeds Creek DWQ ambient monitoring station. The simulated TSS concentrations tracked the observed concentrations pattern fairly well, but seemed to overpredict TSS concentrations periodically throughout the calibration period, especially in November and December.

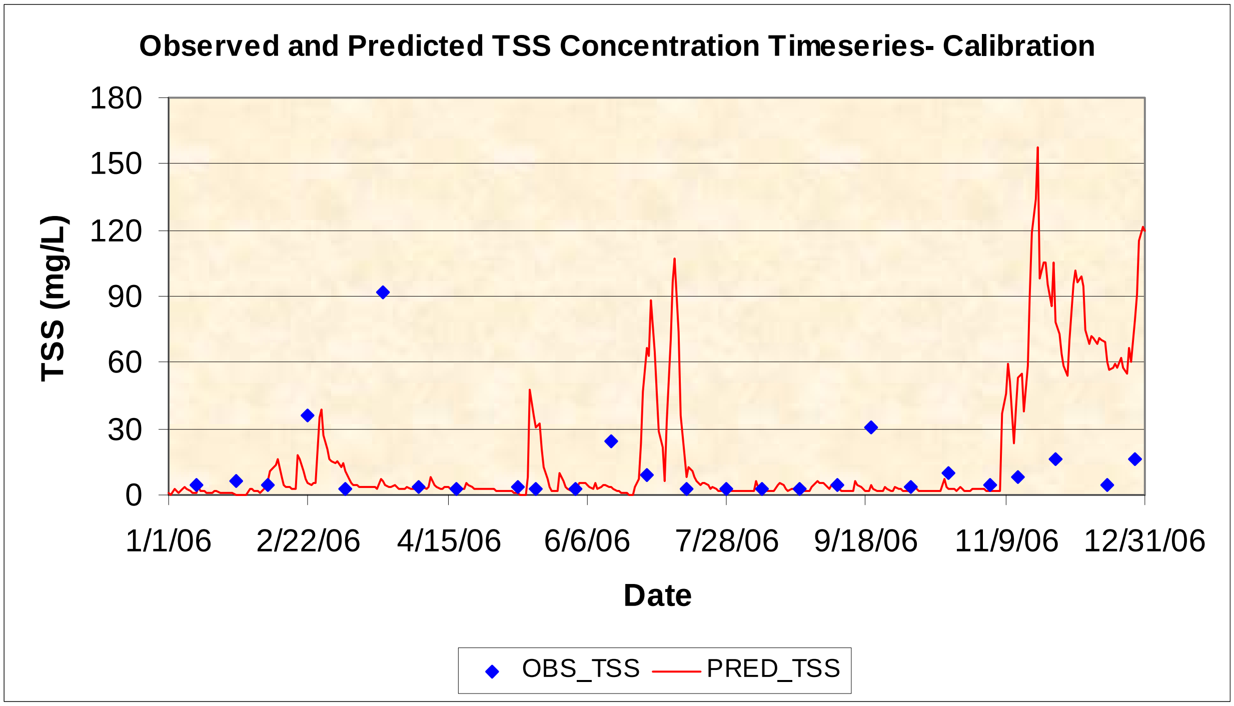

Figure KOR- 3. Calibration – Knap of Reeds Creek TSS concentrations daily time series.

Figure KOR-4 shows the monthly distribution of observed and predicted TSS concentrations. In general, WARMF predicted the general trend and range of most observed TSS data in this watershed.

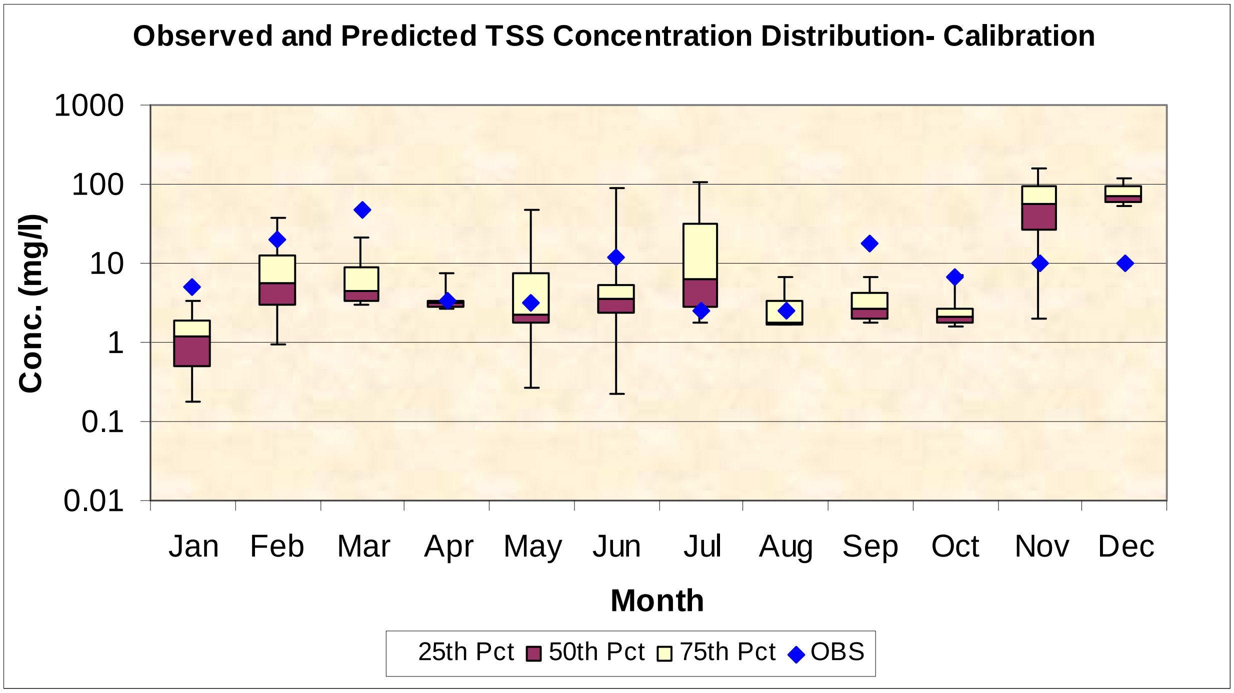

Figure KOR- 4. Calibration - Observed versus predicted TSS concentrations for Knap of Reeds Creek (shown in log scale).

<u>Nitrogen</u>

Figure KOR-5 shows the time series plot of measured TN concentrations and WARMF predicted concentrations. Figure KOR-6 shows the seasonal distribution of TN concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations are included in Appendix C.

These figures show that the WARMF predicted concentrations closely followed the observed pattern for all the simulated nitrogen forms (ammonia, nitrate, and TKN). As shown in Figure KOR-5, there are two peaks in TN concentrations that were not captured by the monitoring data. A review of the point source discharges in this watershed showed very high concentrations of ammonia in the discharge from the Town of Butner WWTP on those dates. These peaks were also captured in the ammonia time series plot (shown in Appendix C, Figure KOR-C1) and the TKN time series (shown in Appendix C, Figure KOR-C5).

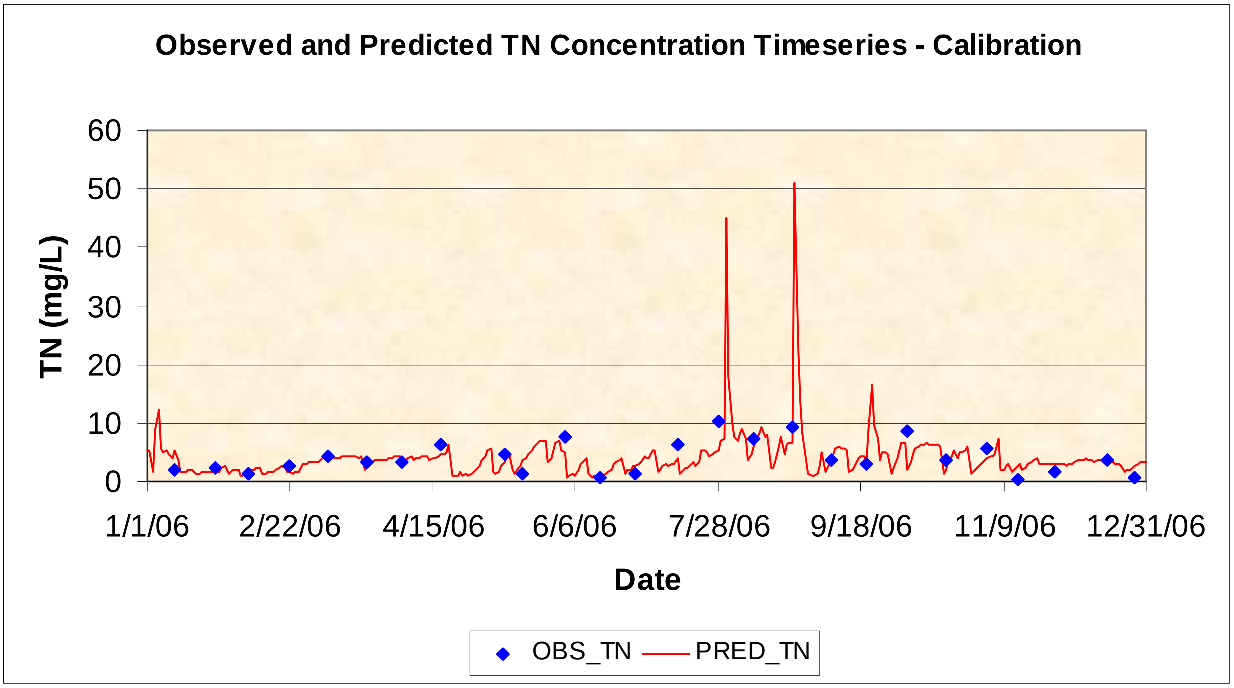

Figure KOR- 5. Calibration – Knap of Reeds Creek TN concentrations daily time series.

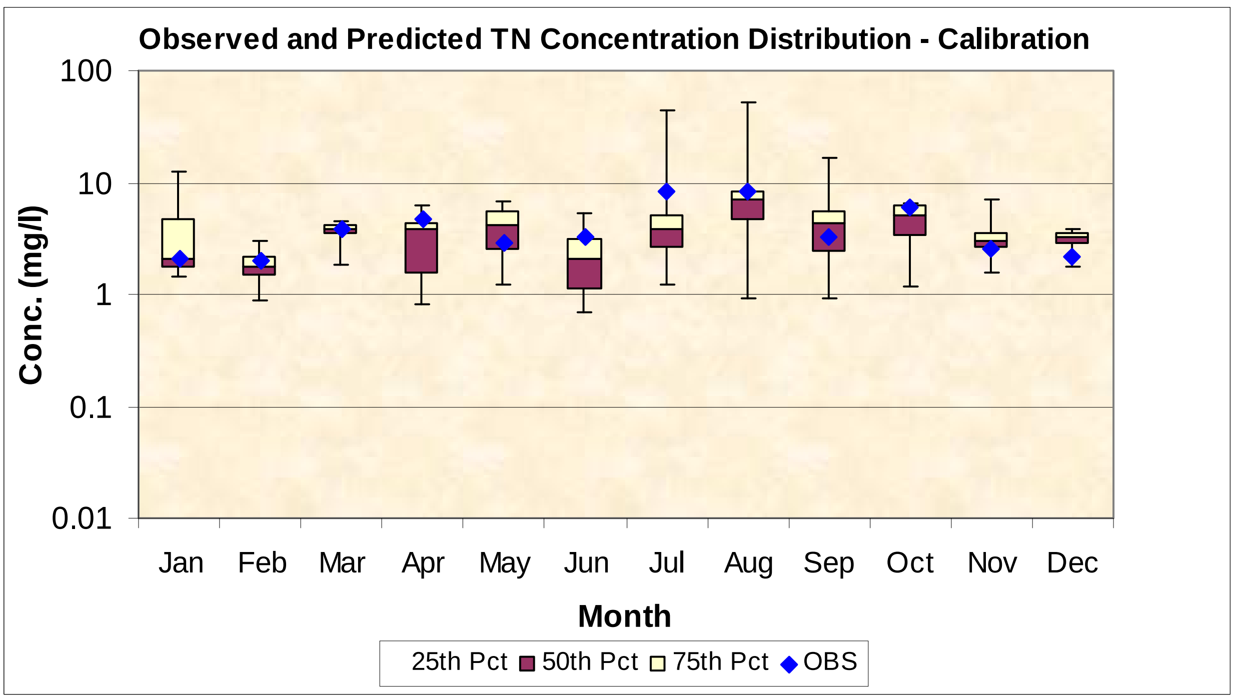

Figure KOR- 6. Calibration - Observed versus predicted TN concentrations for Knap of Reeds Creek (shown in log scale).

Phosphorus

Figure KOR-7 illustrates the time series plot of the simulated and observed TP concentrations and Figure KOR-8 shows the seasonal distribution of TP. WARMF simulated TP concentrations fairly well throughout the calibration period. On the average, the WARMF predicted concentrations were slightly lower than the observed average concentration, especially during the summer months. This could be because of unaccounted nonpoint sources of TP and underestimation of TP concentration from point sources. The average observed TP concentrations fall within the range of predicted values in every month except for February during the calibration period.

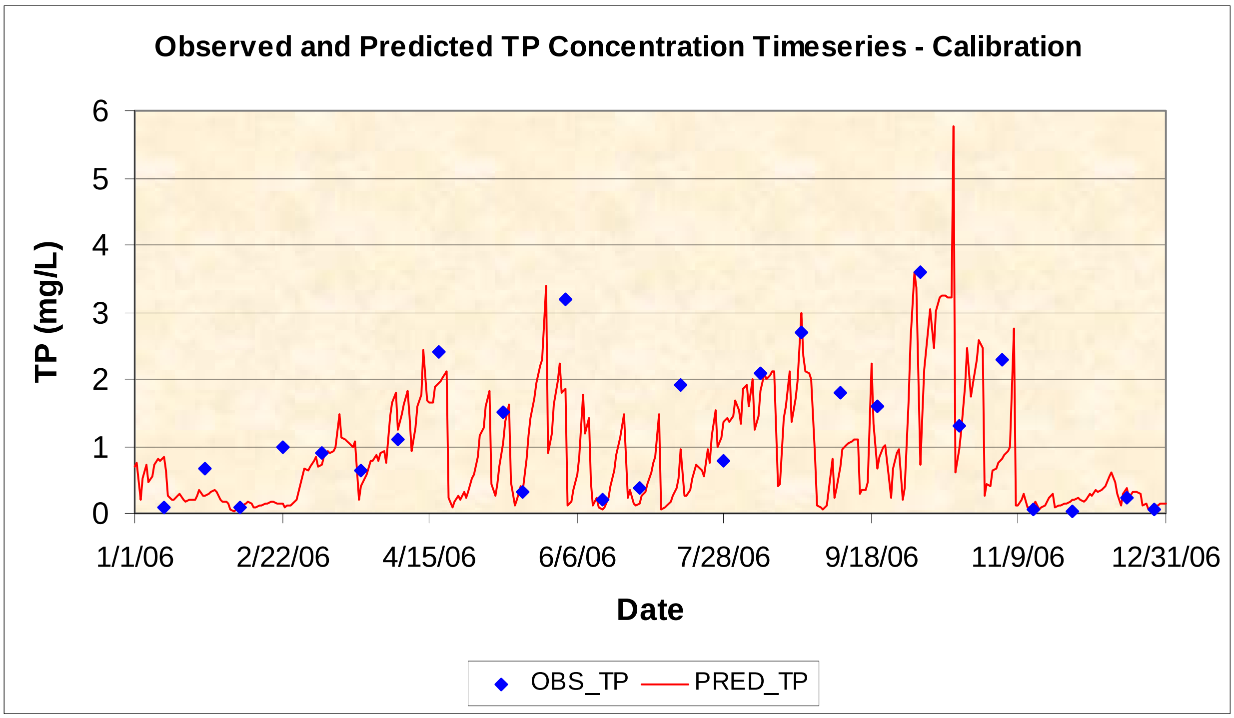

Figure KOR- 7. Calibration – Knap of Reeds Creek TP concentrations daily time series.

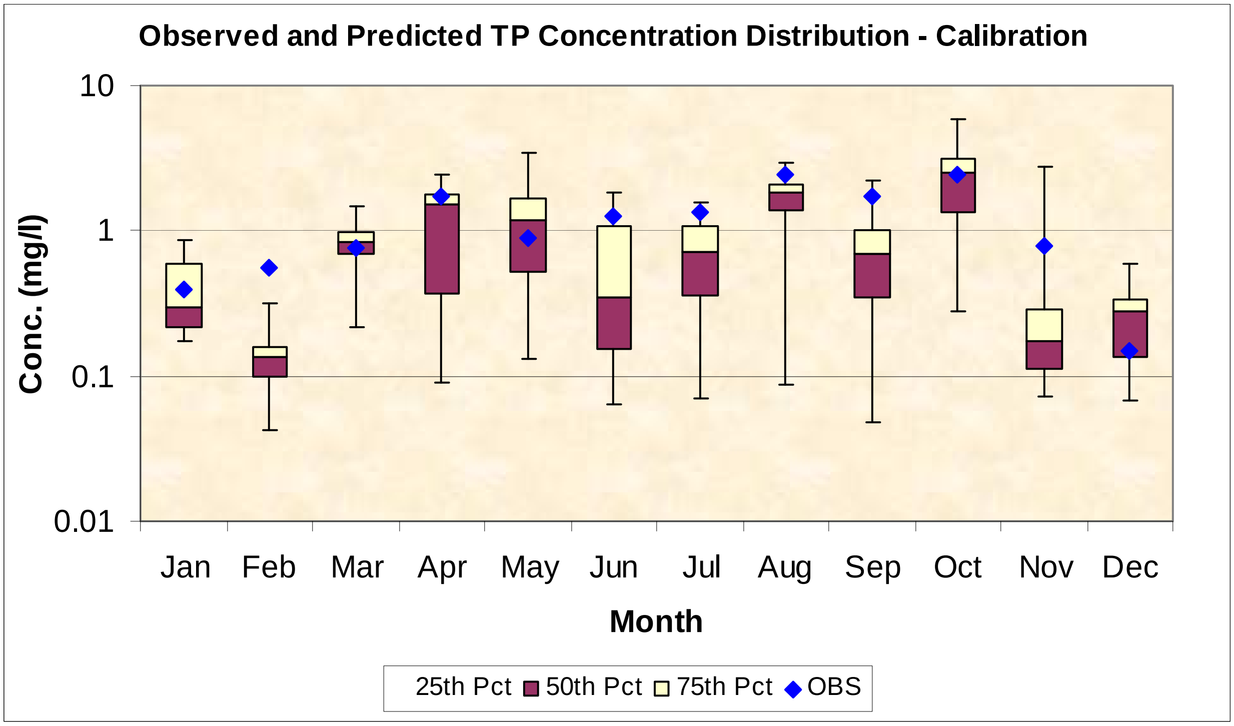

Figure KOR- 8. Calibration - Observed versus predicted TP concentrations for Knap of Reeds Creek (shown in log scale).

5.3 Hydrologic Validation

Validation of the WARMF Knap of Reeds Creek calibration was performed for the January 1, 2007 through September 30, 2007 timeframe. The same USGS gage and water quality DWQ ambient monitoring station used for calibration were used for validation. The extreme drought in 2007 and the short validation period (nine months) presented limitations that were considered in interpretation of the validation results.

Figure KOR-9 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow for the validation period. Overall, WARMF simulates the magnitude and trend of flow very well in this watershed both during calibration and validation periods. It also simulated the seasonal variation of flow and tracked the general trend of flows. Figure KOR-10 is a scatter plot of observed and simulated flow at the same station.

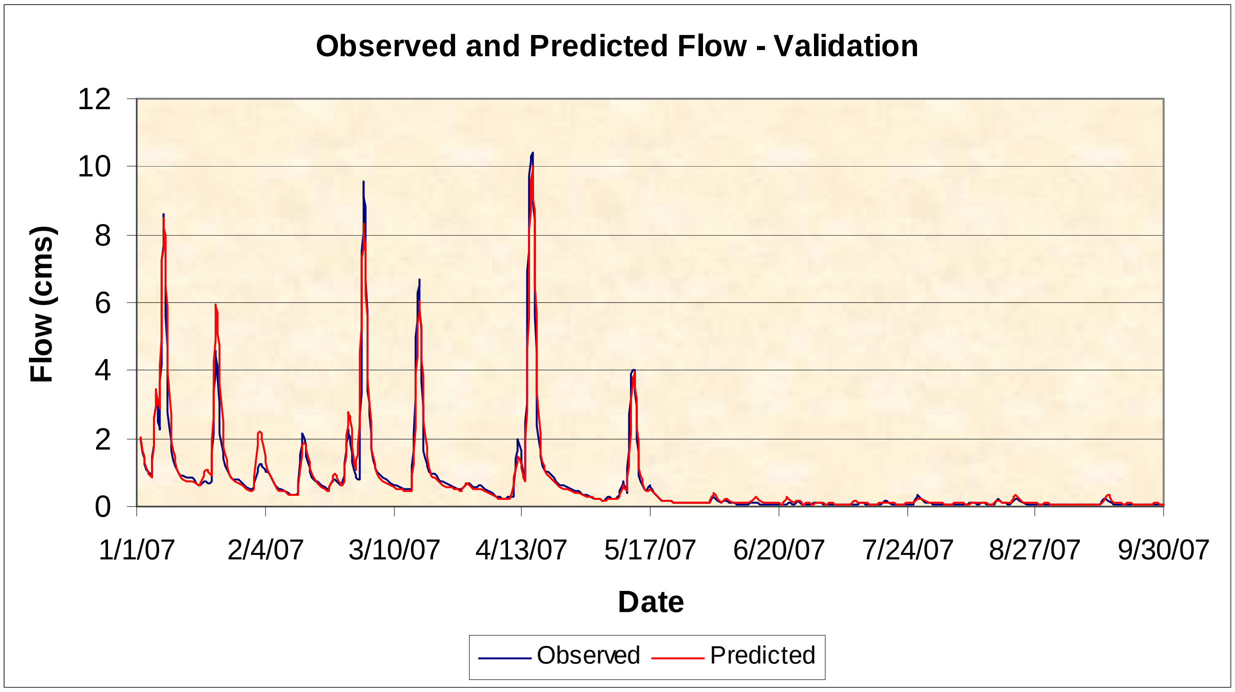

Figure KOR- 9. Validation - Time series of predicted and observed flow for Knap of Reeds Creek.

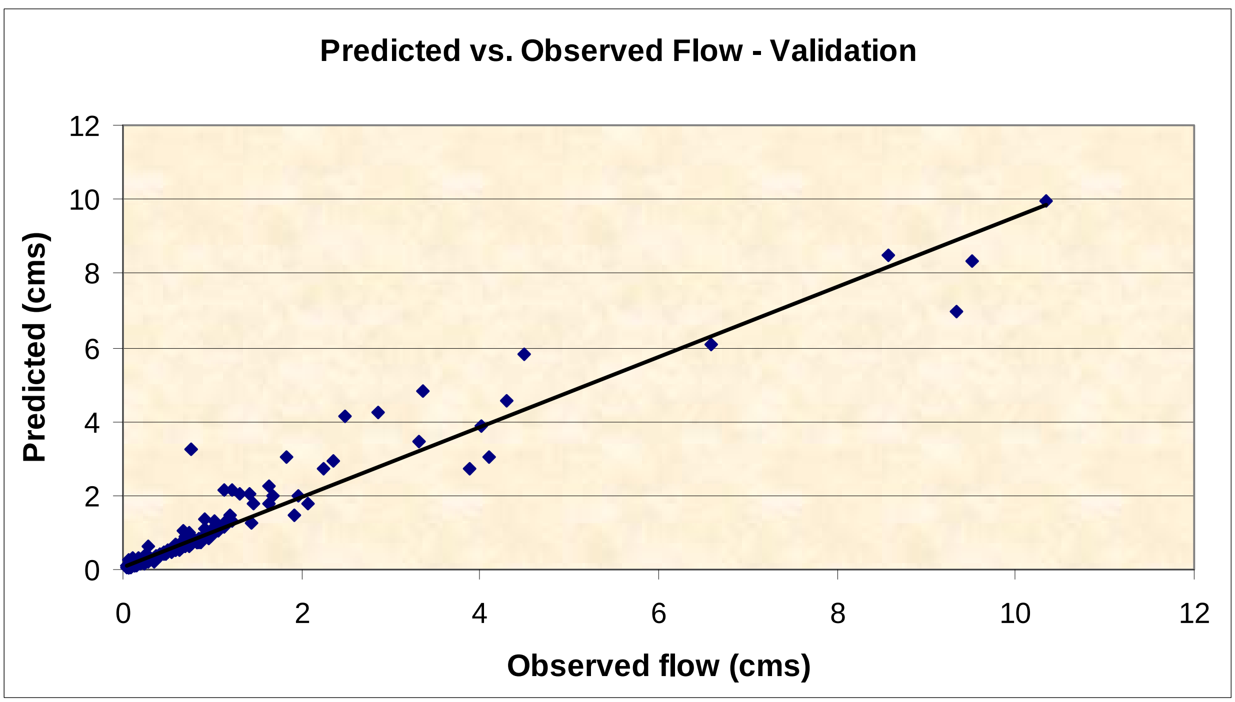

Figure KOR- 10. Validation - Predicted versus observed flow for Knap of Reeds Creek.

Table KOR-3 provides the error statistics for daily and seasonal flow volume. The total volume and seasonal volume errors satisfy the criteria set during the calibration period, except for a slight exceedance of the criteria for total volume of lowest 50% flows. This is most likely due to the extreme low flows observed during the validation period.

Table KOR-4 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the validation period. The mean predicted flow (0.71 m^3/s) and mean observed flow (0.67 m^3/s) are very close in value.

Table KOR- 3. Predicted flow volume statistics for the validation period at USGS Station 02086624 in Knap of Reeds Creek.

	Predicted (m^3)	Observed (m^3)	% Diff[1]	Recommended Criteria
Total predicted in-stream flow volume	16,809,855	15,919,438	5.6%	*10%*
Total volume of highest 10% flows	9,359,753	8,767,056	6.8%	*15%*
Total volume of lowest 50% flows	1,297,494	1,119,922	15.9%	*10%*
Total summer flow volume (months 7-9)	807,018	695,150	16.1%	*30%*
Total winter flow volume (months 1-3)	11,130,692	10,156,866	9.6%	*30%*
Total spring flow volume (months 4-6)	4,872,145	5,067,422	-3.9%	*30%*

[1]. % Diff refers to percent difference and is calculated by (predicted – observed)/observed.

Table KOR- 4. Additional daily flow statistics for predicted versus observed data for the validation period at USGS Station 02086624 in Knap of Reeds Creek.

	Flow Statistics
Relative Error	0.06
Average Error	0.04
Root Mean Square of Error (m^3/s)	0.34
Standard deviation (SD_{obs}) (m^3/s)	1.35
RMSE/SD_{obs}	0.25
R^2	0.94
Coefficient of Efficiency	0.94
Percent Bias	5.59%
Observed Mean Flow (m^3/s)	0.67
Predicted Mean Flow (m^3/s)	0.71

5.4 Water Quality Validation

Water quality validation was performed for the Knap of Reeds Creek watershed using 2007 as the validation year. WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to 2007 data from the same DWQ ambient monitoring station used in calibration.

<u>Total Suspended Sediment (TSS)</u>

Figure KOR-11 illustrates the time series plot of the observed and WARMF predicted TSS in Knap of Reeds Creek. The model simulated higher TSS concentrations in the beginning of the year that were not captured in the ambient monitoring data. The model predictions match well with observed TSS concentrations in the summer months. Figure KOR-11 shows the seasonal distribution of observed and predicted TSS concentrations. WARMF predicted TSS concentrations were higher than the observed concentrations from January to April and slightly lower from May to September.

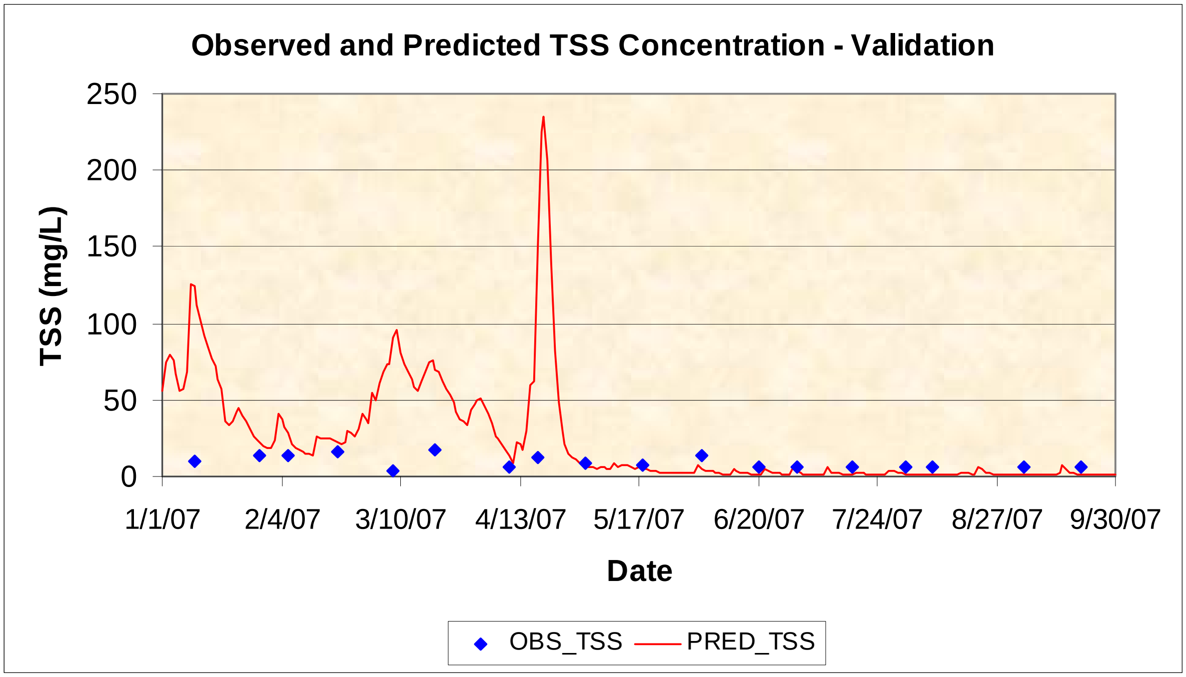

Figure KOR- 11. Validation – Knap of Reeds Creek TSS concentrations daily time series.

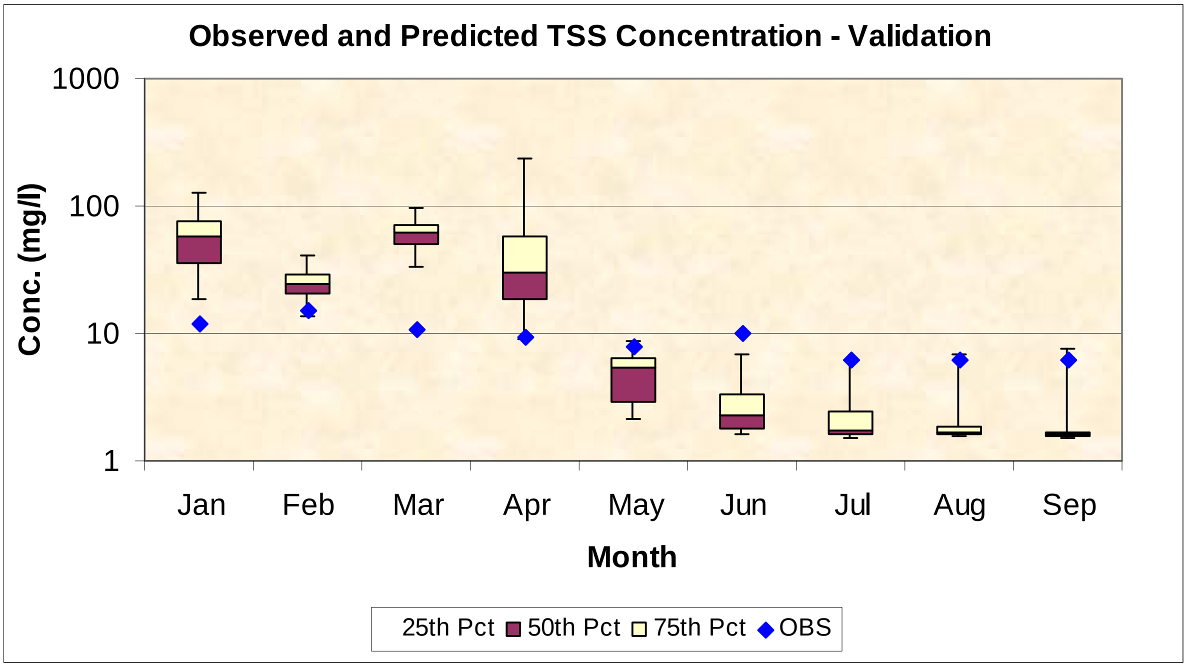

Figure KOR- 12. Validation - Observed versus predicted TSS concentrations for Knap of Reeds Creek (shown in log scale).

Nitrogen

Figure KOR-13 is the time series plot of TN observations and WARMF predicted concentrations in Knap of Reeds Creek for the validation period. Figure KOR-14 shows the seasonal distribution of TN concentrations. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations are included in Appendix C.

On average, WARMF predicted nitrogen constituent concentrations were higher than the observed values for the first three months of 2007 and then have more variance from May through September. This is most likely due to the creek becoming effluent dominated because of the drought conditions. Figure KOR-15 shows a comparison of the model predicted instream load of nitrate and ammonia versus the load from the WWTP effluent discharge. As shown in this figure, beginning in May, the creek becomes effluent dominated, with the load instream almost equal to the load from the discharge.

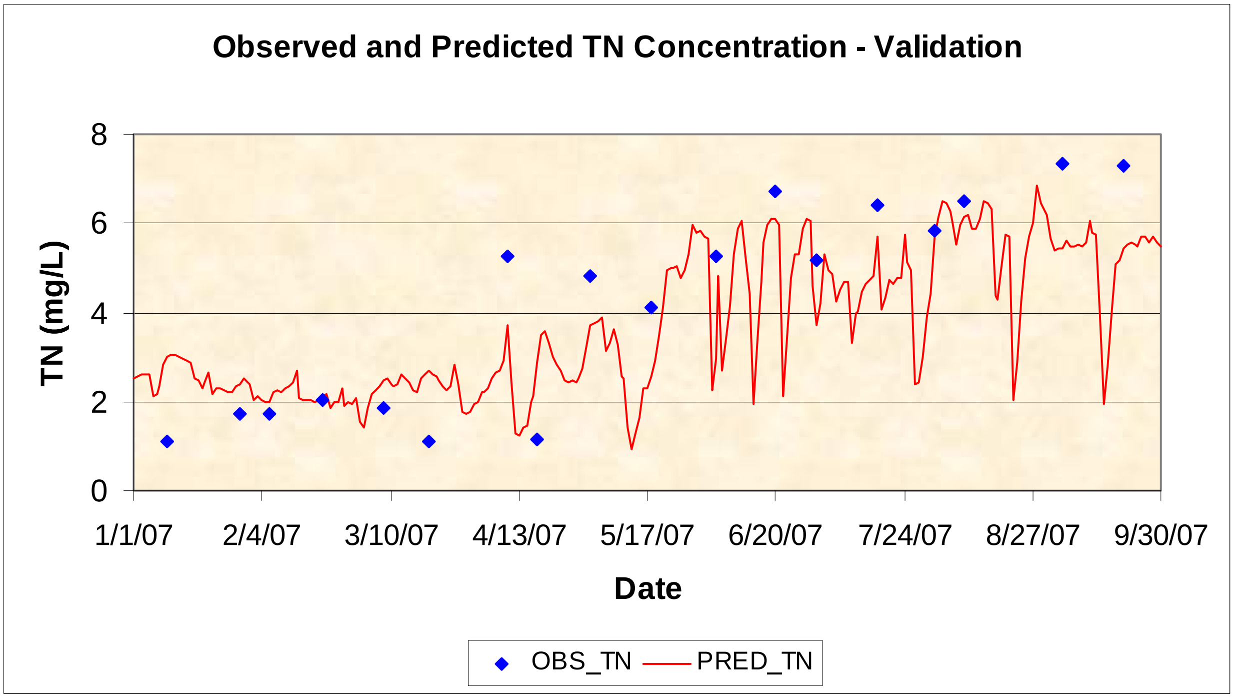

Figure KOR- 13. Validation – Knap of Reeds Creek TN concentrations daily time series.

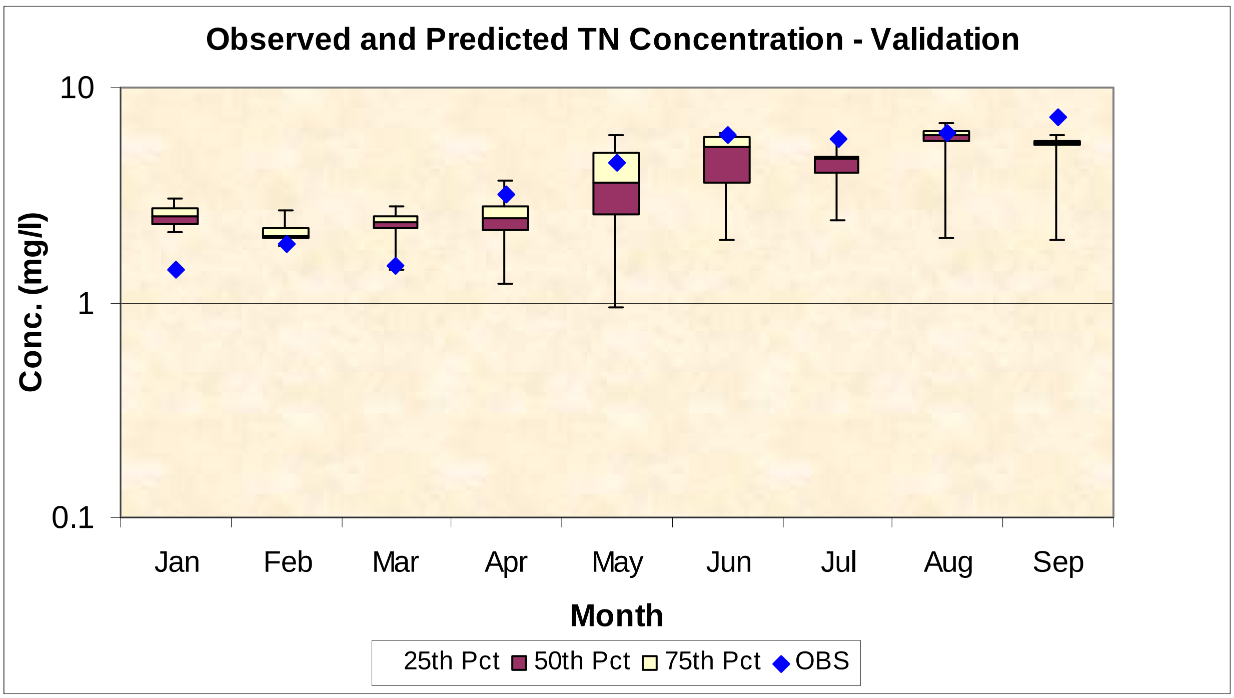

Figure KOR- 14. Validation - Observed versus predicted TN concentrations for Knap of Reeds Creek (shown in log scale).

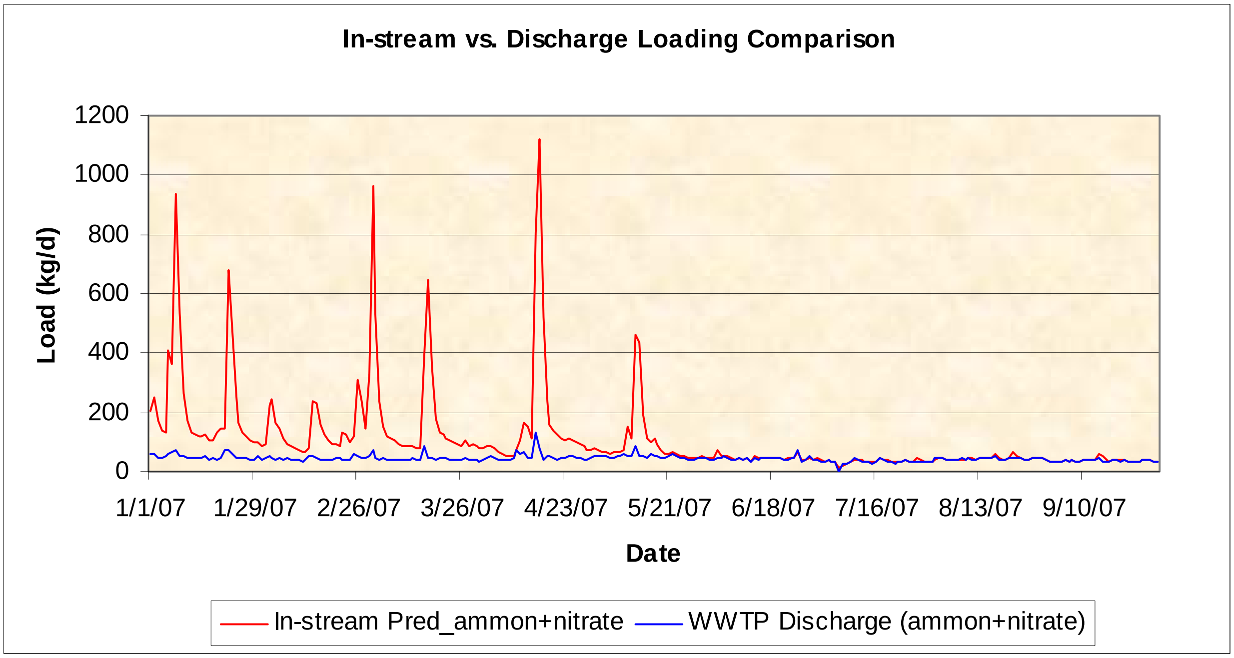

Figure KOR- 15. Comparison of model predicted instream versus discharge load of ammonia and nitrate.

<u>Phosphorus</u>

Figure KOR-16 illustrates the time series comparison plot of the simulated and observed TP concentrations and Figure KOR-17 shows the seasonal distribution of TP. The validation results were mostly similar to the calibration results. WARMF simulated average TP concentrations fairly well, but underestimated large TP concentrations. This could be because of unaccounted nonpoint sources of TP, underestimation of TP concentration from point sources, and the extreme drought in 2007.

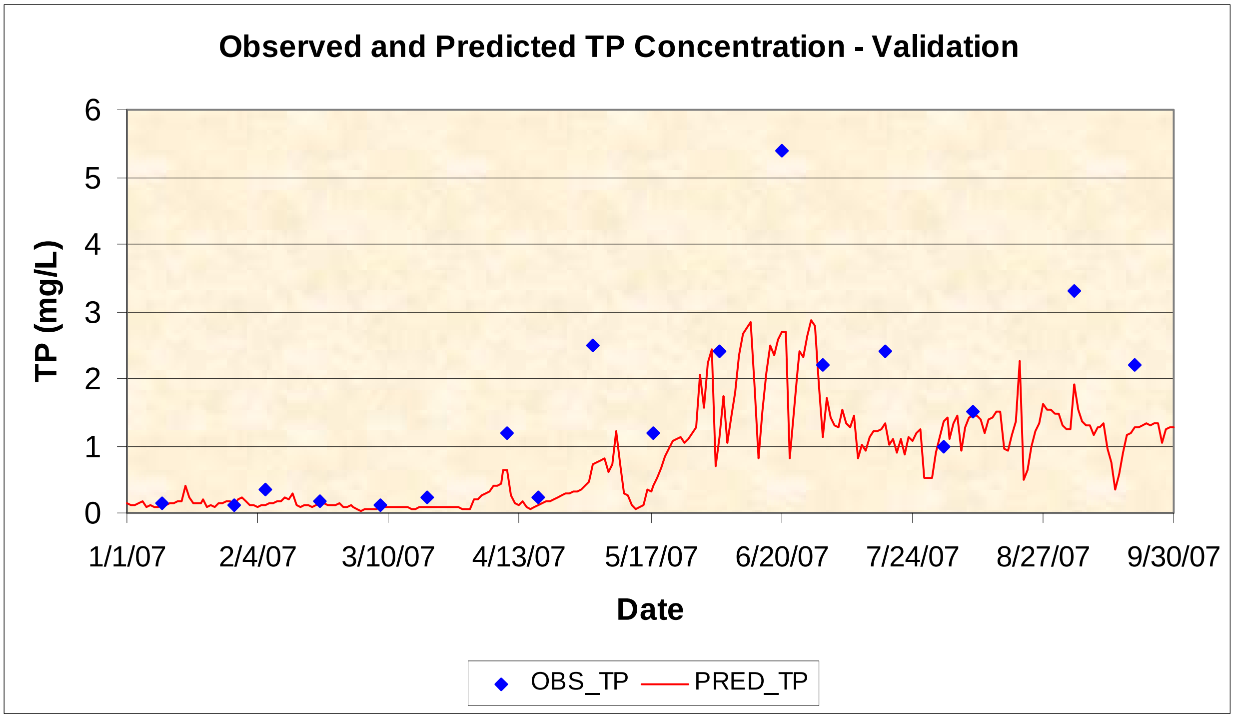

Figure KOR- 16. Validation – Knap of Reeds Creek TP concentrations daily time series.

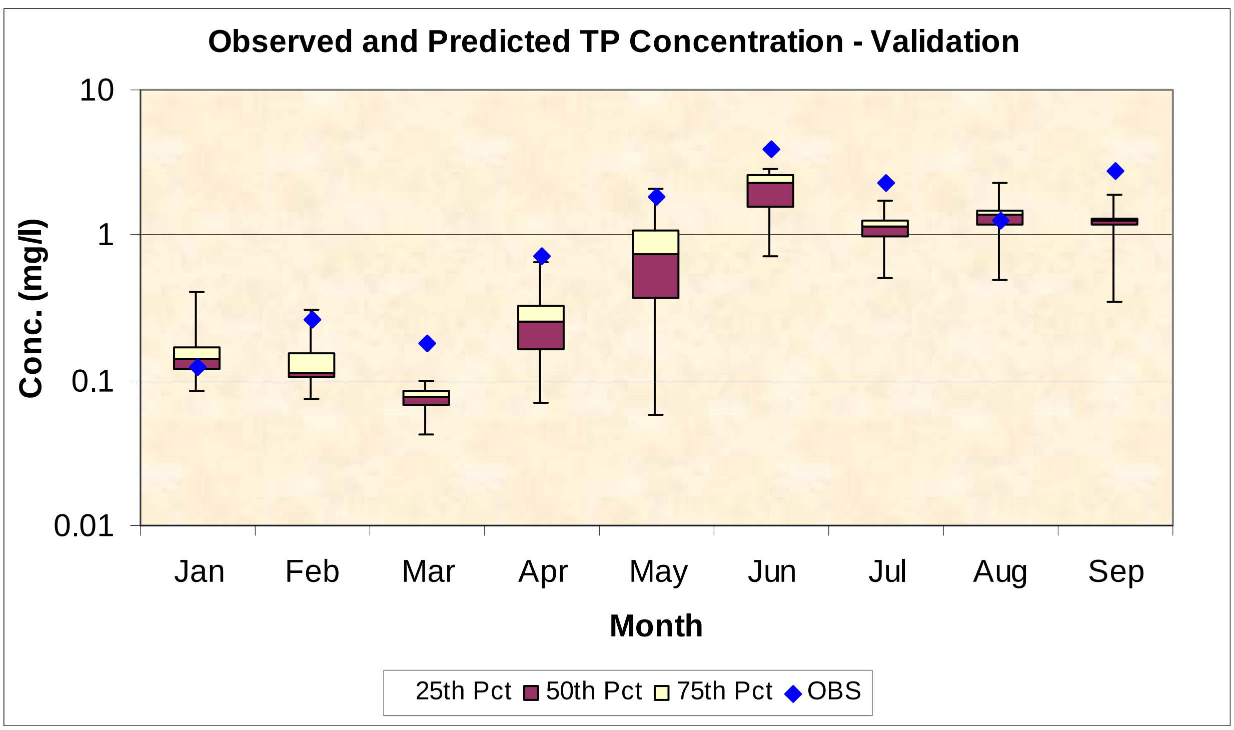

Figure KOR- 17. Validation - Observed versus predicted TP concentrations for Knap of Reeds Creek (shown in log scale).

6.0 Watershed Model Results – Flat River

6.1 Hydrologic Calibration Above Lake Michie

The USGS measured flow as well as physical and chemical constituents of water quality at the USGS station above Lake Michie. Flow was measured daily and water quality constituents were measured monthly. However, the USGS did not measure the constituents for January and September during the model calibration period, 2004-2006.

Figure Flat -1 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at the Flat River USGS gage (USGS 02085500), above Lake Michie. WARMF simulates the magnitude and trend of flow well in this watershed, although there is some slight underestimation of higher peaks. This could be the result of localized rain events not captured in the meteorological data. Figure Flat-2 is a scatter plot of observed and simulated flow at the same station. Linear regression resulted in a low R^2 value of 0.38. This was because the model underpredicted some higher flow peaks. In general, R^2 value is easily influenced by extreme values.

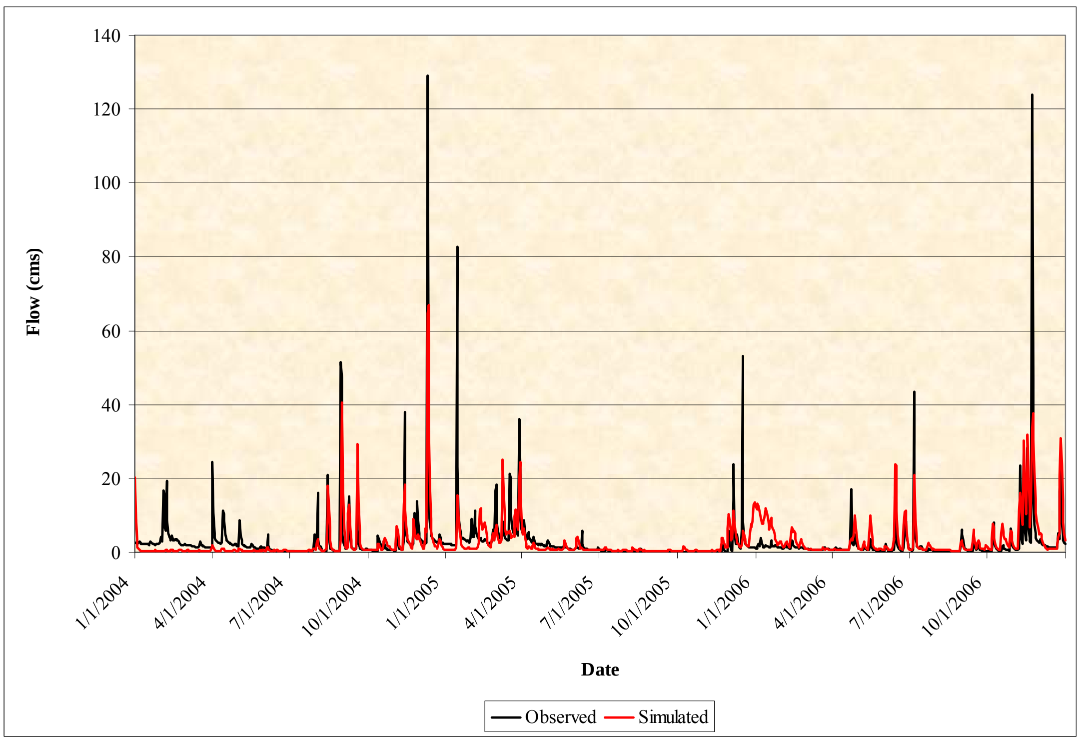

Figure Flat- 1. Observed and simulated daily total flow from Flat River at USGS 2085500, above Lake Michie. Model simulation periods are 2004 through 2006.

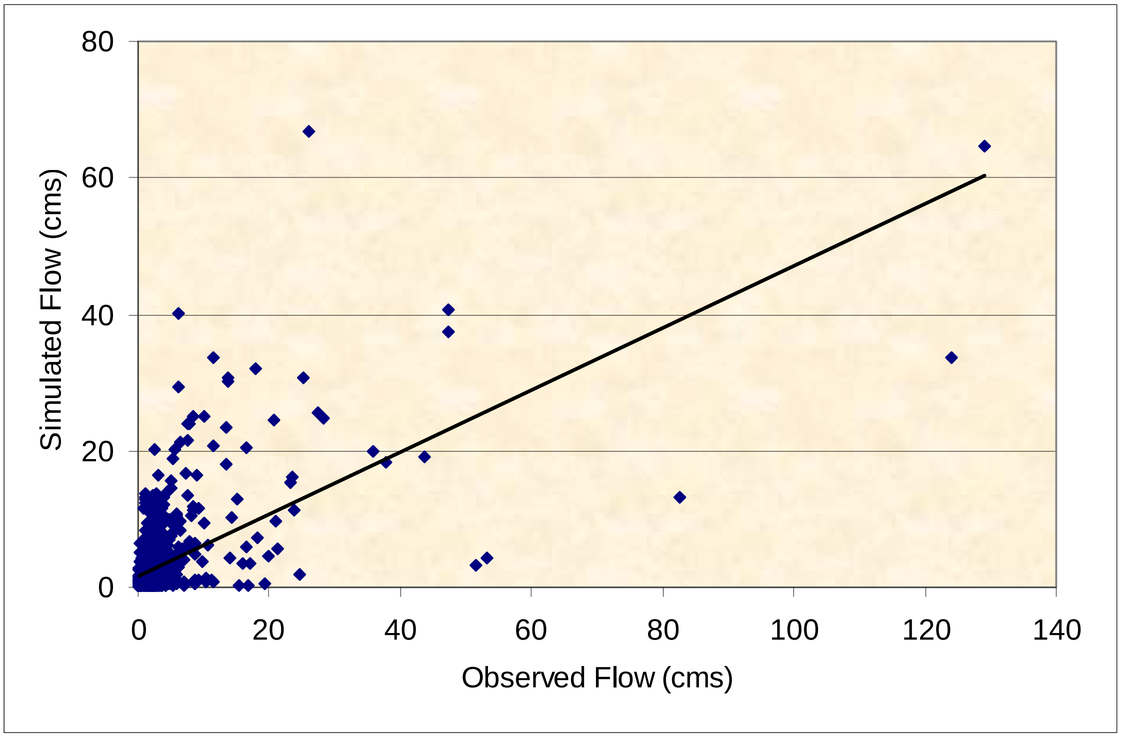

Figure Flat- 2. Relation between observed and simulated daily total flow from Flat River at USGS 02085500, above Lake Michie. Model simulation periods are 2004 through 2006.

Table Flat -1 provides the error statistics for total and seasonal flow volume. The total volume and seasonal volume errors more than satisfy the calibration criteria set during the calibration process. In general, while not exceeding any of the recommended error criteria, WARMF slightly overestimated flow during summer and fall months and slightly underestimated flow during winter and spring months.

Table Flat- 1. Flow volume statistics for WARMF versus observed data for the calibration period (2004-2006) at Flat River USGS station 02085500, above Lake Michie.

Parameters	Predicted (m^3)	Observed (m^3)	Error (%)	Recommended Criteria (%)
Total In-stream Flow:	266,559,699	259,637,070	2.67	10
Total of highest 10% flows:	149,329,613	147,674,493	1.12	15
Total of lowest 50% flows:	23,757,224	21,644,037	9.76	10
Summer Flow Volume (months 7-9):	44,763,401	34,955,644	28.06	30
Fall Flow Volume (months 10-12):	114,510,472	96,155,290	19.09	30
Winter Flow Volume (months 1-3):	71,524,183	82,719,427	-13.53	30
Spring Flow Volume (months 4-6):	35,701,601	45,806,709	-22.06	30

Table Flat-2 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flows are very close to the observed mean. The percent bias, relative error, and average error are all very small, indicating a very close match between observed and predicted flow.

Table Flat- 2. Additional daily flow statistics for WARMF versus Observed data for the calibration period at Flat River USGS station 02085500, above Lake Michie.

	Statistics
Relative Error	0.03
Average Error	0.07
Absolute Error	2.29
Standard deviation (SD_{obs}) (m^3/s)	7.60
$RMSE/SD_{obs}$	0.80
Coefficient of Determination (R^2)	0.38
Coefficient of Efficiency	0.37
Percent Bias	0.03
Observed Mean (m^3/s)	2.76
Predicted Mean (m^3/s)	2.83

6.2 Water Quality Calibration Above Lake Michie

Total Suspended Sediment

Figures Flat-3 and Flat-4 illustrate the time series plot and the monthly distribution of observed and predicted TSS concentrations at the Flat River USGS monitoring station, respectively. The time series plot indicated that the simulated TSS concentrations followed the monthly distribution of the observed TSS concentrations, except during the first six months of 2004. WARMF requires a few months to adjust atmospheric and soil properties at the beginning of the simulation period. As a result, WARMF simulated moderately lower TSS concentrations than the observed concentrations during the first six months. Overall, the monthly-observed values of TSS concentrations were within the range of daily-predicted concentrations in each month (Figure Flat-4). The result suggests that the simulated and observed TSS concentrations matched well.

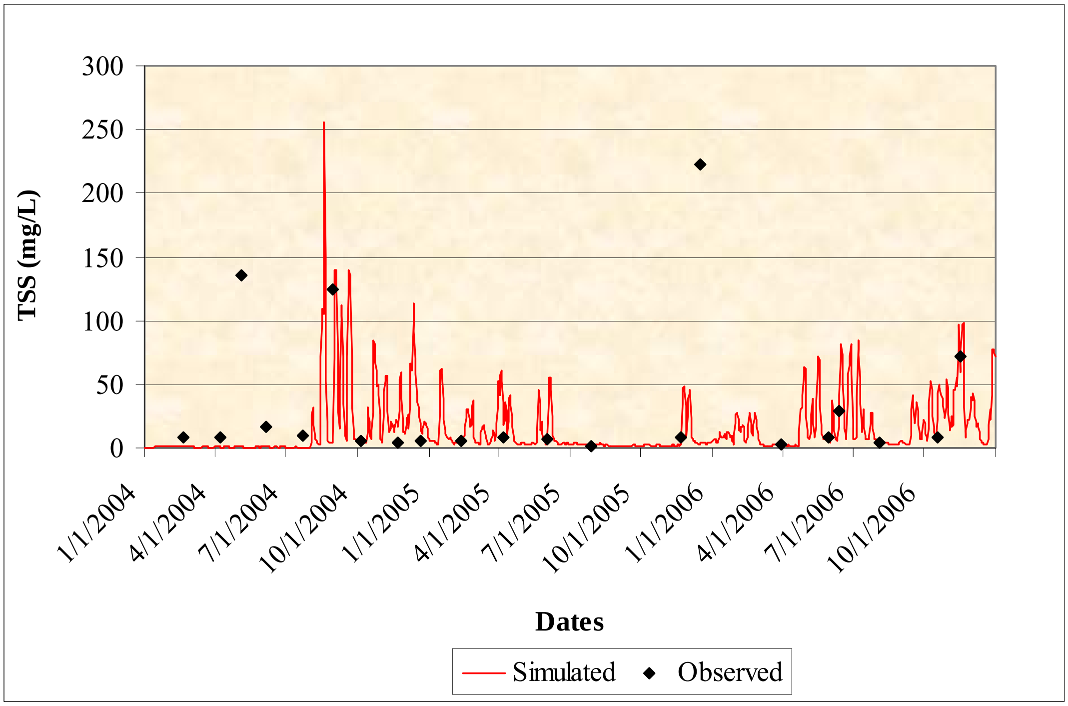

Figure Flat- 3. Time series distribution of predicted and observed total suspended solids (TSS) in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation periods are 2004 through 2006.

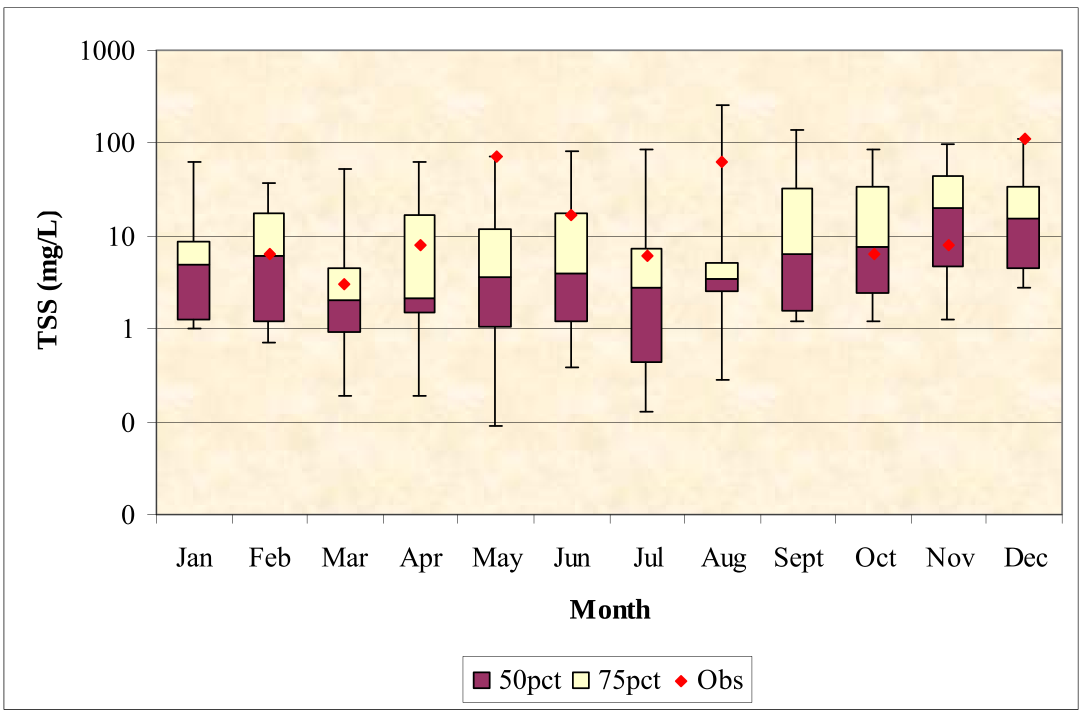

Figure Flat- 4. Monthly observed concentration of total suspended solids (TSS) vs. quantile distribution of predicted daily TSS in Flat River Watershed at USGS 02085500, above Lake Michie.

Nitrogen

Figures Flat-5 and Flat-6 illustrate the time series plot and the monthly distribution of observed and predicted TN concentrations at the Flat River USGS monitoring station, respectively. Both the time series and monthly distributions plots suggested an acceptable calibration. A similar result was also observed for ammonia, NO_3, and TKN concentrations (shown in Appendix C, Figure FlatCalA_C1-6). However, the model underestimated TKN concentrations in May and overestimated NO_3 concentrations in March. Since TN is the sum of TKN and NO_3, the model simulated correspondingly higher TN concentrations in March and lower in May as compared to the observed TN concentrations (Figure Flat-6).

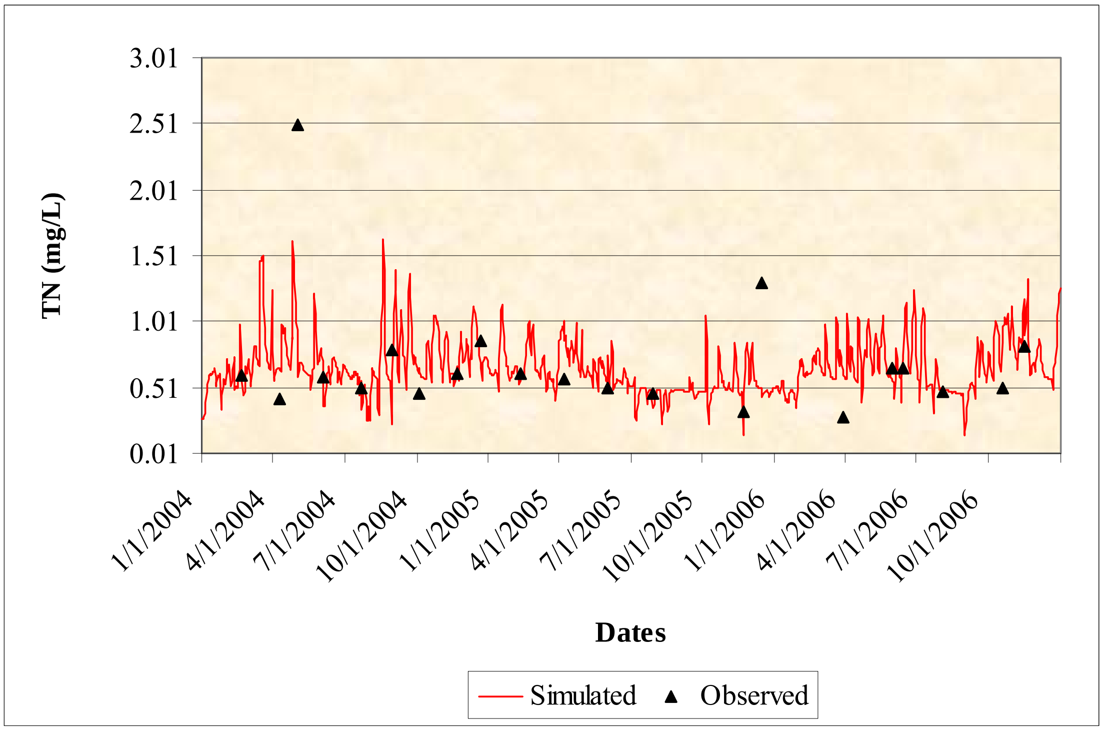

Figure Flat- 5. Time series distribution of predicted and observed total nitrogen in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation periods are 2004 through 2006

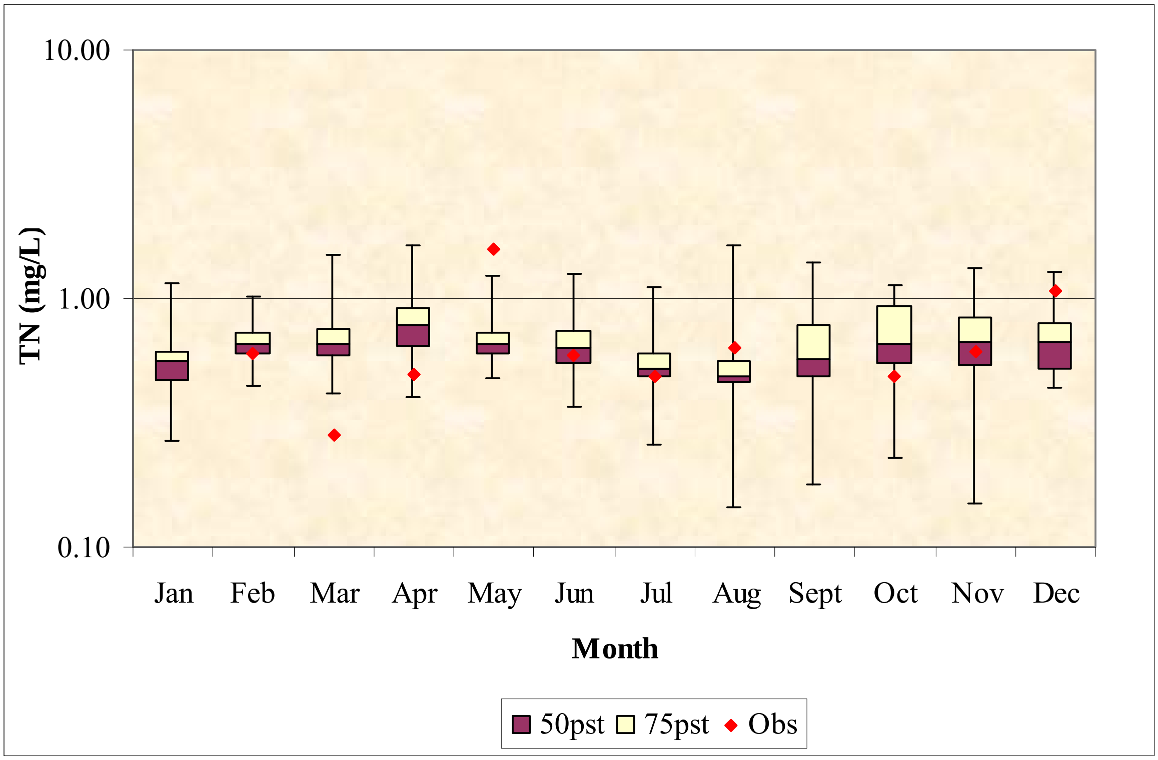

Figure Flat- 6. Monthly observed concentration of total nitrogen vs. quantile distribution of predicted daily total nitrogen in Flat River Watershed at USGS 02085500, above Lake Michie.

<u>Phosphorus</u>

There was no TP measured at this station during the calibration period, 2004 -2006.

6.3 Hydrologic Calibration Below Lake Michie

Figure Flat - 7 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at the Flat River USGS gage (USGS 02086500), below Lake Michie. The flow at this station is controlled by the release from the Lake Michie Reservoir. Overall, WARMF simulates the magnitude and trend of flow very well in this watershed. Figure Flat-8 is a scatter plot of observed and simulated flow at the same station. Linear regression resulted in an R^2 value of 0.88, indicating a very good match between observed and model predicted flows.

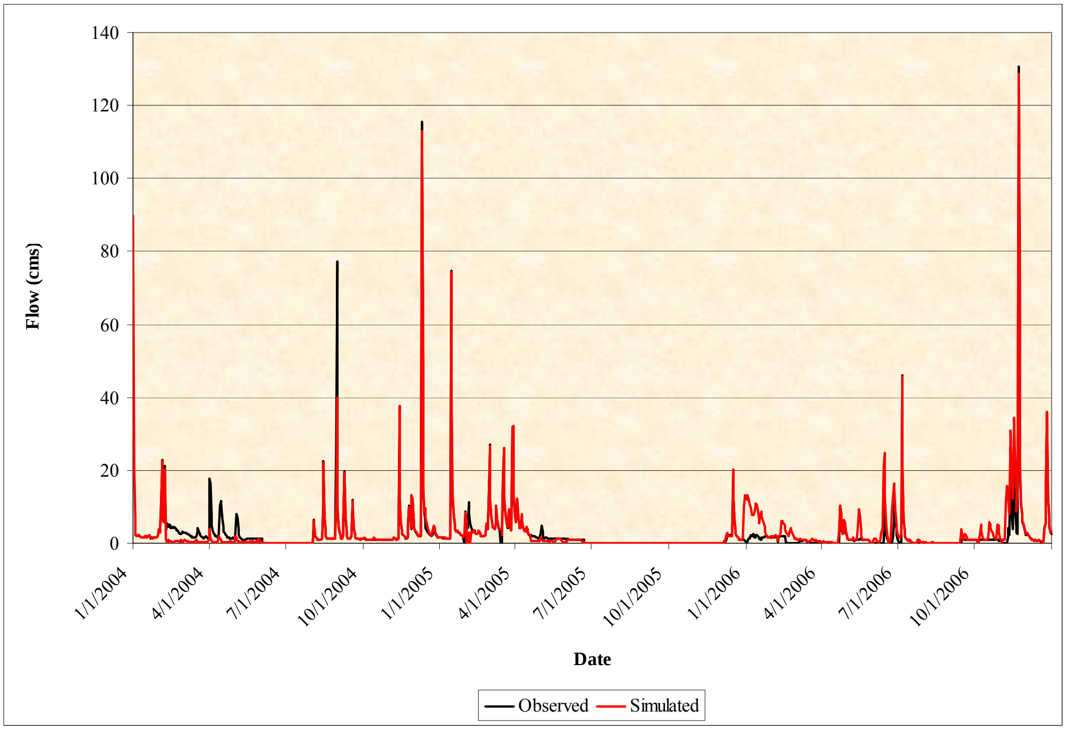

Figure Flat- 7. Observed and simulated daily total flow from Flat River at USGS 02086500, below Lake Michie. Model simulation periods are 2004 through 2006.

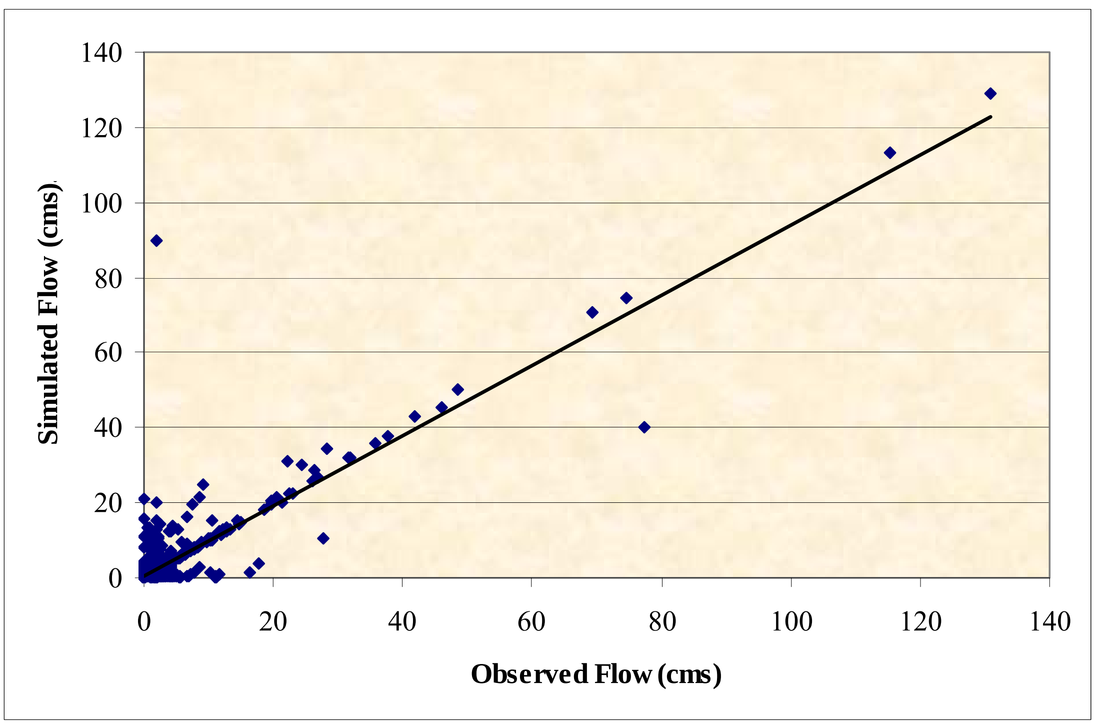

Figure Flat- 8. Relation between observed and simulated daily total flow from Flat River at USGS 02086500, below Lake Michie. Model simulation periods are 2004 through 2006.

Table Flat-3 provides the error statistics for total and seasonal flow volume. The total volume and seasonal volume errors more than satisfy the calibration criteria set during the calibration process. The total volume stream flow error was less than ten percent. In general, while not exceeding any of the recommended error criteria, the model slightly overpredicted high and low flows.

Table Flat- 3. Flow volume statistics for WARMF versus observed data for the calibration period (2004-2006) at Flat River USGS station 02086500, below Lake Michie.

Parameters	Predicted	Observed	Error	Recommended Criteria
	(m^3)	(m^3)	(%)	(%)
Total In-stream Flow:	274,682,424	251,027,642	9.42	10
Total of highest 10% flows:	171,260,483	156,275,514	9.59	15
Total of lowest 50% flows:	12,002,667	10,917,845	9.94	10
Summer Flow Volume (months 7-9):	31,903,853	34,102,119	-6.45	30
Fall Flow Volume (months 10-12):	111,524,963	90,520,367	23.20	30
Winter Flow Volume (months 1-3):	93,095,370	84,515,813	10.15	30
Spring Flow Volume (months 4-6):	38,135,280	41,889,343	-8.96	30

Table Flat-4 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flows are very close to the observed mean. The percent bias, relative error, and average error are all very small, indicating a very close match between observed and predicted flow.

Table Flat- 4. Additional daily flow statistics for WARMF versus Observed data for the calibration period at Flat River USGS station 02086500, below Lake Michie.

	Statistics
Relative Error	0.09
Average Error	0.25
Absolute Error	1.01
Standard deviation (SD_{obs}) (m^3/s)	7.89
$RMSE/SD_{obs}$	0.35
Coefficient of Determination (R^2)	0.88
Coefficient of Efficiency	0.88
Percent Bias	0.09
Observed Mean (m^3/s)	2.67
Predicted Mean (m^3/s)	2.92

6.4 Water Quality Calibration Below Lake Michie

Total Suspended Sediment

Figures Flat-9 and Flat-10 illustrate the time series plot and the monthly distribution of observed and predicted TSS concentrations at the Flat River ambient monitoring station, respectively. The model simulated moderately lower TSS concentrations than the observed concentrations during the beginning of the simulation period. Overall, the monthly-observed values of TSS were within the range of daily-predicted values, suggesting that the model simulated TSS concentrations were close to the observed TSS concentrations during the calibration years.

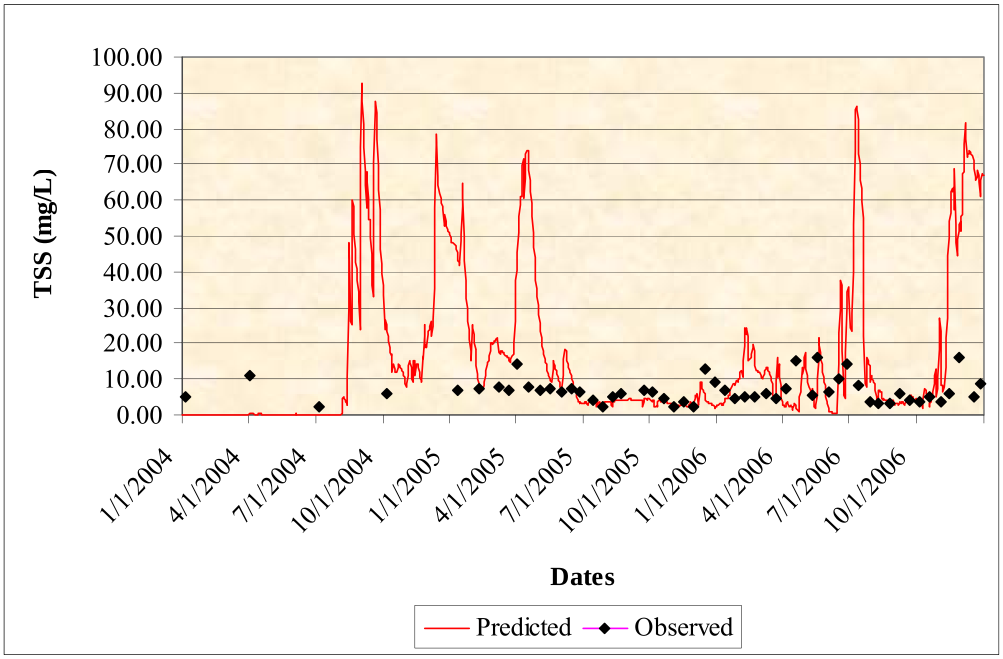

Figure Flat- 9. Time series distribution of predicted and observed total suspended solids (TSS) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation periods are 2004 through 2006.

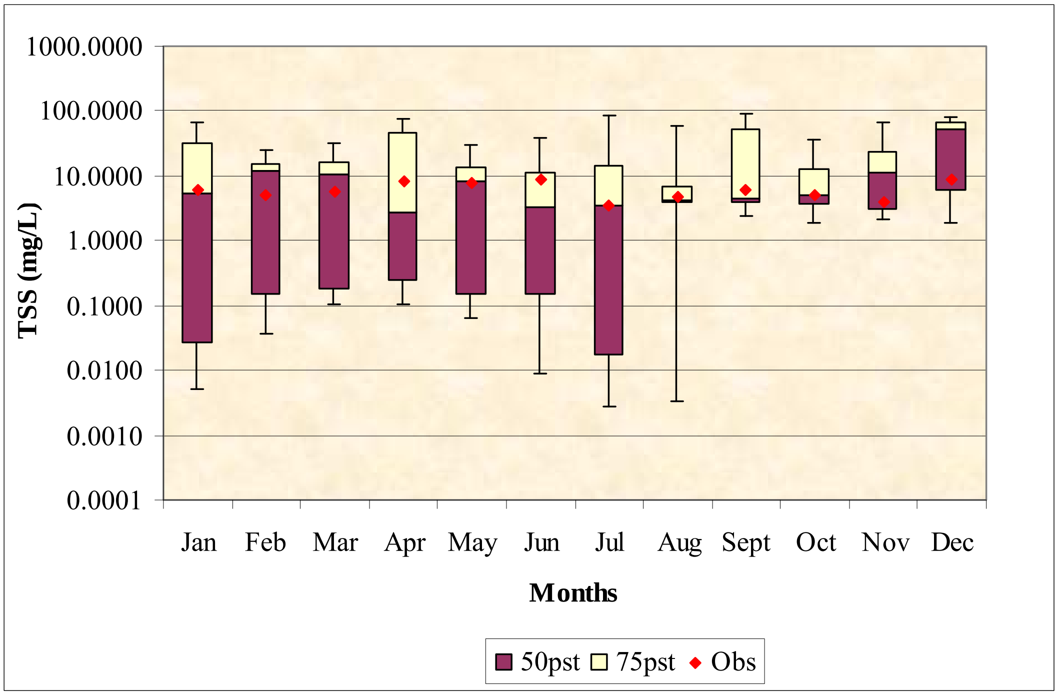

Figure Flat- 10. Monthly-observed concentration of total suspended solids (TSS) vs. quantile distribution of predicted daily TSS in Flat River Watershed at the ambient station J1100000, below Lake Michie.

<u>Nitrogen</u>

Figures Flat-11 and Flat-12 illustrate the time series plot and the monthly distribution of observed and predicted TN concentrations at the Flat River ambient monitoring station, respectively. The time series and seasonal distributions plots suggested an acceptable calibration. A similar result was also observed for ammonia and TKN concentrations (shown in Appendix C, FlatCalB_C1-6). However, the model underestimated NO_3 concentrations in January through March and overestimated in August and September.

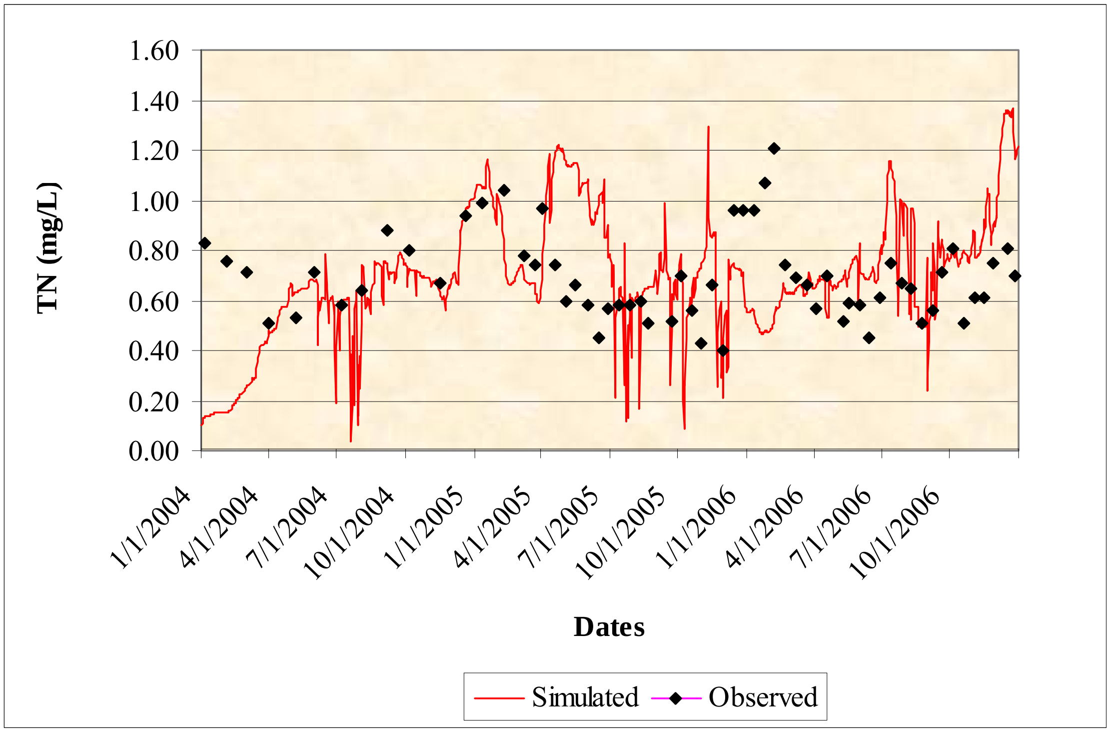

Figure Flat- 11. Time series distribution of predicted and observed total nitrogen in Flat River Watershed at the ambient station J1100000, above Lake Michie. Model simulation periods are 2004 through 2006.

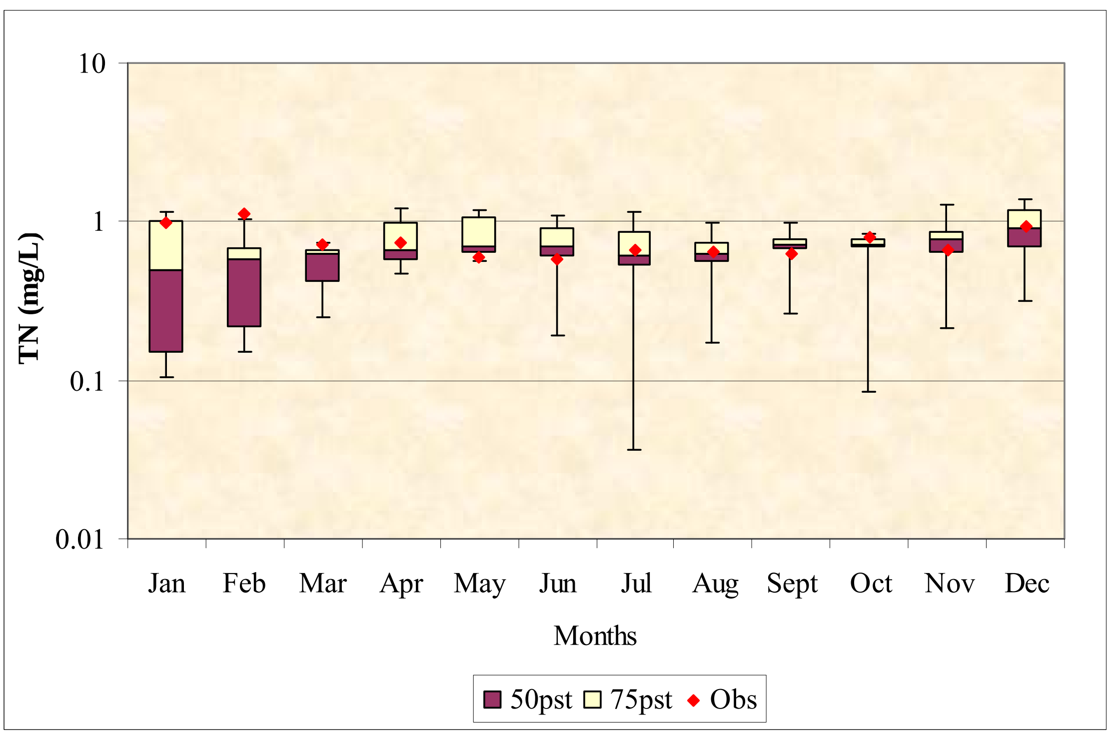

Figure Flat- 12. Monthly-observed concentration of total nitrogen vs. quantile distribution of predicted daily total nitrogen in Flat River Watershed at the ambient station J1100000, below Lake Michie.

Phosphorus

Figures Flat-13 and Flat-14 illustrate the time series plot and the monthly distribution of observed and predicted TP concentrations at the Flat River ambient monitoring station, respectively. During 2004, the model underestimated TP concentrations, but for subsequent years, the model simulated TP concentrations relatively close to the observed concentrations. Overall, the monthly-observed values of TP clustered around the interquantile range of daily-predicted values in each month, suggesting that the model simulated TP concentrations close to the observed concentrations during the calibration periods (Figure Flat-14).

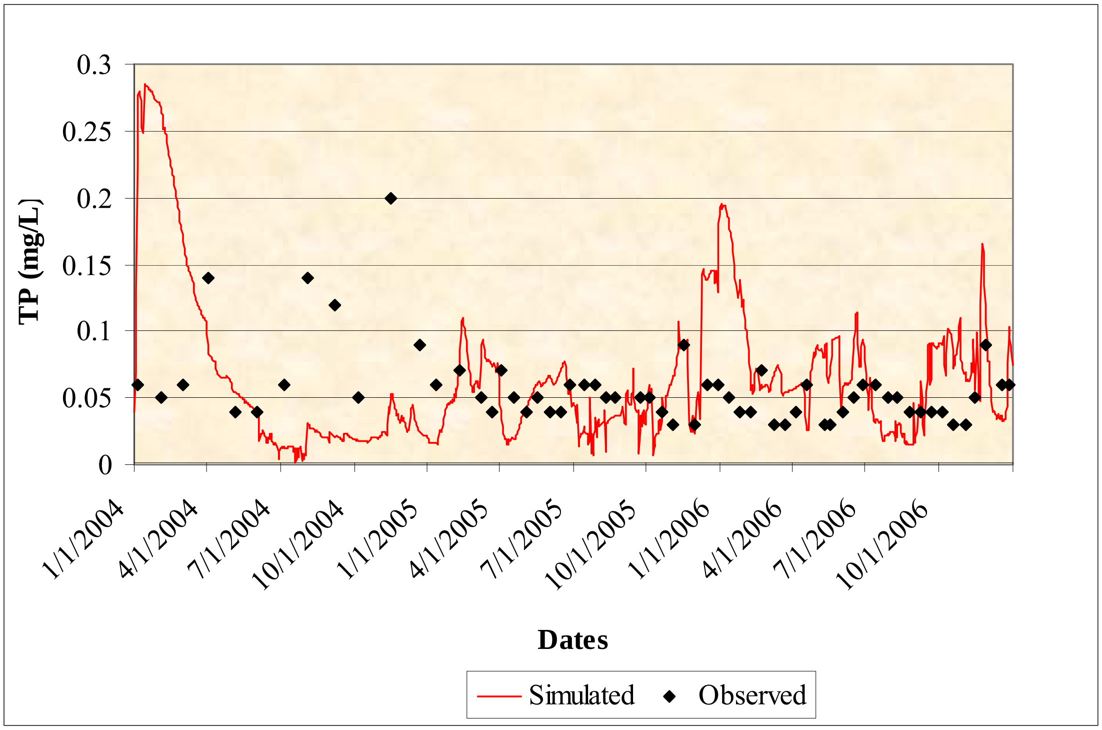

Figure Flat- 13. Time series distribution of predicted and observed total phosphorus (TP) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation periods are 2004 through 2006.

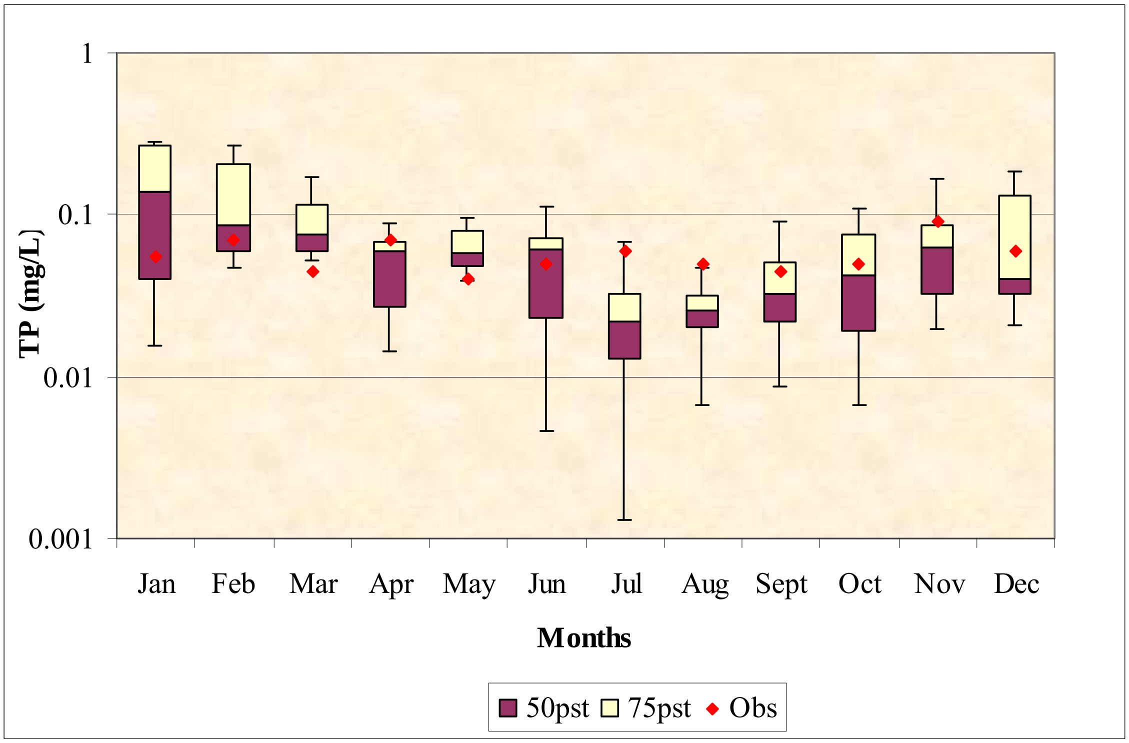

Figure Flat- 14. Monthly-observed concentration of total phosphorus (TP) vs. quantile distribution of predicted daily TP in Flat River Watershed at the ambient station J1100000, below Lake Michie.

6.5 Hydrologic Validation Above Lake Michie

Validation of the WARMF Flat River was performed for the January 1, 2007 through September 30, 2007 timeframe. The same USGS gage and water quality DWQ ambient station used for calibration was used for validation. The extreme drought in 2007 and the short validation period (nine months) presented some modeling limitations.

Figure Flat -15 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow for the validation period. WARMF simulates the magnitude and trend of flow well in this watershed, although there is some slight underestimation of higher peaks. This could be the result of localized rain events not captured in the meteorological data. The model overpredicts the lowest 50% of flow volumes during the low flow period. Overall, the high coefficient of determination and coefficient of efficiency suggest that the model performed well (Table Flat-6); and the low error values associated with the predictions of total flow volumes, average flow volumes, high flow volumes, and seasonal flow volumes (Table Flat-5). Moreover, the statistical errors estimated for daily flow rates were also lower (Table Flat-6). In addition, the mean predicted and observed flows are very close in value.

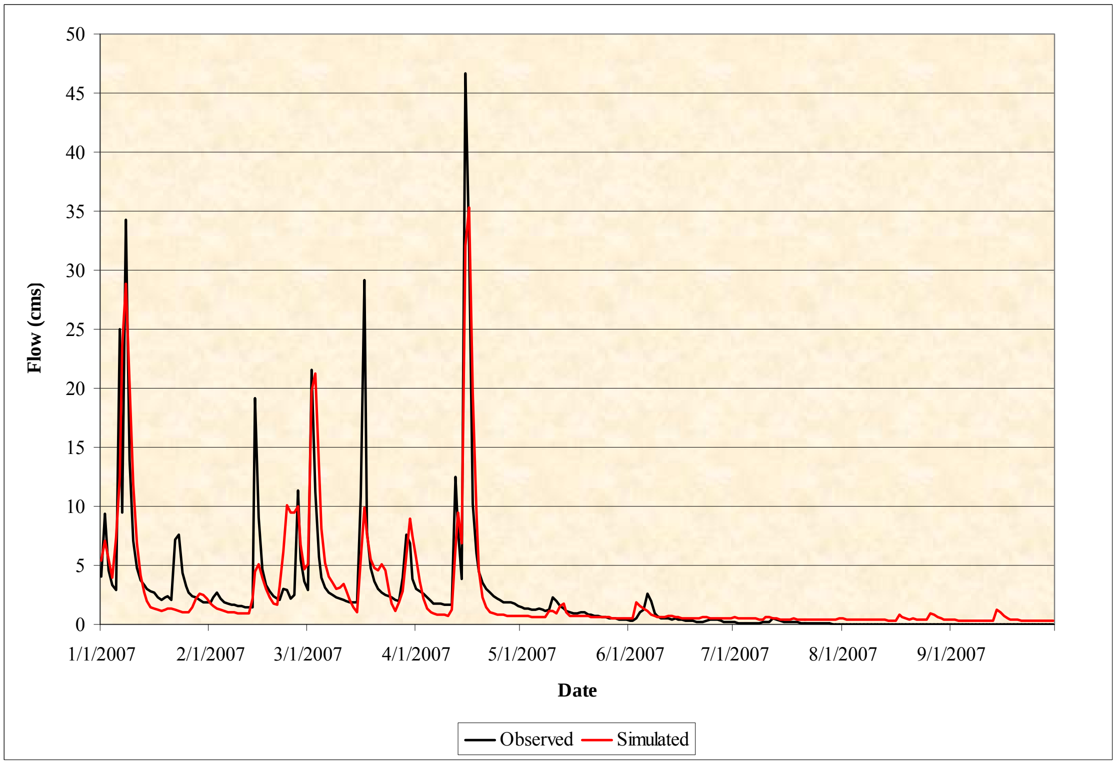

Figure Flat- 15. Observed and simulated daily total flow from Flat River at USGS 02085500, above Lake Michie. Model simulation period is 2007.

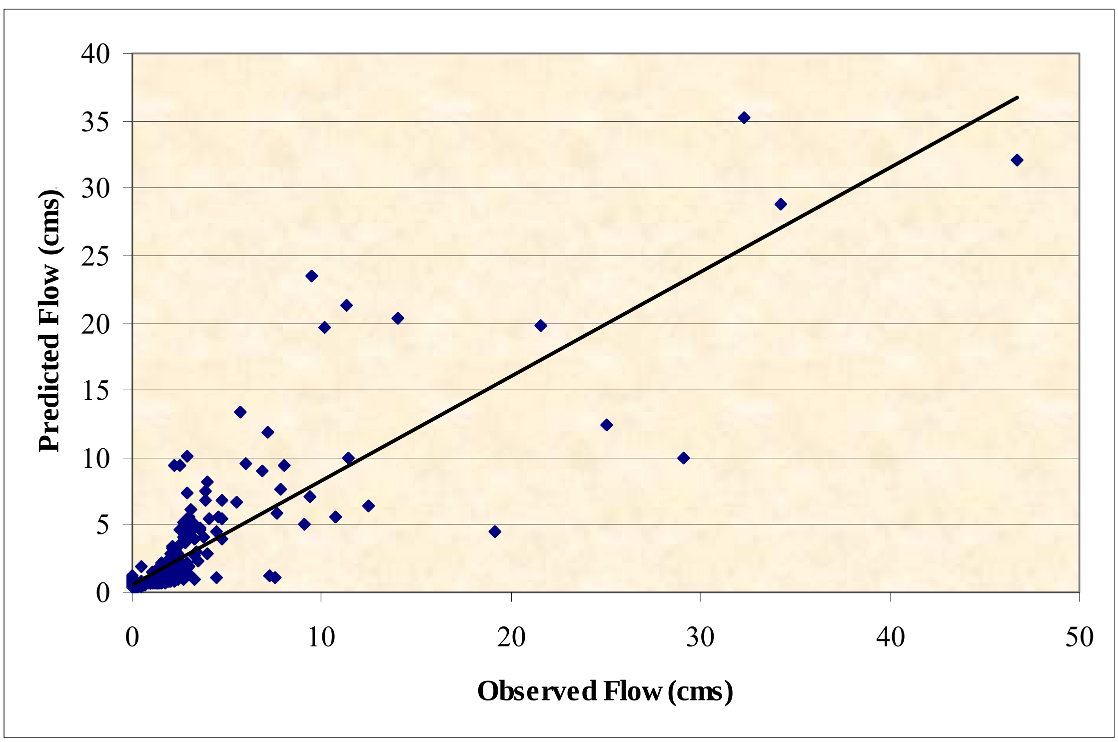

Figure Flat- 16. Relation between observed and simulated daily total flow from Flat River at USGS 02085500, above Lake Michie. Model simulation period is 2007.

Table Flat- 5. Flow volume statistics for WARMF versus observed data for the validation period (2007) at Flat River USGS station 02085500, above Lake Michie.

Parameters	Predicted	Observed	Error	Recommended Criteria
	(m^3)	**(m^3)**	**(%)**	**(%)**
Total In-stream Flow:	59,090,112	58,101,583	1.70	10
Total of highest 10% flows:	32,279,463	33,272,113	-2.98	15
Total of lowest 50% flows:	5,871,741	2,723,037	115.63	10
Summer Flow Volume (months 7-9):	3,600,815	509,460	606.79	30
Winter Flow Volume (months 1-3):	38,307,114	38,496,781	-0.49	30
Spring Flow Volume (months 4-6):	17,182,183	19,095,342	-10.02	30

Table Flat- 6. Additional daily flow statistics for WARMF versus Observed data for the validation period at Flat River USGS station 02085500, above Lake Michie.

Statistical Measures	Statistics
Relative Error	0.02
Average Error	0.04
Absolute Error	1.27
Standard deviation (SD_{obs}) (m^3/s)	5.20
$RMSE/SD_{obs}$	0.53
Coefficient of Determination (R^2)	0.72
Coefficient of Efficiency	0.72
Percent Bias	0.02
Observed Mean (m^3/s)	2.46
Predicted Mean (m^3/s)	2.51

6.6 Water Quality Validation Above Lake Michie

Validation of the model for water quality constituents is limited to four months, January and March through May. For TSS, the simulated and observed TSS concentrations matched significantly well, except in January (Figures Flat-17 and Flat-18). For TN, the simulated and observed concentrations matched significantly well throughout the validation period (Figures Flat-19 and Flat-20). Similar results were also observed for ammonia and TKN (shown in Appendix C, FlatValA_C1-6). For NO_3, the simulated concentrations were lower than the observed concentrations in January and March. There was no TP measured at this station during the validation period.

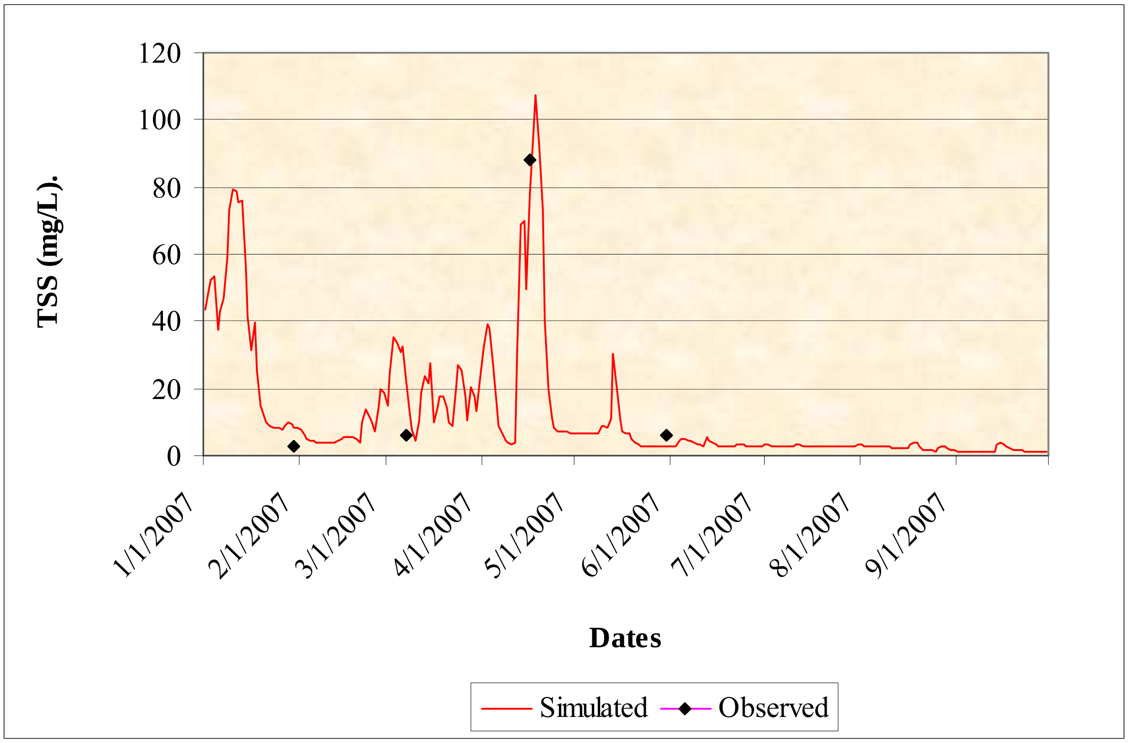

Figure Flat- 17. Time series distribution of predicted and observed total suspended solids (TSS) in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation period is 2007.

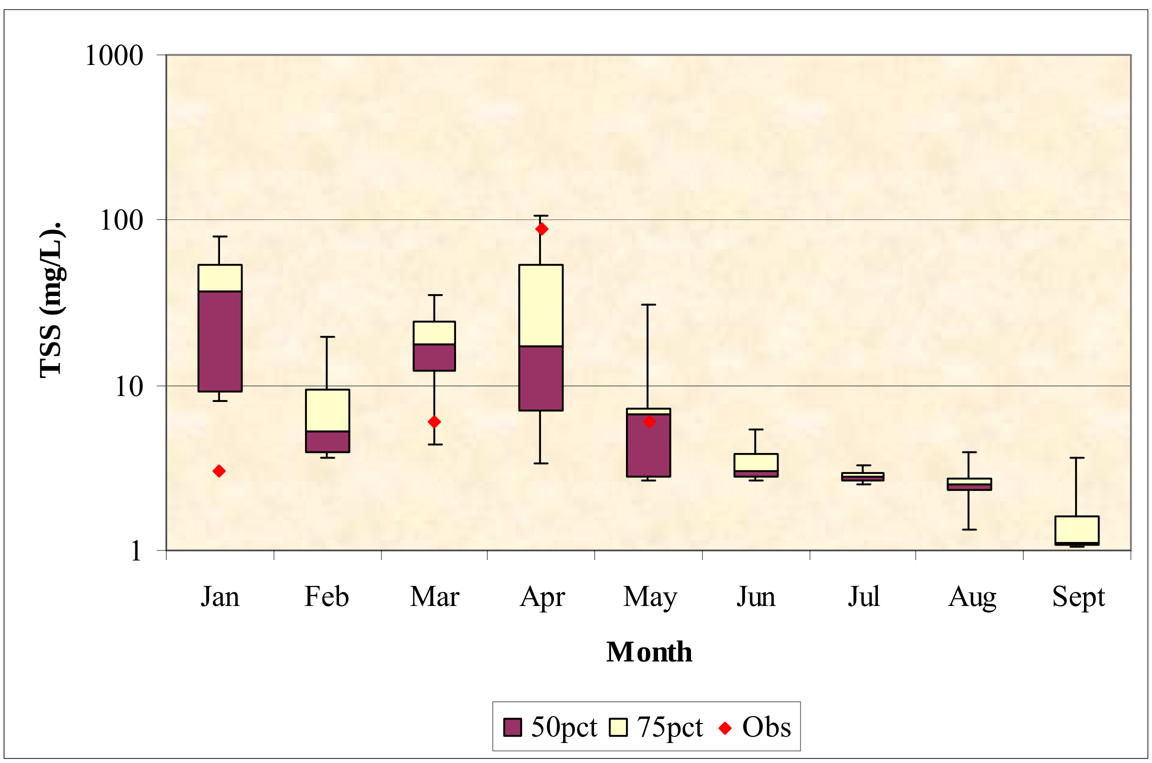

Figure Flat- 18. Monthly observed concentration of total suspended solids (TSS) vs. quantile distribution of predicted daily TSS in Flat River Watershed at USGS 02085500, above Lake Michie.

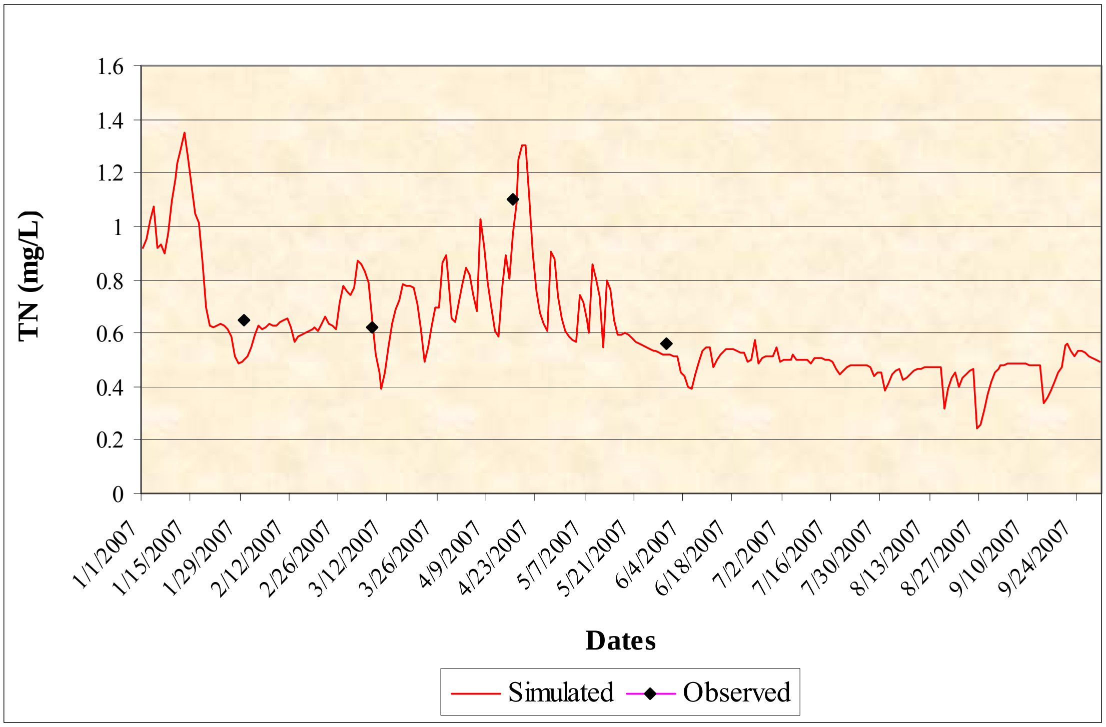

Figure Flat- 19. Time series distribution of predicted and observed total nitrogen in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation period is 2007.

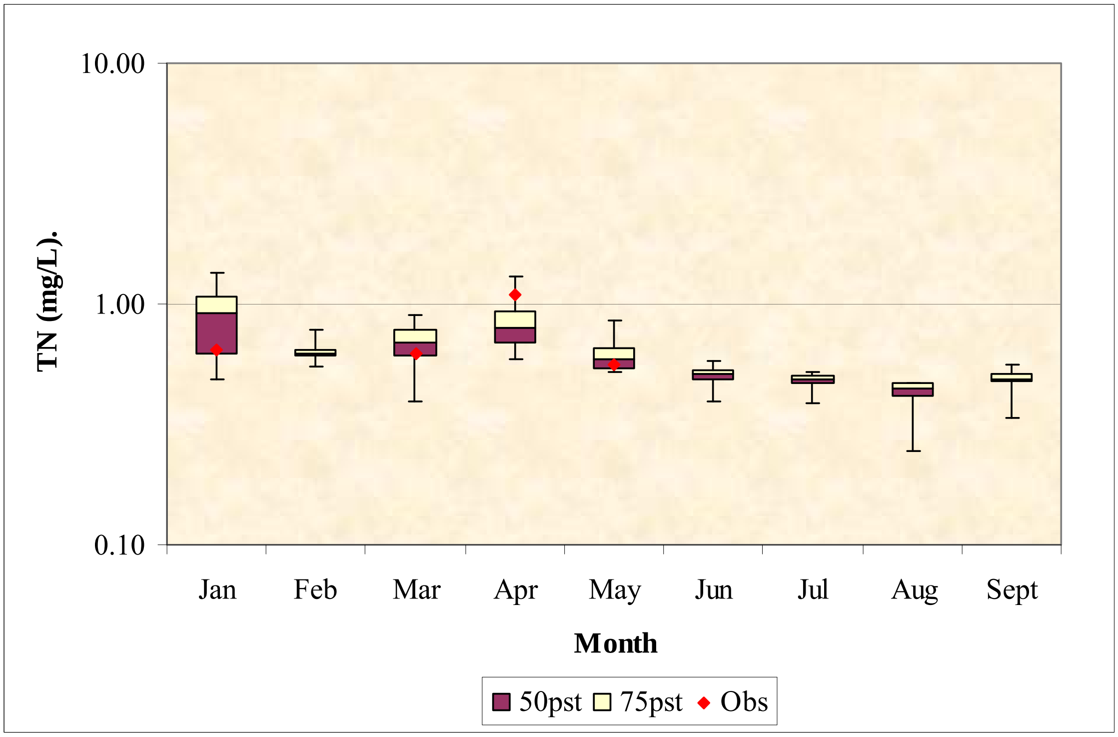

Figure Flat- 20. Monthly observed concentration of total nitrogen vs. quantile distribution of predicted daily total nitrogen in Flat River Watershed at USGS 02085500, above Lake Michie.

6.7 Hydrologic Validation Below Lake Michie

Figure Flat -21 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow for the validation period. WARMF simulates the magnitude and trend of flow well in this watershed. However, the model could not predict the summer flow volume and the lowest 50% of flow volumes during the low flow period (Table Flat-7). Overall, the high coefficient of determination and coefficient of efficiency values and the low error values associated with the predictions of total flow volumes, average flow volumes, high flow volumes, and seasonal flow volumes indicate the model is performing well for flow (Figure Flat-22 and Tables Flat 7-8). Moreover, the statistical errors estimated for daily flow rates were also substantially lower (Table Flat-8). In addition, the mean predicted and observed flows are very close in value.

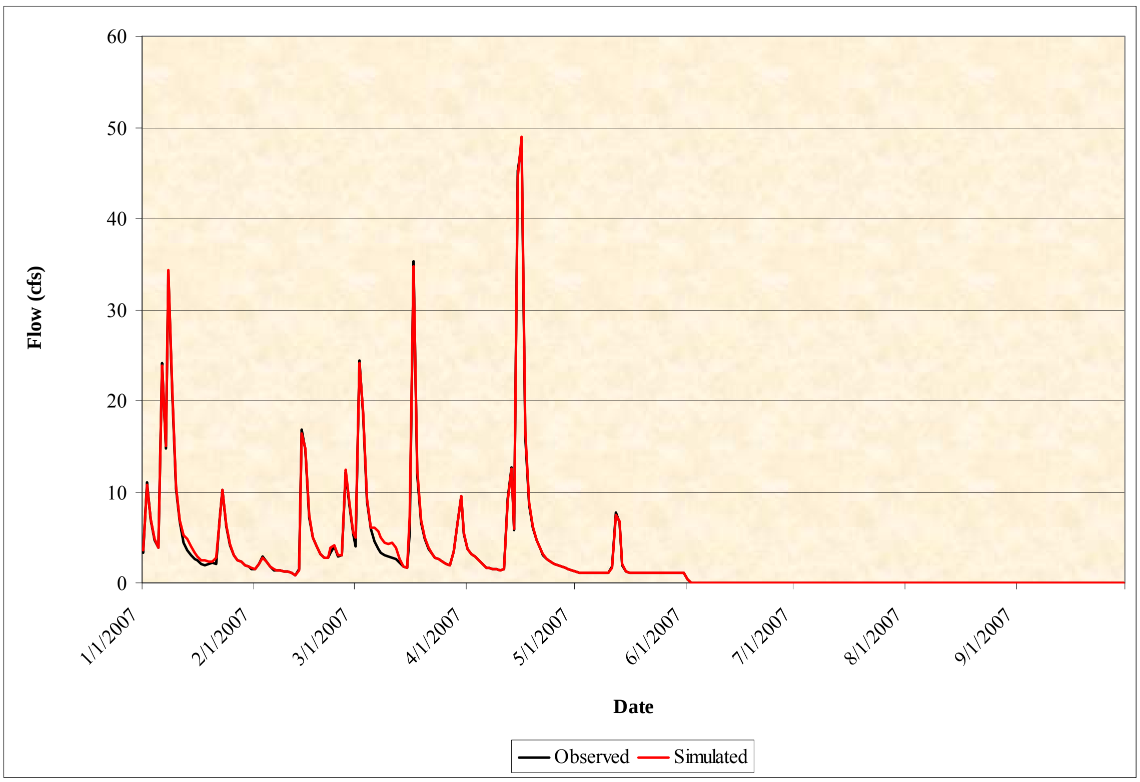

Figure Flat- 21. Observed and simulated daily total flow from Flat River at USGS 02086500, below Lake Michie. Model simulation period is 2007.

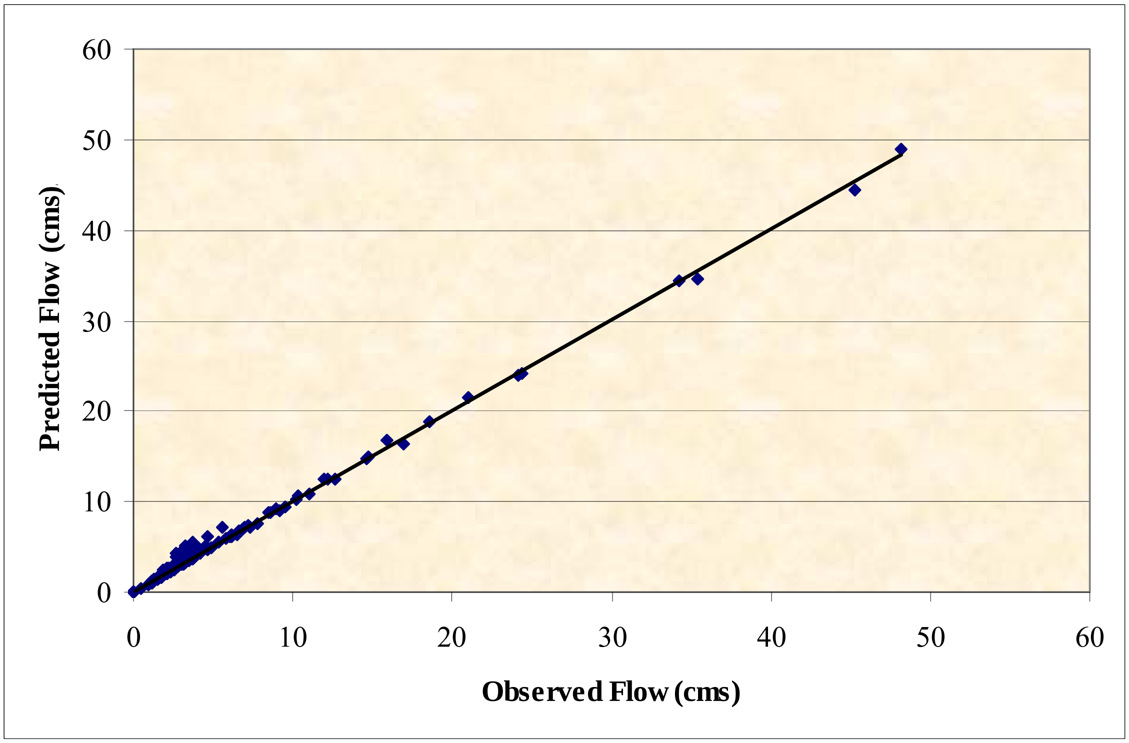

Figure Flat- 22. Relation between observed and simulated daily total flow from Flat River at USGS 02086500, below Lake Michie. Model simulation period is 2007.

Table Flat- 7. Flow volume statistics for WARMF versus observed data for the validation period (2007) at Flat River USGS station 02086500, below Lake Michie.

Parameters	Predicted (m^3)	Observed (m^3)	Error (%)	Recommended Criteria (%)
Total In-stream Flow:	69,029,459	66,863,672	3.24	10
Total of highest 10% flows:	39,509,638	39,372,041	0.35	15
Total of lowest 50% flows:	1,582,132	148,305	966.81	10
Summer Flow Volume (months 7-9):	23,059	6,112	277.26	30
Winter Flow Volume (months 1-3):	47,245,502	45,251,932	4.41	30
Spring Flow Volume (months 4-6):	21,760,898	21,605,628	0.72	30

Table Flat- 8. Additional daily flow statistics for WARMF versus Observed data for the validation period at Flat River USGS station 02086500, below Lake Michie.

Statistical Measures	Statistics
Relative Error	0.03
Average Error	0.09
Absolute Error	0.12
Standard deviation (SD_{obs}) (m^3/s)	6.07
RMSE/SD_{obs}	0.05
Coefficient of Determination (R^2)	1.00
Coefficient of Efficiency (ME)	1.00
Percent Bias	0.03
Observed Mean (m^3/s)	2.84
Predicted Mean (m^3/s)	2.93

6.8 Water Quality Validation Below Lake Michie

There were some weaknesses in simulating nutrient and TSS concentrations for 2007. The simulated TSS closely followed the observed TSS concentrations only in June, July and September (Figures Flat-23 and Flat-24). The simulated TN concentrations closely followed the observed TN concentrations only in March and June through September (Figures Flat-25 and Flat-26). The simulated TP concentrations were underestimated during January and April through July (Figures Flat-27 and Flat-28). The simulated TKN concentrations were overestimated during January through May, whereas the NO_3 and ammonia concentrations were overestimated during June through September (shown in Appendixes C, FlatValB_C1-6). These inconsistencies in the model simulations are most likely due to the extreme drought condition in 2007.

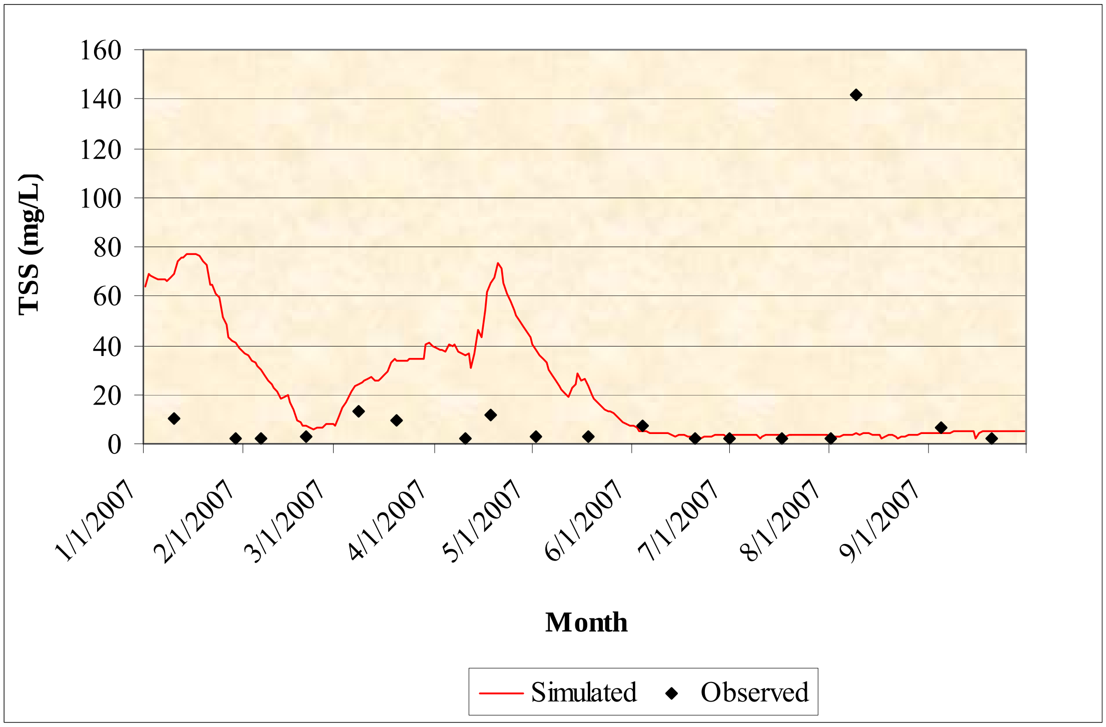

Figure Flat- 23. Time series distribution of predicted and observed total suspended solids (TSS) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation period is 2007.

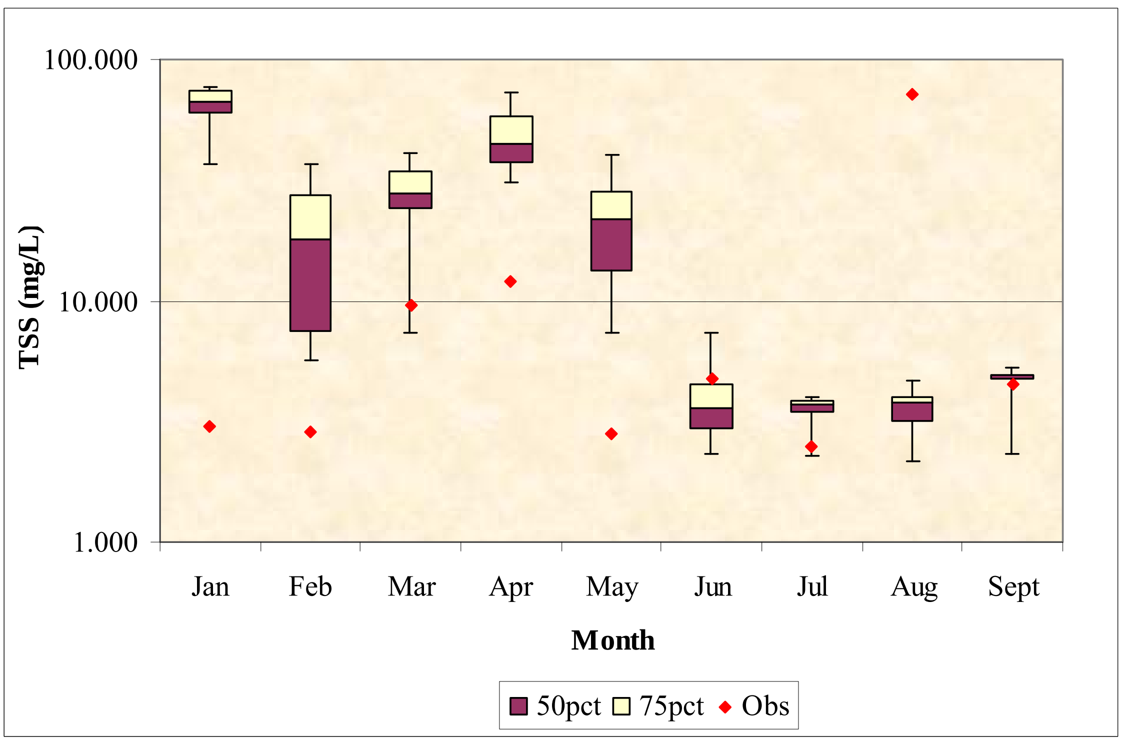

Figure Flat- 24. Monthly-observed concentration of total suspended solids (TSS) vs. quantile distribution of predicted daily TSS in Flat River Watershed at the ambient station J1100000, below Lake Michie.

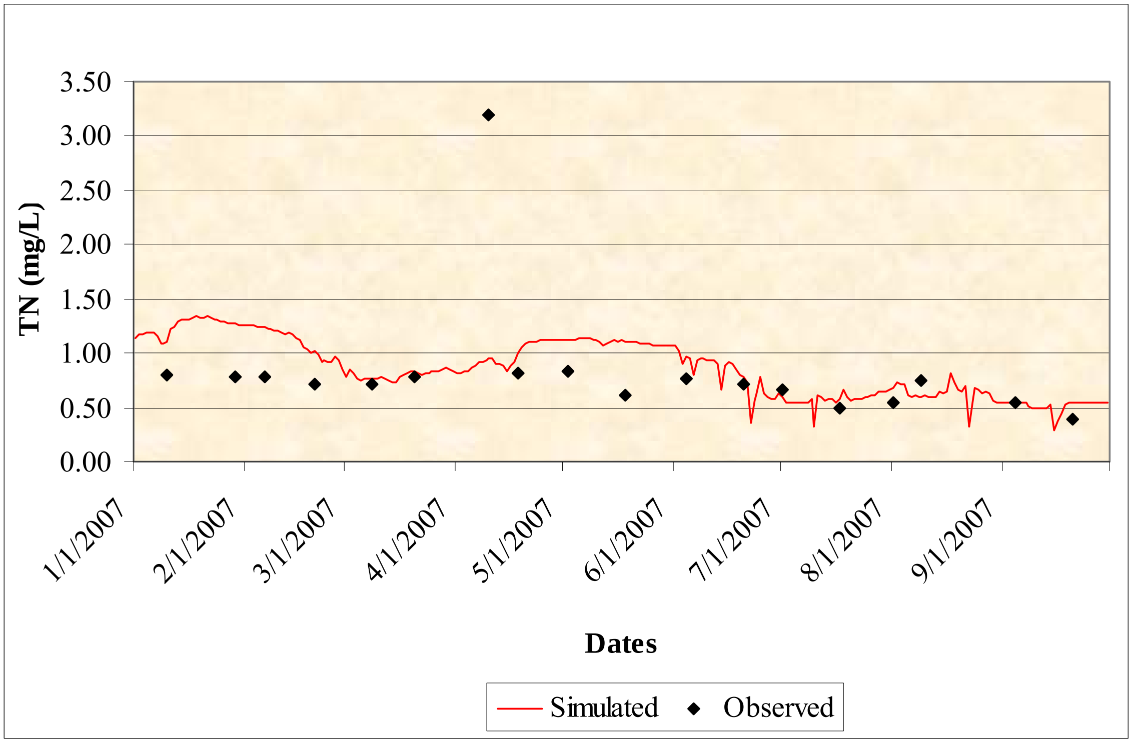

Figure Flat- 25. Time series distribution of predicted and observed total nitrogen in Flat River Watershed at the ambient station J1100000, above Lake Michie. Model simulation period is 2007.

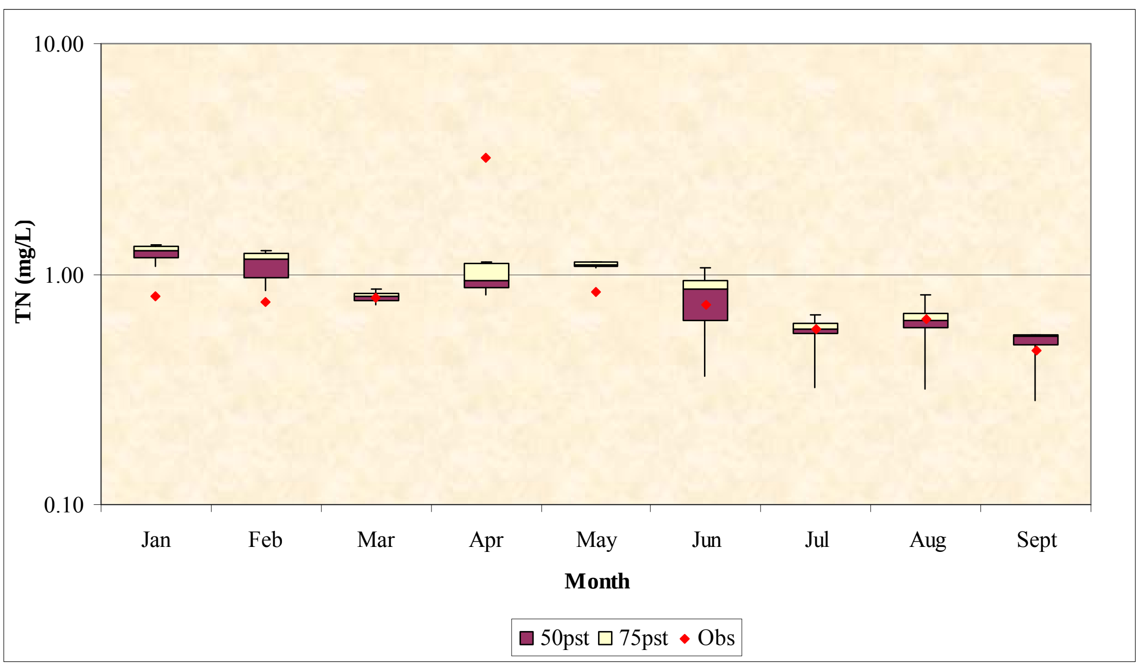

Figure Flat- 26. Monthly-observed concentration of total nitrogen vs. quantile distribution of predicted daily total nitrogen in Flat River Watershed at the ambient station J1100000, below Lake Michie.

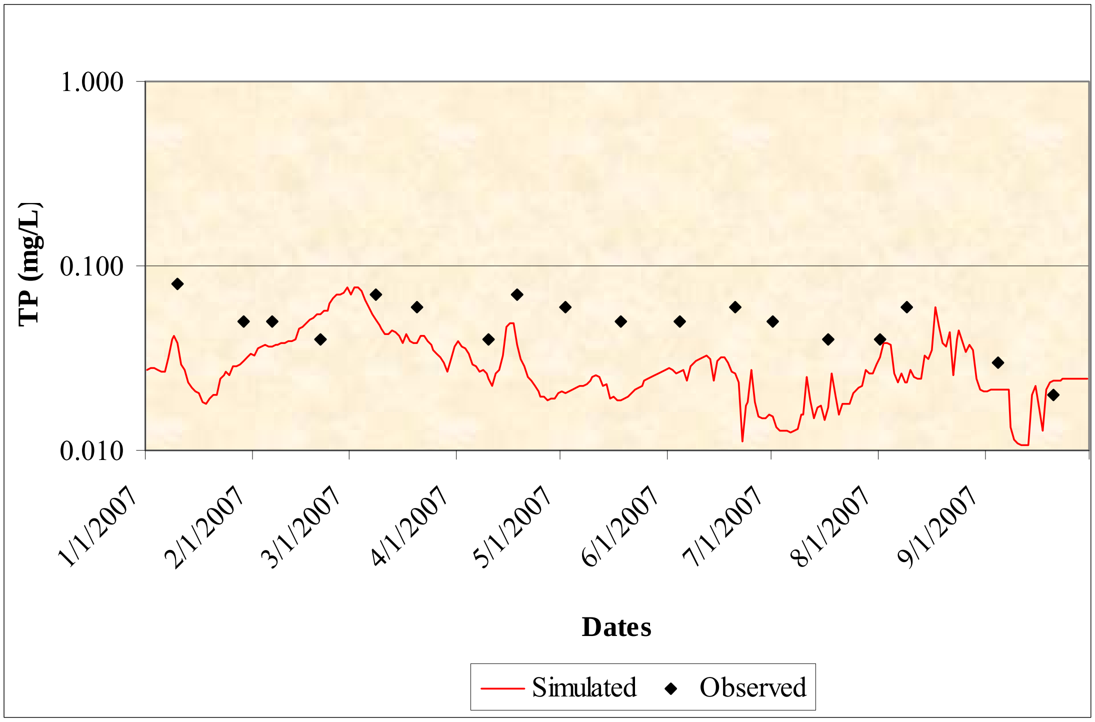

Figure Flat- 27. Time series distribution of predicted and observed total phosphorus (TP) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation period is 2007.

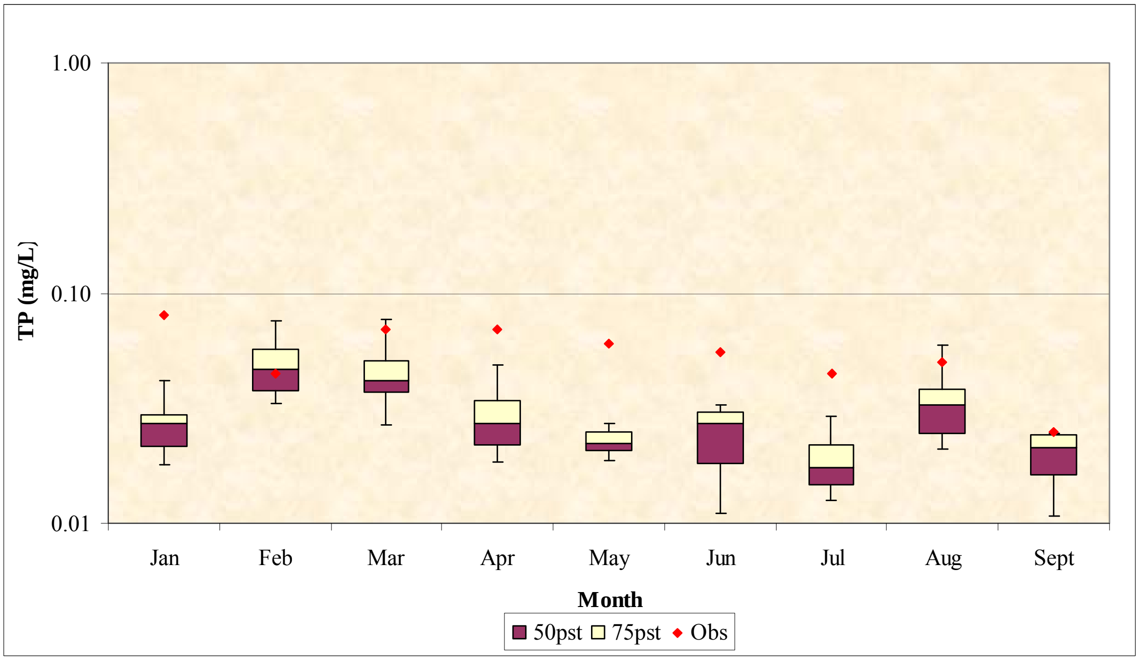

Figure Flat- 28. Monthly-observed concentration of total phosphorus (TP) vs. quantile distribution of predicted daily TP in Flat River Watershed at the ambient station J1100000, below Lake Michie.

7.0 Watershed Model Results - Little River Above Little River Reservoir

7.1 Hydrologic Calibration

Figure LRA-1 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at Little River USGS gaging station at SR 1461 near Orange Factory (USGS 0208521324). Overall, WARMF simulates the magnitude and trend of flow fairly well in this watershed. WARMF seems to overestimate some higher peaks. Figure LRA-2 is a scatter plot of observed and simulated flow at the same station. Linear regression was performed and correlation coefficient (r) calculated for average daily flow. WARMF has a moderately high R^2 value of 0.61 and underestimates flow on average as shown by the slope of the regression line being less than one. In general, R^2 is easily influenced by extreme values.

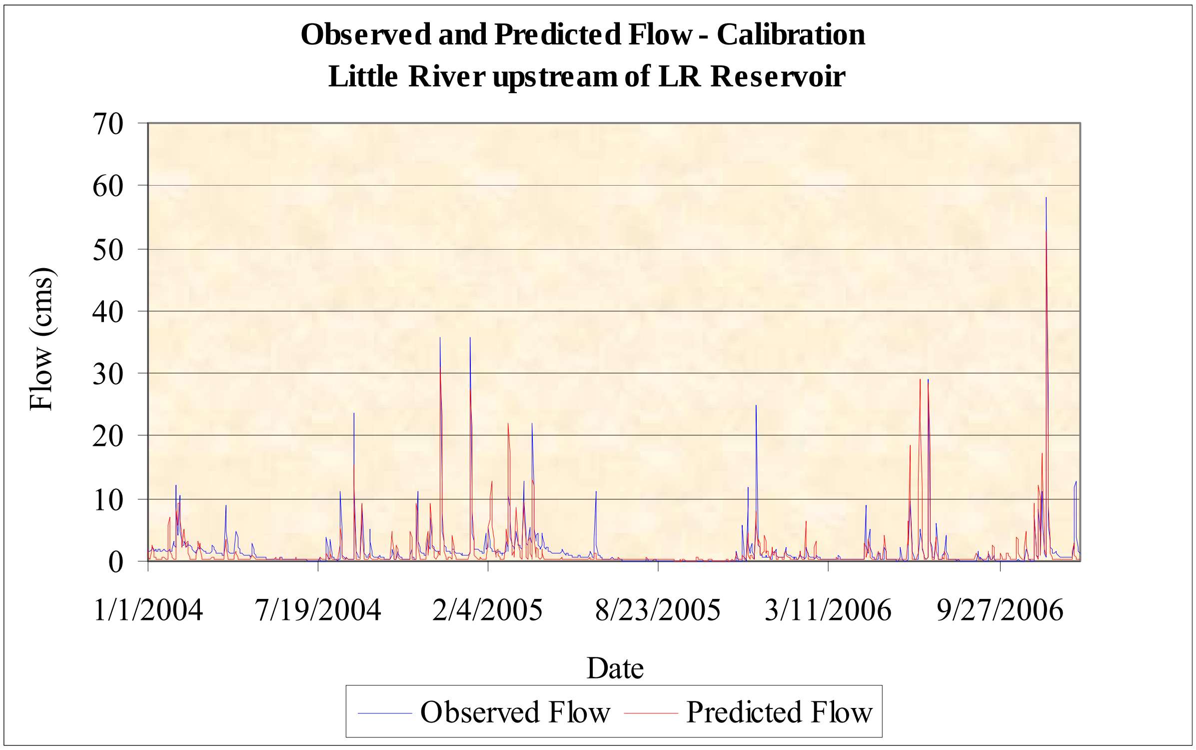

Figure LRA- 1. Time series plots of average daily-observed flows and WARMF flows for the calibration period at Little River USGS station at SR 1461 near Orange Factory

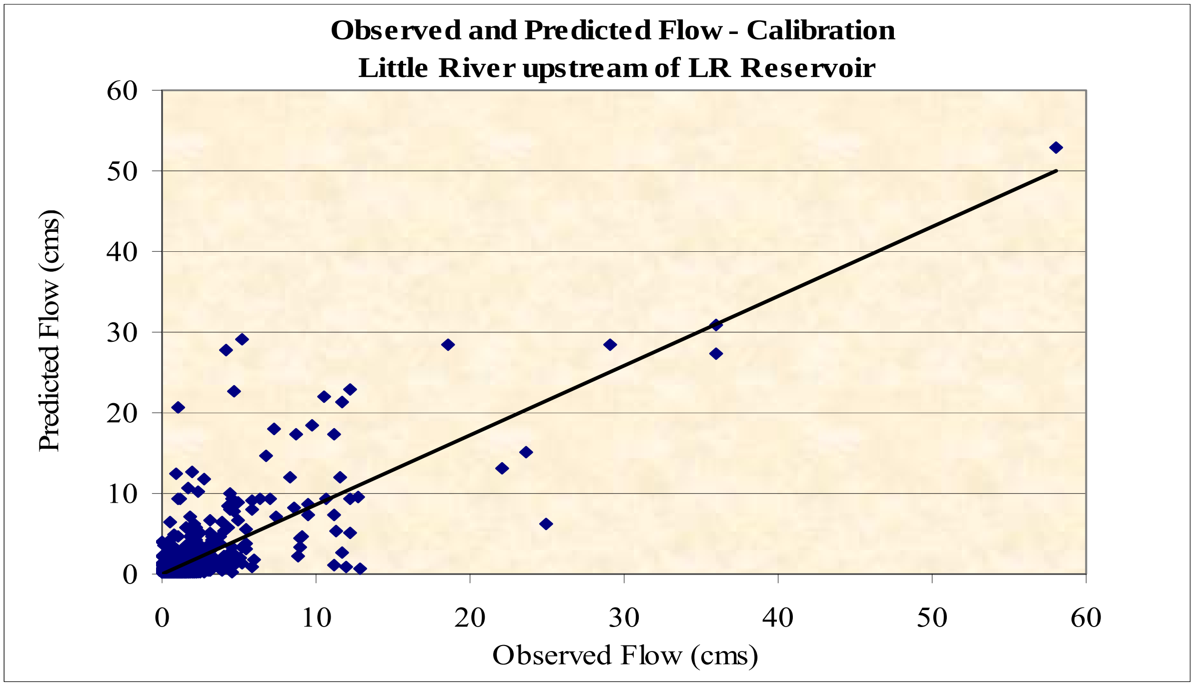

Figure LRA- 2. Scatter plot of daily-observed flows and simulated WARMF flows for the calibration period at Little River USGS station at SR 1461 near Orange Factory

Table LRA-1 provides the error statistics for daily and seasonal flow volume. The total volume and seasonal volume errors satisfy the calibration criteria set during the calibration process. The total stream flow error was eight percent. In general, WARMF slightly overestimated flow during fall months and slightly underestimated flow during the other seasons. It also slightly underestimated the total flow volume at this station.

Table LRA- 1. Flow volume statistics for WARMF versus observed data for the calibration period at Little River USGS continuous recording station at SR 1461 near Orange Factory[1]

	Predicted (m^3)	Observed (m^3)	Error	Recommended Criteria
Total Predicted In-stream Flow:	126,561,275	137,178,645	-7.7%	*10%*
Total of highest 10% flows:	84,424,218	72,346,125	14.3%	*15%*
Total of lowest 50% flows:	10,644,358	10,691,136	-0.4%	*10%*
Predicted Summer Flow Volume (months 7-9):	16,925,008	19,303,511	-12.3%	*30%*
Predicted Fall Flow Volume (months 10-12):	43,733,485	41,633,640	5.0%	*30%*
Predicted Winter Flow Volume (months 1-3):	43,361,625	48,941,946	-11.4%	*30%*
Predicted Spring Flow Volume (months 4-6):	22,541,157	27,299,549	-17.4%	*30%*

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

Table LRA-2 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flow is close to the observed mean. The mean error values show the predicted and observed flows are very close. The RMSE is also lower than the SDobs as shown by the low RMSE/SDobs ratio. The relative error, percent bias, and average error are all very small, indicating a very close agreement between the predicted and the observed values.

Table LRA- 2. Additional statistics for WARMF predicted versus observed flow data for the calibration period at Little River USGS continuous recording station at SR 1461.

	Flow statistics
Relative Error (RE)	-0.08
Average Error (AE) (m^3/s)	-0.11
Root Mean Square of Error (RMSE) (m^3/s)	2.30
Standard Deviation (SDobs) (m^3/s)	3.30
RMSE/SDobs	0.61
R^2	0.61
Coefficient of Efficiency	0.51
Percent Bias (PBIAS)	-7.7%
Observed mean (m^3/s)	1.45
Predicted mean (m^3/s)	1.34

7.2 Water Quality Calibration

In the water quality simulation, WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to the DWQ ambient monitoring data from the Little River DWQ monitoring station (J0820000) at SR 1461 near Orange Factory (see Figure 8 for a map of the station locations).

Total Suspended Sediment (TSS)

Figure LRA-3 illustrates the time series plot of the observed and WARMF predicted TSS at the Little River DWQ monitoring station at SR 1461 near Orange Factory (J0820000). The simulated TSS concentrations tracked the observed concentrations pattern throughout the calibration period, but missed large TSS concentration. A possible explanation for this could be that the observed TSS concentration is measured as a surface grab sample and as a result TSS measurements after a storm event may be higher than the depth average values estimated by the model. WARMF represents a river segment as vertically mixed. Figure LRA-4 shows the seasonal distribution of observed and predicted TSS concentrations at the same station. WARMF predicted the general trend and range of most observed TSS data in this watershed. The average observed TSS concentrations were comparable to the WARMF predicted concentrations for most months, but were much lower than the predicted values in January and February.

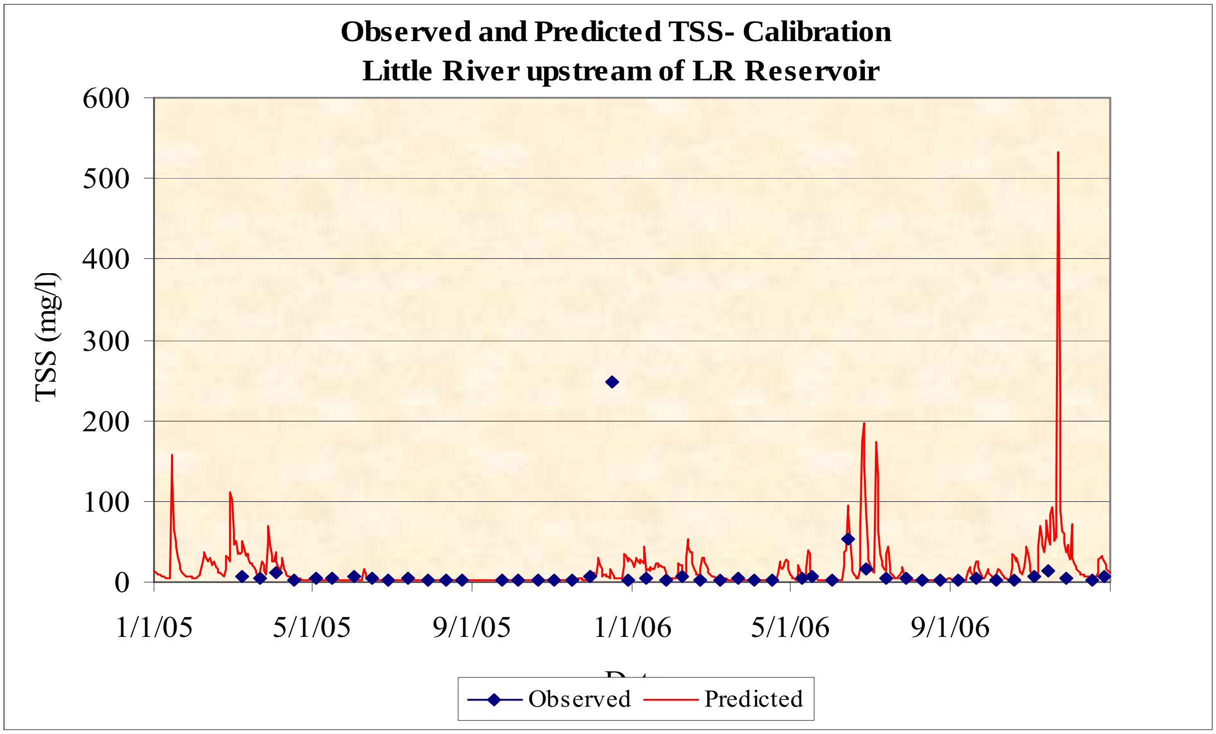

Figure LRA- 3. Time series plots of observed and simulated total sediment (TSS) Little River DWQ monitoring station at SR 1461 near Orange Factory

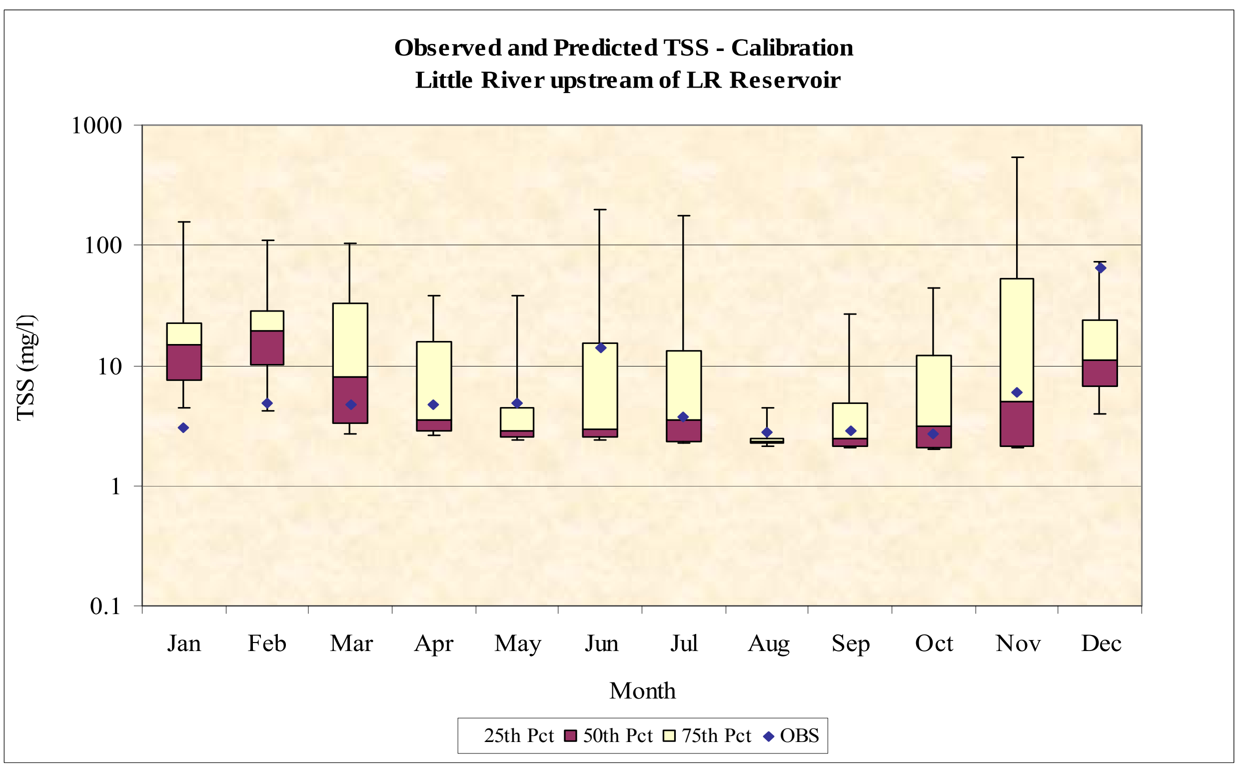

Figure LRA- 4. Seasonal distribution of observed and simulated total suspended sediment (TSS) at Little River DWQ monitoring station at SR 1461 near Orange Factory.

Nitrogen

Figure LRA-5 is the time series plot of TN observations and WARMF predicted concentrations at the Little River DWQ monitoring station at SR 1461 near Orange Factory (J0820000). Figure LRA-6 shows the seasonal distribution of TN observations and WARMF predicted concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations for the same station are included in Appendix C. These figures show that the WARMF predicted concentrations followed the observed pattern well. The time series plots show that the WARMF predicted ammonia concentrations were higher in 2005 and lower in 2006, but most of the observed ammonia concentrations were at the detection limit. The seasonal distribution plots for ammonia, nitrate, TKN, and TN show that the WARMF predicted concentrations track the general pattern of the observed trend. The seasonal plots also show that the average observed ammonia, nitrate, TKN, and TN concentrations fall within the daily ranges of the predicted values in most months throughout the calibration period. WARMF simulated the trend and magnitude of TN concentrations fairly well in this watershed.

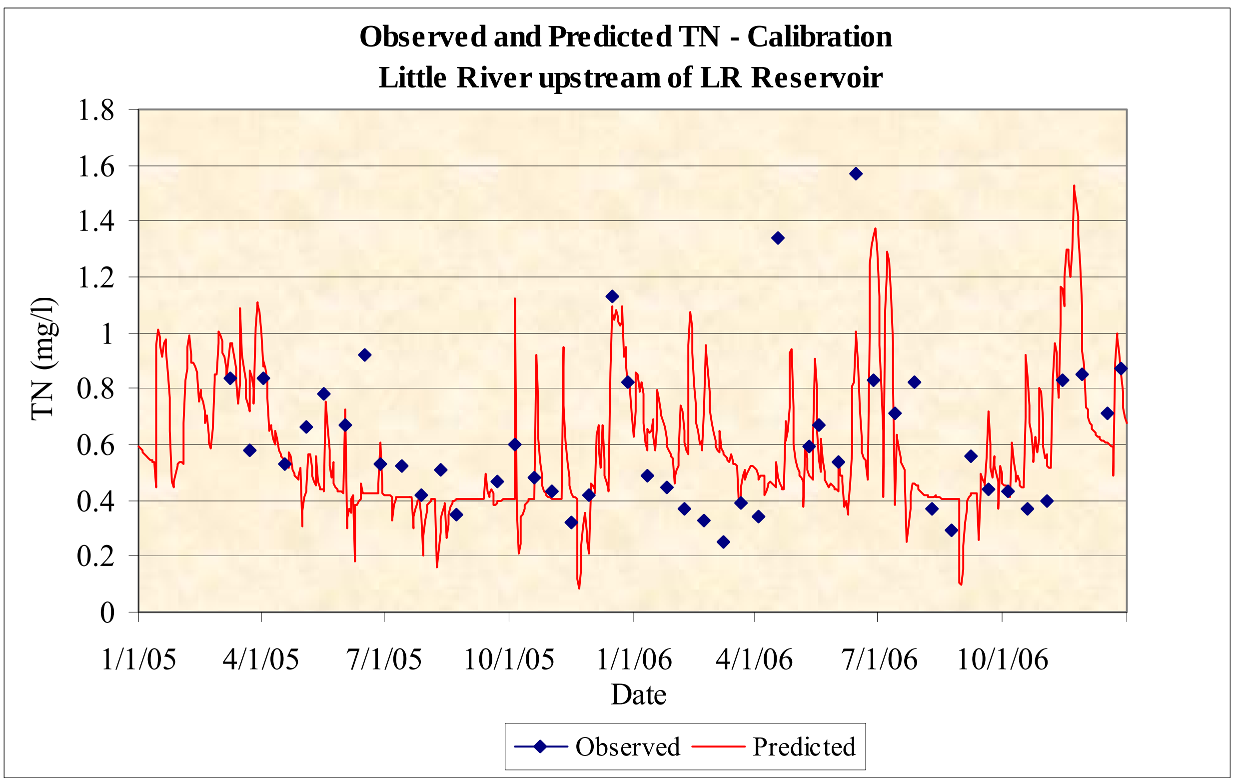

Figure LRA- 5. Time series plots of observed and simulated TN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

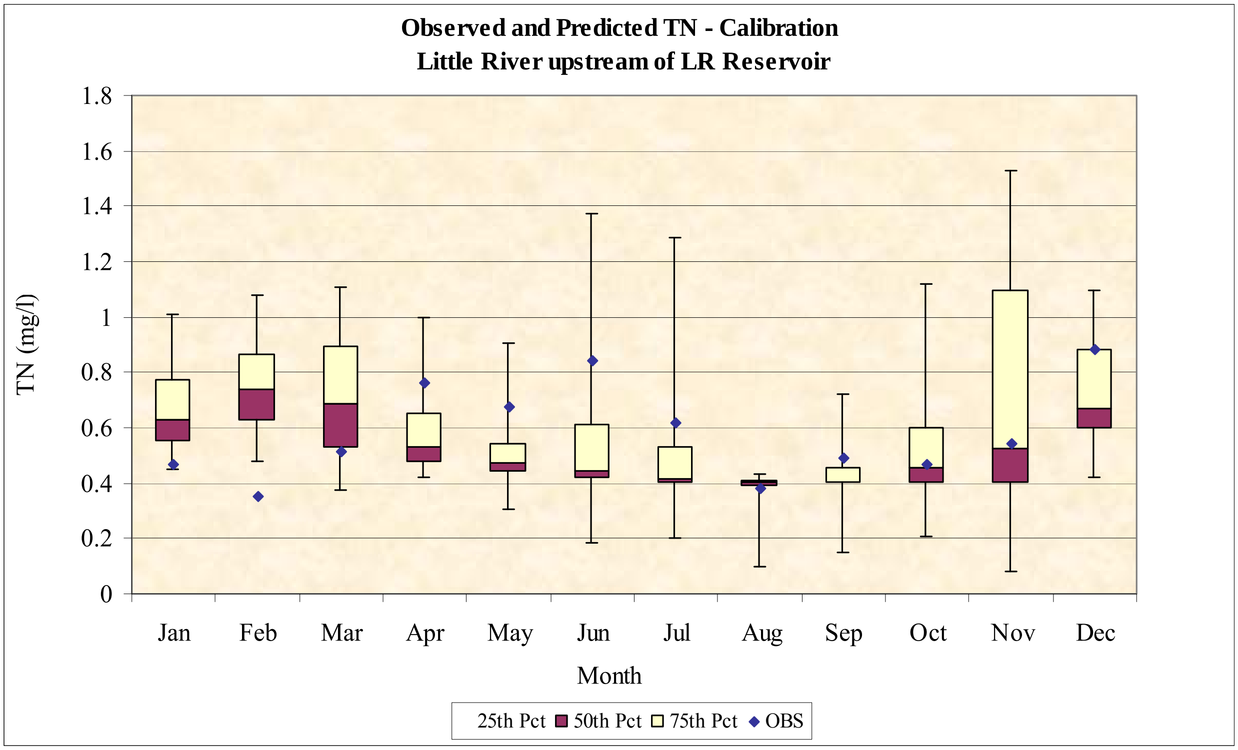

Figure LRA- 6. Seasonal distribution of observed and simulated TN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

Phosphorus

Figure LRA-7 illustrates the time series plot of the observed and simulated TP concentrations and Figure LRA-8 shows the seasonal distribution of TP. WARMF simulated TP concentrations fairly well throughout the calibration period. The predicted concentrations followed the observed concentrations pattern and magnitude, but occasionally missed large concentrations. On the average, the WARMF predicted concentrations were slightly lower than the observed average concentration. This could be because of unaccounted nonpoint sources of TP loads. The average observed TP concentrations fall within the range of predicted values in every month during the calibration period.

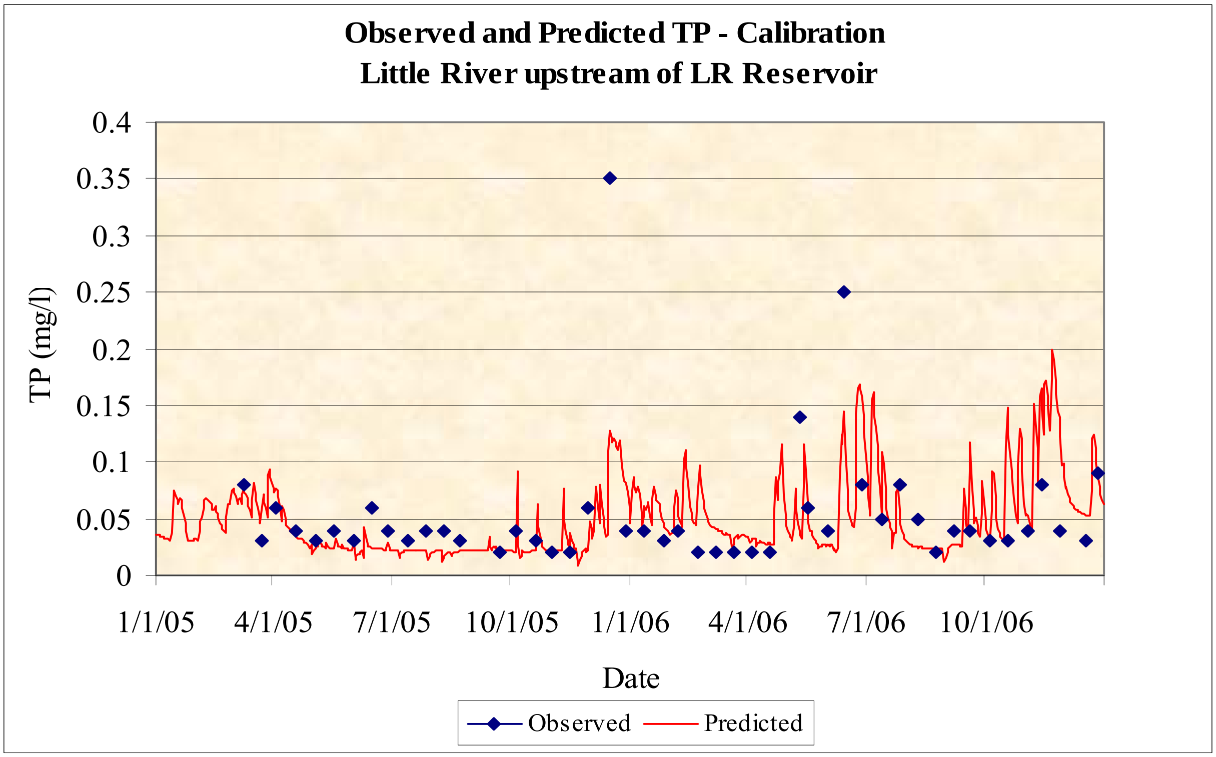

Figure LRA- 7. Time series plots of observed and simulated TP concentrations at Little River DWQ monitoring station at SR 1461 near Orange Factory.

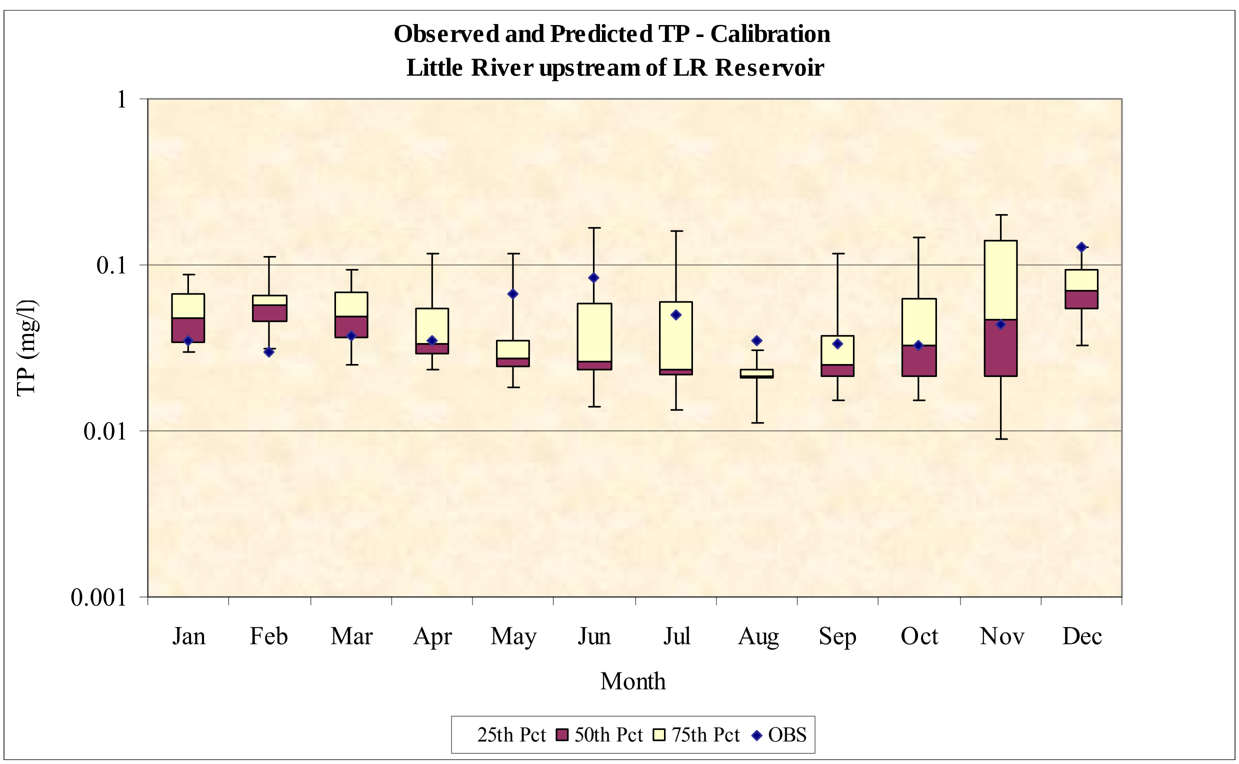

Figure LRA- 8. Seasonal distribution of observed and simulated TP concentrations at Little River DWQ monitoring station at SR 1461 near Orange Factory.

7.3 Hydrologic Validation

Figure LRA-9 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow during the validation period (2007) at Little River USGS Gage at SR 1461 near Orange Factory (USGS 0208521324). Overall, WARMF simulates the magnitude and trend of flow fairly well in this watershed. WARMF seems to overestimate some higher peaks. Figure LRA-10 is a scatter plot of observed and simulated flow at the same station. The discrepancy between the observed and the predicted flows is much larger than that observed during the calibration period. Linear regression was performed and correlation coefficient (r) calculated for average daily flow. WARMF has a moderately high R^2 value of 0.61, which is similar to the value calculated during the calibration period. WARMF underestimates flow on average as shown by the slope of the regression line being less than one. In general, R^2 is easily influenced by extreme values.

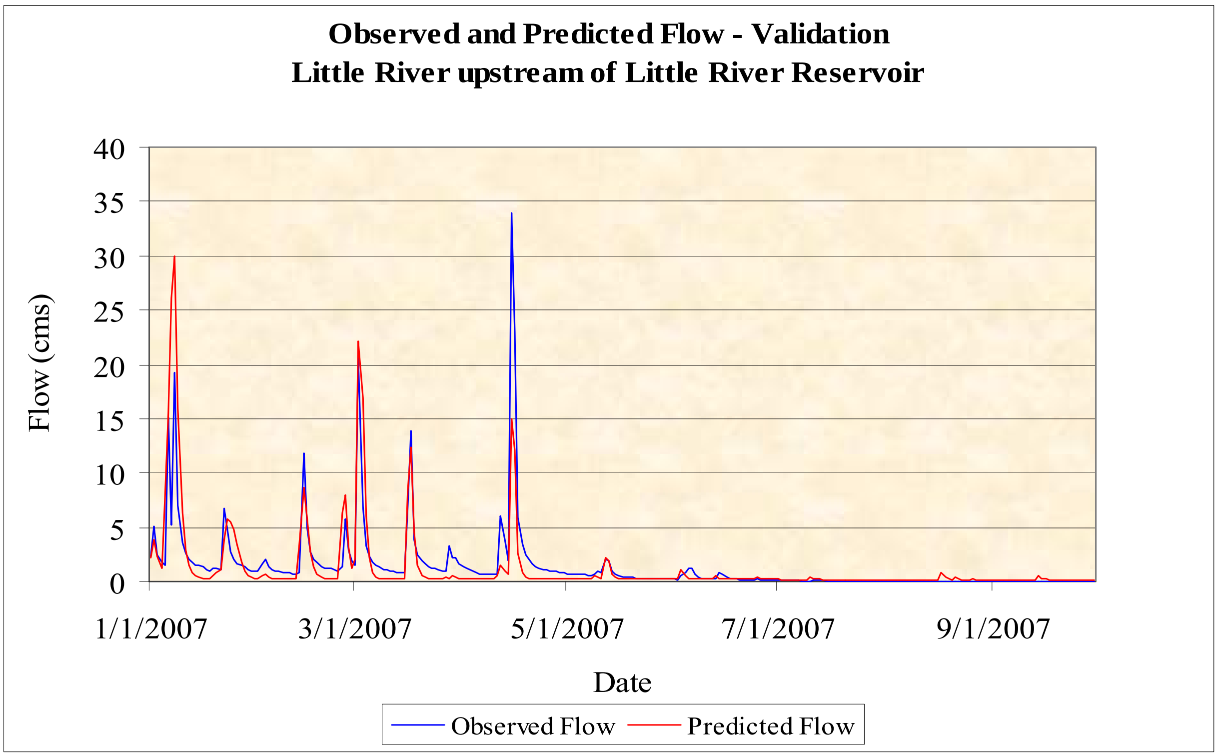

Figure LRA- 9. Time series plots of average daily-observed flows and WARMF flows for the validation period at Little River USGS station at SR 1461 near Orange Factory.

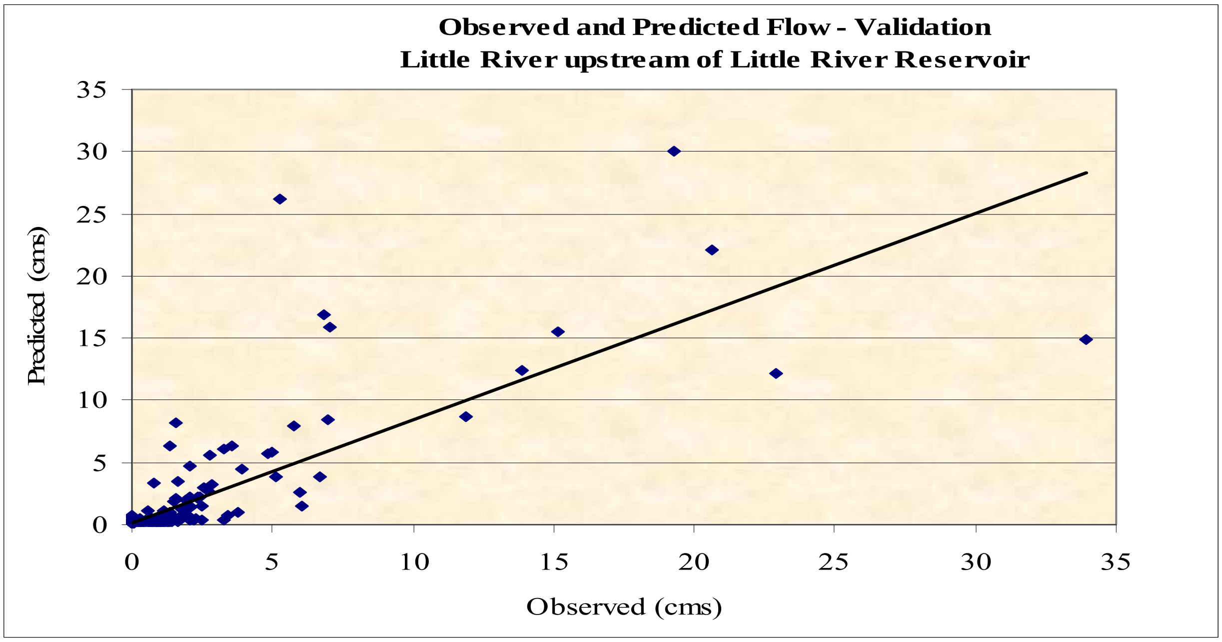

Figure LRA- 10. Scatter plot of daily-observed flows and simulated WARMF flows for calibration period at Little River USGS station at SR 1461 near Orange Factory.

Table LRA-3 provides the error statistics for daily and seasonal flow volume for the validation period. While the total volume, total of highest 10% flows, and winter flow volume errors satisfy the criteria set during the calibration step, errors in total of lowest 50%, summer, and spring flow volumes did not satisfy the criteria. The total stream flow error was very small (8.5%). WARMF overestimated flow significantly during summer months and underestimated flow during the spring seasons. The large error values for validation could be because of the extreme drought in 2007.

Table LRA- 3. Flow volume statistics for WARMF versus observed data for the validation period at Little River USGS continuous recording station at SR 1461 near Orange Factory[1]

	Predicted (m^3)	Observed (m^3)	Error	Recommended Criteria
Total Predicted In-stream Flow:	30738176	33597825	-8.50%	*10%*
Total of highest 10% flows:	22893703	20096651	13.90%	*15%*
Total of lowest 50% flows:	2360350	1467902	60.80%	*10%*
Predicted Summer Flow Volume (months 7-9):	1621269	551548	193.90%	*30%*
Predicted Winter Flow Volume (months 1-3):	24178670	21871610	10.50%	*30%*
Predicted Spring Flow Volume (months 4-6):	4938238	11174667	-55.80%	*30%*

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

Table LRA-4 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the validation period. The mean error values show the predicted flows are less than the observed flows. Also the relative error, average error, and percent bias are very small. The RMSE is much lower than the SDobs as shown by the low RMSE/SDobs ratio. Considering the extreme drought in 2007, the error values in flow are reasonable.

Table LRA- 4. Additional statistics for WARMF predicted versus observed flow data for the validation period at Little River USGS continuous recording station at SR 1461.

	Flow statistics
Relative Error (RE)	-0.08
Average Error (AE) (m^3/s)	-0.13
Root Mean Square of Error (RMSE) (m^3/s)	2.42
Standard Deviation (SDobs) (m^3/s)	3.52
RMSE/SDobs	0.69
Percent Bias (PBIAS)	-8.5%
R^2	0.61
Coefficient of Efficiency	0.53
Observed mean (m^3/s)	1.52
Predicted mean (m^3/s)	1.39

7.4 Water Quality Validation

In the water quality validation, WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to the DWQ ambient monitoring data from the Little River DWQ monitoring station at SR 1461 near Orange Factory see Figure 8 for a map of the station locations. The extreme drought in 2007 and the short validation period (nine months) were the limitations considered in interpretation of the validation results.

Total Suspended Sediment (TSS)

Figure LRA-11 illustrates the time series plot of the observed and WARMF predicted TSS concentrations at the Little River DWQ monitoring station at SR 1461 near Orange Factory. The simulated TSS concentrations tracked the observed concentrations pattern, but missed the magnitude. WARMF predicted TSS concentrations were consistently higher than the observed values from January to March and much lower from June to September. Figure LRA-12 shows the seasonal distribution of observed and predicted TSS concentration at the same station. The seasonal plots show that WARMF predicted TSS concentrations were substantially higher than the observed concentrations from January to March and lower from May to September. Overall, the validation results were similar to the calibrated results.

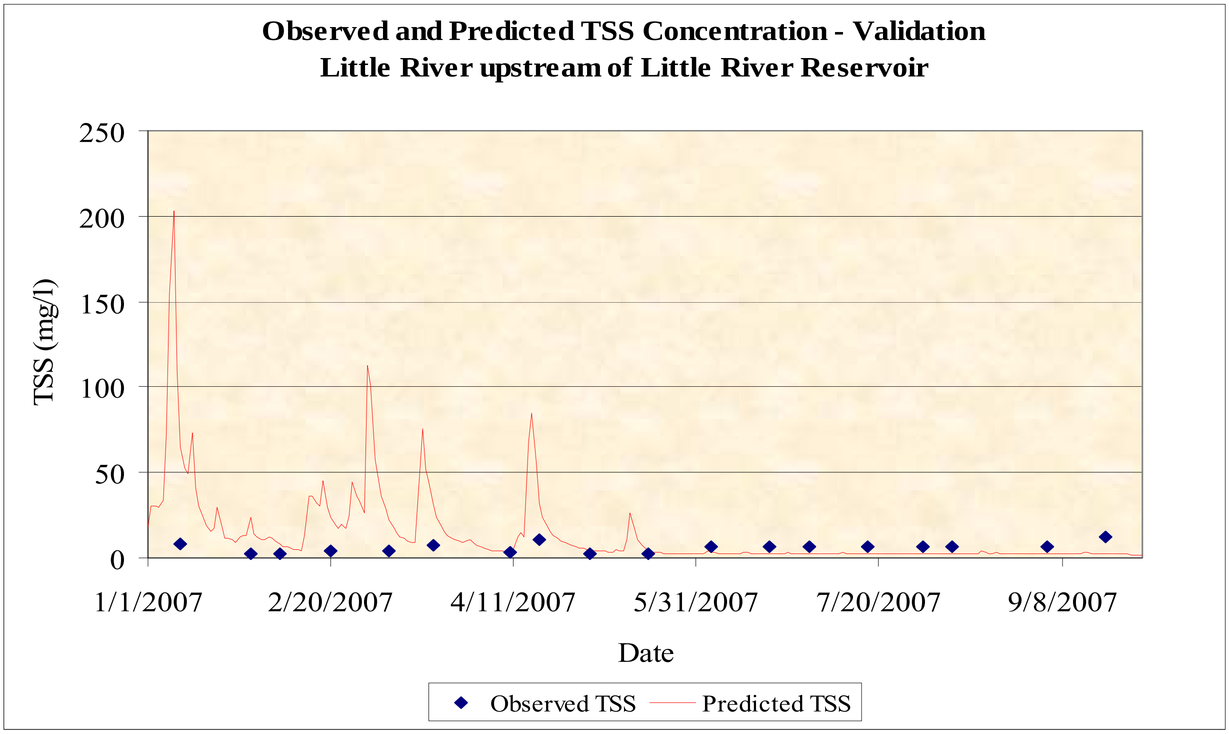

Figure LRA- 11. Time series plots of observed and simulated TSS at Little River DWQ monitoring station at SR 1461 near Orange Factory.

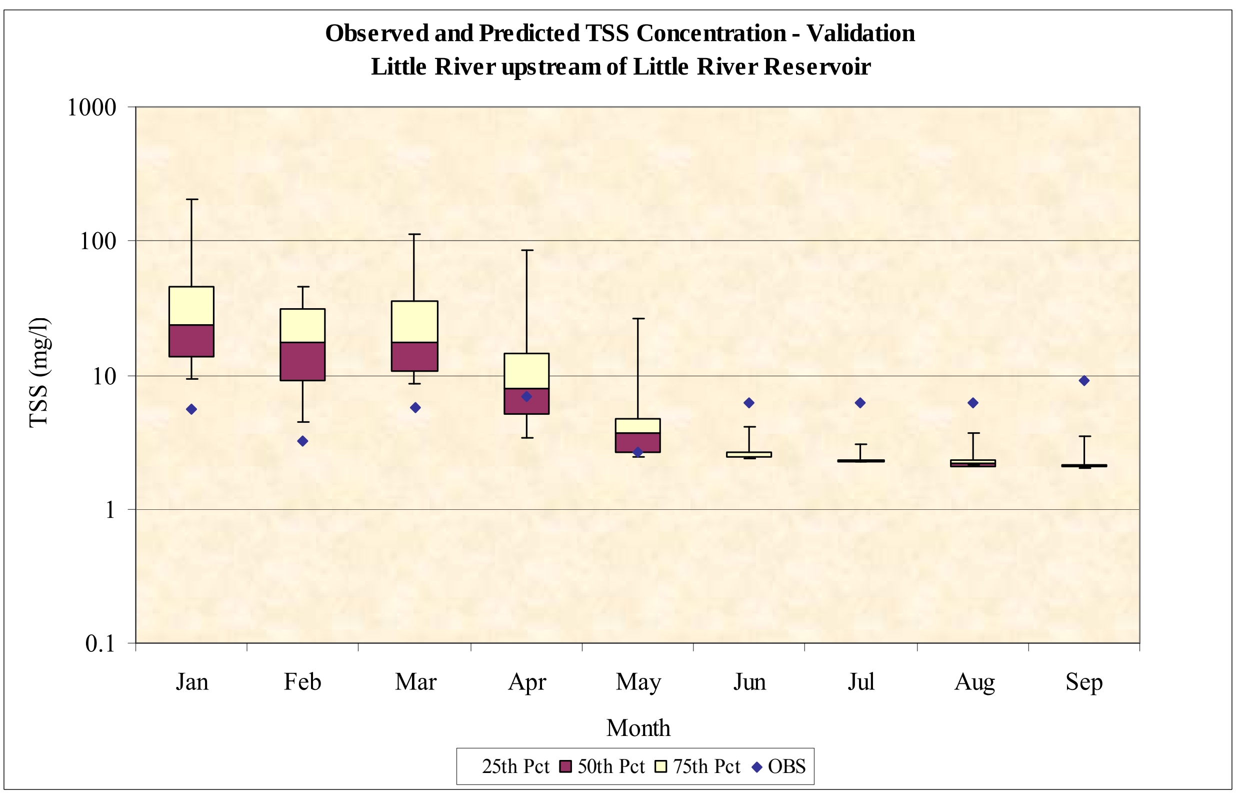

Figure LRA- 12. Seasonal distribution of observed and simulated total suspended sediment (TSS) at Little River DWQ monitoring station at SR 1461 near Orange Factory.

Nitrogen

Figure LRA-13 is the time series plot of TN observations and WARMF predicted concentrations at the Little River DWQ monitoring station at SR 1461 near Orange Factory (J0820000). Figure LRA-14 shows the seasonal distribution of TN observations and WARMF predicted concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations for the same station are included in Appendix C. These figures show that the validation results were mostly similar to the calibration results. The time series plots show that the WARMF predicted ammonia concentrations were lower from January to March and higher from May to September, but most of the observed ammonia concentrations were at the detection limit. The seasonal distribution plots for nitrate, TKN, and TN show that the WARMF predicted concentrations track the general pattern of the observed trend. The seasonal plots also show that the average observed nitrate, TKN, and TN concentrations fall within the daily ranges of the predicted values in most months throughout the validation period. WARMF simulated the trend and magnitude of TN concentration fairly well in this watershed. Considering the extreme drought and low flow conditions, the validation results show a fairly well calibrated model for TN.

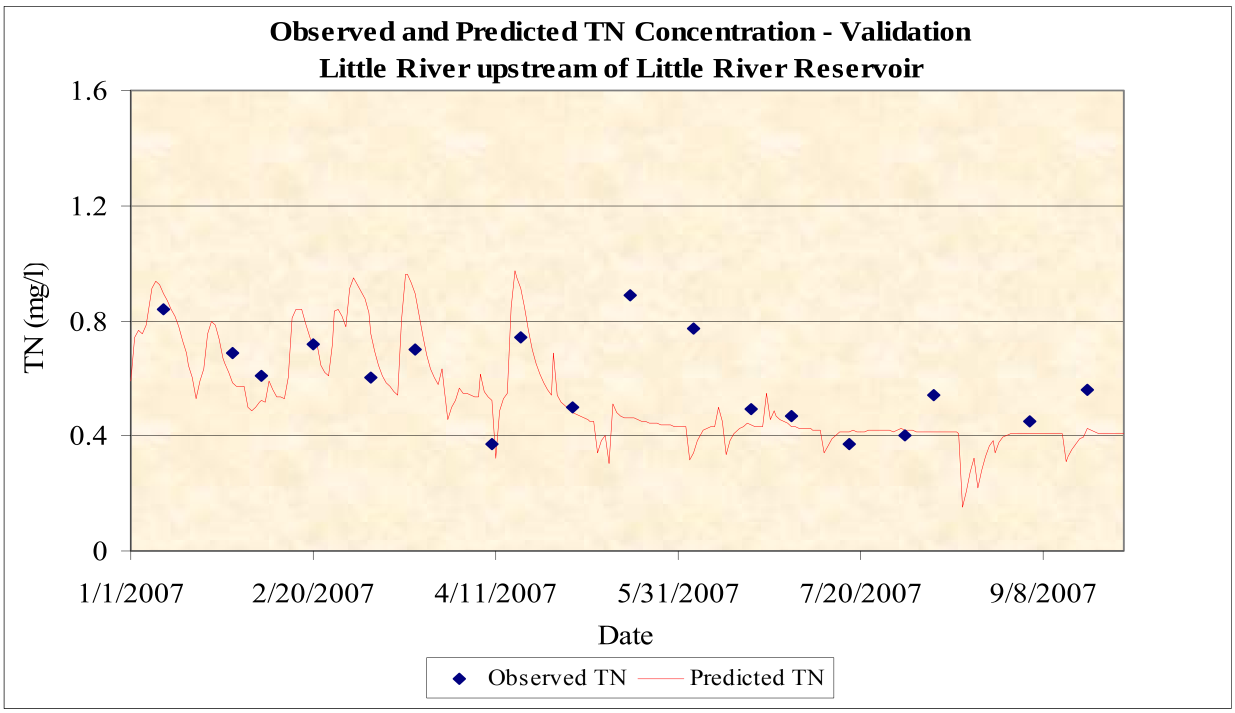

Figure LRA- 13. Time series plots of observed and simulated TN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

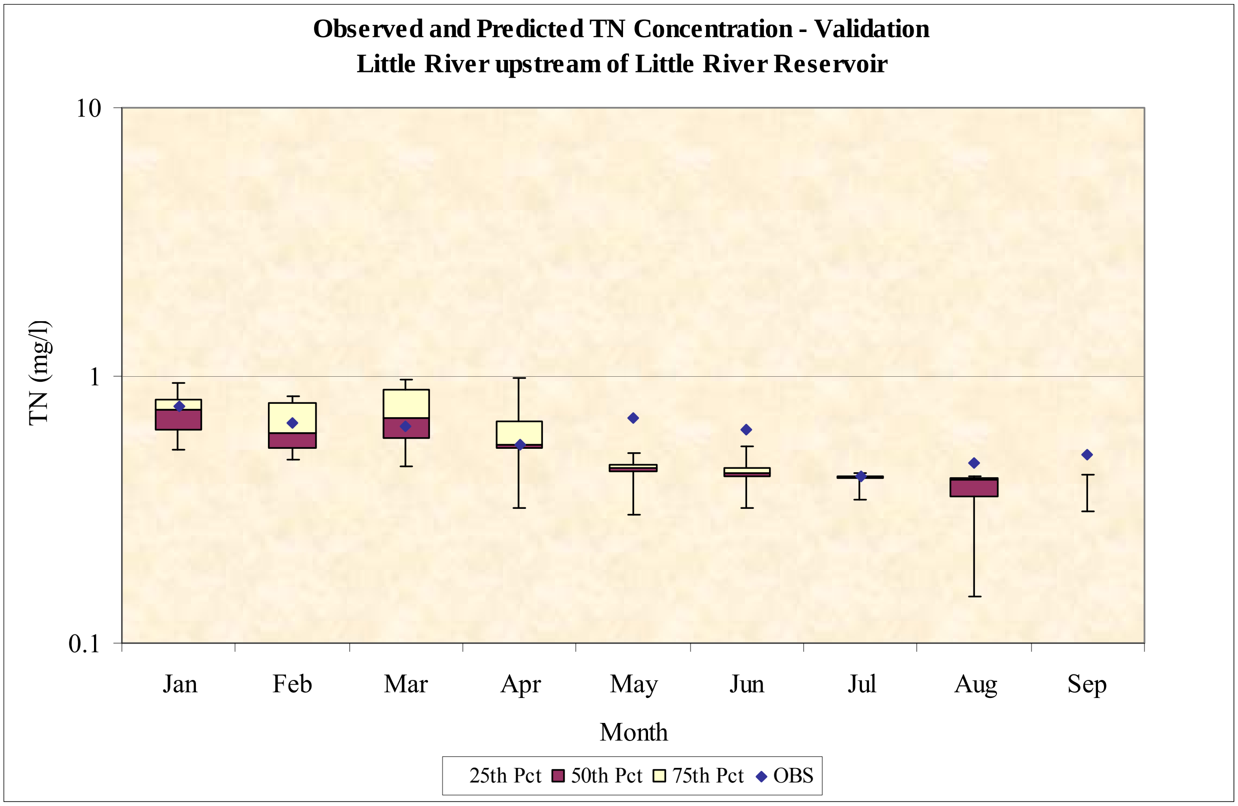

Figure LRA- 14. Seasonal distribution of observed and simulated TN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

<u>Phosphorus</u>

Figure LRA-15 illustrates the time series plot of the observed and simulated TP concentrations and Figure LRA-16 shows the seasonal distribution of TP. WARMF simulated TP concentrations fairly well throughout the validation period. The predicted concentrations followed the observed concentrations pattern and magnitude, but occasionally missed some concentrations. The discrepancy between the observed and predicted concentration could be because of unaccounted nonpoint sources of TP loads and the extreme drought period in 2007. The average observed TP concentrations fall within the range of predicted values in every month except June and September. The validation results were mostly similar to the calibration results.

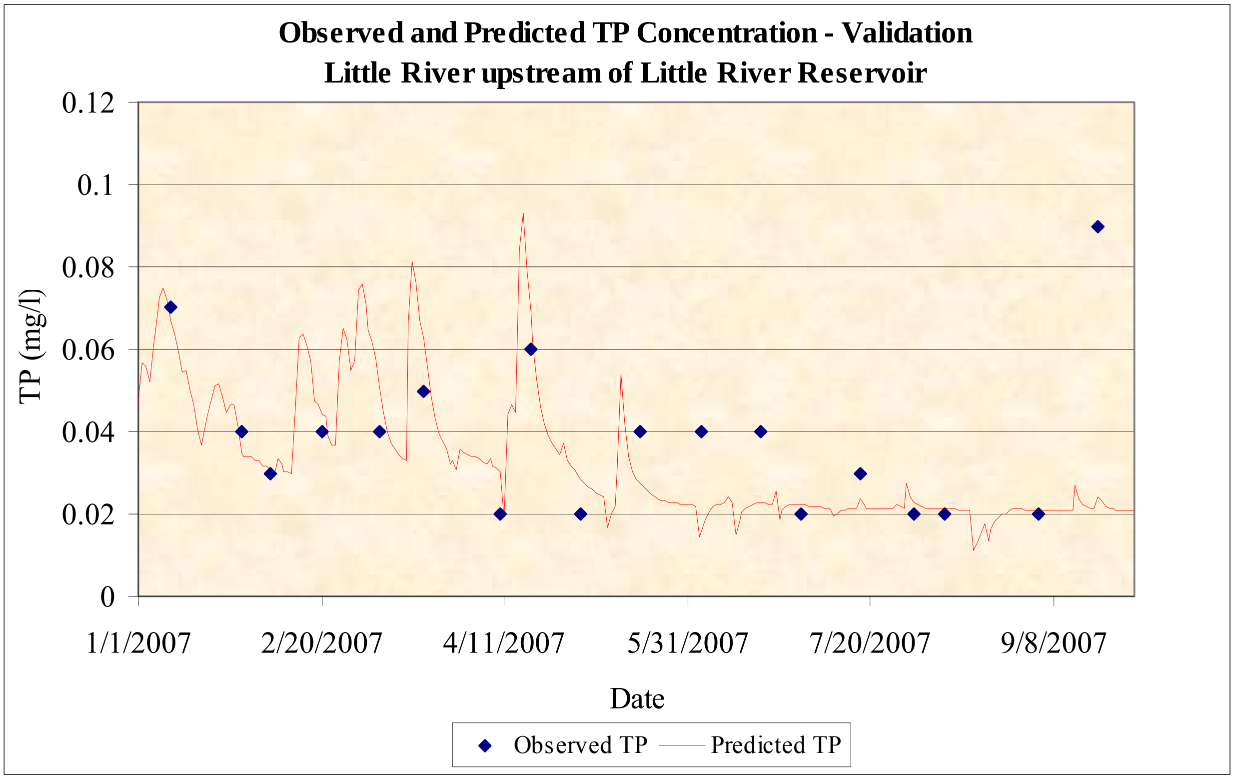

Figure LRA- 15. Time series plots of observed and simulated TP concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

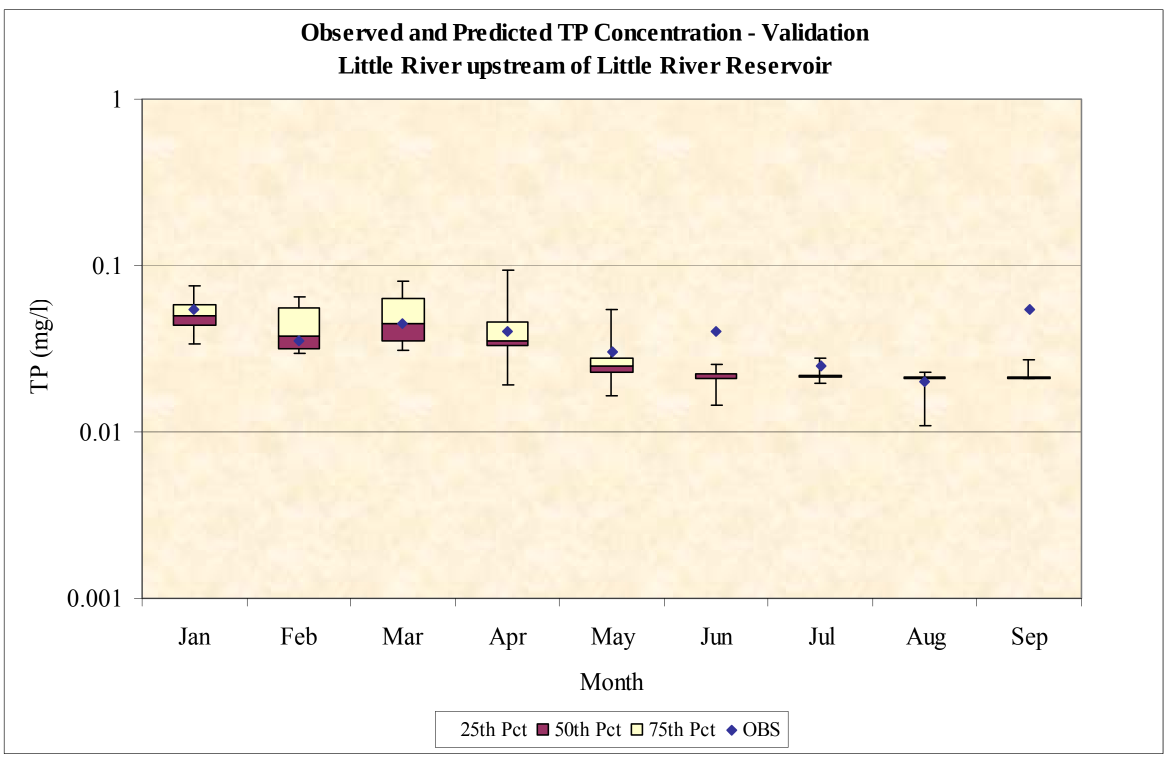

Figure LRA- 16. Seasonal distribution of observed and simulated TP concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

8.0 Watershed Model Results – Little River Below Little River Reservoir

8.1 Hydrologic Calibration

Figure LRB-1 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at Little River USGS continuous recording station (USGS208524975) below Little River tributary at Fairntosh. The flow at this station is controlled by the release from the Little River reservoir. Overall, WARMF simulates the magnitude and trend of flow very well in this watershed. WARMF seems to overestimate some higher peaks. Figure LRB-2 is a scatter plot of observed and simulated flow at the same station. Linear regression was performed and correlation coefficient (r) calculated for average daily flow. The high R^2 (0.95) and coefficient of efficiency (0.96) show that there is strong agreement between the model predicted and observed flows.

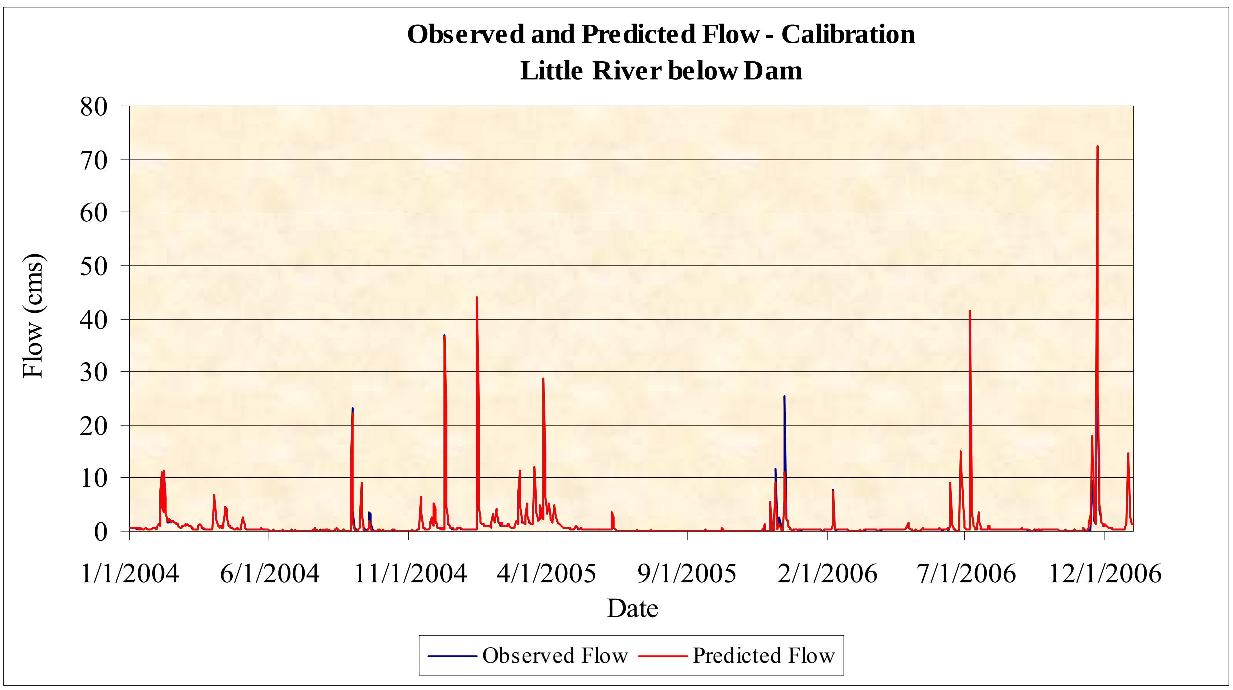

Figure LRB- 1. Time series plots of average daily-observed flows and flows at Little River USGS gaging station below Little River tributary at Fairntosh.

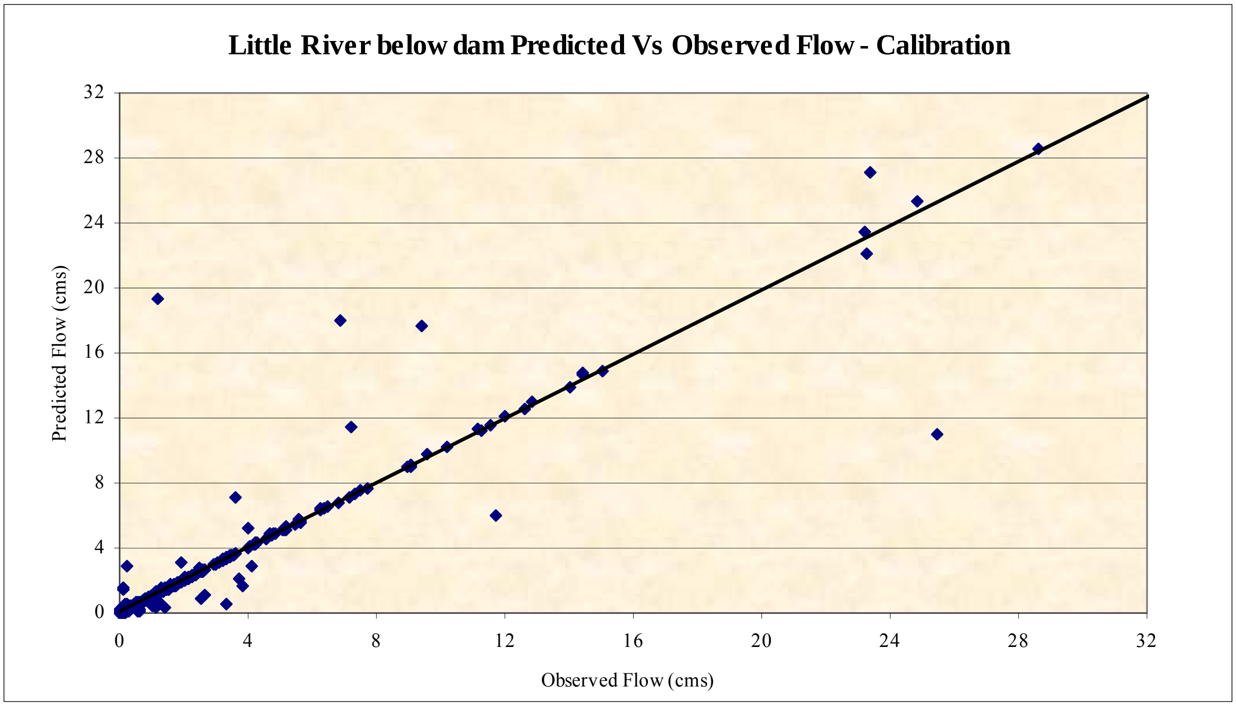

Figure LRB- 2. Scatter plot of daily-observed flows and simulated flows for the calibration period at Little River USGS gaging station below Little River tributary at Fairntosh.

Table LRB-1 provides the error statistics for daily and seasonal flow volume. The total volume and seasonal volume errors satisfy the calibration criteria set during the calibration process. The total stream flow error was only three percent. In general, WARMF simulated flows were close to the observed flows.

Table LRB- 1. Flow volume statistics for WARMF versus observed data at Little River USGS continuous recording station below Little River tributary at Fairntosh[1]

	Predicted (m^3)	Observed (m^3)	Error	Recommended Criteria
Total Predicted In-stream Flow:	109,474,588	106,149,121	3.1%	*10%*
Total of highest 10% flows:	77,256,342	74,827,910	3.2%	*15%*
Total of lowest 50% flows:	6,169,880	5,768,954	6.9%	*10%*
Predicted Summer Flow Volume (months 7-9):	13,744,204	14,567,816	-5.7%	*30%*
Predicted Fall Flow Volume (months 10-12):	38,473,109	35,433,697	8.6%	*30%*
Predicted Winter Flow Volume (months 1-3):	38,173,082	37,503,743	1.8%	*30%*
Predicted Spring Flow Volume (months 4-6):	19,084,194	18,653,649	2.3%	*30%*

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

Table LRB-2 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flows are close to the observed mean. The RMSE is much lower than the SDobs as shown by the low RMSE/SDobs ratio. The relative error, average error, and percent bias were also very small, indicating a good agreement between predicted and observed flows. WARMF performed very well over a range of flow conditions in this watershed.

Table LRB- 2. Additional statistics for WARMF predicted versus observed flow data at Little River USGS continuous recording station below Little River tributary at Fairntosh.

	Flow statistics
Relative Error (RE)	0.03
Average Error (AE) (m^3/s)	0.03
Root Mean Square of Error (RMSE) (m^3/s)	0.88
Standard Deviation (SDobs) (m^3/s)	3.91
RMSE/SDobs	0.23
Percent Bias (PBIAS)	3.1%
R^2	0.95
Coefficient of Efficiency	0.95
Observed mean (m^3/s)	1.12
Predicted mean (m^3/s)	1.16

8.2 Water Quality Calibration

In the water quality simulation, WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to the data from the Little River USGS station (USGS 0208524975) below Little River tributary at Fairntosh (see Figure 8 for a map of the station locations).

<u>Total Suspended Sediment (TSS)</u>

Figure LRB-3 illustrates the time series plot of the observed and WARMF predicted TSS at the Little River USGS station below Little River tributary at Fairntosh. The simulated TSS concentrations tracked the observed concentrations pattern throughout the calibration period, but occasionally missed a few large TSS concentrations. A possible explanation for this could be that the observed TSS concentration is measured as a surface grab sample and as a result, TSS measurements after a storm event may be higher than the depth average values estimated by the model. Figure LRB-4 shows the seasonal distribution of observed and predicted TSS concentration at the same station. WARMF predicted the general trend and range of most observed TSS data in this watershed. The average observed TSS concentration was comparable to the WARMF predicted concentrations for most months, but the average TSS concentration was underestimated during the summer months.

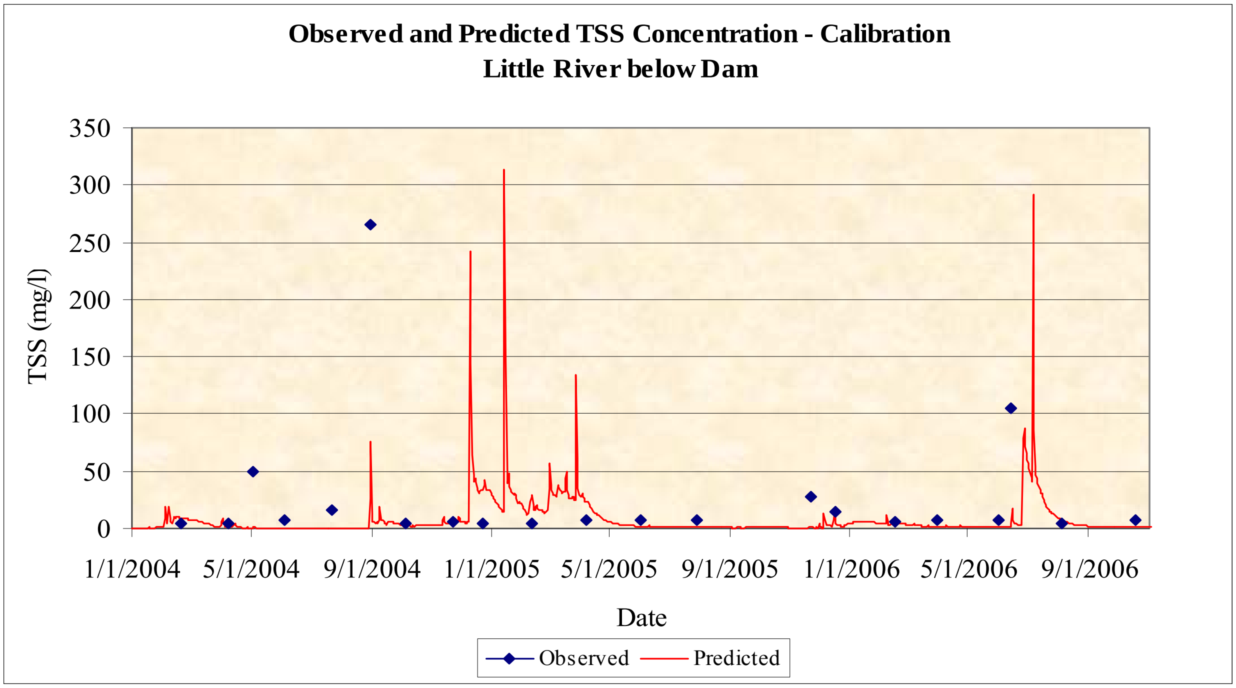

Figure LRB- 3. Time series plots of observed and simulated TSS at Little River USGS station below Little River tributary at Fairntosh.

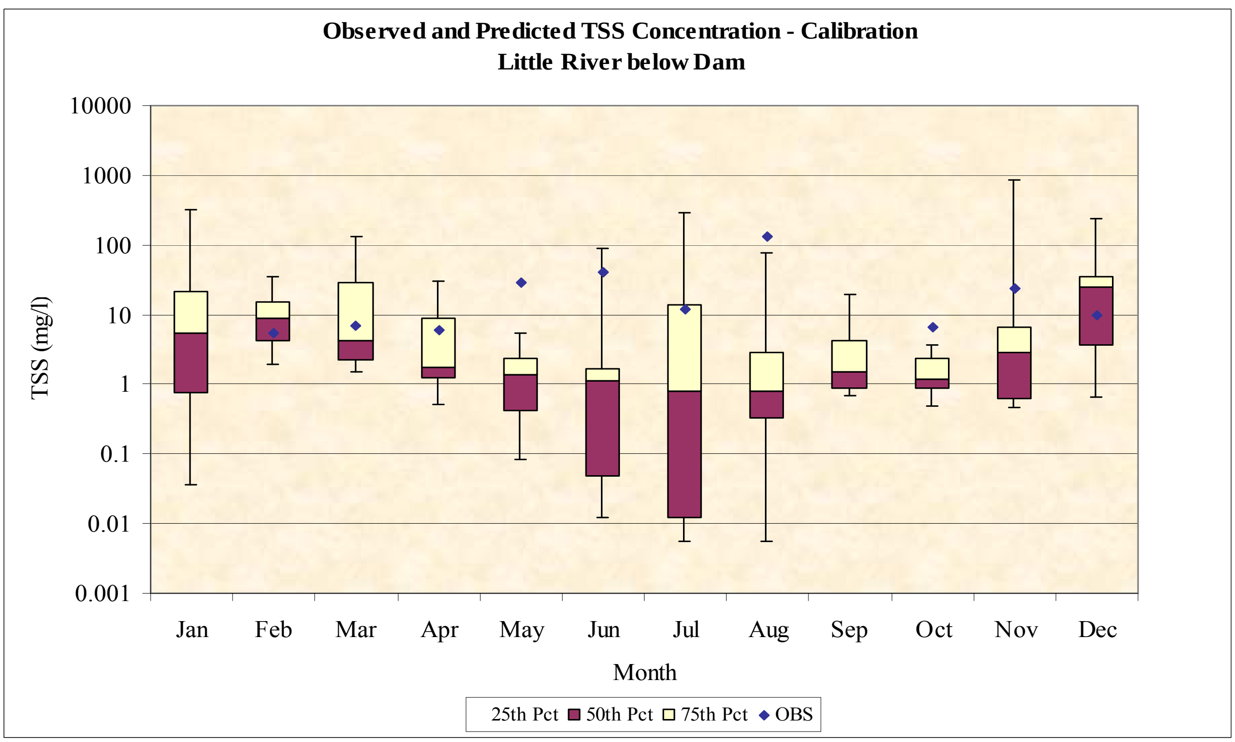

Figure LRB- 4. Seasonal distribution of observed and simulated total suspended sediment (TSS) at Little River USGS station below Little River tributary at Fairntosh.

<u>Nitrogen</u>

Figure LRB-5 is the time series plot of TN observations and WARMF predicted concentrations at the Little River USGS station below Little River tributary at Fairntosh (USGS 0208524975). Figure LRB-6 shows the seasonal distribution of TN observations and WARMF predicted concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations for the same station are included in Appendix C. These figures show that the WARMF predicted concentrations followed the observed pattern fairly well. The time series plots show that there was some discrepancy between the predicted and observed concentrations. WARMF simulations missed some large observed concentrations. The area below Little River Reservoir including Little River tributary has a greater density of residential land use and golf courses as compared to the other parts of the watershed. Application of fertilizer associated with these land uses may account for greater observed concentrations, which may not be captured by the model. The seasonal distribution plots for ammonia, nitrate, TKN, and TN show that the WARMF predicted concentrations track the general pattern of the observed trend. The seasonal plots also show that the average observed ammonia nitrate, TKN, and TN concentrations fall within the daily ranges of the predicted values in most months throughout the calibration period. WARMF simulated the trend and magnitude of TN concentrations fairly well in this watershed.

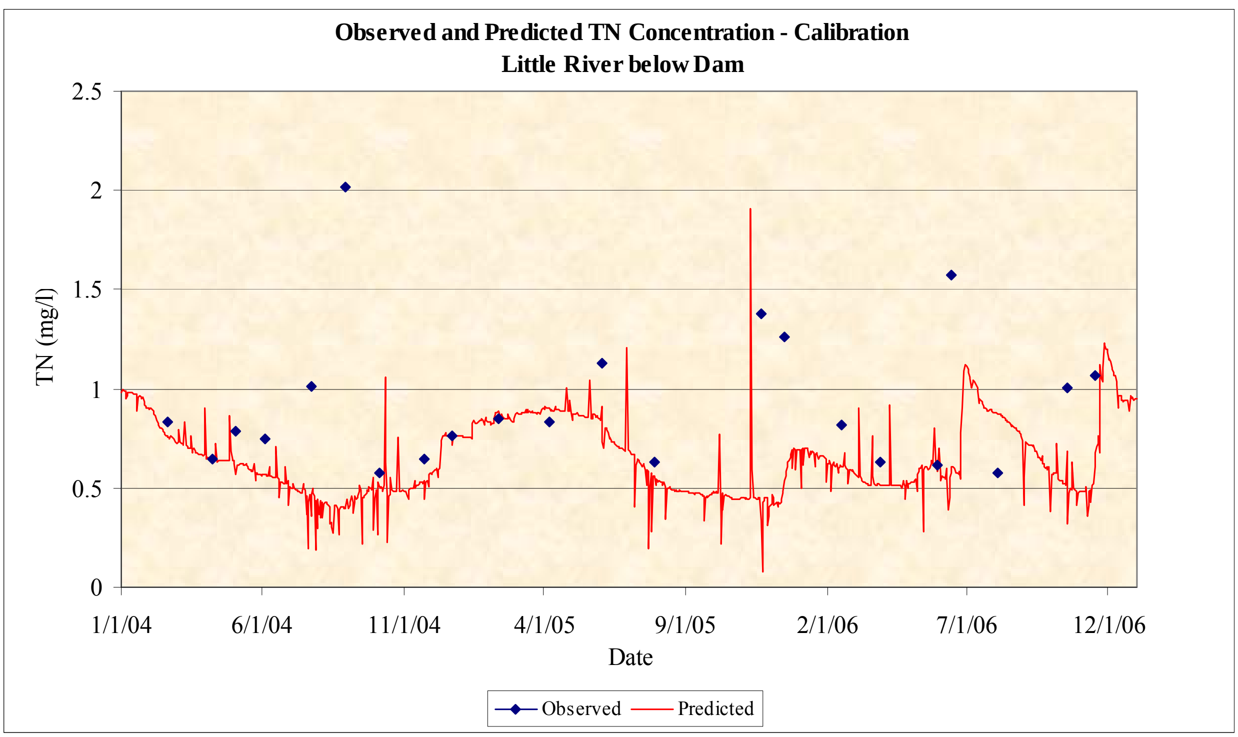

Figure LRB- 5. Time series plots of observed and simulated TN concentration at Little River USGS station below Little River tributary at Fairntosh.

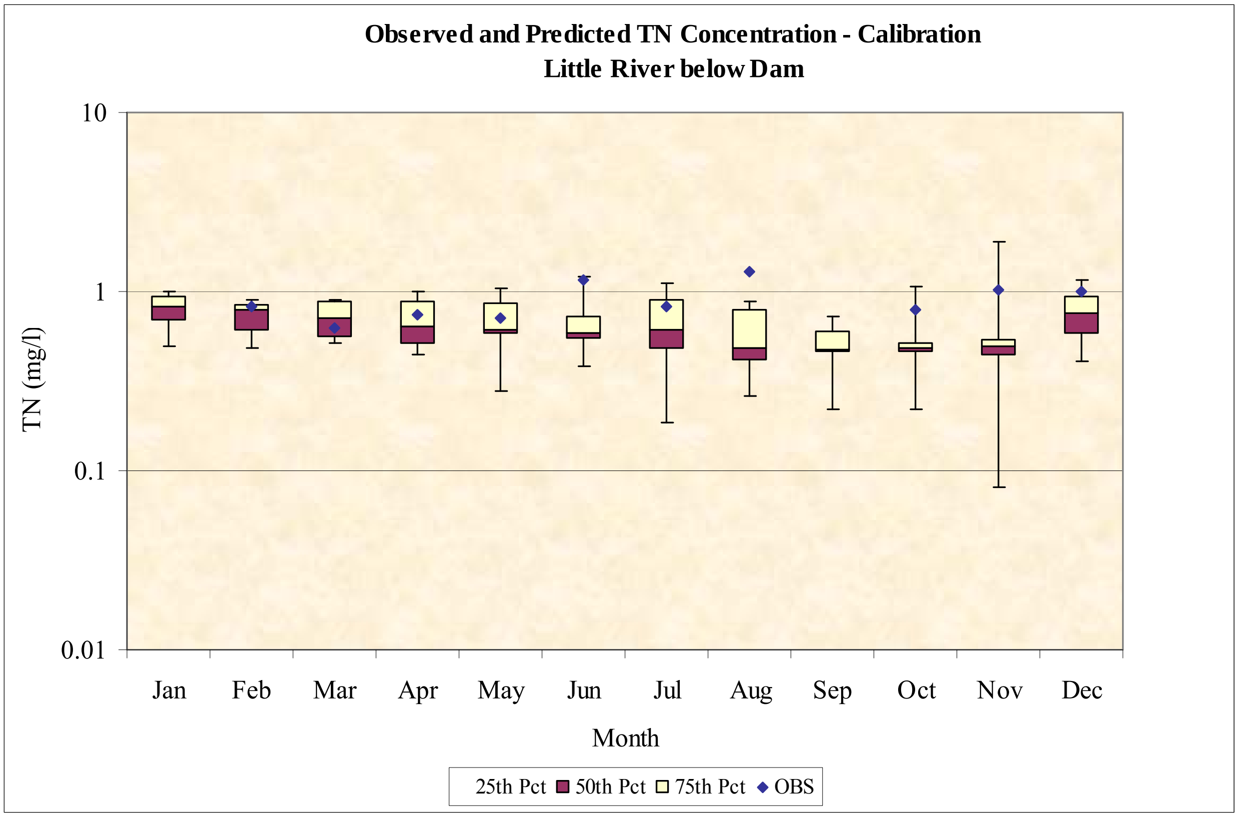

Figure LRB- 6. Seasonal distribution of observed and simulated TN concentration at Little River USGS station below Little River tributary at Fairntosh.

Phosphorus

Figure LRB-7 illustrates the time series plot of the observed and simulated TP concentrations and Figure LRB-8 shows the seasonal distribution of TP. WARMF simulated TP concentrations fairly well throughout the calibration period. The predicted concentrations followed the observed concentrations pattern, but frequently missed large concentrations. WARMF predicted TP concentrations were reasonable for low TP concentrations, but high TP concentrations were underestimated. This could be because of unaccounted nonpoint sources of TP loads. The area below Little River Reservoir including Little River tributary has a greater density of residential land use and golf courses as compared to the other parts of the watershed. Application of fertilizer associated with these land uses may account for greater observed concentrations, which may not be captured by the model. The average observed TP concentrations fall within the range of predicted values in most months during the calibration period as shown in the seasonal plots. WARMF underestimated TP concentrations in June, August, and November.

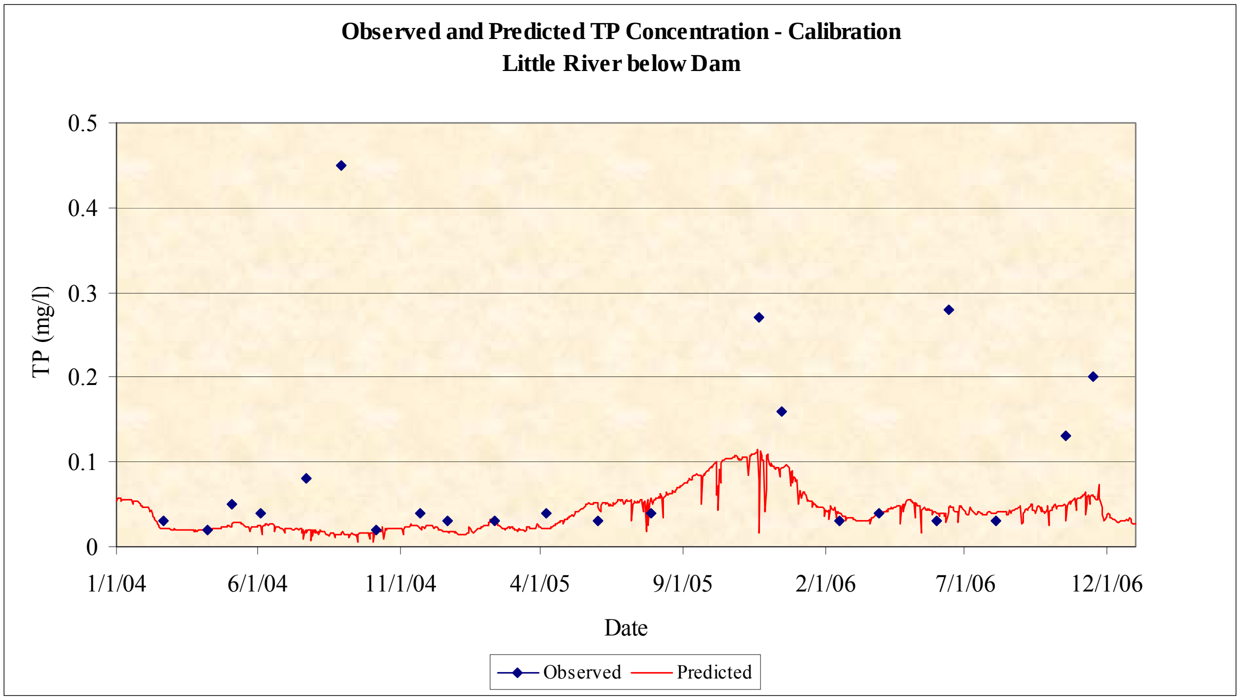

Figure LRB- 7. Time series plots of observed and simulated TP concentration at Little River USGS station below Little River tributary at Fairntosh.

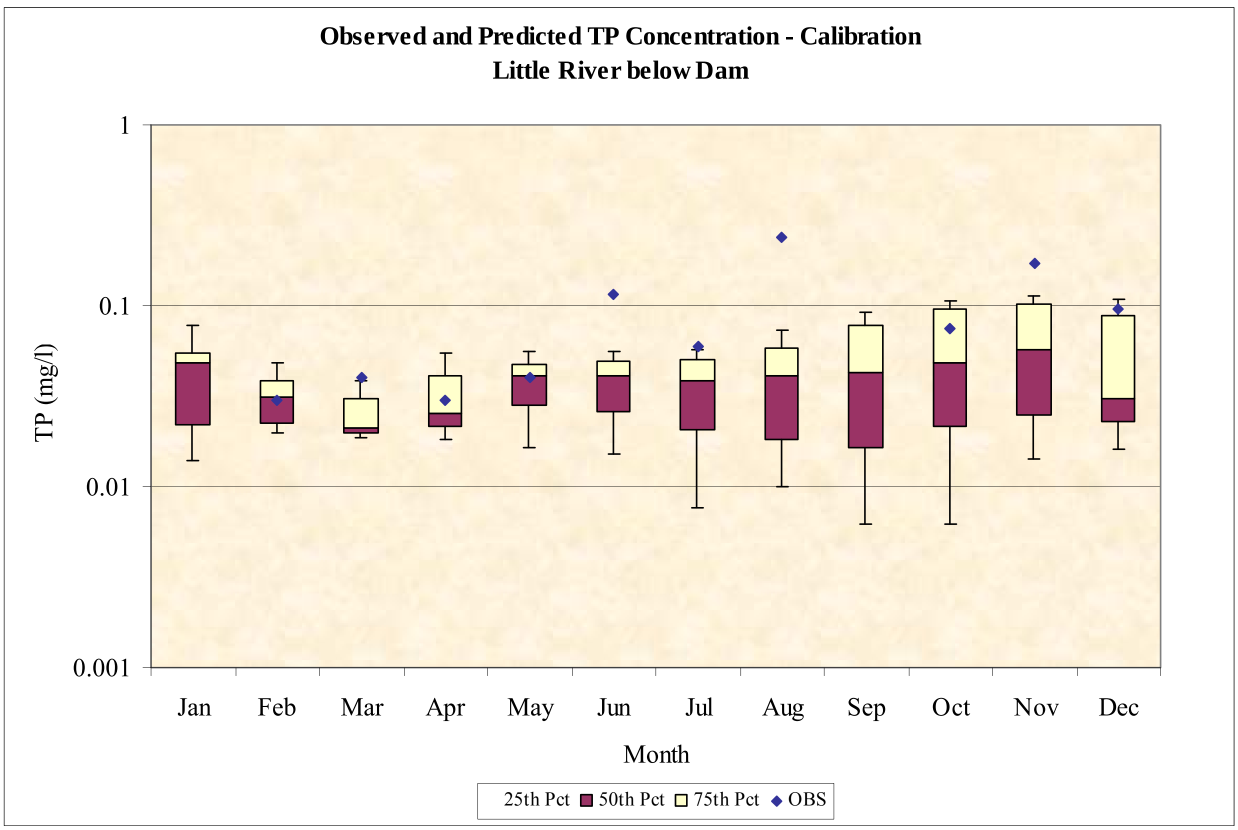

Figure LRB- 8. Seasonal distribution of observed and simulated TP concentration at Little River USGS station below Little River tributary at Fairntosh.

8.3 Hydrologic Validation

Figure LRB-9 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at Little River USGS continuous recording station below Little River tributary at Fairntosh (USGS 0208524975). Overall, WARMF simulates the magnitude and trend of flow very well in this watershed. Figure LRB-10 is a scatter plot of observed and simulated flow at the same station. Linear regression was performed and correlation coefficient (r) calculated for average daily flow. WARMF has an R^2 value of 0.92 indicating a strong agreement between predicted and observed flow. The flow statistic for the validation period is similar to that of the calibration period, indicating that WARMF performed very well over a range of flows in this watershed.

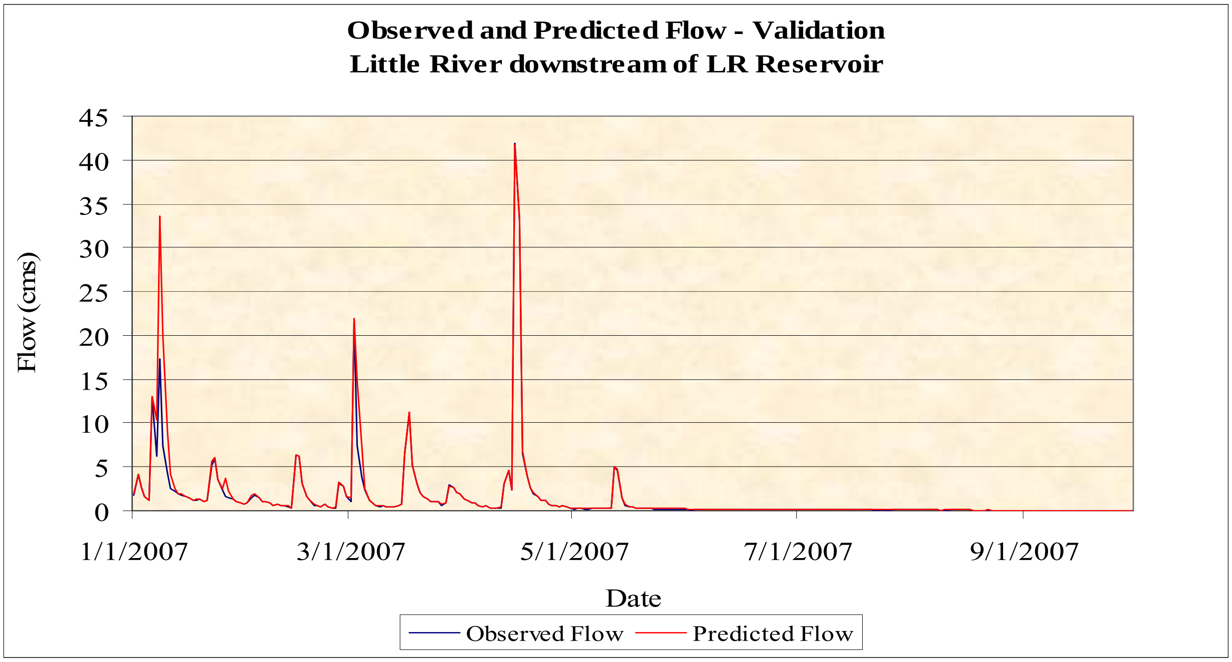

Figure LRB- 9. Time series plots of average daily-observed flows and flows at Little River USGS gaging station below Little River tributary at Fairntosh.

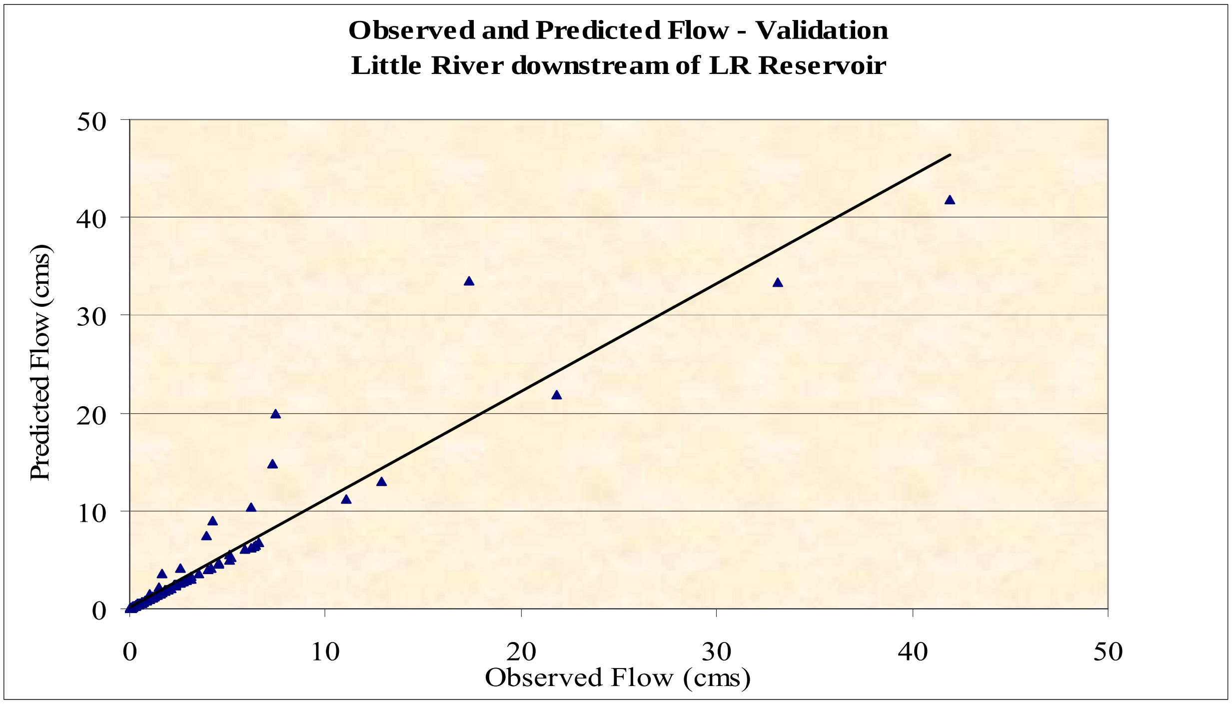

Figure LRB- 10. Scatter plot of daily-observed flows and simulated flows for the validation period at Little River USGS station below Little River tributary at Fairntosh.

Table LRB-3 provides the error statistics for daily and seasonal flow volume. While the seasonal and the total 50% lowest flows satisfy the criteria set during the calibration process, the errors in total and total 10% highest flows were greater than the recommended criteria. The total stream flow error was 15.6 percent. WARMF overestimated flow during the winter and spring months and slightly underestimated flow during the summer months. This could be the result of the extreme drought in 2007.

Table LRB- 3. Flow volume statistics for WARMF versus observed data at Little River USGS continuous recording station below Little River tributary at Fairntosh[1]

	Predicted (m^3)	Observed (m^3)	Error	Recommended Criteria
Total Predicted In-stream Flow:	37,247,796	32,228,350	15.6	*10%*
Total of highest 10% flows:	25,590,630	21,106,608	21.2	*15%*
Total of lowest 50% flows:	1,130,152	1,053,838	7.2	*10%*
Predicted Summer Flow Volume (months 7-9):	512,614	523,910	-2.2	*30%*
Predicted Winter Flow Volume (months 1-3):	24,807,136	19,912,679	24.6	*30%*
Predicted Spring Flow Volume (months 4-6):	11,928,046	11,671,879	2.2	*30%*

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

Table LRB-4 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the validation period. The mean error values show the predicted flows are larger than the observed flows. The RMSE is much lower than the SDobs as shown by the small RMSE/SDobs ratio. The high R^2 (0.92) and coefficient of efficiency (0.87) show that there is strong agreement between the model predicted and observed flows. Considering the extreme drought in 2007, the error values in flow are reasonable. The additional validation statistics are similar to the calibration statistics and confirms the calibration results.

Table LRB- 4. Additional statistics for WARMF predicted versus observed flow data at Little River USGS continuous recording station below Little River tributary at Fairntosh.

	Flow statistics
Relative Error (RE)	0.16
Average Error (AE) (m^3/s)	0.21
Root Mean Square of Error (RMSE) (m^3/s)	1.40
Standard Deviation (SDobs) (m^3/s)	3.91
RMSE/SDobs	0.36
Percent Bias (PBIAS)	15.6%
R^2	0.92
Coefficient of Efficiency	0.87
Observed mean (m^3/s)	1.37
Predicted mean (m^3/s)	1.58

8.4 Water Quality Validation

In the water quality simulation, WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to the data from the Little River USGS station (USGS 0208524975) below Little River tributary at Fairntosh (See Figure 8 for a map of the station locations). The extreme drought in 2007 and the short validation period (nine months, with only four data points for each parameter) were the limitations considered in interpretation of the validation results.

Total Suspended Sediment (TSS)

Figure LRB-11 illustrates the time series plot of the observed and WARMF predicted TSS at the Little River USGS station below Little River tributary at Fairntosh. The validation comparisons are based on four observed data points only. The simulated TSS concentrations tracked the observed concentrations pattern, but missed the magnitude. WARMF overestimated TSS concentrations in January and March and underestimated in April and May. Figure LRB-12 shows the seasonal distribution of observed and predicted TSS concentration at the same station.

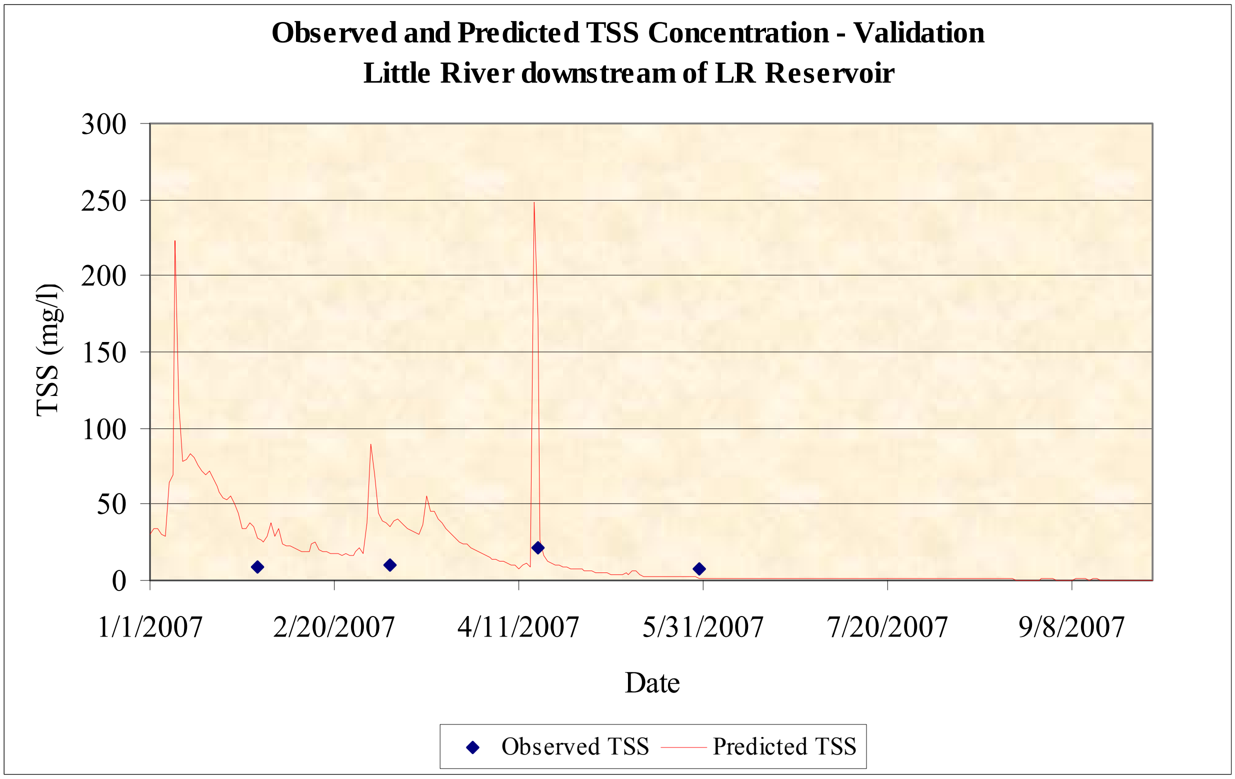

Figure LRB- 11. Time series plots of observed and simulated TSS at Little River USGS station below Little River tributary at Fairntosh.

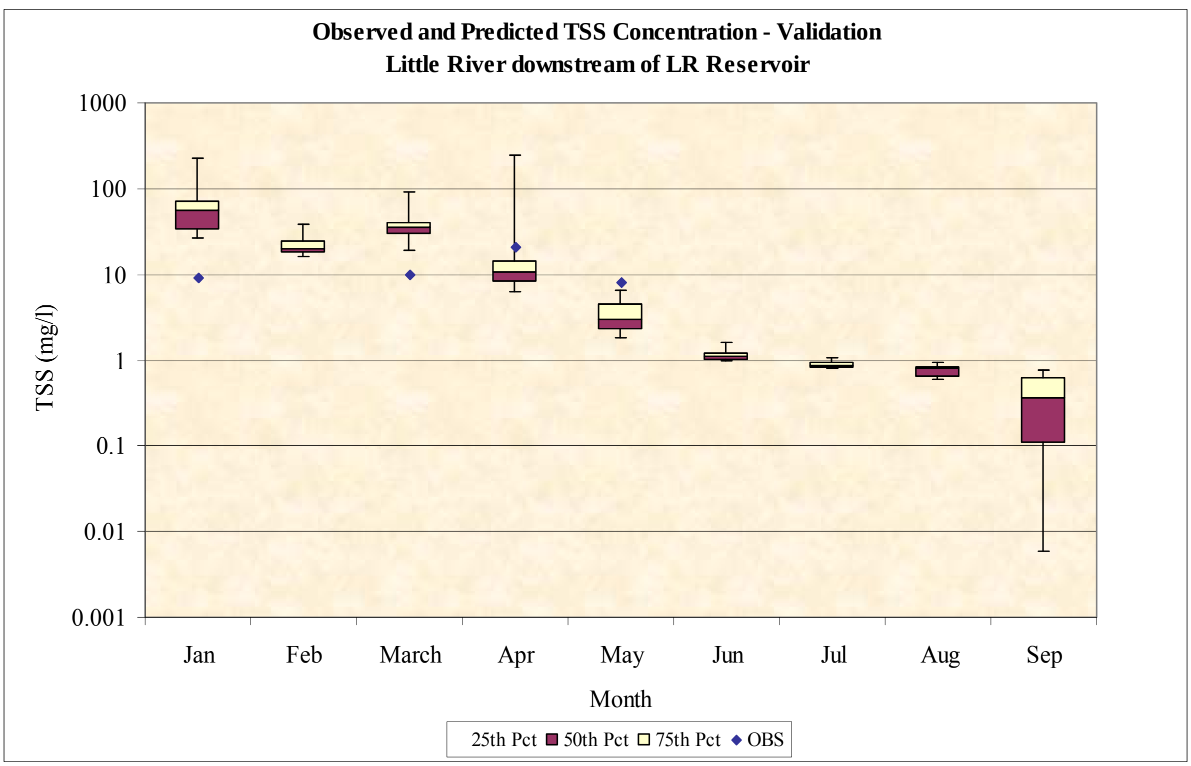

Figure LRB- 12. Seasonal distribution of observed and simulated TSS at Little River USGS station below Little River tributary at Fairntosh.

Nitrogen

Figure LRB-13 is the time series plot of TN observations and WARMF predicted concentrations at the Little River USGS station below Little River tributary at Fairntosh (USGS 0208524975). Figure LRB-14 shows the seasonal distribution of TN observations and WARMF predicted concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations for the same station are included in Appendix C. The validation comparisons are based on four observed data points only. As a result reasonable comparison of observed and predicted values cannot be made. The time series plots show that there was some discrepancy between the predicted and observed concentrations. WARMF overestimated nitrate and underestimated ammonia and TKN. Overall, the average predicted and observed TN concentration during the validation period are comparable. Considering the extreme drought and low flow condition the validation results show a fairly well calibrated model for TN.

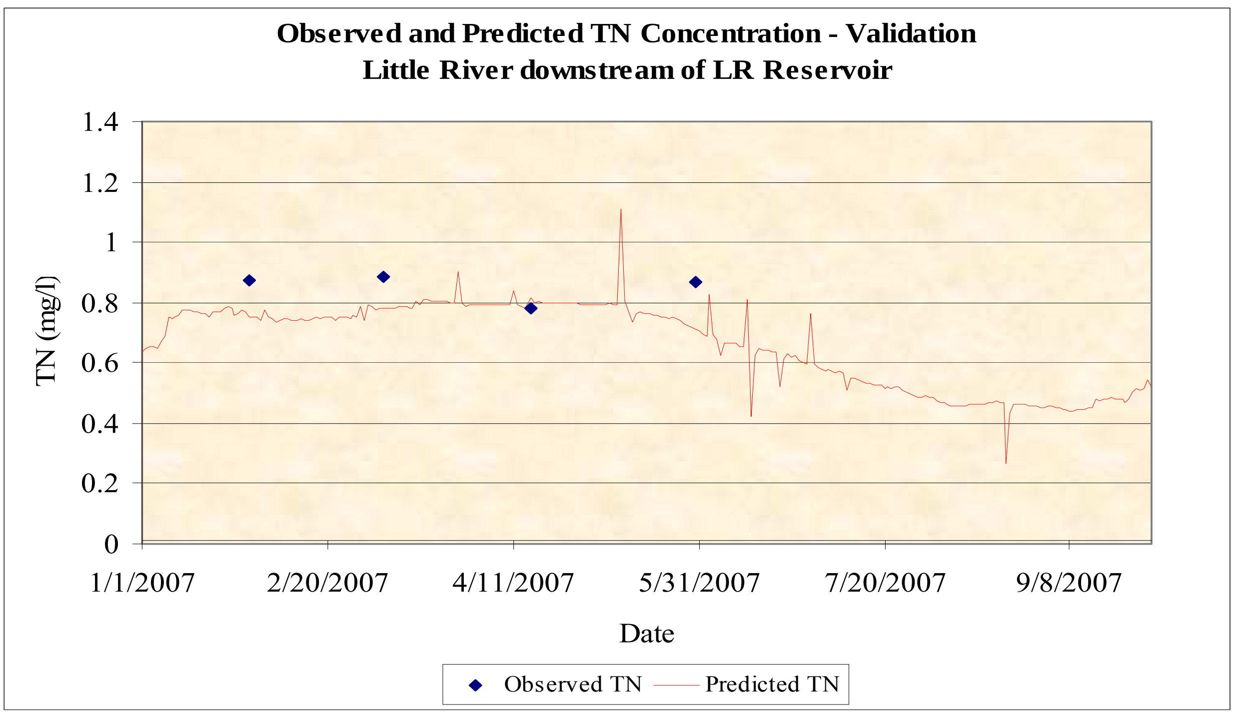

Figure LRB- 13. Time series plots of observed and simulated TN concentration at Little River USGS station below Little River tributary at Fairntosh.

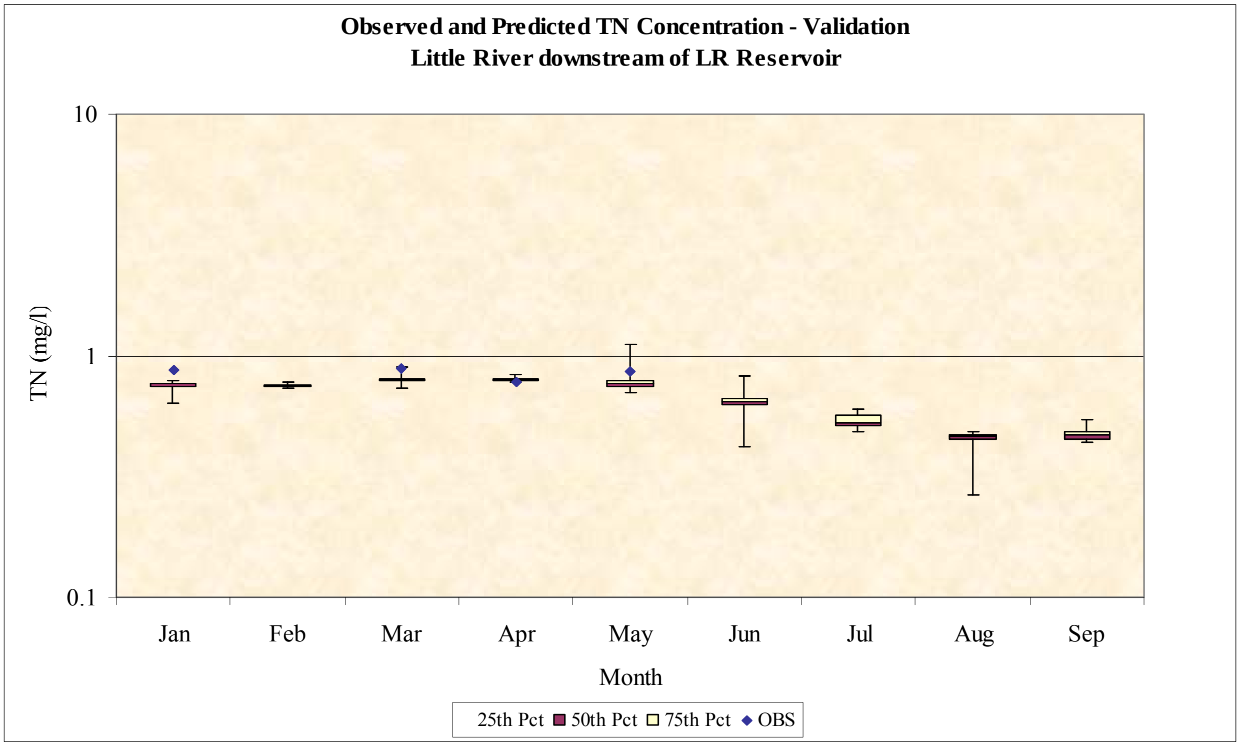

Figure LRB- 14. Seasonal distribution of observed and simulated TN concentration at Little River USGS station below Little River tributary at Fairntosh.

<u>Phosphorus</u>

Figure LRB-15 illustrates the time series plot of the observed and simulated TP concentrations and Figure LRB-16 shows the seasonal distribution of TP. WARMF simulated TP concentrations fairly well throughout the calibration period. The predicted concentrations followed the observed concentrations pattern. The average WARMF predicted TP concentration was comparable to the average observed concentration during the validation period. Large observed TP concentrations were underestimated by WARMF. This could be because of unaccounted nonpoint sources of TP loads. Considering the extreme drought and low flow conditions, the validation results show a fairly well calibrated model for TP.

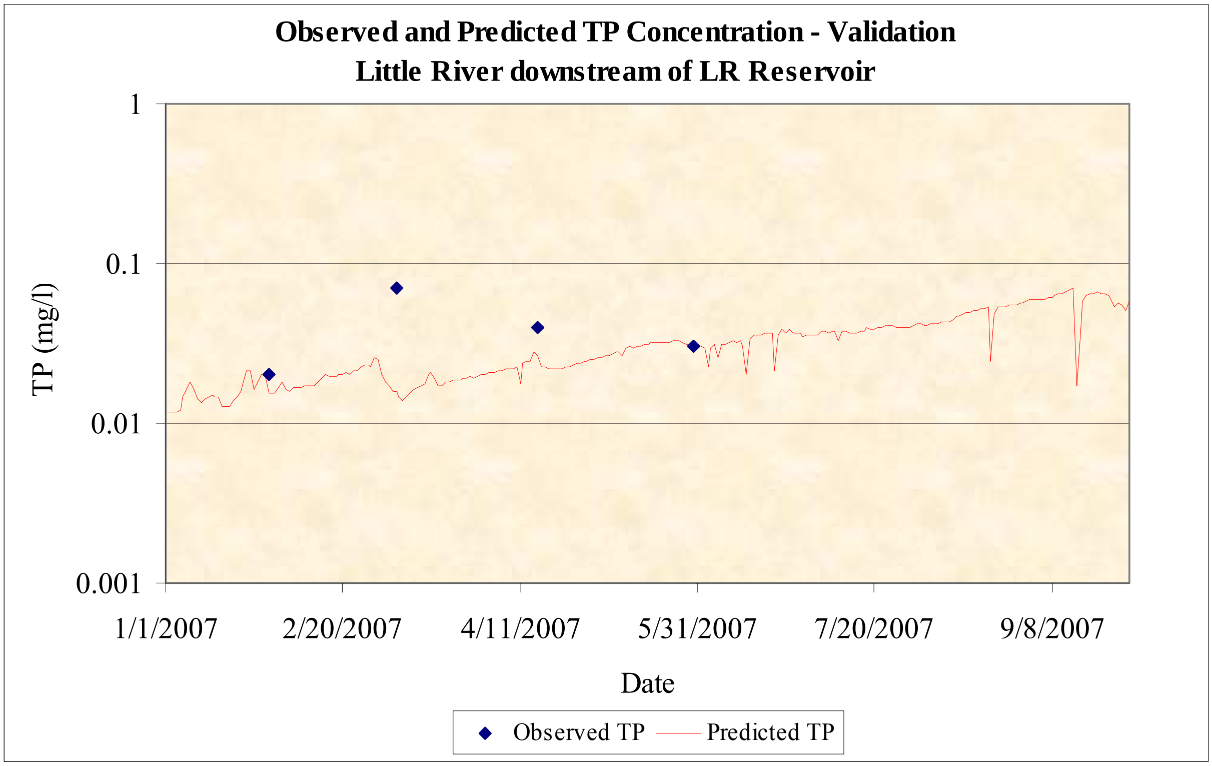

Figure LRB- 15. Time series plots of observed and simulated TP concentration at Little River USGS station below Little River tributary at Fairntosh.

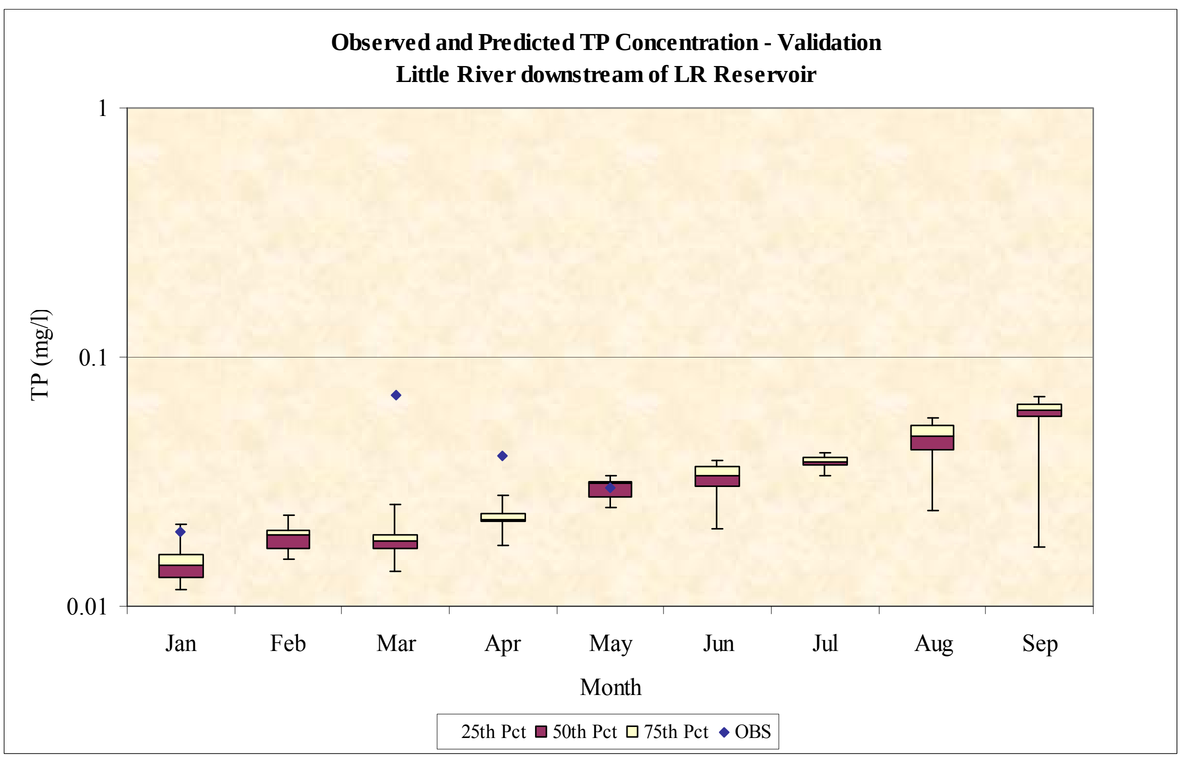

Figure LRB- 16. Seasonal distribution of observed and simulated TP concentration at Little River USGS station below Little River tributary at Fairntosh.

9.0 Watershed Model Results - Eno River

9.1 Hydrologic Calibration

There are two USGS flow gages on the Eno River, shown in Figure 8. USGS Gage 02085000 is near Hillsborough and USGS Gage 02085070 is further downstream near Durham. USGS Gage 02085070 was the primary calibration point for this watershed as it is co-located with a DWQ ambient monitoring station (J0770000).

Because the flow in this system is managed intensively, it was difficult to simulate flow conditions without daily release data from all of the reservoirs. As mentioned above in Section 3.5, daily releases from the upstream reservoirs were estimated using the USGS Gage near Hillsborough.

Figure ENO-1 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at the Hillsborough USGS gage (02085000). WARMF simulates the magnitude and trend of flow fairly well in this watershed, although there is some underestimation of observed higher peaks and in other cases, overestimation of peak flows (e.g. June 2006, shown in Figure ENO-1). This could be the result of the method used to estimate daily release from Lake Orange, or the result of localized rain events not captured in the meteorological data. Figure ENO-2 is a scatter plot of observed and simulated flow at the same station.

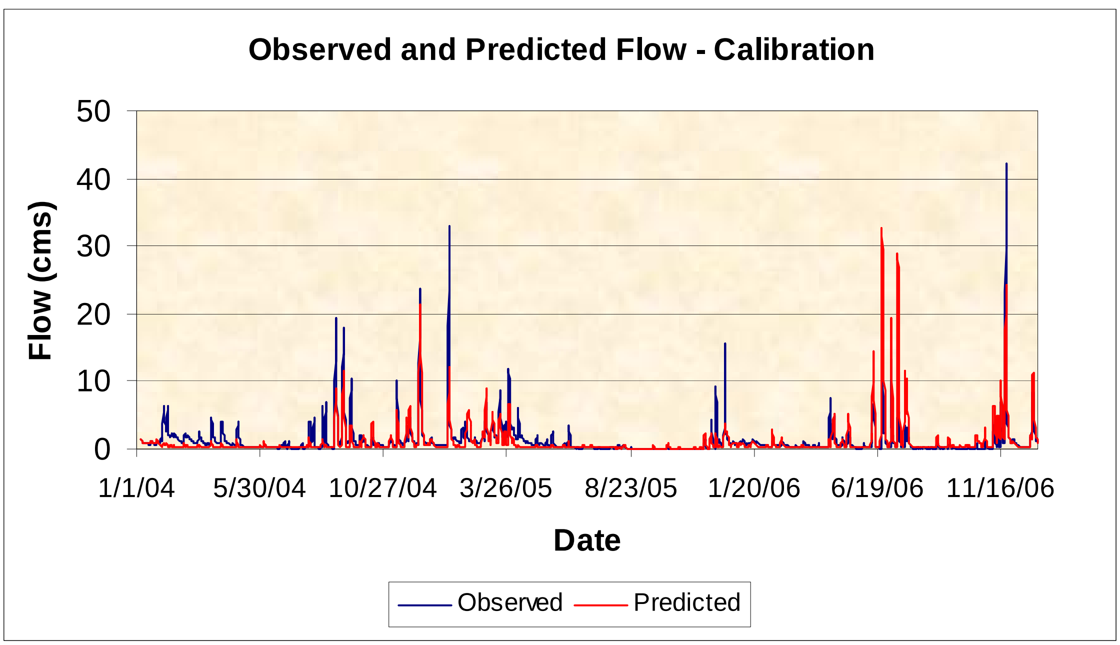

Figure ENO- 1. Calibration - Time series of predicted and observed flow for Eno River (USGS Station 02085000).

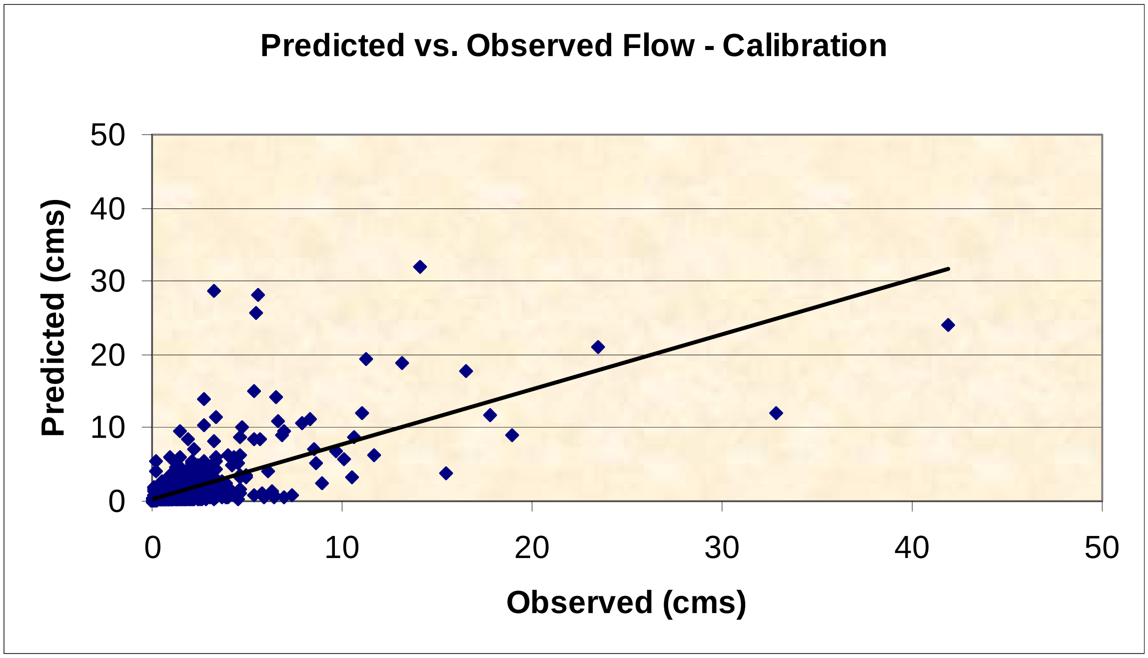

Figure ENO- 2. Calibration - Predicted versus observed flow for Eno River (USGS Station 02085000).

Table ENO-1 provides the error statistics for total and seasonal flow volume. The total volume and seasonal volume errors satisfy most of the calibration criteria, except for a slight exceedance of the criteria for highest 10% flows and underprediction of total winter flow volumes. The total volume stream flow was underpredicted by 5.5%.

Table ENO-2 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flows are close to the observed mean flow.

Table ENO- 1. Predicted flow volume statistics for the calibration period at USGS Station 02085000 in Eno River.

	Predicted (m^3)	Observed (m^3)	% Diff[1]	Recommended Criteria
Total predicted in-stream flow volume	103,871,482	109,972,679	-5.5%	*10%*
Total volume of lowest 50% flows	9,878,319	10,763,758	-8.2%	*10%*
Total volume of highest 10% flows	65,305,092	57,332,097	13.9%	*15%*
Total summer flow volume (months 7-9)	24,380,162	19,999,897	21.9%	*30%*
Total fall flow volume (months 10-12)	35,003,718	31,199,986	12.2%	*30%*
Total winter flow volume (months 1-3)	23,960,310	35,790,041	-33.1%	*30%*
Total spring flow volume (months 4-6)	20,270,505	22,891,488	-11.4%	*30%*

1. % Diff refers to percent difference and is calculated by (predicted – observed)/observed.

Table ENO- 2. Additional daily flow statistics for predicted versus observed data for the calibration period at USGS Station 02085000 in Eno River.

	Flow Statistics
Relative Error	-0.06
Average Error	-0.06
Root Mean Square of Error (m^3/s)	2.11
Standard deviation (SD_{obs}) (m^3/s)	2.51
$RMSE/SD_{obs}$	0.84
R^2	0.47
Coefficient of Efficiency	0.29
Percent Bias	-5.5%
Observed Mean Flow (m^3/s)	1.17
Predicted Mean Flow (m^3/s)	1.10

Figure ENO-3 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at the Durham USGS gage (02085070). WARMF simulates the magnitude and trend of flow fairly well. As is the case at the upstream gage, there is some underprediction of peak flows and, in other cases, overprediction of peak flows (e.g. June 2006, shown in Figure ENO-3). Errors in flow from the upstream gage are most likely propagated downstream. Figure ENO-4 is a scatter plot of observed and simulated flow at the same station.

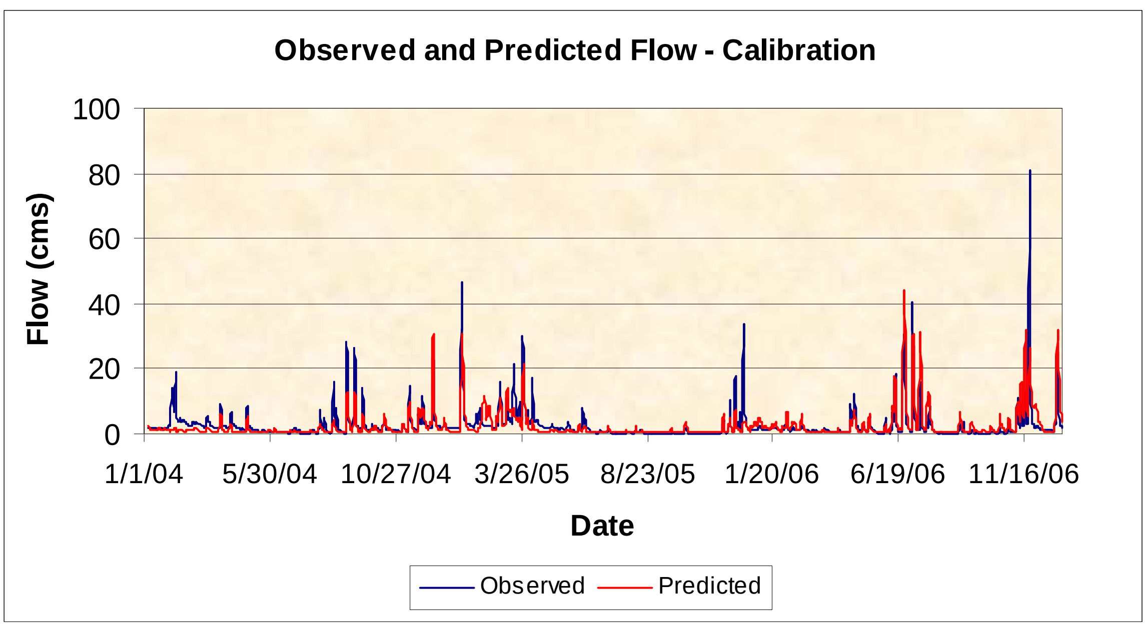

Figure ENO- 3. Calibration - Time series of predicted and observed flow for Eno River (USGS Station 02085070).

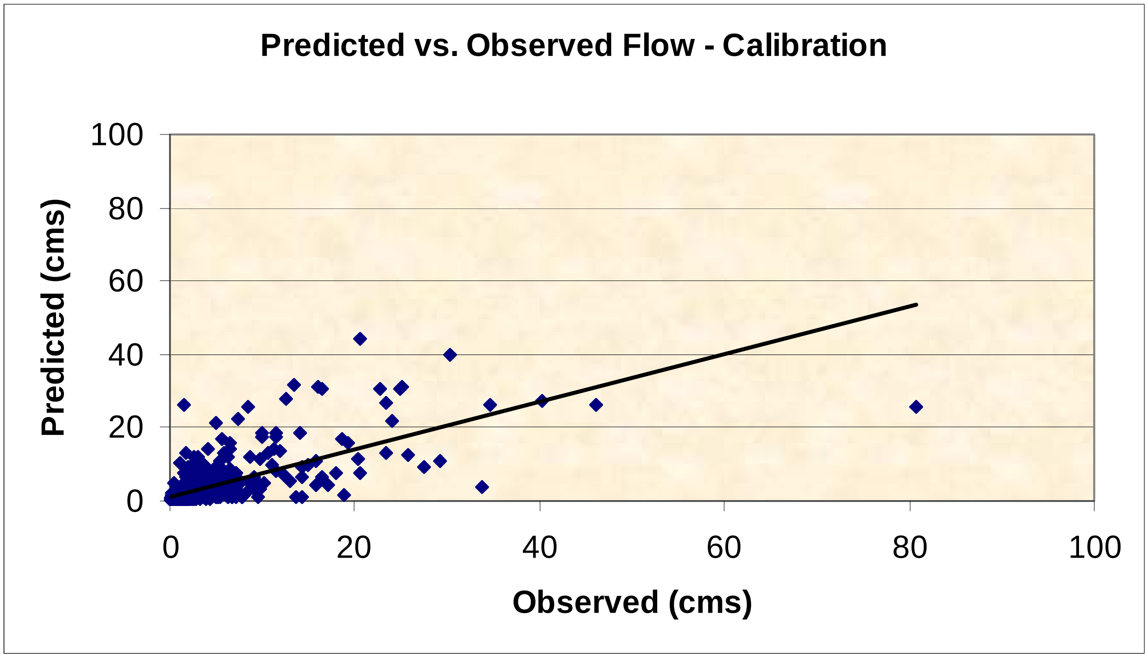

Figure ENO- 4. Calibration - Predicted versus observed flow for Eno River (USGS Station 02085070).

Table ENO-3 provides the error statistics for total and seasonal flow volume. There is some improvement in the calibration at the downstream gage as compared to the upstream gage (shown in Table ENO-1). In this case, the total volume and seasonal volume errors satisfy all of the calibration criteria. The total volume stream flow was underpredicted by 0.8%.

Table ENO-4 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flows are very close to the observed mean flow.

Table ENO- 3. Predicted flow volume statistics for the calibration period at USGS Station 02085070 in Eno River.

	Predicted (m^3)	Observed (m^3)	% Diff[1]	Recommended Criteria
Total predicted in-stream flow volume	239,399,509	241,357,923	-0.8%	*10%*
Total volume of lowest 50% flows	30,483,082	27,971,804	9.0%	*10%*
Total volume of highest 10% flows	123,225,780	120,884,051	1.9%	*15%*
Total summer flow volume (months 7-9)	45,754,917	40,372,141	13.3%	*30%*
Total fall flow volume (months 10-12)	80,997,819	68,142,813	18.9%	*30%*
Total winter flow volume (months 1-3)	63,703,058	77,713,249	-18.0%	*30%*
Total spring flow volume (months 4-6)	48,106,646	54,881,771	-12.3%	*30%*

1. % Diff refers to percent difference and is calculated by (predicted – observed)/observed.

Table ENO- 4. Additional daily flow statistics for predicted versus observed data for the calibration period at USGS Station 02085070 in Eno River.

	Flow Statistics
Relative Error	-0.01
Average Error	-0.02
Root Mean Square of Error (m^3/s)	3.62
Standard deviation (SD_{obs}) (m^3/s)	4.86
$RMSE/SD_{obs}$	0.75
R^2	0.49
Coefficient of Efficiency	0.44
Percent Bias	-0.8%
Observed Mean Flow (m^3/s)	2.56
Predicted Mean Flow (m^3/s)	2.54

9.2 Eno River Water Quality Calibration

There are two DWQ ambient monitoring stations in the Eno River: J0770000 and J0810000 (shown in Figure 8). Station J0770000 is co-located with USGS Gage 02085070 near Durham. Station J0810000 is just downstream of J0770000 and has similar water quality characteristics. For this reason, calibration focused on J0770000. Water quality calibration results for J0810000 are provided in Appendix C.

Total Suspended Sediment (TSS)

Figure ENO-5 illustrates the time series plot of the observed and WARMF predicted TSS concentrations for the Eno River at DWQ ambient monitoring station J0770000. The simulated TSS concentrations tracked the observed concentrations pattern fairly well throughout the calibration period, but the model does overpredict TSS concentrations periodically. This is most likely due to the difference in the observed data captured through surface grab samples and WARMF calculating water quality constituents as vertically averaged over the depth of the water column.

Figure ENO-6 shows the monthly distribution of observed and predicted TSS concentrations. In general, WARMF predicted the general trend and range of most observed TSS data in this watershed, although the model does overpredict TSS in the winter months.

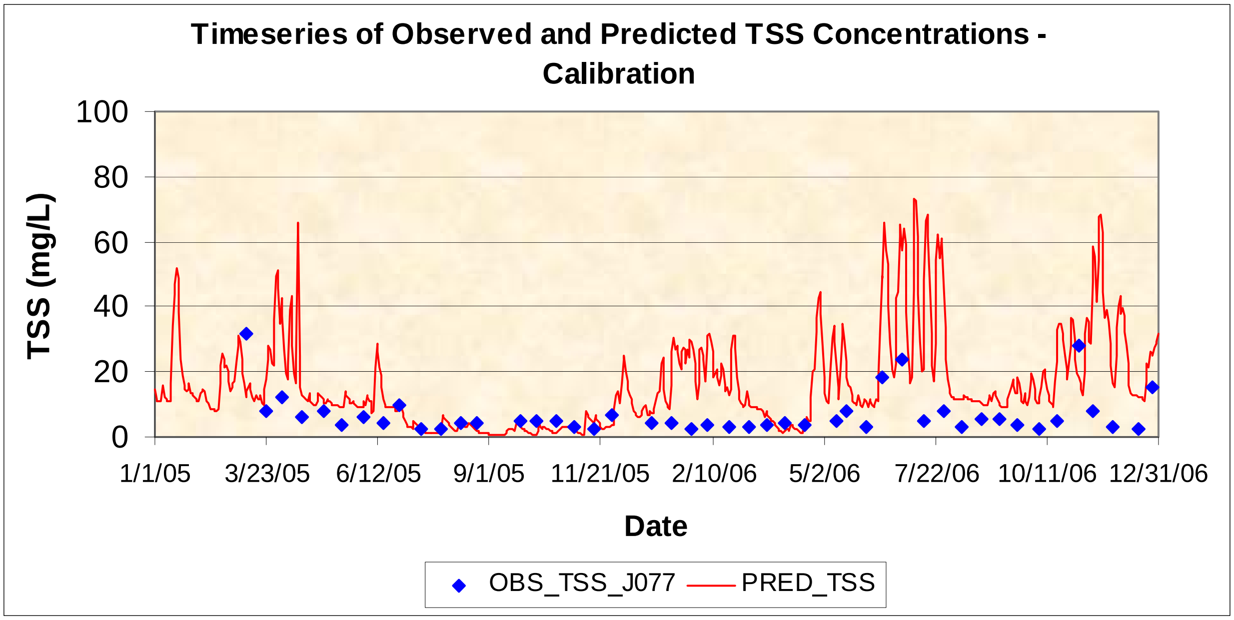

Figure ENO- 5. Calibration – Eno River (at Ambient Monitoring Station J0770000) TSS concentrations daily time series.

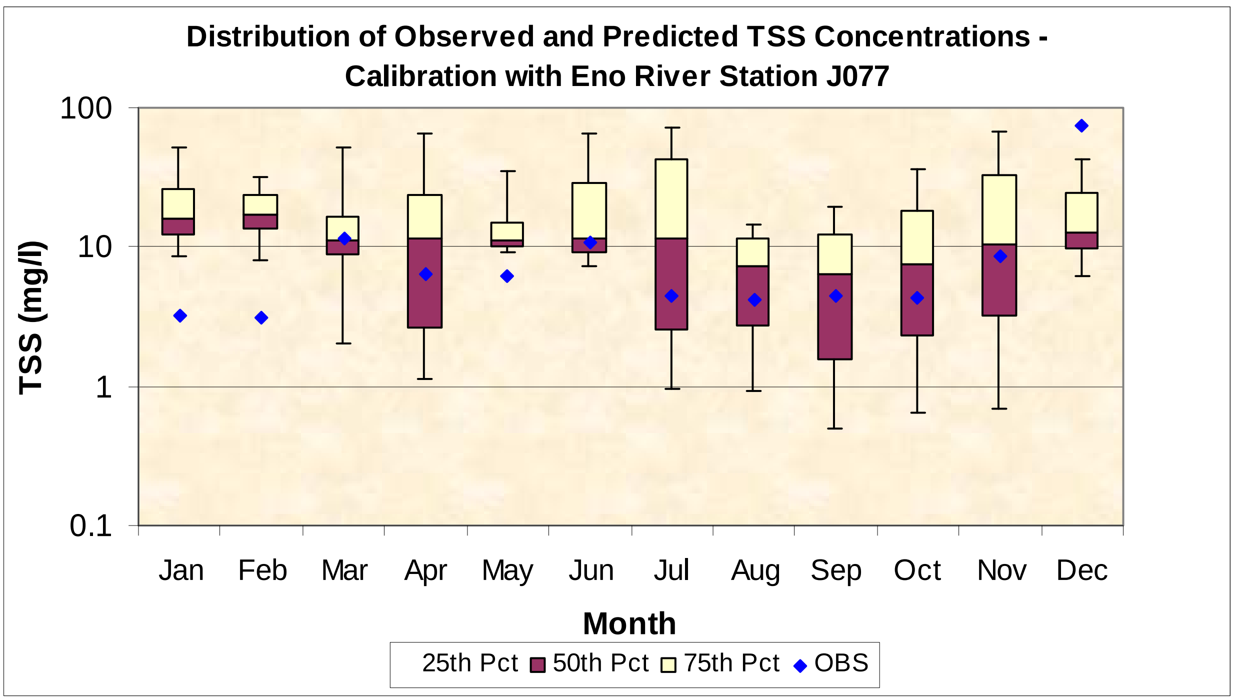

Figure ENO- 6. Calibration - Observed versus predicted TSS concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

Nitrogen

Figure ENO-7 shows the time series plot of TN observations and WARMF predicted concentrations. Figure ENO-8 shows the seasonal distribution of TN concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations are included in Appendix C.

The figures show that the WARMF predicted concentrations generally follow the observed pattern for all the nitrogen series parameters, although the model seems to slightly overpredict TN in the summer months of 2005. However, the range of predicted TN concentrations is within the range of observed concentrations, as shown in Figure ENO-8. A review of the nitrogen series provided in Appendix C shows that the slight overprediction of TN is most likely due to overprediction of nitrate during the same time period (Figure ENO-C3). This could be due to an overprediction of the land application of nitrate in the Eno River watershed.

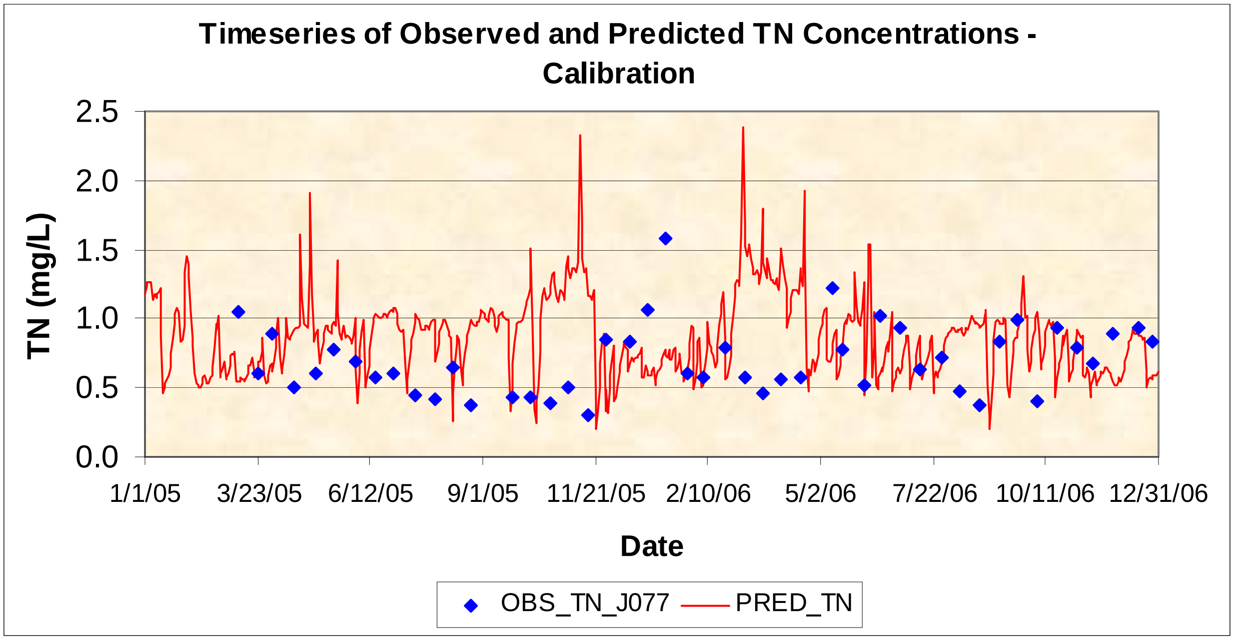

Figure ENO- 7. Calibration – Eno River (at Ambient Monitoring Station J0770000) TN concentrations daily time series.

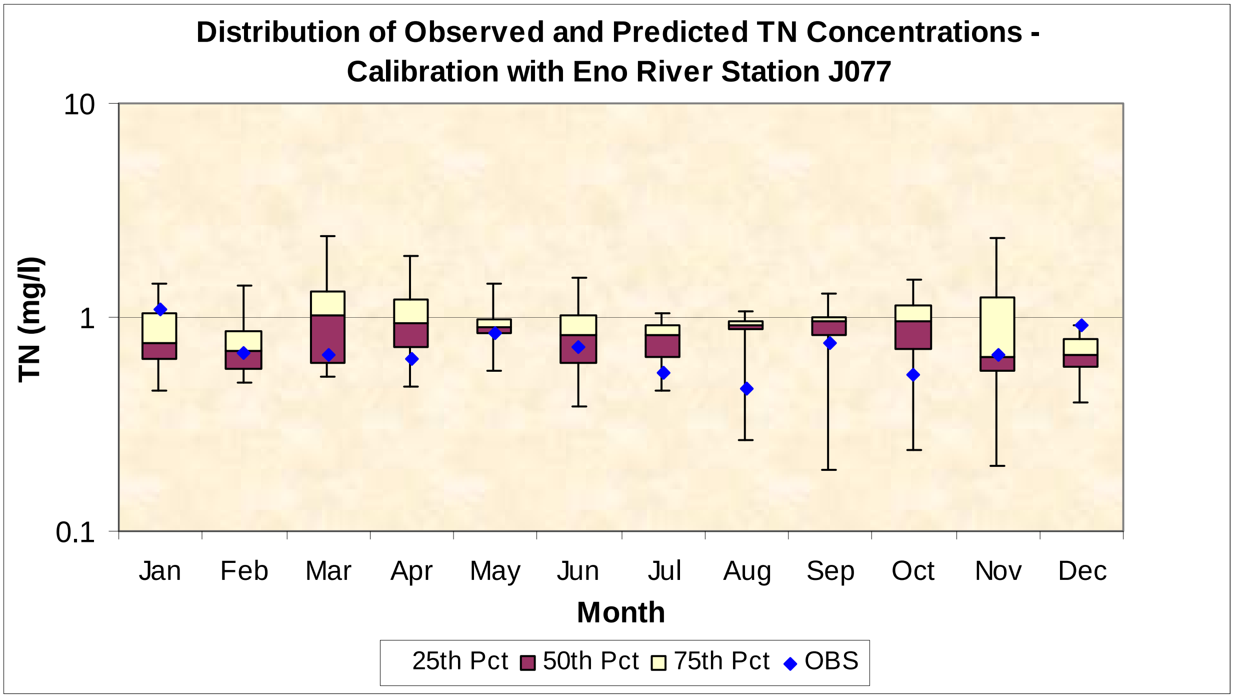

Figure ENO- 8. Calibration - Observed versus predicted TN concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

<u>Phosphorus</u>

Figure ENO-9 illustrates the time series plot of the observed and simulated TP concentrations and Figure ENO-10 shows the seasonal distribution of TP. WARMF simulated TP concentrations very well throughout the calibration period, although the model did not capture spikes in TP concentrations observed in December 2005, February 2006, and May 2006. As a result, the average observed TP concentrations fall within the range of predicted values in every month during the calibration period except for February, May, and December. This could be due to underestimation of point source discharges or other unaccounted for sources.

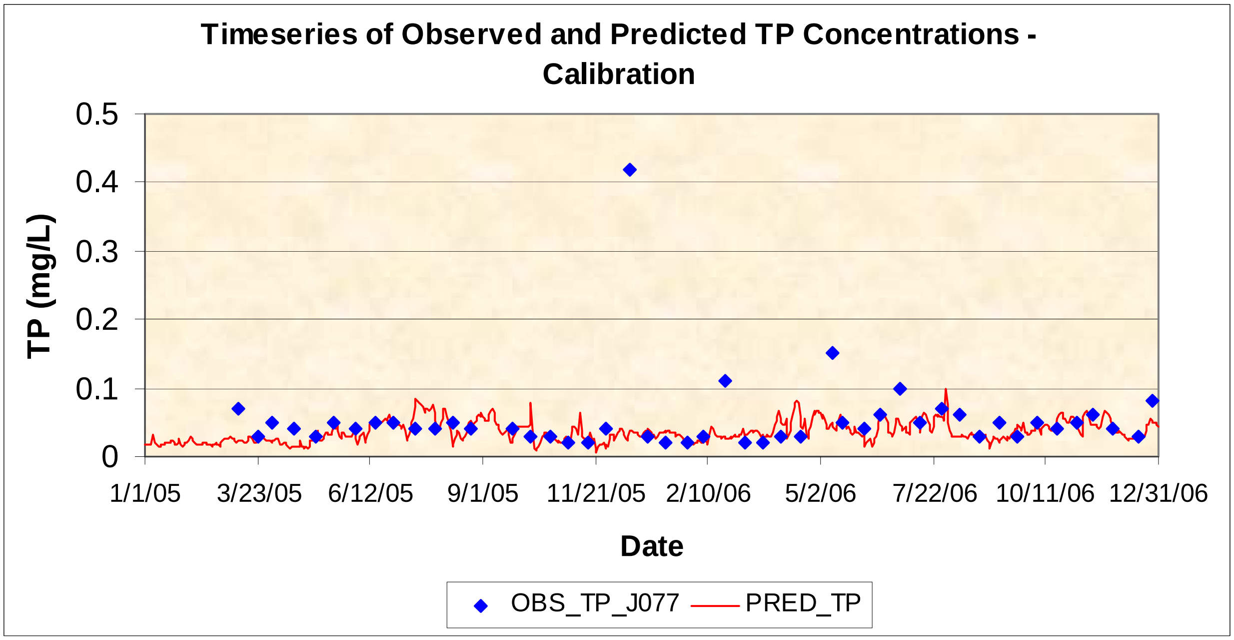

Figure ENO- 9. Calibration – Eno River (at Ambient Monitoring Station J0770000) TP concentrations daily time series.

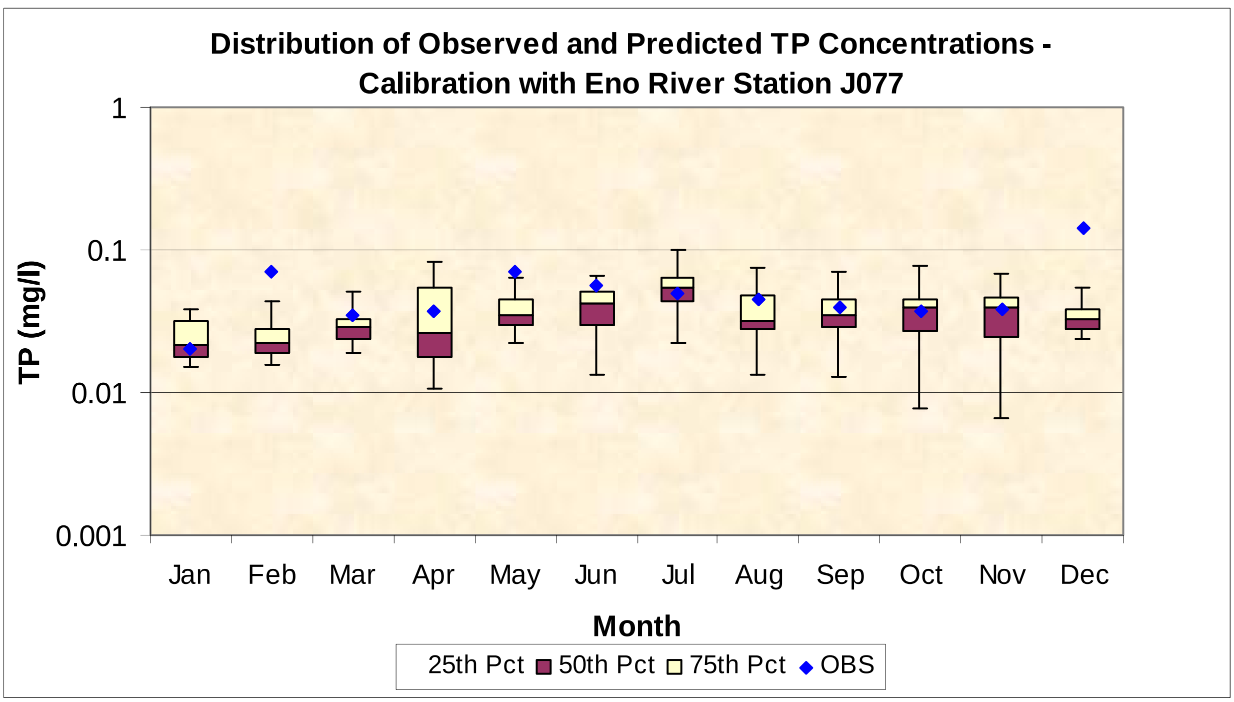

Figure ENO- 10. Calibration - Observed versus predicted TP concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

9.3 Hydrologic Validation

Figure ENO-11 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow for the validation period for the upstream USGS Gage 02085000. Overall, WARMF simulates the magnitude and trend of flow reasonably well in this watershed, although WARMF underestimates some peak observed flows. Figure ENO-11 is a scatter plot of observed and simulated flow at the same station and shows that the model generally underestimates flow during the spring and overestimates during the extreme dry conditions of the summer. Errors associated with flow estimation are most likely due to the lack of daily release rates for the upstream reservoirs (especially the West Fork Eno Reservoir and Lake Orange) and the extreme drought conditions of 2007.

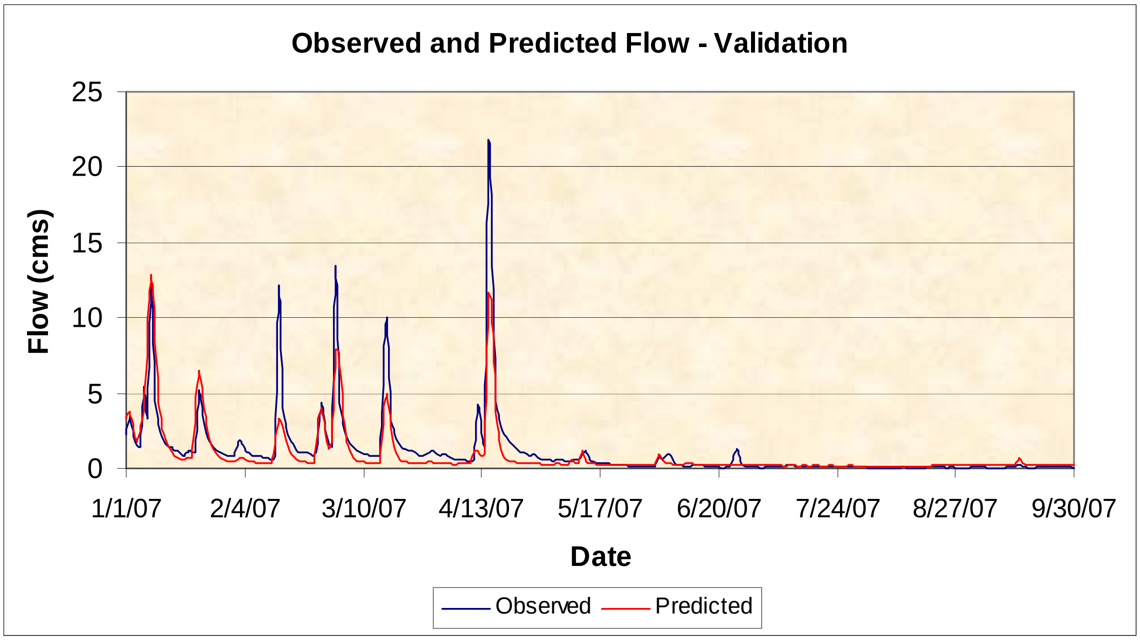

Figure ENO- 11. Validation - Time series of predicted and observed flow for Eno River (USGS Station 02085000).

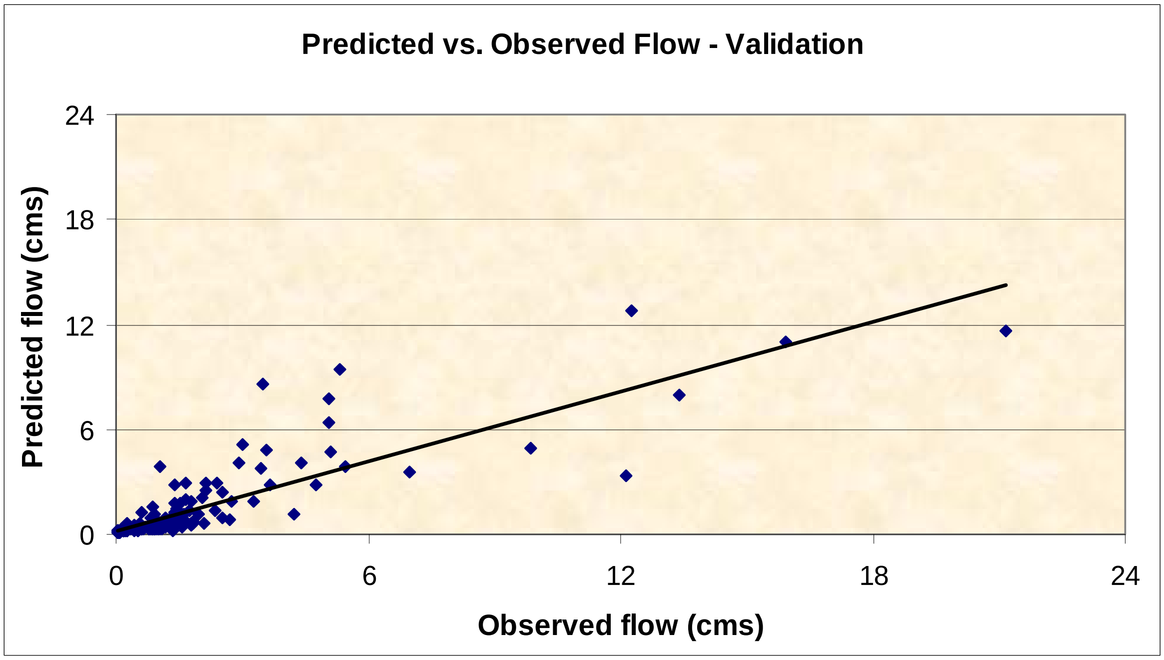

Figure ENO- 12. Validation - Predicted versus observed flow for Eno River (USGS Station 02085000).

Table ENO-5 provides the error statistics for daily and seasonal flow volume. Most of the calibration criteria are exceeded during the validation time period, except for total volume of highest 10% flows and winter flow volume. Table ENO-6 provides additional descriptive statistics and error measures for the simulated and observed daily flow during the validation period. The mean predicted flow is lower than the mean observed flow.

Table ENO- 5. Predicted flow volume statistics for the validation period at USGS Station 02085000 in Eno River.

	Predicted (m^3)	Observed (m^3)	% Diff[1]	Recommended Criteria
Total predicted in-stream flow volume	21,138,794	26,260,567	-19.5%	*10%*
Total volume of lowest 50% flows	2,431,074	1,496,003	62.5%	*10%*
Total volume of highest 10% flows	12,732,818	14,668,869	-13.2%	*15%*
Total summer flow volume (months 7-9)	1,524,255	633,978	140.4%	*30%*
Total winter flow volume (months 1-3)	14,429,095	17,098,582	-15.6%	*30%*
Total spring flow volume (months 4-6)	5,185,444	8,528,006	-39.2%	*30%*

1. % Diff refers to percent difference and is calculated by (predicted – observed)/observed.

Table ENO- 6. Additional daily flow statistics for predicted versus observed data for the validation period at USGS Station 02085000 in Eno River.

	Flow Statistics
Relative Error	-0.20
Average Error	-0.22
Root Mean Square of Error (m^3/s)	1.21
Standard deviation (SD_{obs}) (m^3/s)	2.31
$RMSE/SD_{obs}$	0.54
R^2	0.74
Coefficient of Efficiency	0.73
Percent Bias	-19.5%
Observed Mean Flow (m^3/s)	1.11
Predicted Mean Flow (m^3/s)	0.90

Figure ENO-13 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow for the validation period for the downstream USGS Gage 02085070. Errors observed at the upstream flow gage are most likely propagated downstream. As seen with the upstream gage, WARMF overestimates summer flows and underestimates peak spring flows. Figure ENO-14 is a scatter plot of observed and simulated flow at the same station and shows that the model generally overpredicts flow during the validation period.

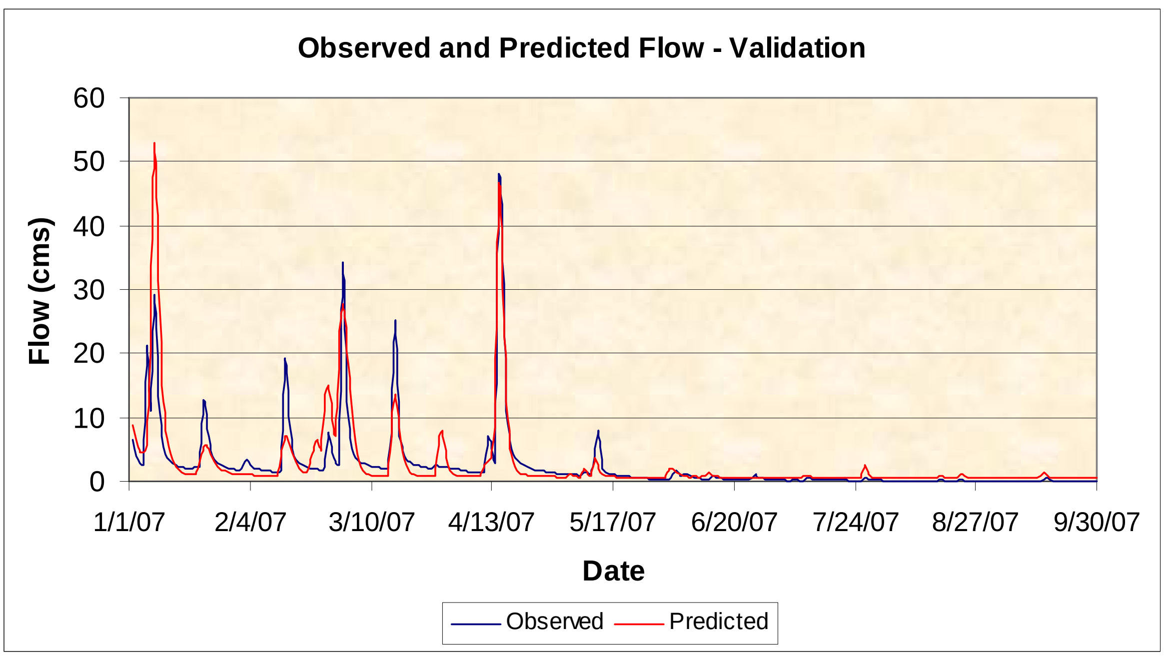

Figure ENO- 13. Validation - Time series of predicted and observed flow for Eno River (USGS Station 02085070).

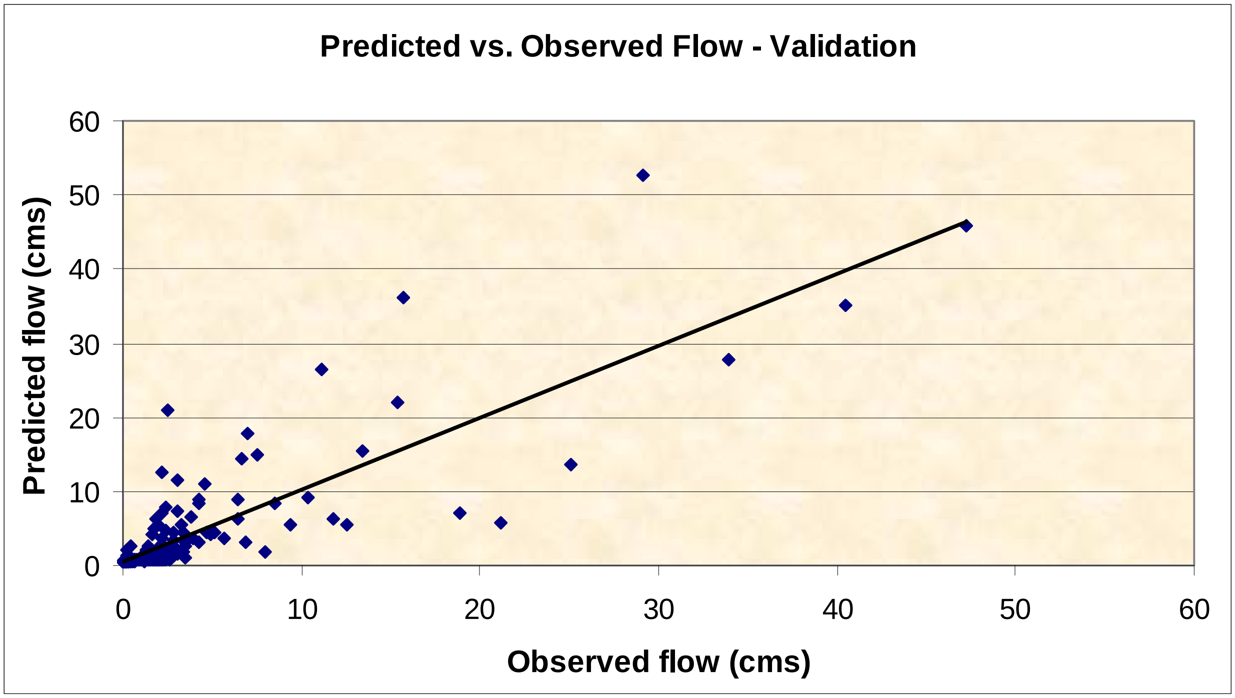

Figure ENO- 14. Validation - Predicted versus observed flow for Eno River (USGS Station 02085070).

Table ENO-7 provides the error statistics for daily and seasonal flow volume. Most of the calibration criteria are exceeded during the validation time period, especially the total flow volume in the summer months and the total volume of lowest 50% flows. This is most likely due to WARMF not representing the extreme low flows observed during the validation period, especially the summer months when average observed flow is only 0.1 m^3/s. Table ENO-8 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the validation period. The mean predicted flow is higher than the mean observed flow, which is consistent with the high overprediction of flow during the lowest 50% flows and the summer months, most likely due to the extreme drought conditions. The results of the Eno River flow calibration and validation highlight the importance of daily release data from upstream reservoirs in a flow-managed system to predict flow volumes.

Table ENO- 7. Predicted flow volume statistics for the validation period at USGS Station 02085070 in Eno River.

	Predicted (m^3)	Observed (m^3)	% Diff[1]	Recommended Criteria
Total predicted in-stream flow volume	65,869,013	58,088,227	13.4%	*10%*
Total volume of lowest 50% flows	6,898,818	3,205,063	115.2%	*10%*
Total volume of highest 10% flows	40,846,967	34,400,393	18.7%	*15%*
Total summer flow volume (months 7-9)	4,617,140	991,496	365.7%	*30%*
Total winter flow volume (months 1-3)	44,026,091	37,779,549	16.5%	*30%*
Total spring flow volume (months 4-6)	17,225,782	19,317,182	-10.8%	*30%*

1. % Diff refers to percent difference and is calculated by (predicted – observed)/observed.

Table ENO- 8. Additional daily flow statistics for predicted versus observed data for the validation period at USGS Station 02085070 in Eno River.

	Flow Statistics
Relative Error	0.13
Average Error	0.33
Root Mean Square of Error (m^3/s)	3.38
Standard deviation (SD_{obs}) (m^3/s)	5.45
$RMSE/SD_{obs}$	0.62
R^2	0.71
Coefficient of Efficiency	0.62
Percent Bias	13.4%
Observed Mean Flow (m^3/s)	2.46
Predicted Mean Flow (m^3/s)	2.79

9.4 Water Quality Validation

Water quality validation was performed for the Eno River watershed using January through September 2007 as the validation time period. WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to 2007 data from the same DWQ ambient monitoring stations used in calibration.

Total Suspended Sediment (TSS)

Figure ENO-15 illustrates the time series plot of the observed and WARMF predicted TSS concentrations in the Eno River. The model simulated higher TSS concentrations in the beginning of the year that were not captured in the ambient monitoring data. The model predictions match well with observed TSS concentrations in the summer months. Figure ENO-16 shows the seasonal distribution of observed and predicted TSS concentrations at the same station. WARMF predicted TSS concentrations were higher than the observed concentrations from January to May.

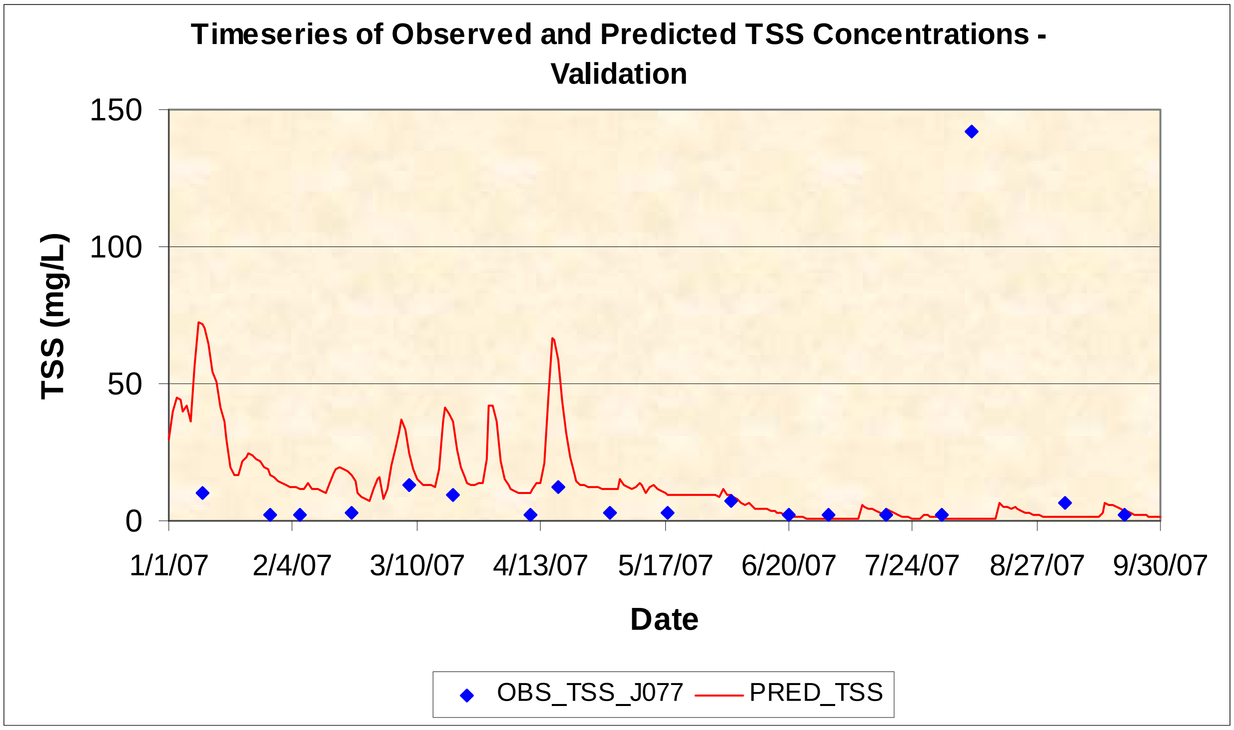

Figure ENO- 15. Validation – Eno River (at Ambient Monitoring Station J0770000) TSS concentrations daily time series.

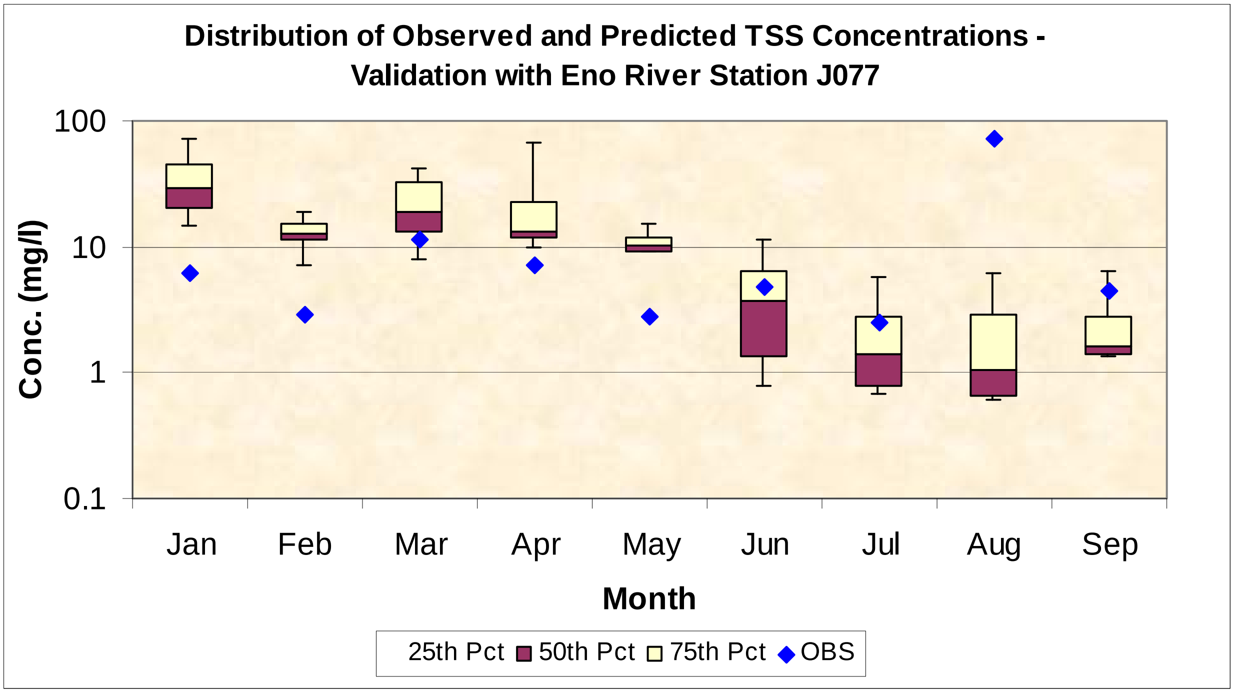

Figure ENO- 16. Validation - Observed versus predicted TSS concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

<u>Nitrogen</u>

Figure ENO-17 is the time series plot of TN observations and WARMF predicted concentrations in the Eno River for the validation period. Figure ENO-18 shows the seasonal distribution of TN concentrations. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations are included in Appendix C.

On average, WARMF predicted nitrogen constituent concentrations were higher than the observed values. The ranges of both observed and predicted TN concentrations are very similar though. The overprediction of TN is caused by an overprediction of nitrate (see Figure ENO-C9 in Appendix C). As with the calibration results, this could be due to an overprediction of land application of nitrate in the Eno River watershed.

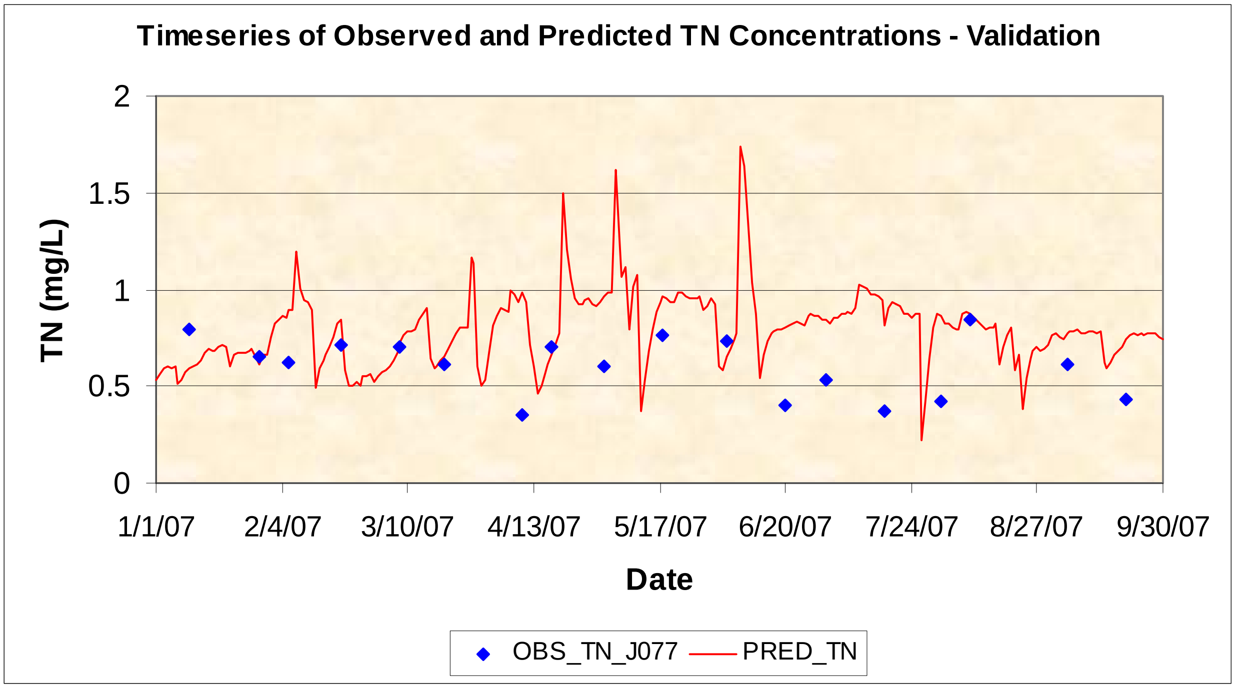

Figure ENO- 17. Validation – Eno River (at Ambient Monitoring Station J0770000) TN concentrations daily time series.

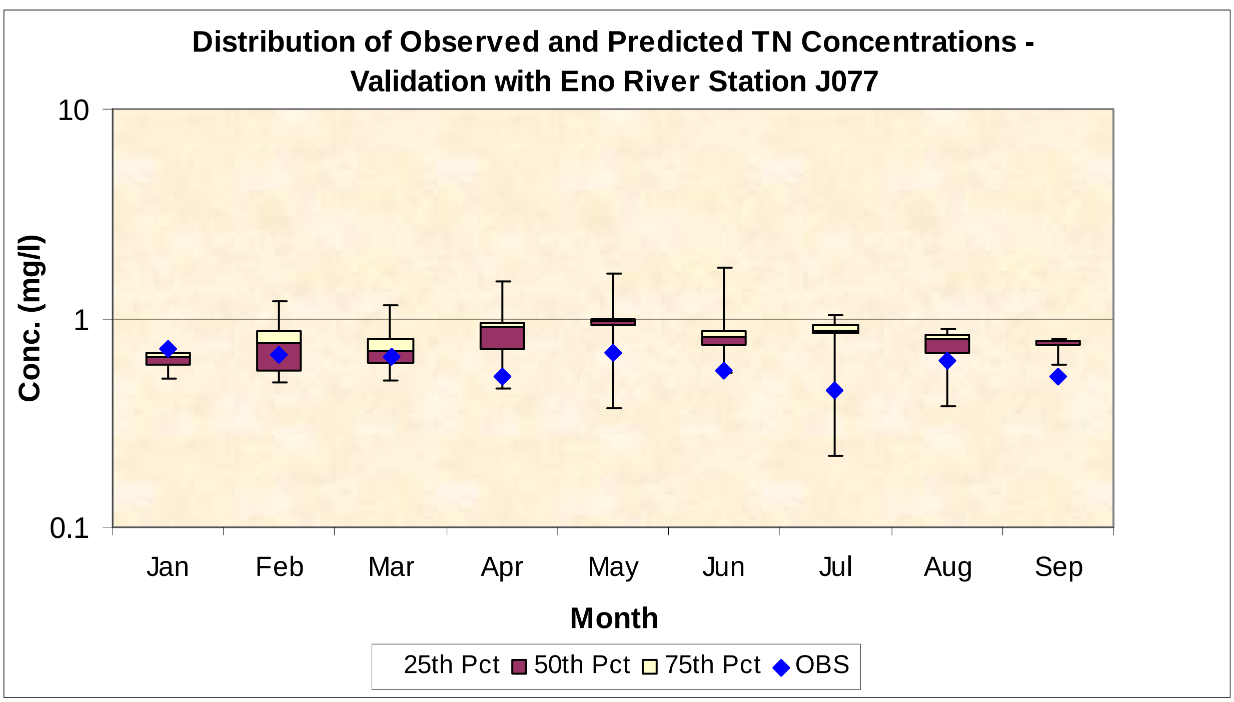

Figure ENO- 18. Validation - Observed versus predicted TN concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

Phosphorus

Figure ENO-19 illustrates the time series plot of the observed and simulated TP concentrations and Figure ENO-20 shows the seasonal distribution of TP. The validation results were mostly similar to the calibration results. WARMF simulated average TP concentrations fairly well, capturing the range of low TP concentrations observed during the validation period. However, the model does not capture a spike in TP in August.

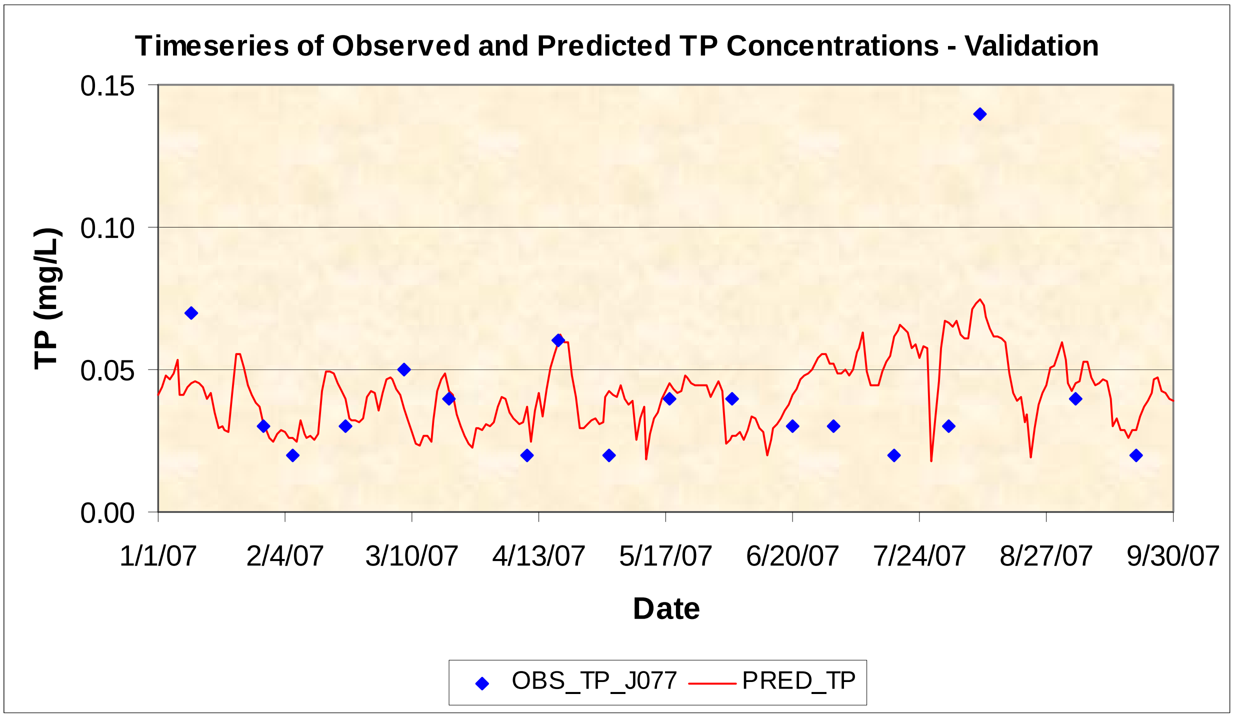

Figure ENO- 19. Validation – Eno River (at Ambient Monitoring Station J0770000) TP concentrations daily time series.

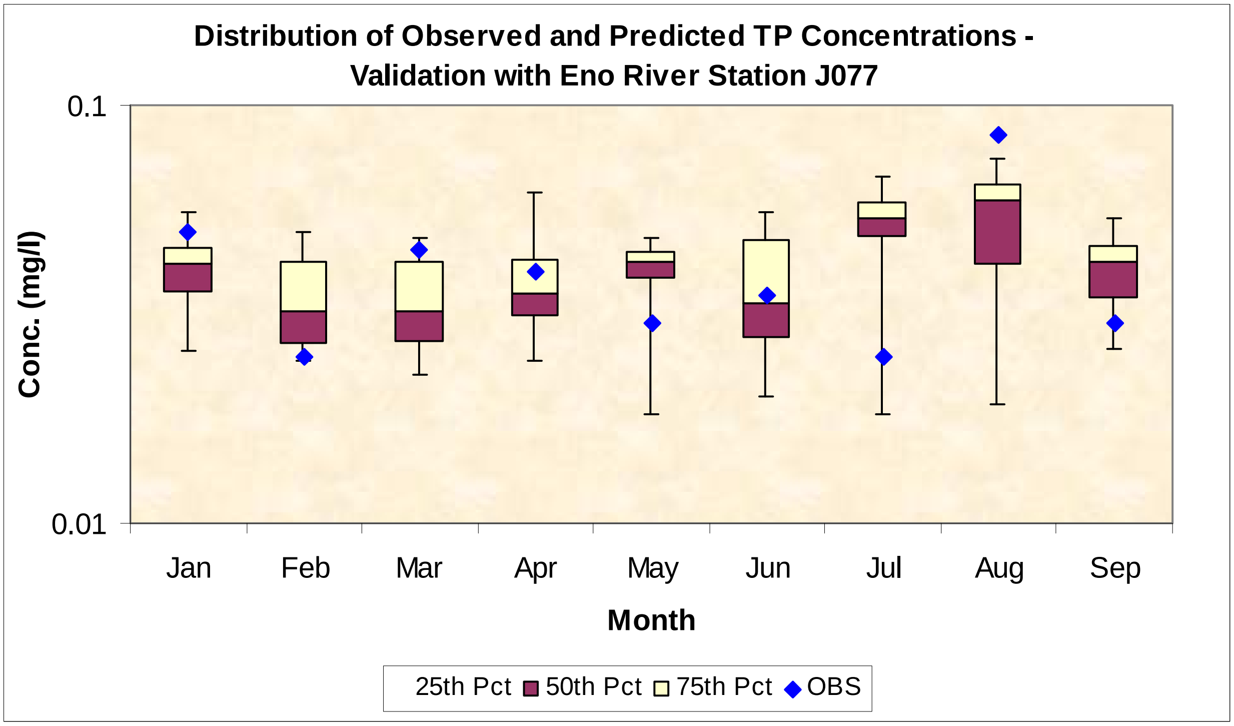

Figure ENO- 20. Validation - Observed versus predicted TP concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

10.0 Watershed Model Results – Ellerbe Creek

10.1 Hydrologic Calibration

In the hydrologic calibration, simulated stream flows were compared to the observed stream flow at the Ellerbe Creek USGS Gage (USGS 02086849). See Figure 8 for a map of the station locations.

Figure ELL-1 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at the Ellerbe Creek USGS Gage. Overall, WARMF simulates the magnitude and trend of flow fairly well in this watershed. It simulated the seasonal variation of flow and tracked the general trend of flows during the calibration period. In general the WARMF modeling component time series seems to underestimate higher peaks. Figure ELL-2 is a scatter plot of observed and simulated flow at the same station. Linear regression was performed and correlation coefficient (r) calculated for average daily flow. WARMF has a moderately high R^2 value of 0.7 and underestimates flow on average as shown by the slope of the regression line being less than one. In general, R^2 is easily influenced by extreme values.

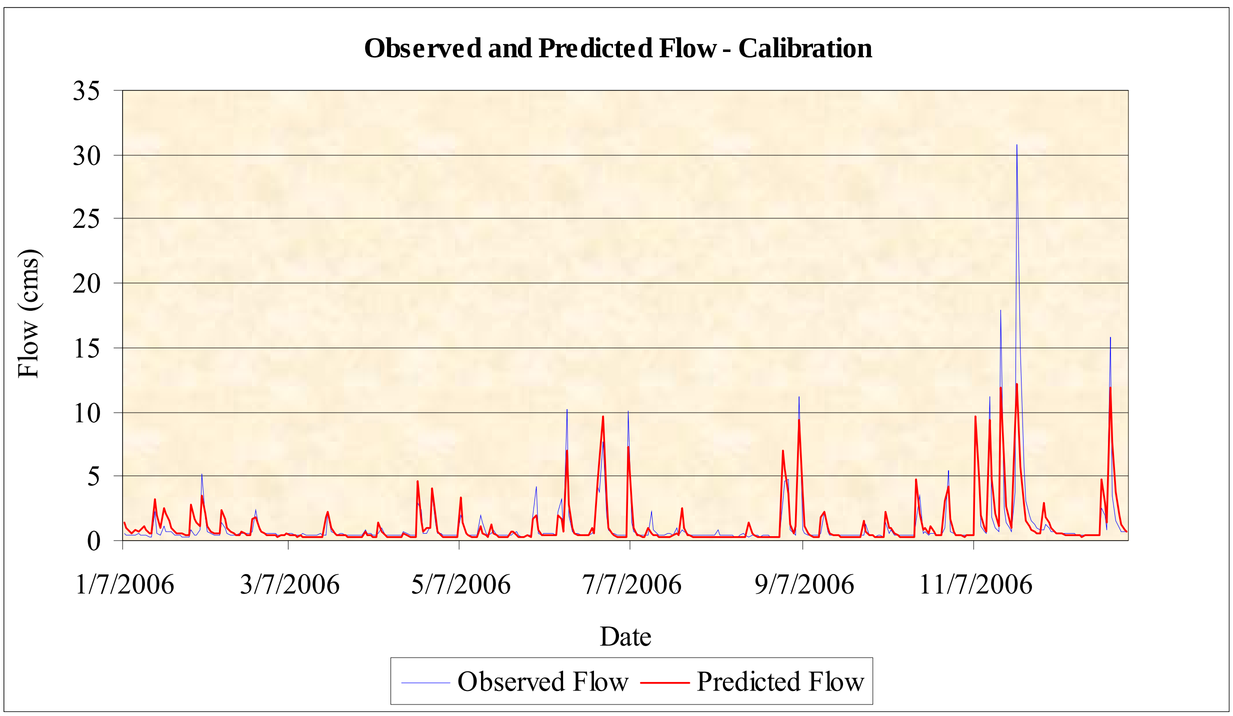

Figure ELL- 1. Time series plots of average daily-observed flows and WARMF flows for the calibration period at Ellerbe Creek USGS gaging station.

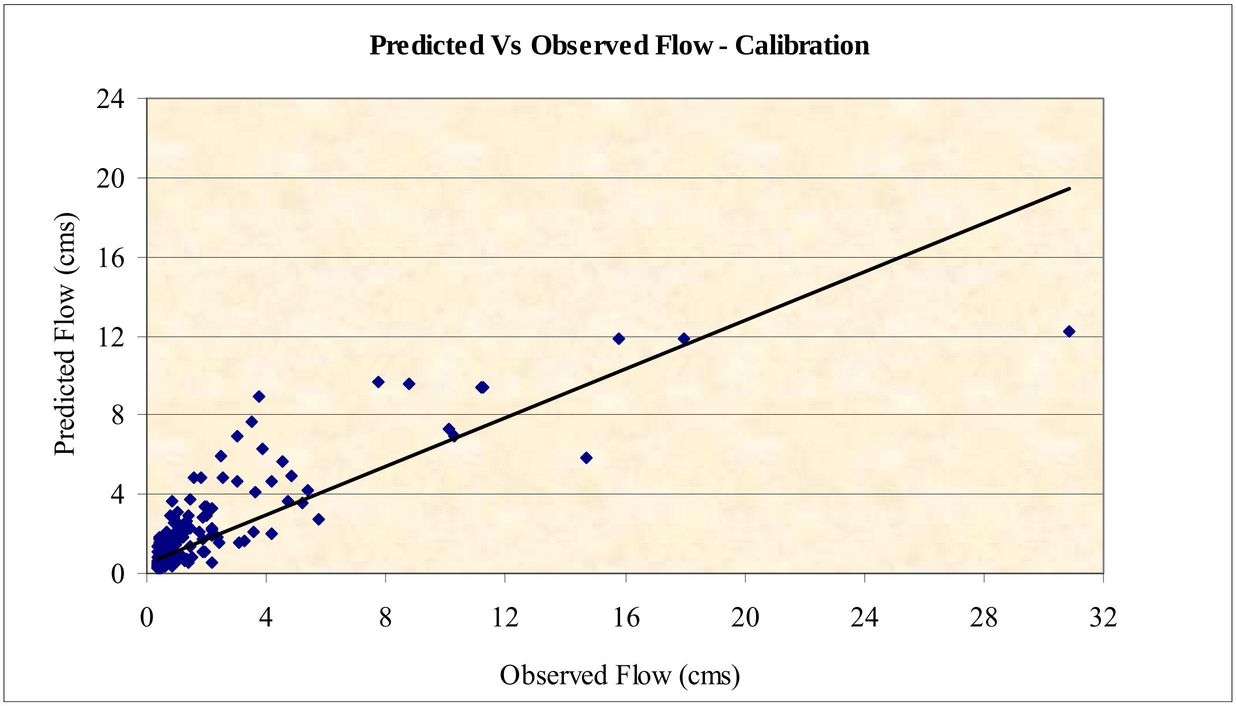

Figure ELL- 2. Scatter plot of daily-observed flows and simulated flows for the calibration period at Ellerbe Creek USGS gaging station.

Table ELL-1 provides the error statistics for daily and seasonal flow volume. The total volume and seasonal volume errors satisfy the criteria set during the calibration process. The total stream flow error was only two percent. The model slightly underpredicted high flows. In general, WARMF overestimated flow during winter months and slightly underestimated flow during the fall and spring seasons. WARMF simulated low flows very well with a very small error value of only 1.2%.

Table ELL- 1. Flow volume statistics for WARMF versus observed data for the calibration period at Ellerbe Creek USGS station [1]

	Predicted (m^3)	Observed (m^3)	Error	Recommended Criteria
Total Predicted In-stream Flow:	36,852,705	36,134,854	2.0%	*10%*
Total of highest 10% flows:	18,547,051	19,925,511	-6.9%	*15%*
Total of lowest 50% flows:	5,241,641	5,178,188	1.2%	*10%*
Predicted Summer Flow Volume (months 7-9):	7,095,166	6,828,461	3.9%	*30%*
Predicted Fall Flow Volume (months 10-12):	15,451,991	16,280,243	-5.1%	*30%*
Predicted Winter Flow Volume (months 1-3):	6,202,867	4,701,443	24.2%	*30%*
Predicted Spring Flow Volume (months 4-6):	8,102,681	8,283,145	-2.2%	*30%*

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

Table ELL-2 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the calibration period. For the entire calibration period, the WARMF predicted mean flows are very close to the observed mean. The mean error values show the predicted and observed flows are very close. The RMSE is much lower than the SDobs as shown by the low RMSE/SDobs ratio. The relative error, average error, and percent bias are also very small, indicating the WARMF performed very well over a range of flows in this watershed.

Table ELL- 2. Additional daily flow statistics for WARMF versus observed data for the calibration period at Ellerbe Creek USGS station 1

	Flow statistics
Relative Error (RE)	0.02
Average Error (AE)	0.03
Root Mean Square of Error (RMSE) (m^3/s)	1.42
Standard Deviation (SDobs) (m^3/s)	2.55
RMSE/SDobs	0.56
Percent Bias (PBIAS)	2.2%
R^2	0.70
Coefficient of Efficiency	0.69
Observed mean (m^3/s)	1.17
Predicted mean (m^3/s)	1.19

10.2 Water Quality Calibration

In the water quality simulation, WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to the DWQ ambient monitoring data from the Ellerbe Creek DWQ ambient monitoring station (see Figure 8 for a map of the station locations).

Total Suspended Sediment (TSS)

Figure ELL-3 illustrates the time series plot of the observed and WARMF predicted TSS at the Ellerbe Creek DWQ ambient monitoring station. The simulated TSS concentrations tracked the observed concentrations pattern throughout the calibration period, but missed large TSS concentration. A possible explanation for this could be that WARMF estimates TSS concentrations as a depth-average value while the TSS measurements are surface grab samples. Figure ELL-4 shows the seasonal distribution of observed and predicted TSS concentration at the same station. WARMF predicted the general trend and range of most observed TSS data in this watershed. The average observed TSS concentrations were comparable to the WARMF predicted concentrations.

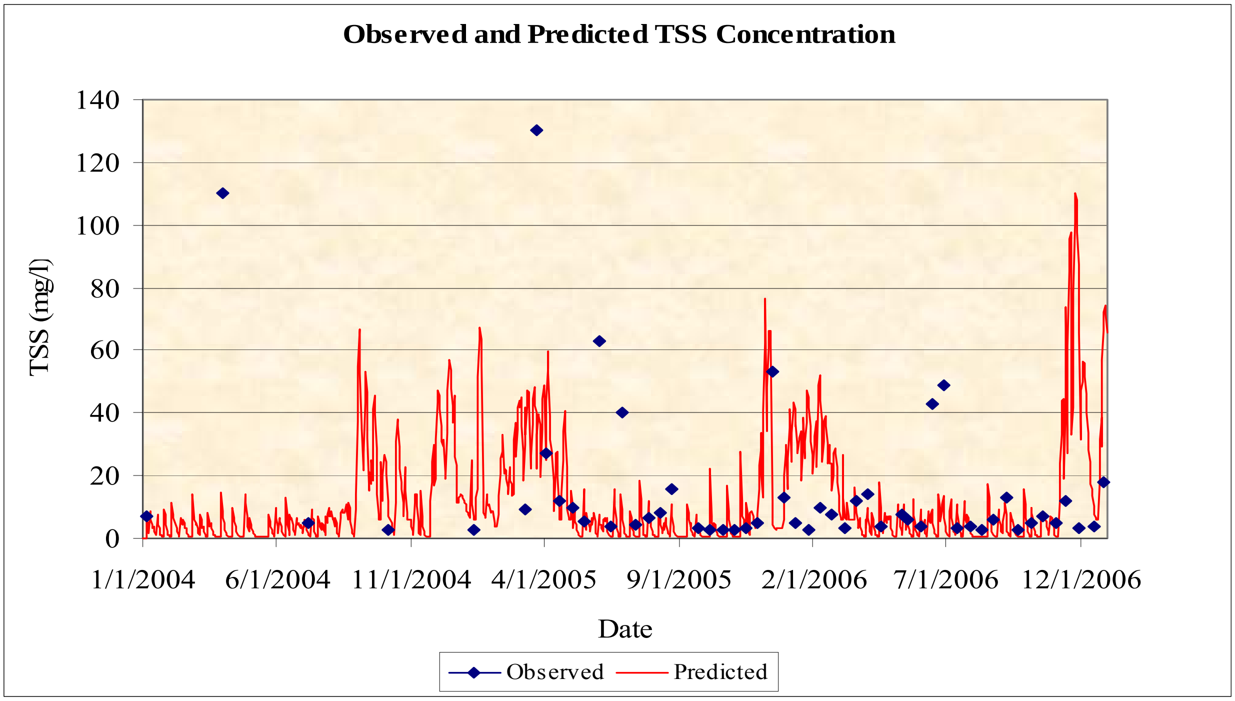

Figure ELL- 3. Time series plots of observed and simulated TSS for the calibration period at Ellerbe Creek DWQ monitoring station.

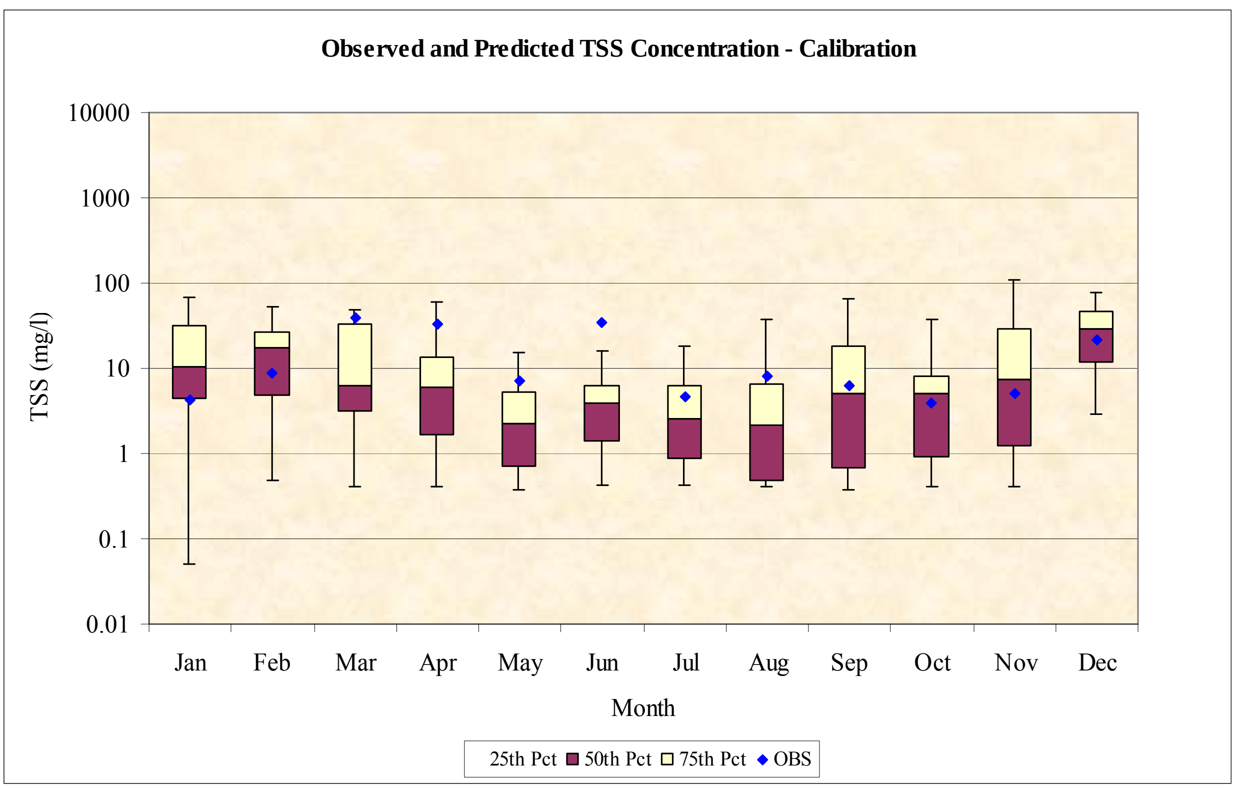

Figure ELL- 4. Seasonal distribution of observed and simulated total suspended sediment (TSS) or the calibration period at Ellerbe Creek DWQ monitoring station.

Nitrogen

Figure ELL-5 is the time series plot of TN observations and WARMF predicted concentrations at the Ellerbe Creek DWQ ambient monitoring station (J13300000) for the calibration period. Figure ELL-6 shows the seasonal distribution of TN concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations are included in Appendix C. These figures show that the WARMF predicted concentrations followed the observed pattern well. On the average, WARMF predicted nitrogen constituent concentrations were lower than the observed values. This could be because of unaccounted nonpoint source loads and underestimation of these constituents from point sources. The Ellerbe Creek watershed is a highly developed watershed and representing all sources of loading is a challenge. The seasonal plots show that the average observed ammonia and nitrate concentrations fall within the daily ranges of the predicted values throughout the calibration period. The average observed TKN concentrations were larger than the 75th percentile-predicted concentrations in all months except March and April. Overall, WARMF simulated the trend and magnitude of TN concentration fairly well. The WARMF predicted and observed TN concentrations are comparable, indicating a reasonable calibration.

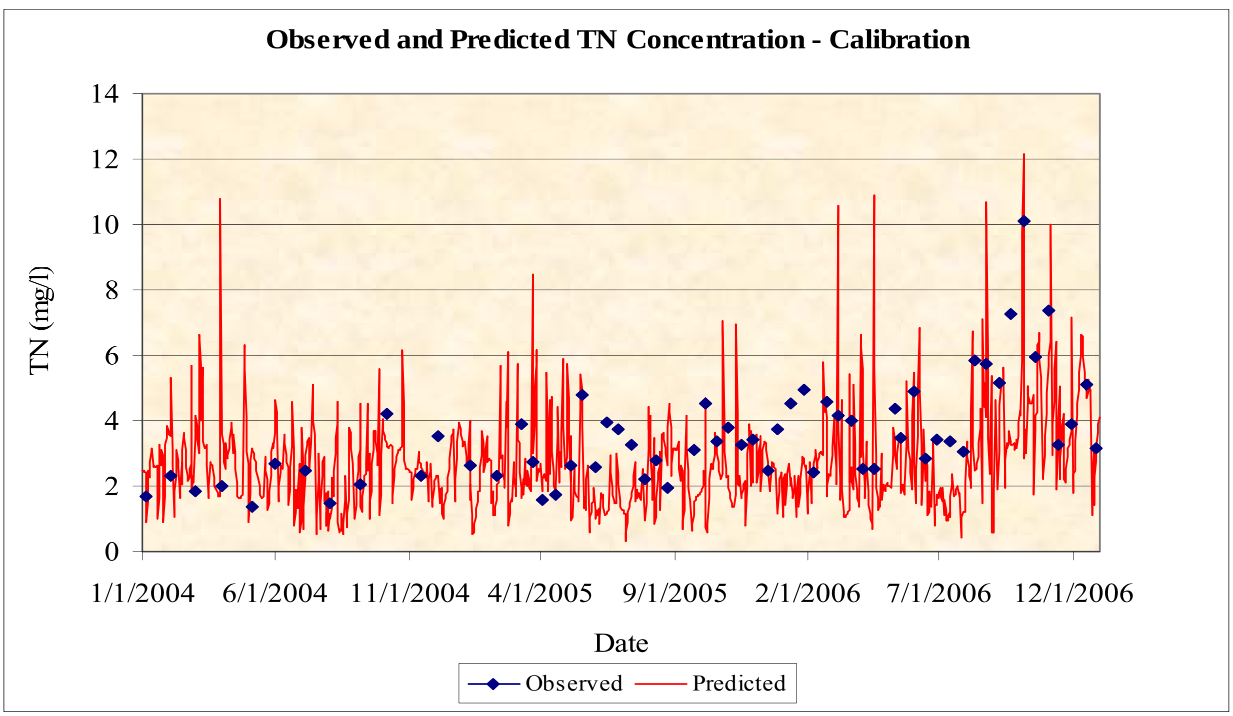

Figure ELL- 5. Time series plots of observed and simulated TN concentration for the calibration period at Ellerbe Creek DWQ monitoring station.

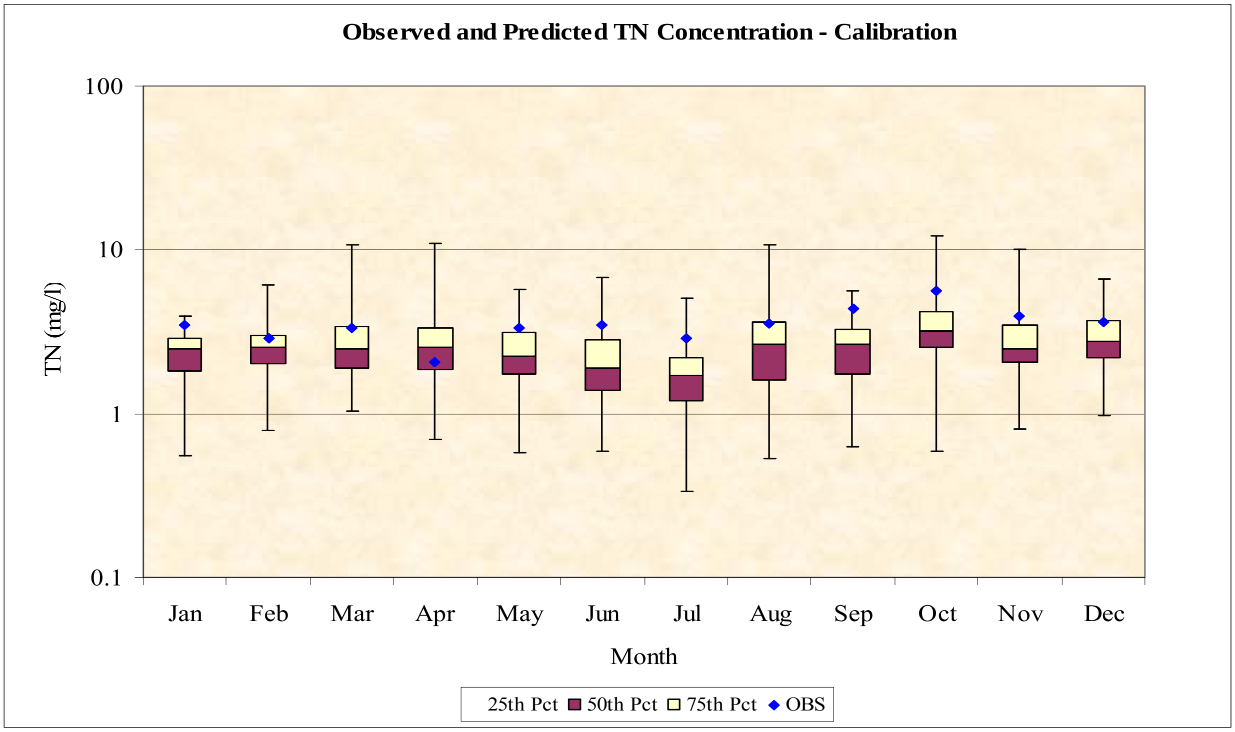

Figure ELL- 6. Seasonal distribution of observed and simulated TN concentration for the calibration period at Ellerbe Creek DWQ monitoring station.

Phosphorus

Figure ELL-7 illustrates the time series plot of the observed and simulated TP concentrations and Figure ELL-8 shows the seasonal distribution of TP. WARMF simulated TP concentrations fairly well throughout the calibration period. WARMF simulations tracked the pattern and magnitude of TP concentrations most of the time, but periodically missed some large concentrations. On the average, the WARMF predicted concentrations were slightly lower than the observed average concentration. This could be because of unaccounted nonpoint sources of TP from residential areas and underestimation of TP load from point sources. The average observed TP concentrations fall within the range of predicted values in every month during the calibration period.

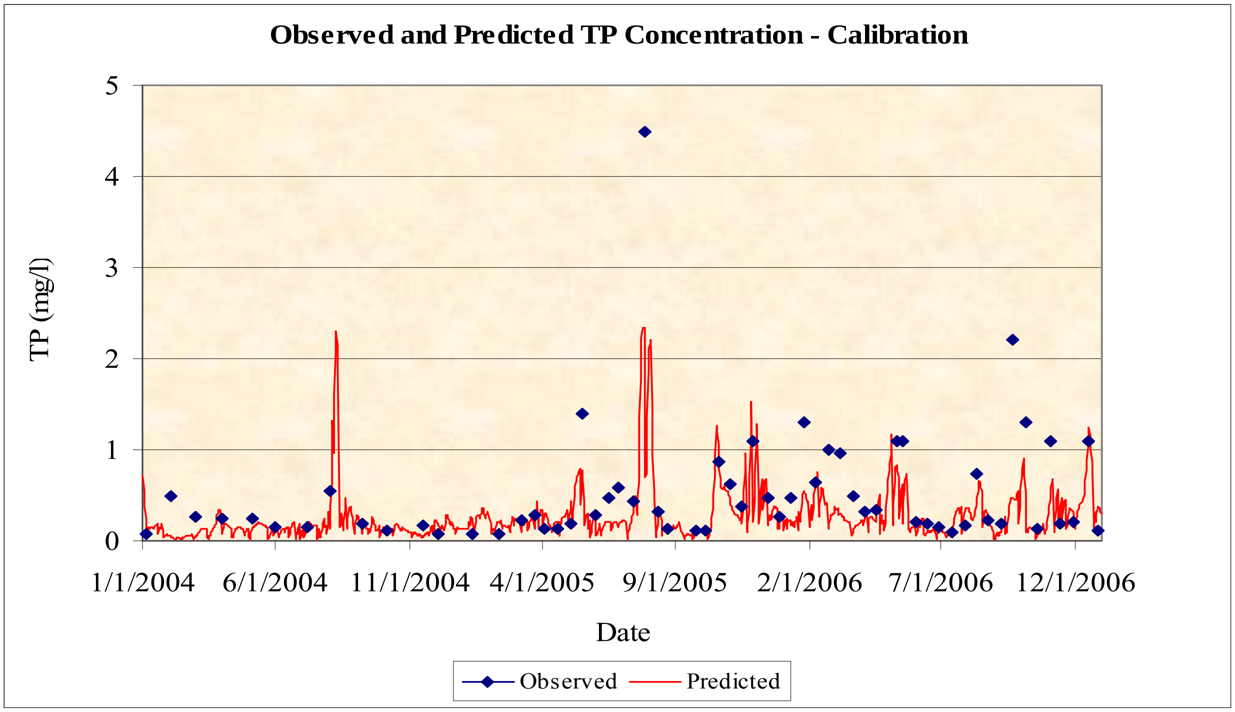

Figure ELL- 7. Time series plots of observed and simulated TP concentration for the calibration period at Ellerbe Creek DWQ monitoring station.

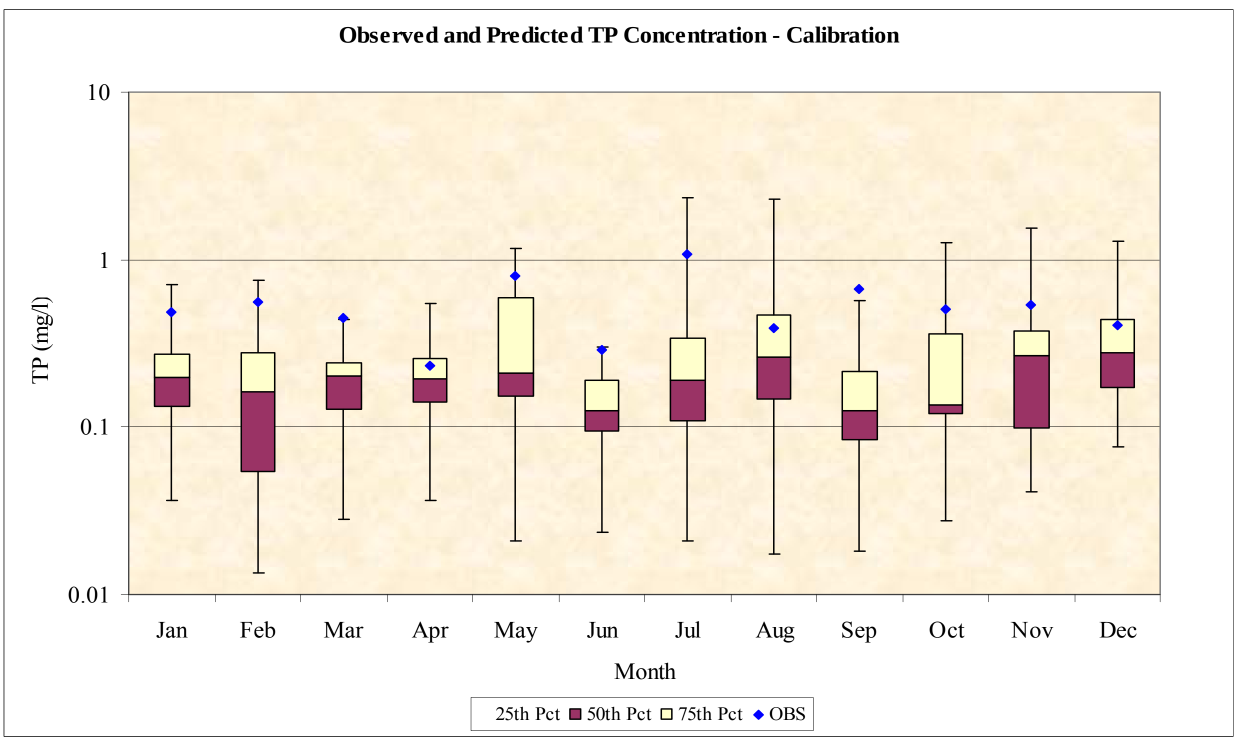

Figure ELL- 8. Seasonal distribution of observed and simulated TP concentration for the calibration period at Ellerbe Creek DWQ monitoring station.

10.3 Hydrologic Validation

Figure ELL-9 illustrates the time series plot of the average daily-observed flow and WARMF predicted flow at the Ellerbe Creek USGS gaging station (USGS 02086849) for the validation period (2007). The results of the validation runs were similar to the calibration model simulations. Overall WARMF simulates the magnitude and trend of flow fairly well in this watershed both during calibration and validation periods. It also simulated the seasonal variation of flow and tracked the general trend of flows. In general, WARMF seems to underestimate higher peaks. Figure ELL-10 is a scatter plot of observed and simulated flow at the same station. Linear regression was performed and correlation coefficient (r) calculated for average daily flow. WARMF has a relatively high R^2 value of 0.8 and CE value of 0.8 for the validation period. Both parameters are slightly higher than the values calculated during calibration. In general, the validations results show the model is calibrated very well for this watershed.

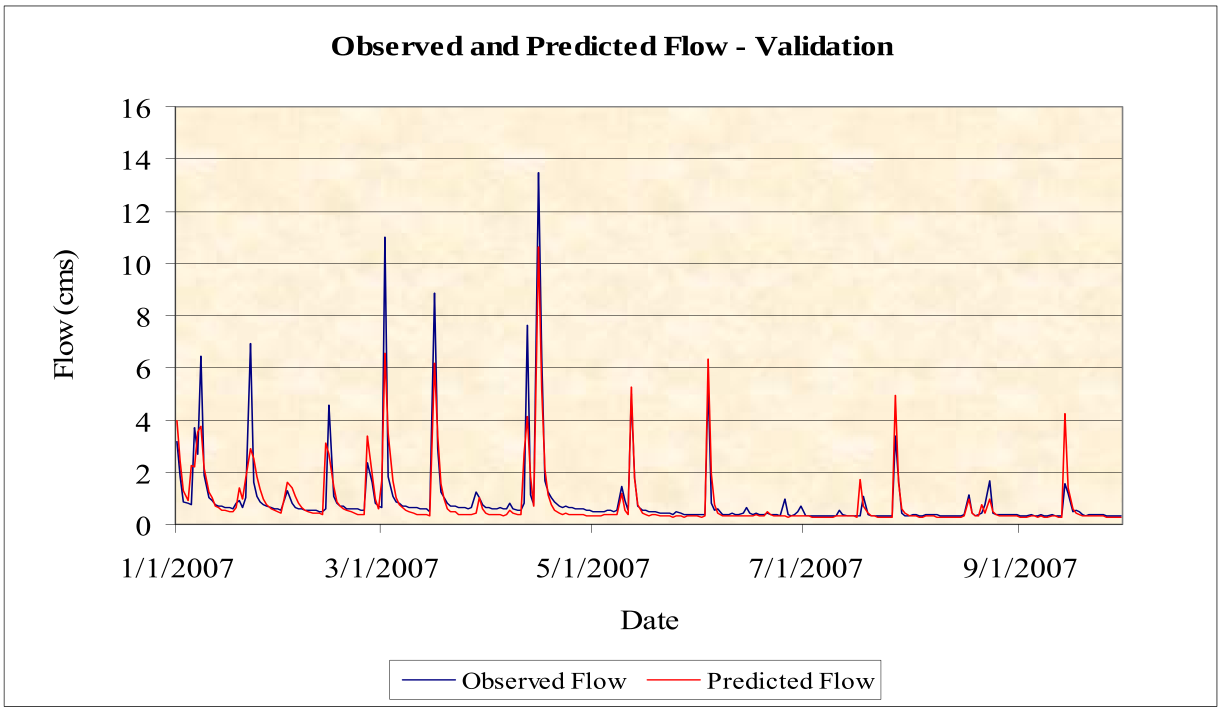

Figure ELL- 9. Time series plots of average daily-observed flows and WARMF flows for the validation period at Ellerbe Creek USGS gaging station.

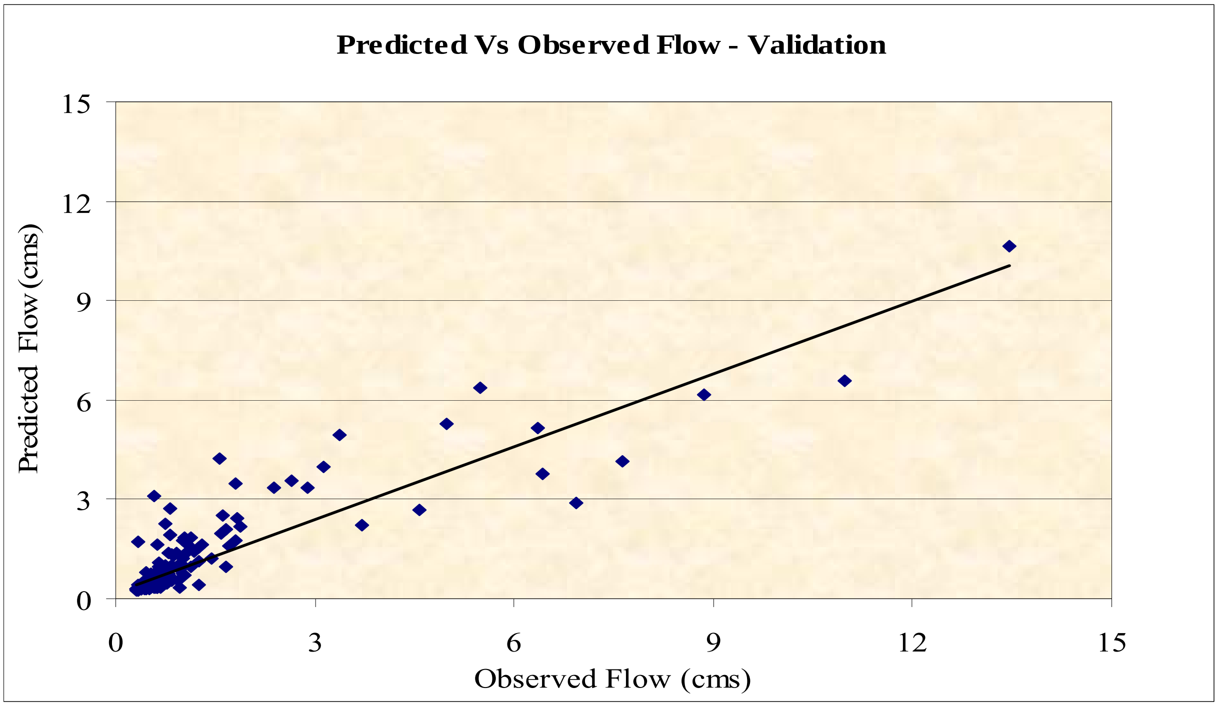

Figure ELL- 10. Scatter plot of daily-observed flows and simulated flows for the validation period at Ellerbe Creek USGS gaging station.

Table ELL-3 provides the error statistics for daily and seasonal flow volume. The total volume and seasonal volume errors satisfy the criteria during the validation period. The error for the total lowest 50% flow was very close to the 10% criteria. The total stream flow error for the validation period was -7.6% which is slightly higher than the error during the calibration period. WARMF slightly underestimated flow throughout the validation period except for the summer months. This could be because the validation year (2007) was an extreme drought year. The total summer flow volume was overestimated by 2.4 percent.

Table ELL- 3. Flow volume statistics for WARMF versus observed data for the validation period at Ellerbe Creek USGS station [1]

	Predicted (m^3)	**Observed (m^3)**	**Error**	**Recommended Criteria**
Total Predicted In-stream Flow:	19,652,210	21,260,398	-7.6%	*10%*
Total of highest 10% flows:	8,973,006	9,713,381	-7.6%	*15%*
Total of lowest 50% flows:	3,775,781	4,219,808	-10.5%	*10%*
Predicted Summer Flow Volume (months 7-9):	3,784,155	3,677,051	2.4%	*30%*
Predicted Winter Flow Volume (months 1-3):	9,522,766	9,977,425	-4.6%	*30%*
Predicted Spring Flow Volume (months 4-6):	6,362,522	7,552,136	-15.8%	*30%*

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

Table ELL-4 provides additional descriptive statistics and error measures for the simulated and observed daily flows during the validation period. The RMSE is much lower than the SDobs as shown by the small RMSE/SDobs ratio. The relative error, average error, and percent bias are also very small, confirming the calibration results.

Table ELL- 4. Additional daily flow statistics for WARMF versus observed data for the calibration period at Ellerbe Creek USGS station

	Flow statistics
Relative Error (RE)	-0.08
Average Error (AE) (m^3/s)	-0.07
Root Mean Square of Error (RMSE) (m^3/s)	0.67
Standard Deviation (SDobs) (m^3/s)	1.48
RMSE/SDobs	0.45
Percent Bias (PBIAS)	-7.6%
R^2	0.80
Coefficient of Efficiency	0.80
Observed mean (m^3/s)	1.17
Predicted mean (m^3/s)	1.19

10.4 Water Quality Validation

In the water quality validation, WARMF simulated TSS, ammonia, nitrate, TKN, TN, and TP concentrations were compared to the DWQ ambient monitoring data from the Ellerbe Creek DWQ ambient monitoring station (J13300000) in 2007 (see Figure 8 for a map of the station locations). The extreme drought in 2007 and the short validation period (nine months) were the limitations considered in interpretation of the validation results.

Total Suspended Sediment (TSS)

Figure ELL-11 illustrates the time series plot of the observed and WARMF predicted TSS concentrations at the Ellerbe Creek DWQ ambient monitoring station. The simulated TSS concentrations tracked the observed concentrations pattern throughout the validation period, but did not closely match the magnitude. A major reason for this could be that the observed TSS concentrations are measured as surface grab samples and as a result, TSS measurements after a storm event may be higher than the depth average values estimated by the model. Figure ELL-12 shows the seasonal distribution of observed and predicted TSS concentration at the same station. WARMF predicted TSS concentrations were substantially higher than the observed concentration from January to March and lower from May to August.

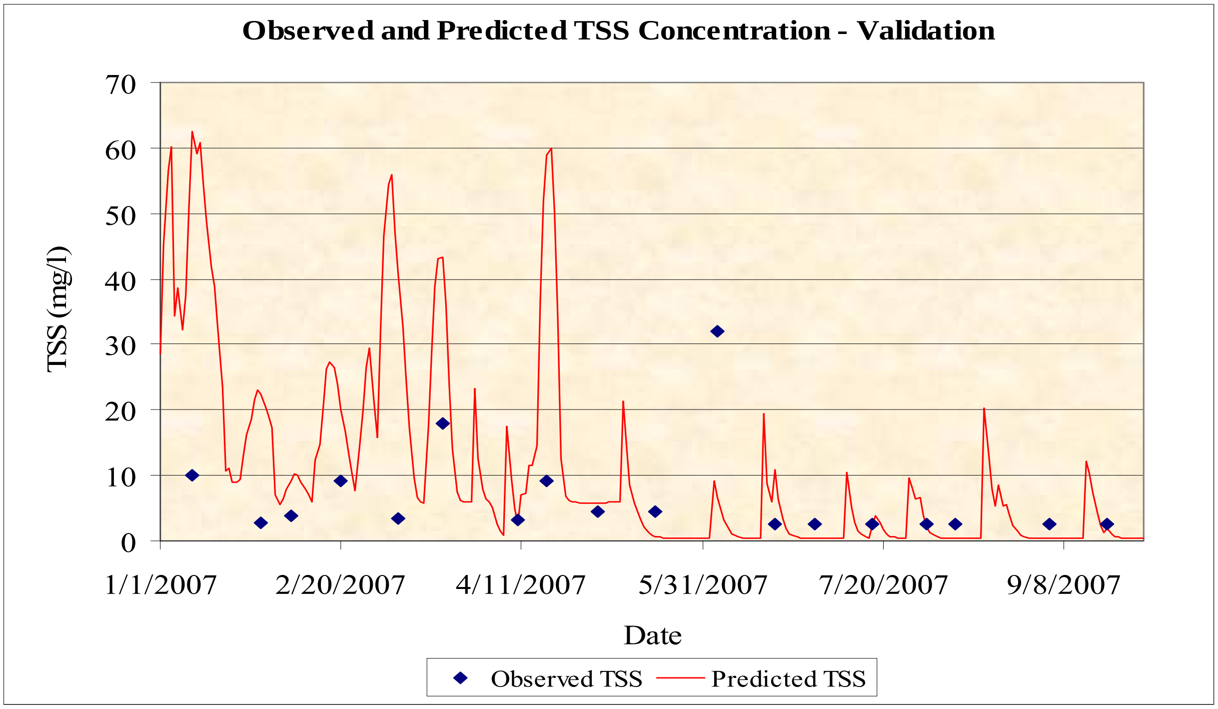

Figure ELL- 11. Time series plots of observed and simulated total suspended sediment for the validation period at Ellerbe Creek DWQ monitoring station.

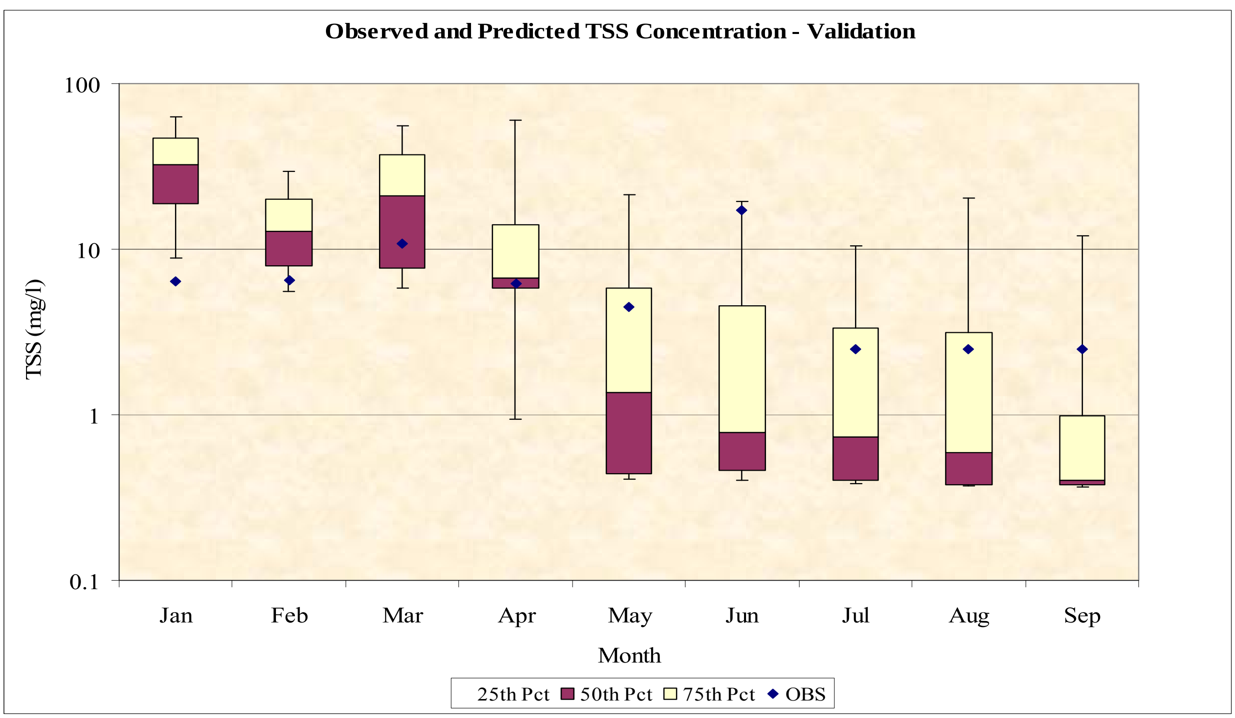

Figure ELL- 12. Seasonal distribution of observed and simulated total suspended sediment (TSS) for the validation period at Ellerbe Creek USGS gaging station.

Nitrogen

Figure ELL-13 is the time series plot of TN observations and WARMF predicted concentrations at the Ellerbe Creek DWQ ambient monitoring station (J13300000) for the validation period. Figure ELL-14 shows the seasonal distribution of TN concentrations at the same station. Time series and seasonal plots of ammonia, nitrate, and TKN observations and WARMF predicted concentrations are included in Appendix C. These figures show that the validation results were mostly similar to the calibration results. On the average, WARMF predicted nitrogen constituent concentrations were lower than the observed values. This could be because of unaccounted nonpoint source loads and underestimation of these constituents from point sources. In addition, the extreme drought in 2007 and the resulting low flows may have resulted in big differences between observed and predicted concentrations. The seasonal plots show that the average observed ammonia and nitrate concentrations fall within the ranges of the predicted values throughout the calibration period. The averaged observed TKN concentrations were larger than the 75 percentile predicted concentrations in all months during the validation year. Overall, WARMF simulated the trend and magnitude of TN concentration fairly well. The WARMF predicted and the observed TN concentrations are comparable showing a fairly reasonable calibration. WARMF performed well in simulating TN concentrations in this watershed.

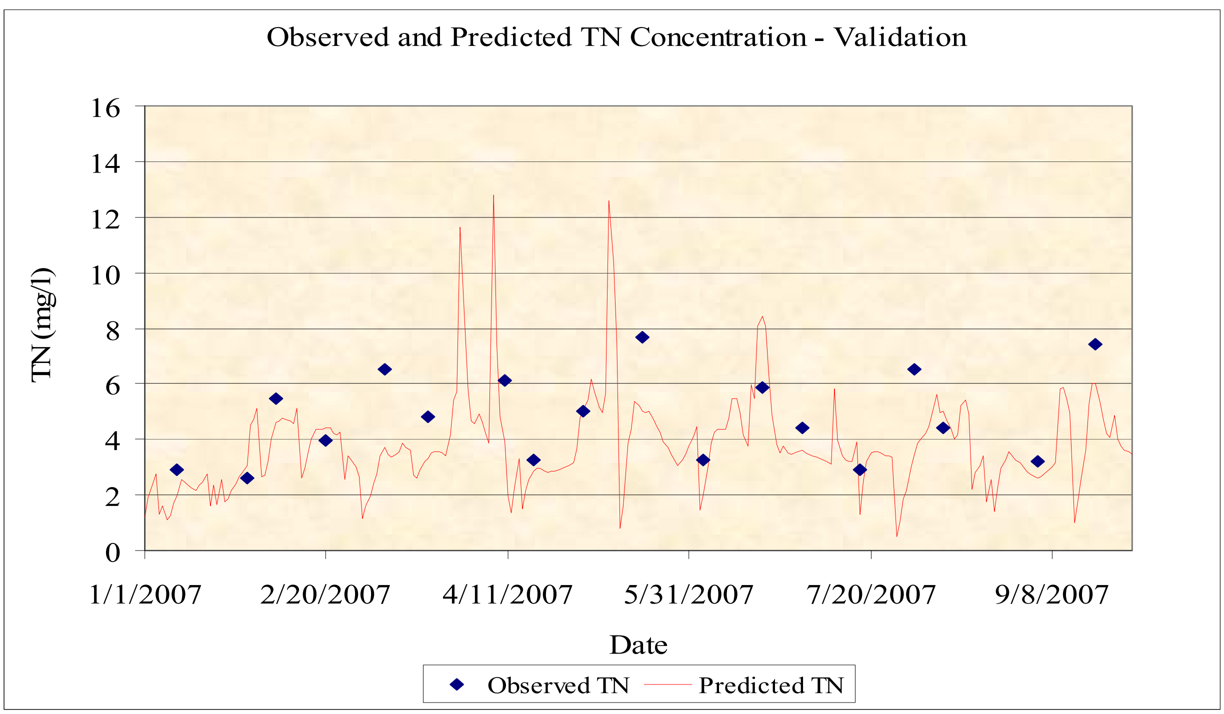

Figure ELL- 13. Time series plots of observed and simulated TN concentrations for the validation period at Ellerbe Creek DWQ monitoring station.

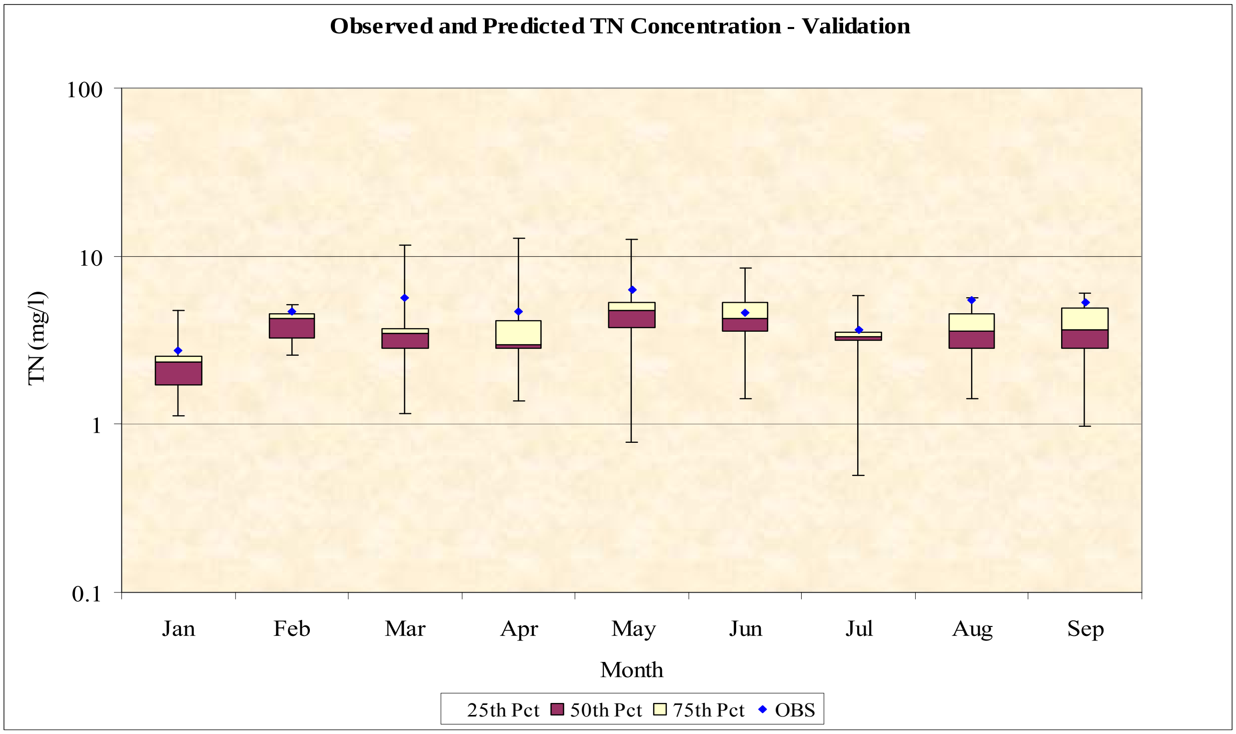

Figure ELL- 14. Seasonal distribution of observed and simulated TN concentration for the validation period at Ellerbe Creek DWQ monitoring station.

<u>Phosphorus</u>

Figure ELL-15 illustrates the time series plot of the observed and simulated TP concentrations and Figure ELL-16 shows the seasonal distribution of TP. The validation results were mostly similar to the calibration results. WARMF simulated average TP concentration fairly well, but underestimated large TP concentrations. This could be because of unaccounted nonpoint sources of TP, underestimation of TP concentration from point sources, and the extreme drought in 2007. Overall, WARMF performed well in simulating TP concentrations in this watershed.

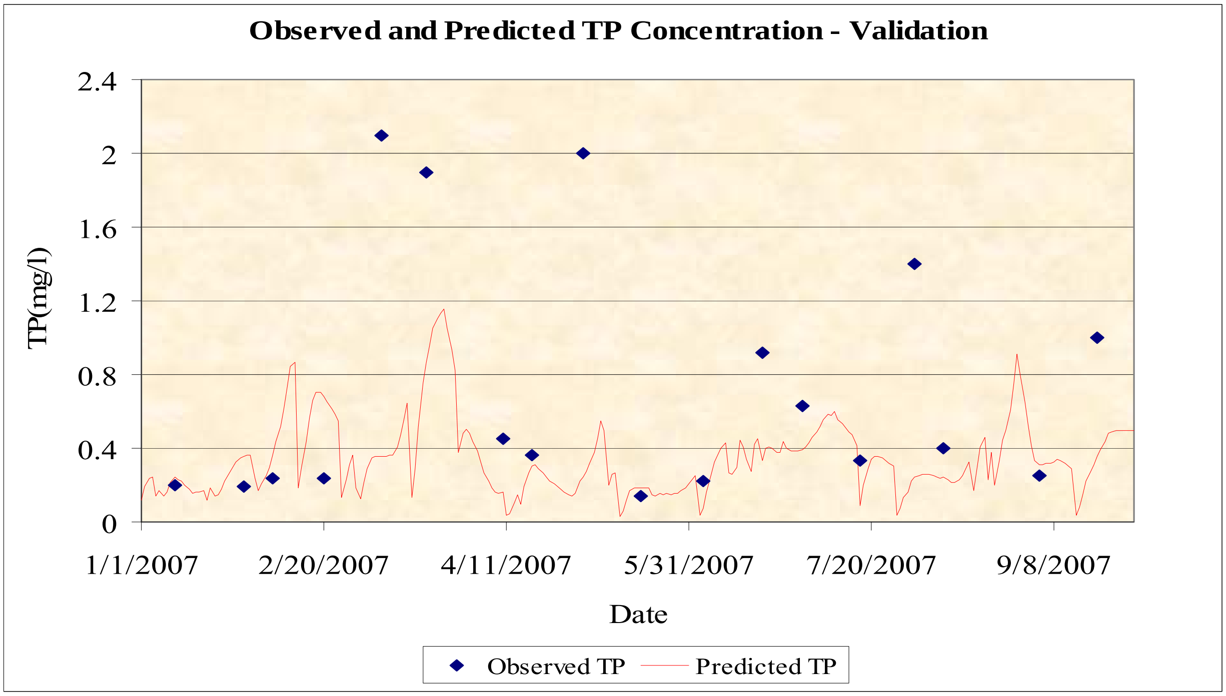

Figure ELL- 15. Time series plots of observed and simulated TP concentrations for the validation period at Ellerbe Creek DWQ monitoring station.

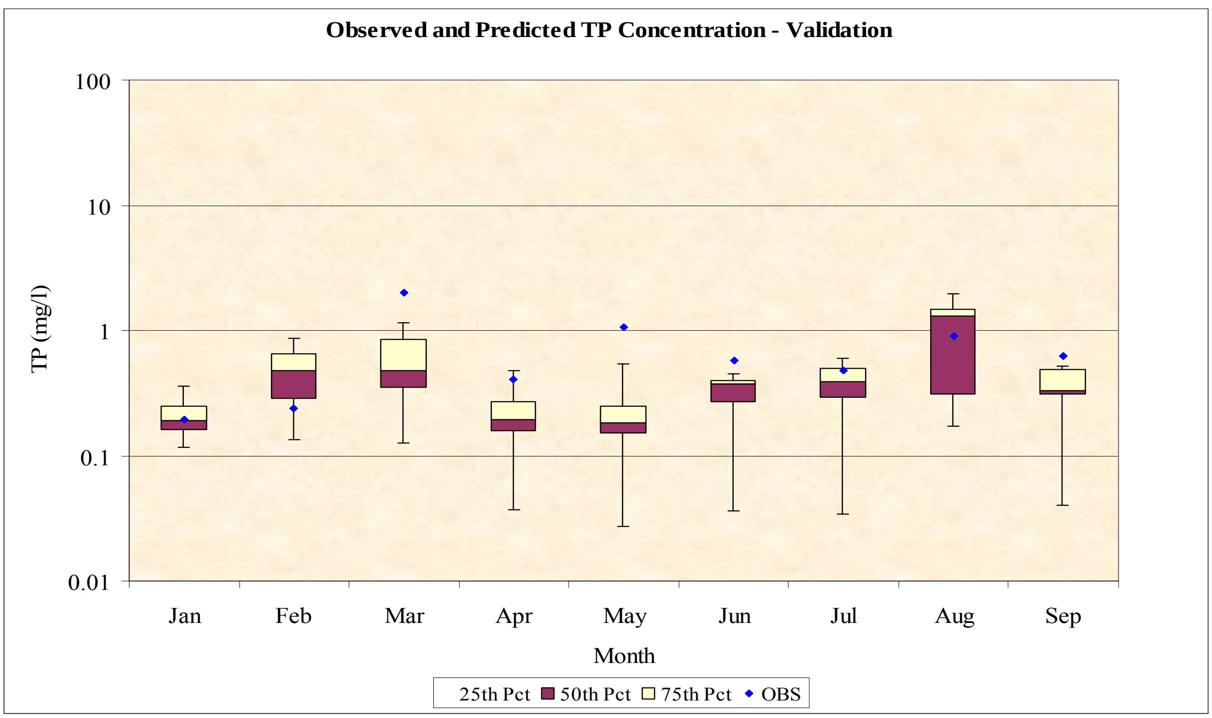

Figure ELL- 16. Seasonal distribution of observed and simulated TP concentration for the validation period at Ellerbe Creek DWQ monitoring station.

11.0 Nutrient Loading

Sections 11.1 to 11.5 present nutrient source loading estimates from nonpoint and point source categories for each subwatershed. The point source category represents loadings directly into the stream and includes WWTPs, WTPs, WRFs, and SSOs. Portions of sand filter loading are included in both the point source and septic categories (as discussed above in Section 3.9). Although NCDOT and certain developed lands are considered point sources in TMDL development, they are represented below in separate categories.

The loading results presented in sections 11.1 to 11.5 are based on the regional loading values generated by WARMF. Regional load is loading to the local water bodies from land and point sources within the subwatershed and is presented as an average daily load over the model simulation period. Regional load does not take into account in-stream processes and therefore, is not the load that is delivered to Falls Lake.

It should be noted that, as presented below, atmospheric deposition refers only to the portion of atmospheric deposition that is deposited directly on the surface of the reservoirs and represents only a fraction of the total atmospheric deposition. WARMF does not generate separate loading estimates for atmospheric deposition on land surfaces.

Section 11.6 provides a comparison of the total nutrient source contributions from all of the calibrated subwatersheds for each land cover and point source category. This was calculated as the sum of the average daily load presented in Sections 11.1 to 11.5 from each calibrated subwatershed.

Finally, Section 11.7 presents a subwatershed comparison of the total average daily load of TN and TP delivered to Falls Lake from the calibrated subwatersheds. These loading results are based on the source contribution values generated by the WARMF model. Source contribution traces the pollutant from a given location in the water back to its sources. It reflects not only everything upstream, but also any attenuation processes that occur in-stream. It is the most direct measurement of the load leaving a watershed and, in this case, can be considered an estimate of delivered load to Falls Lake from each subwatershed.

11.1 Knap of Reeds Creek Subwatershed

Figures 12 and 13 summarize TN and TP load distributions, respectively, for the Knap of Reeds Creek subwatershed. Table 11 shows the average loading (kg/d) by land cover categories. Knap of Reeds Creek subwatershed land cover is comprised primarily of forested (about 66%) and agricultural lands (about 16%).

Total Nitrogen (TN)

Forest, agriculture, and point sources are significant sources of total nitrogen in Knap of Reeds Creek, contributing 35%, 21%, and 28% of the TN load, respectively, in the subwatershed. Developed land, shrub and grassland, and septic systems each contribute about 4% of the TN load. All other sources contribute one percent or less.

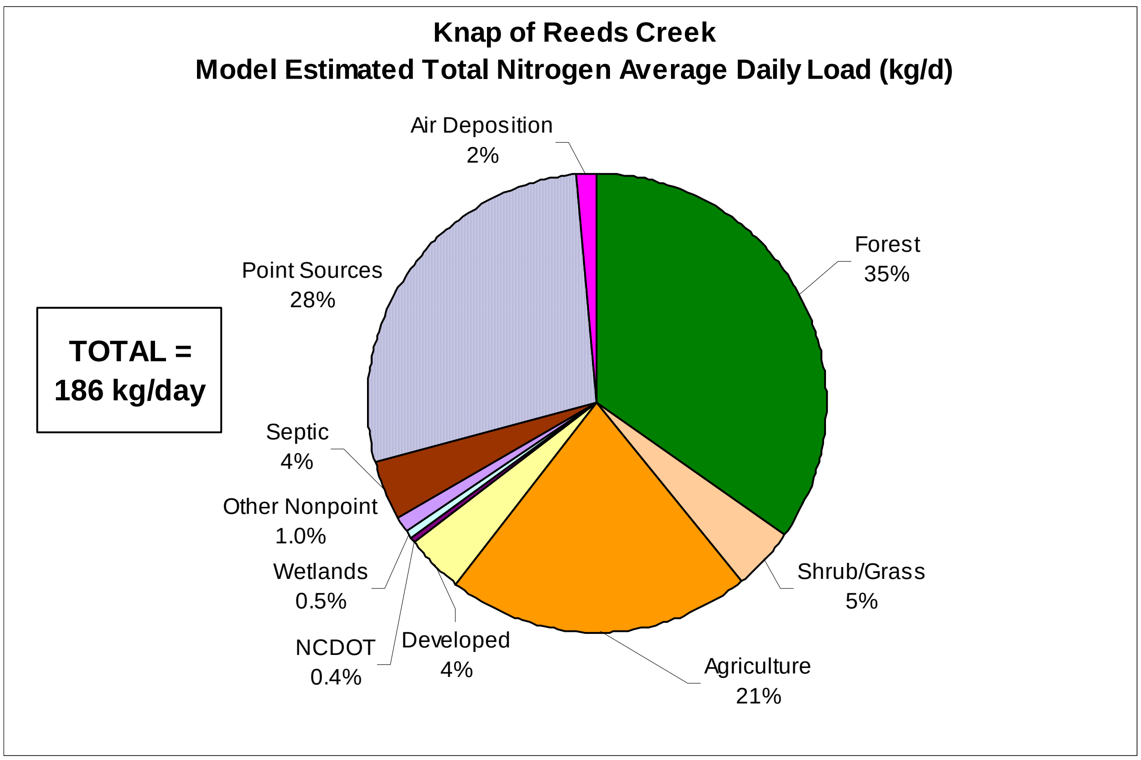

Figure 12. Summary of WARMF simulated TN loading in Knap of Reeds Creek subwatershed.

Total Phosphorus (TP)

Point sources contribute almost 70% of the TP load in the subwatershed. The only other major source of total phosphorus in the Knap of Reeds Creek subwatershed is agriculture, contributing 24.5% of the total load.

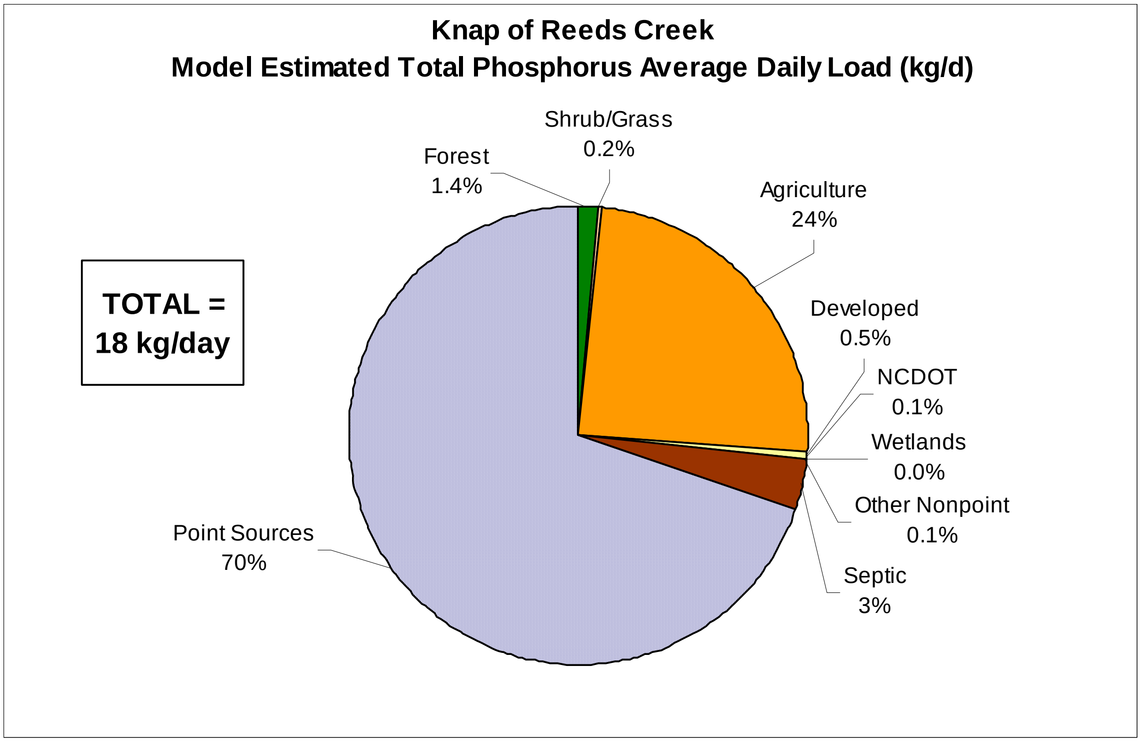

Figure 13. Summary of WARMF simulated TP loading in Knap of Reeds Creek subwatershed.

Table 11. Summary of WARMF simulated TN and TP loading in Knap of Reeds Creek subwatershed.

	TN kg/d	TP kg/d
Forest	64.5	0.25
Shrub/Grassland	8.5	0.04
Agriculture	39.7	4.45
Developed	7.7	0.08
NCDOT	0.8	0.02
Wetlands	1.0	0.001
Other Nonpoint Sources (barren land, water, general nonpoint)	1.9	0.01
Septic	7.7	0.63
Point Sources	51.6	12.70
Air Deposition	2.8	NA

11.2 Flat River Subwatershed

Figures 14 and 15 summarize TN and TP load distributions, respectively, for the Flat River subwatershed. Table 12 shows the average loading (kg/d) by land cover categories. The Flat River subwatershed is primarily comprised of forested and agricultural lands (58% and 27%, respectively).

Total Nitrogen (TN)

Agricultural lands are the major sources of TN loads in the Flat River subwatershed, contributing approximately 57% of the TN load. Forested lands and septic systems also contribute 13 to 16% of TN load to the Flat River. Loadings from shrub/grassland and developed lands contribute approximately 4 to 6% to the Flat River. The percentage of TN loading from point sources was less than 0.02%.

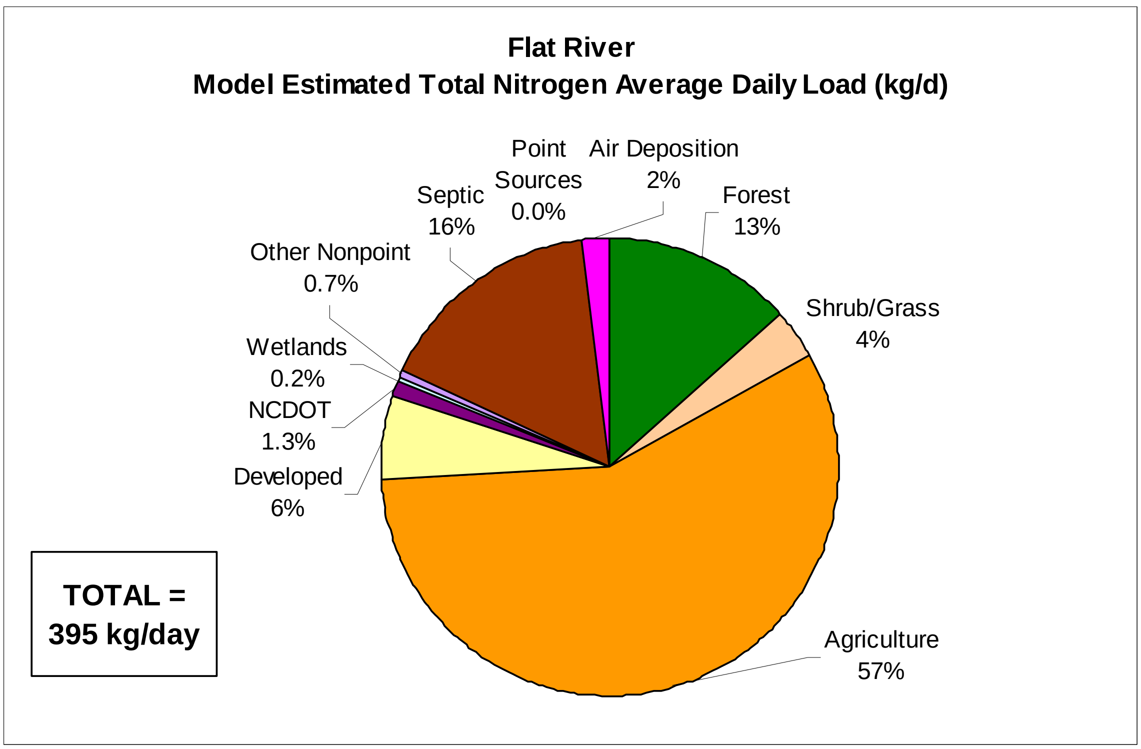

Figure 14. Summary of WARMF simulated TN loading in Flat River subwatershed.

Total Phosphorus (TP)

As with TN, agricultural lands represented the major source of TP loads in the Flat River subwatershed, contributing approximately 94% of the average daily TP load. As compared to the other nonpoint sources, loadings from the septic systems seem comparatively higher for TP. Septic systems contribute approximately 5% of the average daily load in the Flat River subwatershed.

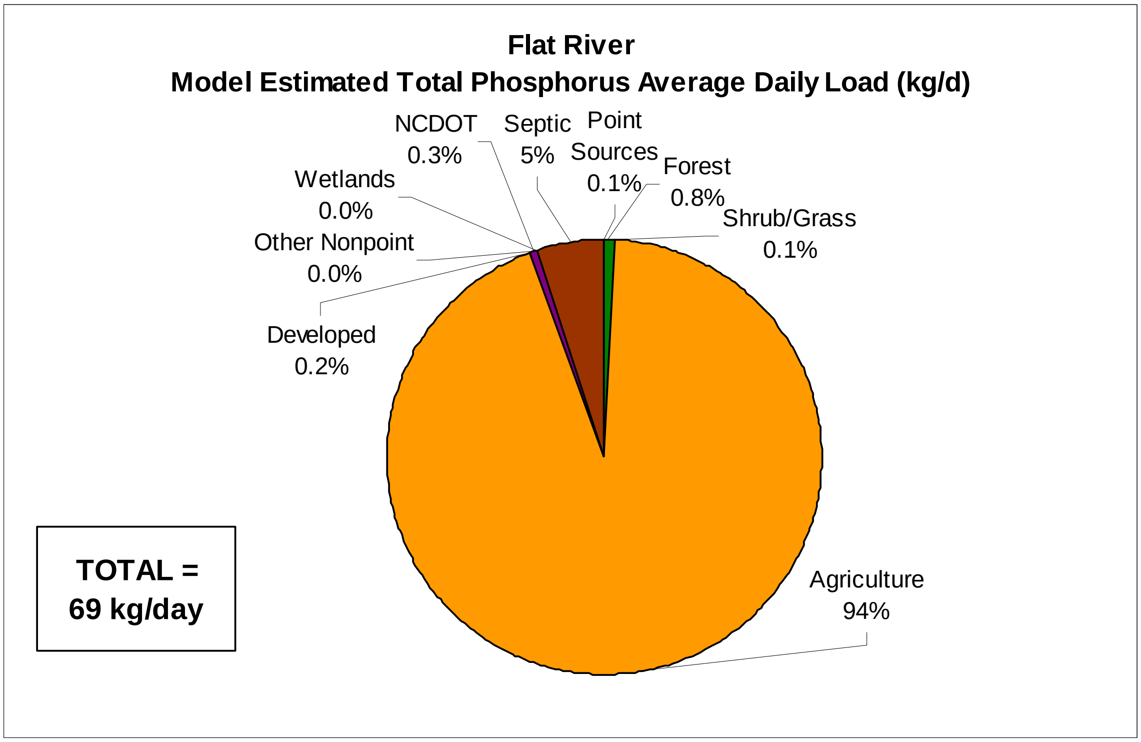

Figure 15. Summary of WARMF simulated TP loading in Flat River subwatershed.

Table 12. Summary of WARMF simulated TN and TP loading in Flat River subwatershed.

	TN (kg/d)	TP (kg/d)
Forest	52.5	0.54
Shrub/Grassland	15.0	0.04
Agriculture	225.3	64.70
Developed	22.7	0.12
NCDOT	5.0	0.21
Wetlands	0.7	0.01
Other Nonpoint Sources (barren land, water, general nonpoint)	2.8	0.01
Septic	63.1	3.47
Point Sources	0.1	0.06
Air Deposition	7.8	NA

11.3 Little River Subwatershed

Figures 16 and 17 summarize TN and TP percent load distributions, respectively, for the Little River subwatershed. Table 13 shows the average loading (kg/d) by land cover categories.

Total Nitrogen (TN)

Agricultural land (pasture and cropland) is a significant source of nutrients in the Little River subwatershed, contributing 47% of the TN load in the subwatershed. Septic systems, forested land, developed land, other nonpoint sources, and air deposition contribute 23%, 18%, 4%, 3%, and 2% of the TN load, respectively. All other sources contribute one percent or less.

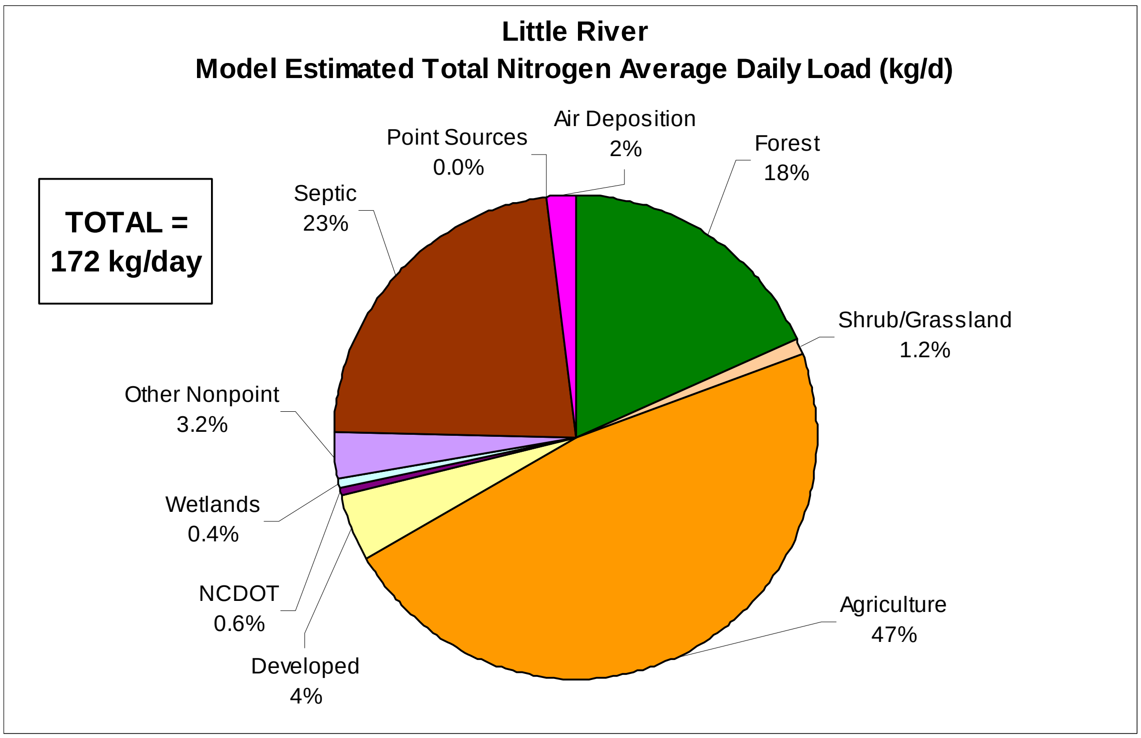

Figure 16. Summary of WARMF simulated TN loading in Little River subwatershed.

Total Phosphorus (TP)

Agricultural land (pasture and cropland) contributes 83% of the TP load in the Little River subwatershed. Septic systems, other nonpoint sources, and forestland contribute 12%, 2%, and 2.4% of the TP load, respectively. NCDOT land and developed land contribute 1%, and 0.4% of the TP load, respectively. All the other sources contribute less than 0.3% of the load.

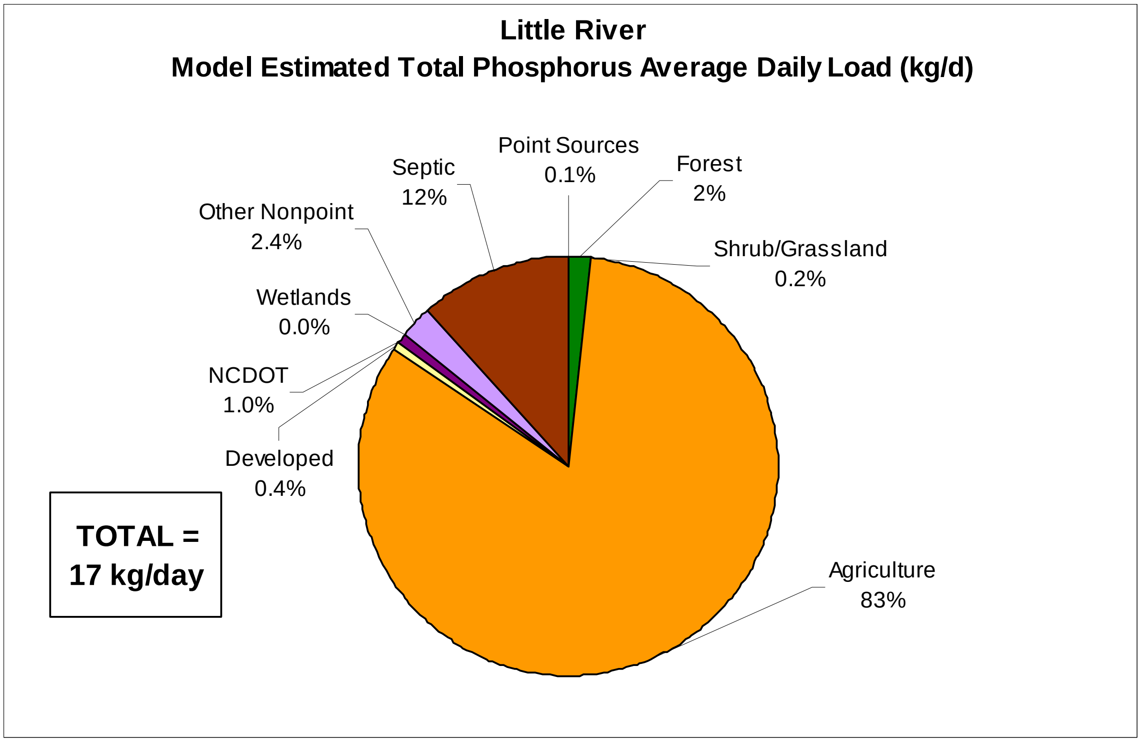

Figure 17. Summary of WARMF simulated TP loading in Little River subwatershed.

Table 13. Summary of WARMF simulated TP and TN loading in Little River subwatershed.

	TN (kg/d)	TP (kg/d)
Forest	31.4	0.27
Shrub/Grassland	2.0	0.03
Agriculture	81.4	14.2
Developed	7.7	0.06
NCDOT	1.0	0.18
Wetlands	0.7	0.01
Other Nonpoint Sources (barren land, water, general nonpoint)	5.4	0.42
Septic	39.2	1.99
Point Sources	0.02	0.01
Air Deposition	3.3	NA

11.4 Eno River Subwatershed

Figures 18 and 19 summarize TN and TP percent load distributions, respectively, for the Eno River subwatershed. Table 14 shows the average loading (kg/d) by land cover categories. The Eno River subwatershed is primarily comprised of forested, agricultural, and developed lands (58%, 16%, and 17%, respectively).

Total Nitrogen (TN)

Septic systems are the highest source of total nitrogen in the Eno River subwatershed, contributing 28% of the total load of TN in the subwatershed. Forest, point sources, agriculture, and developed land contribute 20%, 18%, 17%, and 14% of the TN load, respectively. All other sources contribute one percent or less. The relatively high loading from septic systems reflects the inclusion of sand filter loadings with septic systems.

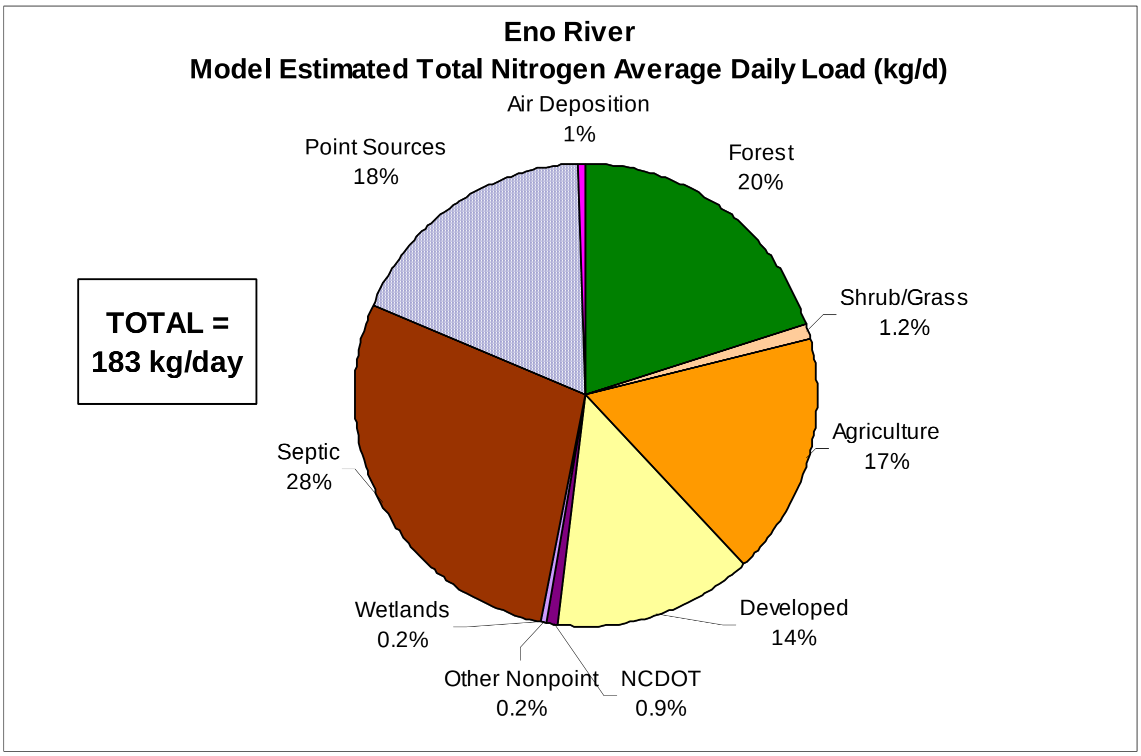

Figure 18. Summary of WARMF simulated TN loading in Eno River subwatershed.

Total Phosphorus (TP)

Agricultural land (cropland and pasture land) contributes the majority of the TP load in the Eno River subwatershed at 61%. The only other notable sources of TP in the Eno River subwatershed are point sources at 21% and septic systems at 12%.

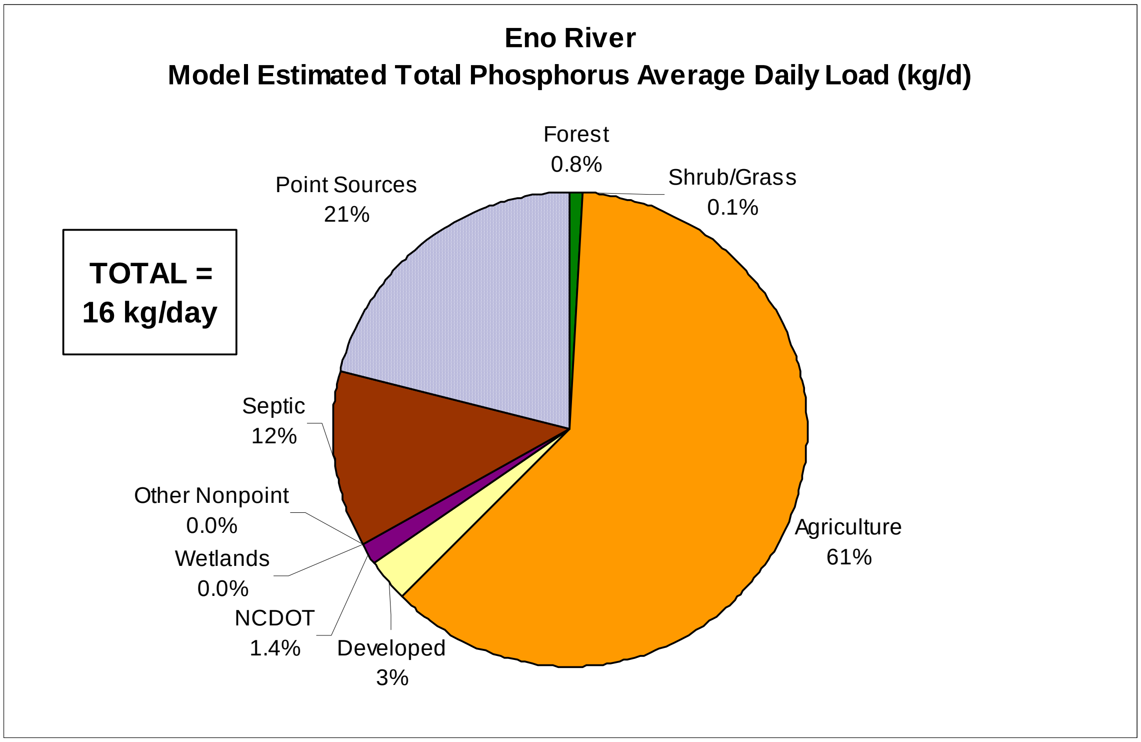

Figure 19. Summary of WARMF simulated TP loading in Eno River subwatershed.

Table 14. Summary of WARMF simulated TN and TP loading in Eno River subwatershed.

	TN kg/d	**TP kg/d**
Forest	36.5	0.13
Shrub/Grassland	2.3	0.02
Agriculture	30.7	10.12
Developed	25.4	0.52
NCDOT	1.6	0.24
Wetlands	0.4	0.001
Other Nonpoint Sources (barren land, water, general nonpoint)	0.3	0.001
Septic	51.7	1.98
Point Sources	33.1	3.46
Air Deposition	1.3	NA

11.5 Ellerbe Creek Subwatershed

Figures 20 and 21 summarize TN and TP percent load distributions, respectively, for the Ellerbe Creek subwatershed. Table 15 shows the average loading (kg/d) by land cover categories.

Total Nitrogen (TN)

Point sources are significant sources of nutrients in Ellerbe Creek subwatershed. They contribute 53% of the TN load in the subwatershed. Developed land, forested land, septic systems, and agricultural land contribute 33%, 5%, 4%, and 2% of the TN load, respectively. Loading from septic systems include load from sand filters. All other sources contribute one percent or less.

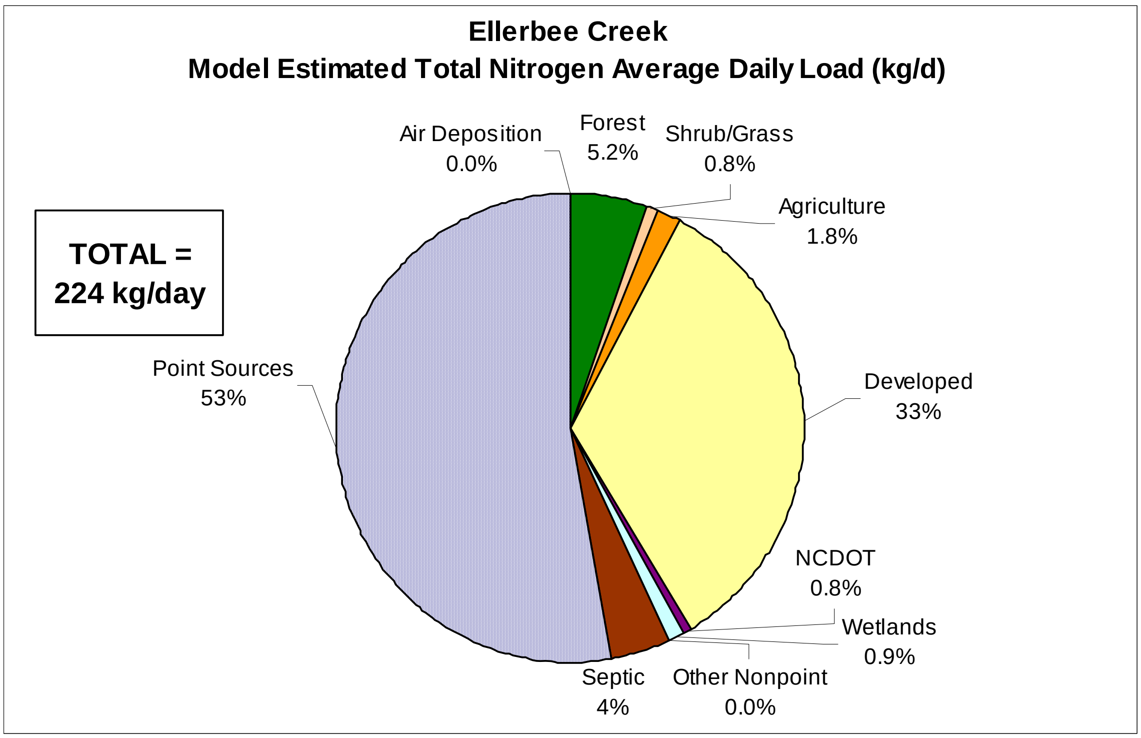

Figure 20. Summary of WARMF simulated TN loading in Ellerbe Creek subwatershed.

Total Phosphorus (TP)

Point sources contribute 58% of the TP load in the subwatershed. Developed land and septic systems contribute about 17% of the TP load each. The relatively high loading from septic systems reflects the inclusion of sand filter loadings with septic systems. Total phosphorus loading in developed areas is lower because land applications in developed areas did not include site-specific information for phosphorus. Forestland and NCDOT land contribute 3% of the TP load each. All the other sources contribute one percent or less.

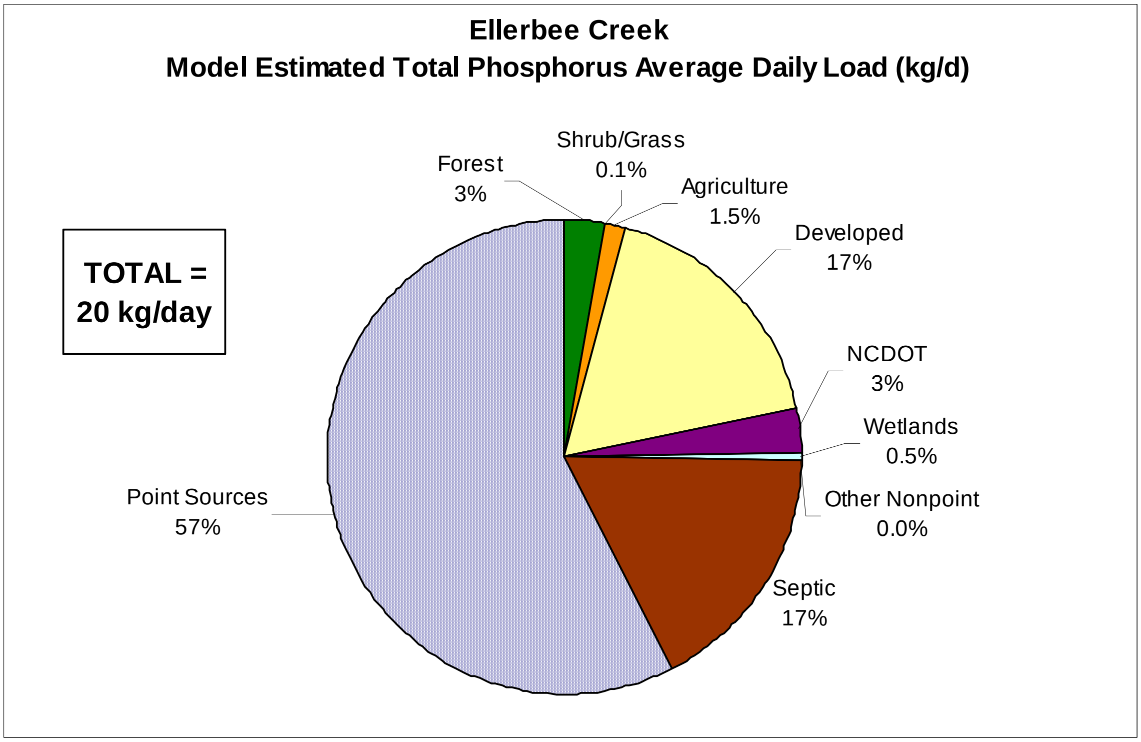

Figure 21. Summary of WARMF simulated TP loading in Ellerbe Creek subwatershed.

Table 15. Summary of WARMF simulated TN and TP loading in Ellerbe Creek subwatershed.

	TN (kg/d)	**TP (kg/d)**
Forest	11.8	0.53
Shrub/Grassland	1.8	0.02
Agriculture	3.9	0.30
Developed	75.1	3.49
NCDOT	1.7	0.62
Wetlands	2.1	0.10
Other Nonpoint Sources (barren land, water, general nonpoint)	0.1	0.01
Septic	9.7	3.50
Point Sources	118.0	11.70
Air Deposition	0	NA

11.6 Distribution of Combined Loading from the Calibrated Subwatersheds

The distribution of land cover for the calibrated subwatersheds is provided in Figure 22. As shown, the majority of the area is forested land, covering about 57% of the total area. Agricultural land covers about 22% of the area and developed land covers about 12%.

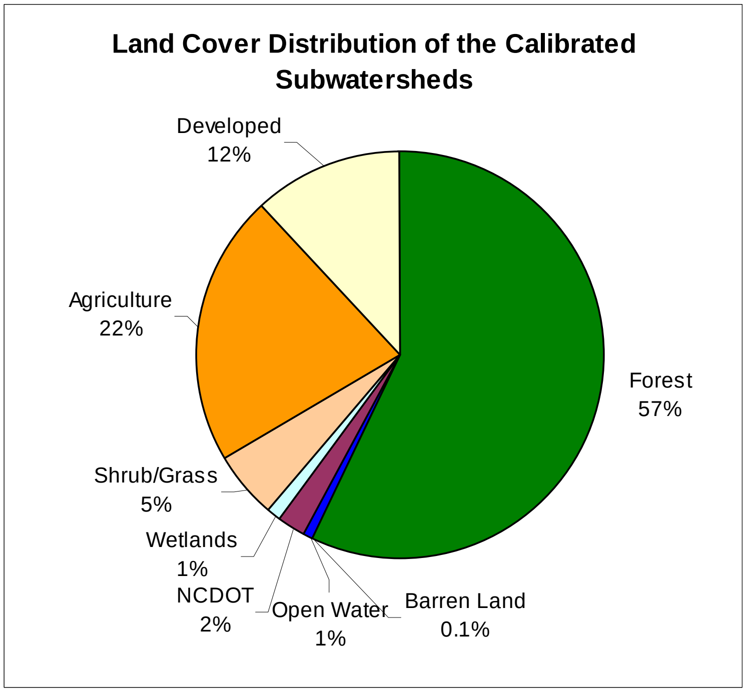

Figure 22. Distribution of land cover in the calibrated subwatersheds.

Figures 23 and 24 provide a relative distribution of the combined loads from the calibrated subwatersheds of TN and TP, respectively, over the simulation period. Overall, loads of TN are dominated by agriculture, which contributes 33% of the total load. Point sources, forest, septic systems, and developed land also contribute 17%, 17%, 15%, and 12% of the total load, respectively.

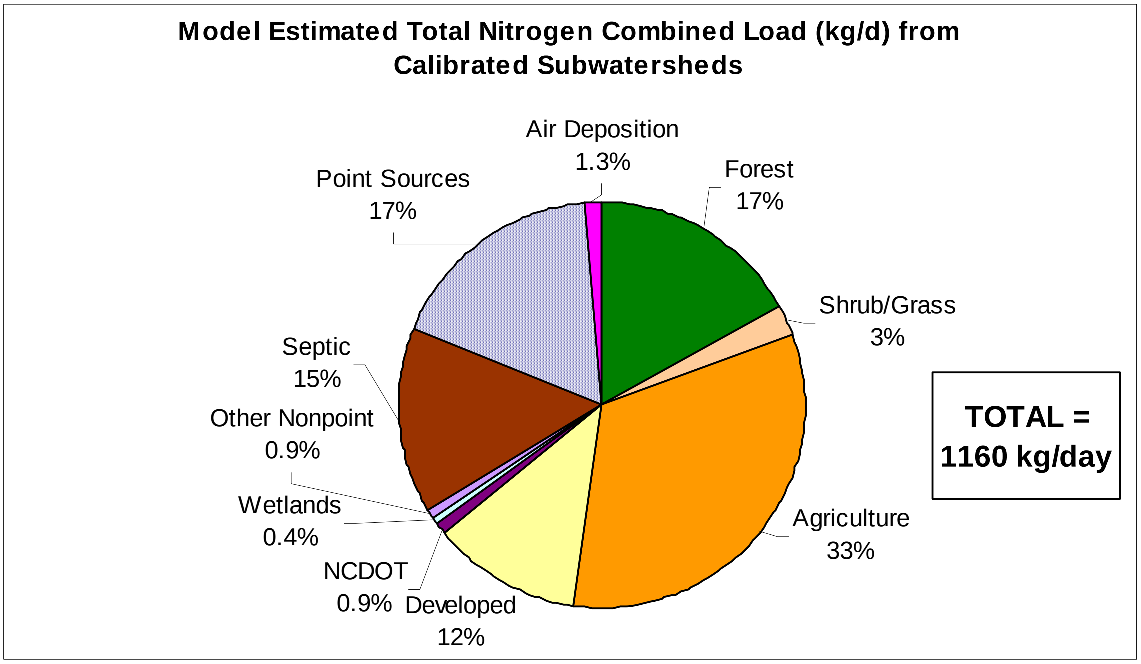

Figure 23. Distribution of WARMF simulated TN loading in the calibrated subwatersheds.

Loads of TP are also dominated by agriculture, which contributes 66% of the total load. Point sources and septic systems also contribute 20% and 8% of the total load, respectively.

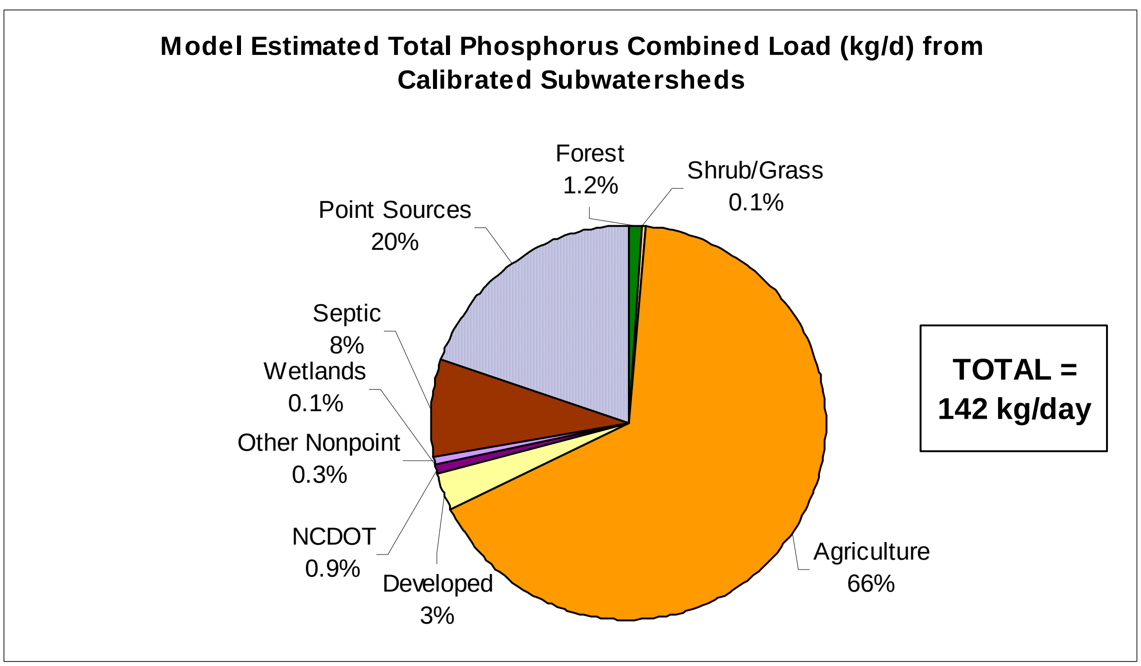

Figure 24. Distribution of WARMF simulated TP loading in the calibrated subwatersheds.

11.7 Delivered Load to Falls Lake

In contrast to the above sections that provided information on regional loading, this section provides information on the delivered loads to Falls Lake by subwatershed and source component. These loading results are based on the source contribution values generated by the WARMF model.

The relative sizes of each calibrated subwatershed are provided in Figure 25. As shown, the Flat River and Eno River are much larger than the other subwatersheds. Ellerbe and Knap of Reeds are the smallest subwatersheds.

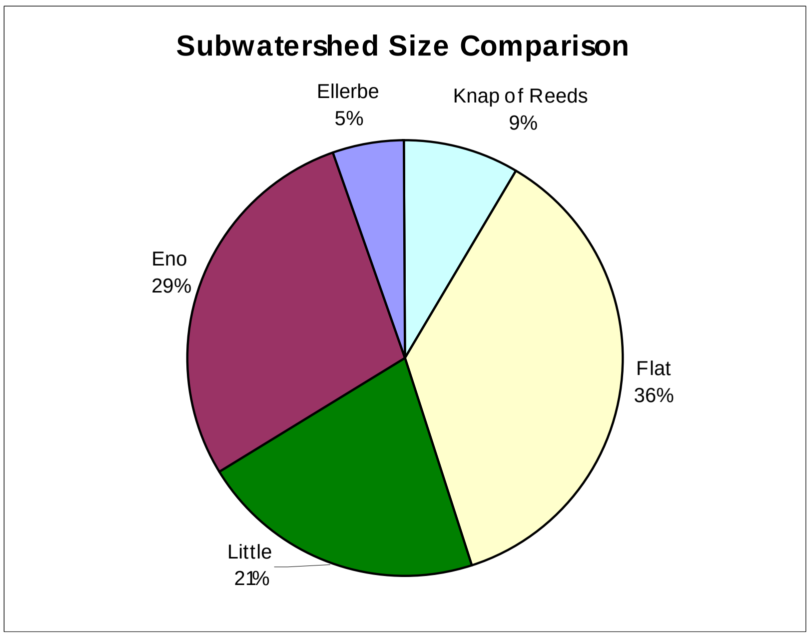

Figure 25. Subwatershed size comparison.

Figures 26 and 27 provide a comparison of the average daily delivered load to Falls Lake for TN and TP, respectively, over the model simulation period. For the most part, the average daily loads are not that different among the subwatersheds, except for Little River subwatershed. Little River subwatershed contributes the lowest average load for both TN and TP. Even though Ellerbe Creek is the smallest subwatershed, this subwatershed contributes the highest average daily load of TN, closely followed by the Flat River subwatershed. Conversely, the Flat River subwatershed contributes the highest average load of TP, closely followed by the Ellerbe Creek subwatershed.

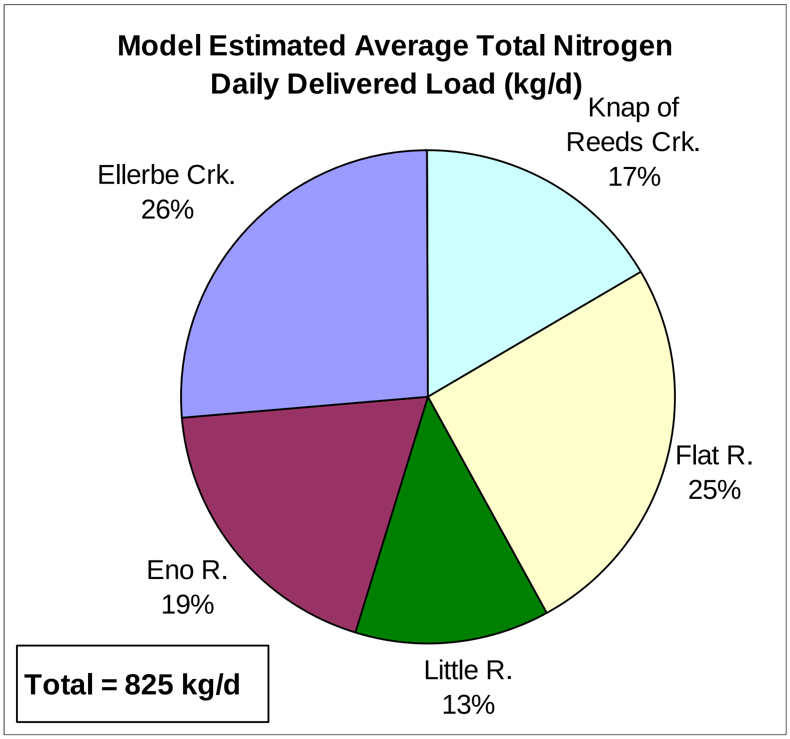

Figure 26. Summary of WARMF simulated TN delivered load in the calibrated subwatersheds.

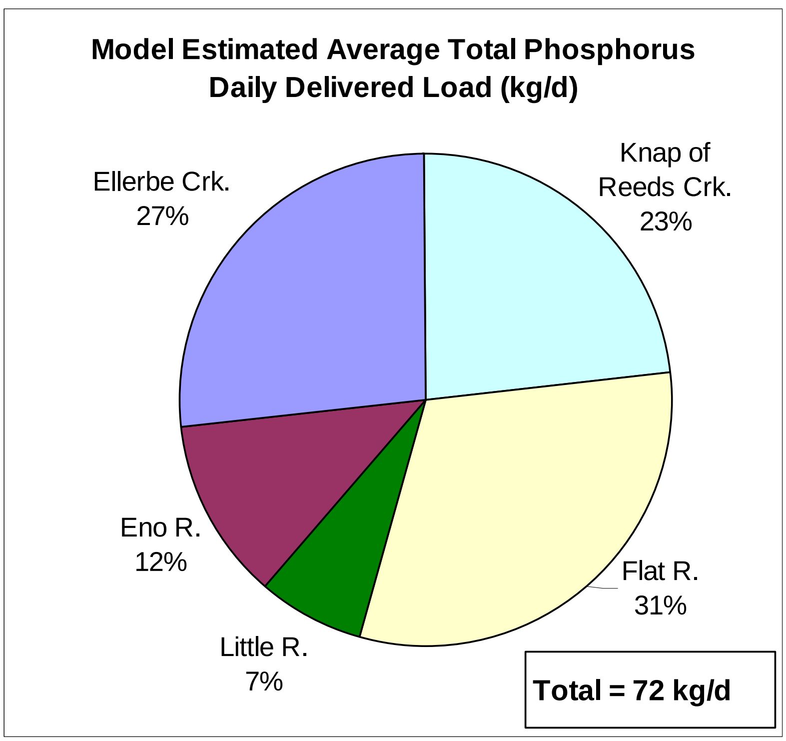

Figure 27. Summary of WARMF simulated TP delivered load in the calibrated subwatersheds.

Figures 28 and 29 provide information on the model estimated delivered load to Falls Lake by source. As compared to Figures 23 and 24, the resulting loads delivered to Falls Lake are lower than the loads delivered to the local streams within the subwatersheds. This is due to in-stream and watershed reservoir processes that assimilate a portion of the source load before it reaches Falls Lake.

As shown in Figure 28, agriculture, point sources, forest, septic (which includes a portion of sand filters), and developed land all contribute more than 10% each of the total load of TN delivered to Falls Lake. In contrast, agriculture and point sources contribute the majority of TP delivered to Falls Lake, at 42% and 37%, respectively (Figure 29).

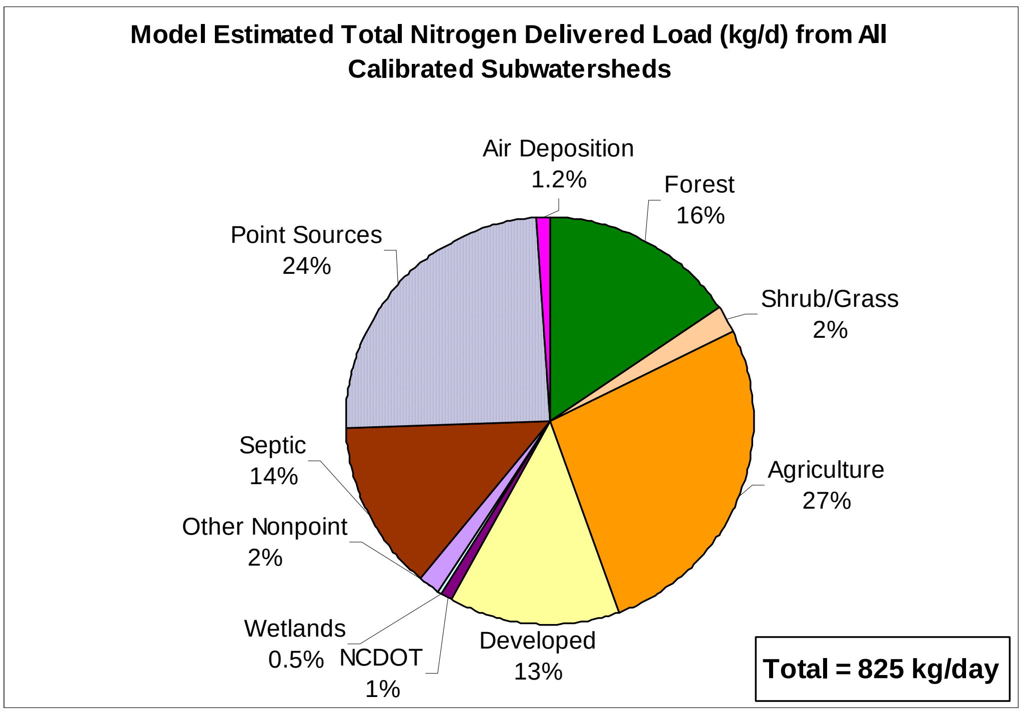

Figure 28. Summary of WARMF simulated TN delivered load by source in the calibrated subwatersheds.

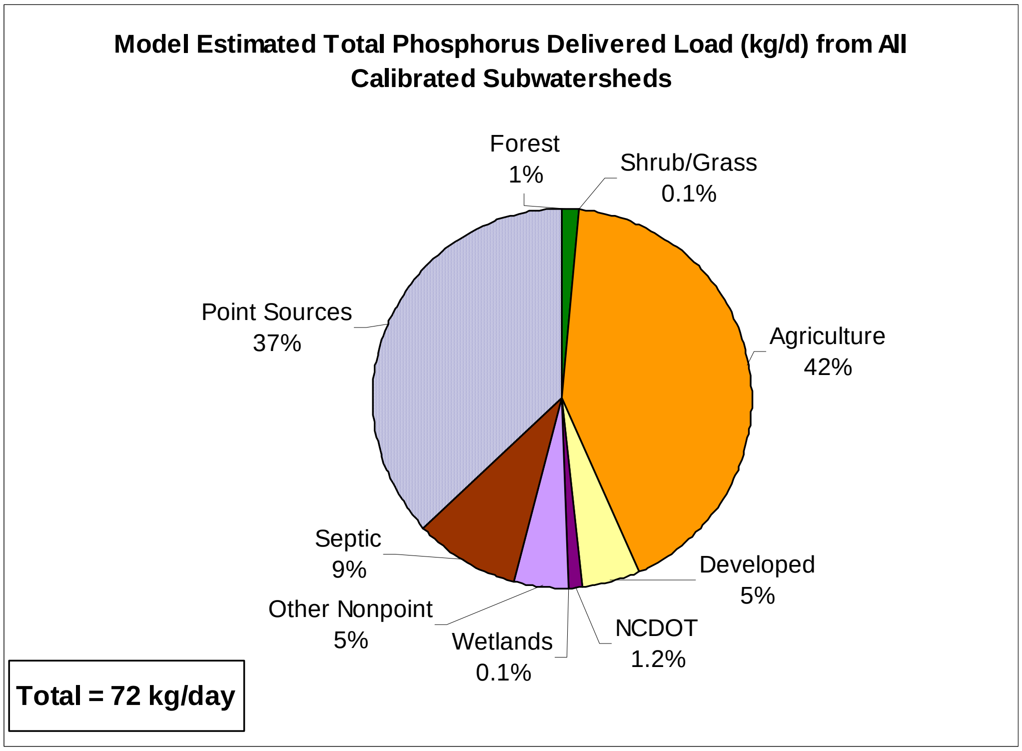

Figure 29. Summary of WARMF simulated TP delivered load by source in the calibrated subwatersheds.

12.0 Falls Lake WARMF Application

WARMF was applied to the Falls Lake watershed in order to determine TN and TP loads from point and nonpoint sources. The model was calibrated for flow, TSS, TN, TKN, nitrate, ammonia, and TP for the five major subwatersheds in the system (Knap of Reeds Creek, Flat River, Little River, Eno River, and Ellerbe Creek).

WARMF was selected for this study because it is a physically-based model and has the capability to assess the impact of point and nonpoint sources in a large watershed with varying land cover and management conditions. It is incorporated with a decision support system designed to support the watershed approach, TMDL calculations, and the stakeholder process. In addition, WARMF has the capability to represent on-site wastewater systems separately, includes reservoirs and lakes in the watershed, and estimates loading from various sources.

The model was calibrated using the best available data for the area and given timeframe. This includes estimates of atmospheric deposition; meteorological information; managed flow; land application in agricultural, developed, and NCDOT land areas; land cover; soil and topographic properties; point sources; sanitary sewer overflows; and sand filter systems. Generally, the model calibration covered the 2004 through 2006 timeframe, but this varied among subwatersheds depending on availability of measured flow data. The model was validated using data from January through September 2007. There were extreme drought conditions in 2005 and 2007, while relatively normal flow conditions were represented in 2004 and 2006.

As with all watershed models, there are inherent model limitations associated with WARMF. All watershed models use simplifying assumptions to represent complex systems and processes. For example, WARMF does not thoroughly simulate ground-water processes.

Every attempt was made to account for major sources of nutrients in the model and, for the most part, data were available to estimate contributions from the majority of sources. However, there are data limitations associated with accounting for all sources of loading in a complex watershed like Falls Lake's and it is possible that some sources are not accounted for in the model as developed. For example, there are no available estimates of application of phosphorus in developed areas; therefore, default values were used.

Other limitations associated specifically with the Falls Lake watershed model include: the relatively short periods of calibration and validation, the extreme drought conditions in 2007, lack of detailed watershed reservoir daily release data, lack of flow data for Ellerbe Creek and Knap of Reeds Creek prior to 2006, uncertainty associated with the reported nutrient effluent concentrations from the North Durham WRF, uncertainly associated with estimated population and concentrations of septic systems, and lack of available data to calibrate the lower part of Falls Lake watershed. Estimates of land application of nutrients on agricultural lands were based on county-level estimates. Finally, the 2001 National Land Cover Data (NLCD) was used to estimate land cover in the watershed. This was the best available dataset given the time constraints of this project. Any changes in land cover from this dataset are not captured in the model.

Given the limitations described above, WARMF simulated the hydrology and water quality in the calibrated subwatersheds reasonably well. The error values associated with model prediction were generally low, suggesting a reasonable agreement between the simulated and observed values. Applications of the model and interpretation of the model results should take the above limitations into consideration. As developed, the calibrated model is adequate to assist with decision-making for the purpose of developing a nutrient management strategy in this watershed.

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Appendix A: Technical Advisory Committee Watershed Model Calibration Comments

Summary of TAC Comments on the Watershed Model Initial Calibration and Validation

DWQ presented initial draft watershed model calibration and validation results to the Falls Lake Nutrient Management Strategy Technical Advisory Committee (TAC) on November 20, 2008, as the TAC had requested the opportunity to review the watershed model. DWQ provided the initial calibrated watershed model and requested that the TAC provide comments specific to improving the calibration. The Upper Neuse Riverkeeper, NCDOT, the City of Durham, and DSWC submitted comments.

A summary of the comments that were directed toward improving the calibration is provided below. Comments are paraphrased. The response is provided in *italics*. The results presented in the main body of this report reflect the calibration improvements that resulted from these comments.

<u>Land Cover/Land Use</u>
The City of Durham recognized that DWQ used the most current watershed-wide land cover available, but commented that the use of 2001 land cover information did not represent current land use in the Ellerbe Creek subwatershed, as well as the lower part of the Eno River subwatershed. The City expressed concern that the unit loads calculated by the model for each land cover category would be inaccurate due to this discrepancy.

The 2001 land cover was the best available dataset available for this project (and was not available until late 2005). This is noted as a model limitation in Section 12 of this report and should be taken into consideration during development of the nutrient management strategy.

After DWQ released the initial calibration version of the model, the City of Durham provided updated land use data (not land cover) for the Ellerbe Creek and lower Eno subwatersheds. However, this data was inconsistent with the land cover coefficients currently applied in the model. This is most likely due to the differences between land cover and land use. Land use refers to how land is used by humans. Land cover refers to the vegetation, structures, or other features that cover the land.

<u>Land Application in Agricultural areas</u>
DSWC presented evidence that the NLCD pasture/hay acreage was much higher, and the cultivated crop acreage lower, than what was reported in the 2002 Agricultural Census.

The NLCD acreages by county were compared to the crop, hay, and pasture acreages by county from the 2002 Agricultural Census and confirmed the observations of DSWC. Therefore, the nutrient inputs for the cultivated crop and pasture/hay land covers have been adjusted (Section 3.8).

<u>Land Application in Developed Areas</u>
The City of Durham recommended that developed land application rates should be applied to account for nutrient application in developed areas (e.g. lawn fertilizer application, pet waste).

DWQ updated the model to include application rates for nitrogen in developed areas based on literature values (see discussion in section 3.8.4). There are no available estimates of phosphorus application in developed areas; therefore, default values in the model were used.

<u>Non-calibrated Subwatersheds</u>
NCDOT and the City of Durham both stated that DWQ should transfer the general loading rates, constants, and coefficients to the non-calibrated subwatersheds in the lower portion of the Falls Lake watershed.

In response to this comment, DWQ ensured that all available model inputs were included for the non-calibrated subwatersheds. These include NPDES-permitted discharges, septic systems, sand filters, sanitary sewer overflows, land application rates (for agricultural, NCDOT, and developed lands), soil properties, and meteorological information.

A discussion of the lower portion of the watershed is provided in Section 2.3 of this report. The lower Falls Lake watershed was not expressly calibrated as part of this effort primarily due to limited available flow and water quality data and the time constraints of this study. DWQ did not transfer any calibrated parameters to the lower portion of the watershed because there is substantial uncertainty associated with differences in land cover, hydrology, topography, and soil properties.

<u>North Durham WRF Effluent Nitrogen Data</u>
The City of Durham provided instream nitrogen data to DWQ for use in the Ellerbe Creek calibration. DWQ identified problems with this data in early 2008. Durham's reported nitrogen concentrations were significantly lower than DWQ monitoring data. As a result, DWQ did not use the data provided by the City of Durham for calibration.

The North Durham WRF uses the same laboratory and could also be reporting significantly lower nitrogen in their effluent. The City of Durham requested that DWQ explicitly describe the uncertainty associated with the use of North Durham WRF effluent nitrogen data.

DWQ recognizes that there may be some underestimation of nitrogen in this subwatershed due to the potential underestimation of nitrogen in the WRF effluent. While there was DWQ monitoring data for the instream water quality parameters, there was no other alternative for the WRF effluent data, which is a required input for the model. As shown in Section 11 of this report, the WRF contributes more than 50% of the total nitrogen load in this subwatershed. Quantifying the uncertainty would require additional monitoring and laboratory studies.

<u>Parameter Justification</u>
NCDOT requested that DWQ provide justification for calibrated parameters that fall one to two orders of magnitude outside of the recommended ranges identified in the WARMF User's Manual.

A summary of the calibration method is provided in Section 4 of this report. While, WARMF guidance is used to estimate the initial input parameters, other relevant literature values were referred to as appropriate.

<u>NCDOT Impervious Cover Rate</u>
NCDOT requested that DWQ provide justification for the use of the impervious cover estimate for NCDOT land in WARMF.

The NCDOT impervious cover ranged from 26% to 78%. The NCDOT provided DWQ with an average impervious percentage; however, the 75th percentile of the imperviousness range provided in the NLCD metadata was used to calculate the impervious percentage system coefficient for each land cover type.

<u>Organic Nitrogen</u>
NCDOT noted that the model was consistently overpredicting ammonia concentrations.

The original draft calibration focused on total nitrogen and did not specifically address ammonia. WARMF does not take direct input of TKN for point sources. To address this deficiency, the original draft calibration applied TKN concentrations in the ammonia field for point sources. Therefore, ammonia was consistently overpredicted.

In the revised calibration, this issue was addressed primarily through adjustment of organic carbon inputs (which is the major source of organic nitrogen), both for point and nonpoint sources. The results of the revised calibrations of TKN and ammonia are provided in Appendix C of this report.

<u>Dissolved Oxygen (DO)</u>
NCDOT requested that DWQ calibrate the model for instream-dissolved oxygen.

The goal of the watershed modeling study was not to calibrate for dissolved oxygen. Therefore, DWQ did not adjust parameters related to DO.

<u>Sediment Fractions in Ellerbe Creek Watershed</u>
The City of Durham noted that the fractions of sand, silt, and clay do not add to 100% in the streambed sediment descriptions in the Ellerbe Creek watershed.

These fractions were adjusted in the model and now add to 100%.

<u>Sand Filter Loading</u>
The City of Durham requested that DWQ represent sand filter loading in the Little Lick and Lick Creek subwatersheds.

Sand filter loading is now represented in these subwatersheds as catchment point sources, as described in Section 3.9 of this report.

<u>Reservoir Load Diversions</u>
NCDOT commented on unusually high nutrient load diversions in watershed reservoirs in WARMF's Flux Output.

DWQ reported this issue to Systech. This was an error in the output calculation, not in the model itself and had no effect on model calibration. Systech provided DWQ with an updated version of the model (Version 6.3) to address the flux output calculation error.

Appendix B: Supplemental Model Setup/Data Information

Systech Engineering, Inc. – Linking Catchments
NCDOT – Method to integrate NCDOT Roads with the NLCD
NCDOT – Fertilizer Application Rates Methodology
NCDOT - Summary of Atmospheric Deposition Data

SYSTECH ENGINEERING, INC.

WATER RESOURCES AND ENWRONMENTAL SYSTEMS ANALYSIS

Systech Engineering, Inc. Release Notes for Falls Lake Watershed WARMF Application

February 20, 2007

The installation set provided for the Falls Lake watershed installs WARN/IF version 6.2 into (by default) the c:\Program Files\Systech\WARMF directory. The files for the Falls Lake watershed project are in the Falls Lake directory. The name of the project is FallsLake2.WSM. Since the project was created in WARMF 6.2, it can not be opened with WARMF 6.1.

Watershed: The imported Falls Lake watershed includes all the tributary area upstream of Falls Lake dam on the Neuse River. A tailwater stub is also included immediately downstream of Falls Lake dam to view output of lake water quality. 114 catchments, 74 river segments, and 6 reservoirs have been imported to create the watershed map. Falls Lake was divided into six segments to facilitate connection with upstream rivers and catchments, but the remaining lakes have just one segment each. Delineation of the watershed was generally done at uniform spatial resolution, but additional break points have been added at the upstream and downstream ends of reservoirs and to accommodate locations of water quality monitoring stations.

Physical Data: As part of the watershed importation process, the following WARMF coefficients were set by calculation from digital elevation model (DEM) data: catchment area, width, slope, and aspect; river upstream and downstream elevations; system latitude and longitude coordinates and map scale.

Reservoir bathymetric data: An Internet search was conducted to find physical data for reservoirs: stage-area (or stage-volume) curves, spillway structural information, and maximum spillway flows. Following is the information found and entered into WARMF:

Lake Orange: Maximum surface elevation is estimated from topozone.com; minimum surface elevation is set 25 feet below maximum based on "hydraulic height" listed in North Carolina dam data file www. eccog. org/common/ewe/documents/NCDAMSO6 08 04.xls. The maximum volume is taken from the "max impoundment capacity" column of the same data file. The maximum area is assumed to be *50%* greater than the entry in the "surface area" column of the file. The stage-area curve is consistent with the surface area and has a volume approximating the max impoundment capacity. The "max discharge" in the data file is assigned to the highest elevation, at the top of the spillway. The spillway is assumed to run *5* feet deep at maximum flow rate and *it is* assumed that flow over the spillway *is* proportional to the head over the spillway crest to the 3/2 power.

Little River Reservoir: The maximum and minimum surface elevations are estimated from topozone.com. The maximum volume of 4.9 billion gallons comes from the following source: http://www.ncwater.org/Reports and Publications/Jordan Lake Cape Fear Rive r Basin/JLAR3-Durham.pdf. The maximum surface area is estimated to be 1.5 times the surface area of the lake as represented in the ArcView shapefile provided by the State of North Carolina. The maximum spillway flow assigned is one half the maximum spillway flow of Lake Michie. The spillway is assumed to run 18 feet deep at maximum flow and flow over the spillway is assumed to be proportional to the head to the 3/2 power.

Lake Michie: The maximum surface elevation is estimated from topozone.com. The minimum elevation is the maximum minus the "hydraulic height" listed in the North Carolina dam data file. The maximum volume is the "maximum impoundment capacity" from the dam data file. The maximum area is assumed to be *50%* greater than the entry in the "surface area" column of the file. The stage- area curve is consistent with the surface area and has a volume approximating the max impoundment capacity. The "max discharge" in the data file is assigned to the highest elevation, at the top of the spillway. The spillway is assumed to run 18 feet deep at maximum flow rate and it is assumed that flow over the spillway is proportional to the head over the spillway crest to the 3/2 power.

Lake Butner: The maximum and minimum elevations are estimated from topozone.com. The maximum surface area is estimated to be *1.5* times the surface area of the lake as represented in the ArcView shapefile provided by the State of North Carolina. A stage-area curve was estimated from the maximum area. The maximum spillway flow assigned is one half the maximum spillway flow of Lake Michie. The spillway is assumed to run 18 feet deep at maximum flow and flow over the spillway is assumed to be proportional to the head to the 3/2 power.

Lake Rogers: The maximum and minimum elevations are estimated from topozone.com. The maximum surface area and volume area from the following source: http://www.nceep.net/services/lwps/Upper Neuse/lakerogplan.pdf. A stage-area curve was estimated from the maximum area with volume calculated from the estimated area. The maximum spillway flow assigned is one quarter the maximum spillway flow of Lake Michie. The spillway is assumed to run *5* feet deep at maximum flow and flow over the spillway is assumed to be proportional to the head to the 3/2 power.

Falls Lake: Reasonably complete structural data is available from the Corps of Engineers: http://epec.saw.usace.army.mil/fallpert.txt. The data includes maximum and minimum elevation; five corresponding sets of elevation, area, and volume; spillway crest elevation; and maximum spillway flow. The stage-area curve was set to follow the stage-area and stage-volume data points provided. Flow over the spillway is assumed to be proportional to the head over the spillway crest to the 3/2 power.

No data was entered for prescribed outflows, diversions, and their outlets for the reservoirs.

Land Use Data: Land uses in WARMF were customized to match the 16 different land uses in the land use/land cover shapefile provided by the State of North Carolina. The data was imported and overlayed with catchment boundaries to calculate the percentage of each land use in each catchment.

Run test: Meteorology and air quality data from the Brier Creek, Georgia demonstration WARMF application have been imported into the watershed to test the WARMF application under simulation conditions. The simulation of one year completed successfully. *It is very important to replace the meteorology file and air quality file in the WARMF project provided with local data for all catchments and all reservoir segments.* Except as noted above, model coefficients retain their default values and should be replaced as needed with watershed specific measured data or modified for calibration purposes.

Method to Integrate NCDOT Roads with Land Use/Land Cover (LULC) for the Falls Lake Watershed

July 20, 2006

Sources of Data

- LULC: National Land Cover Dataset (NLCD) 2001 raster data downloaded from USGS web site (seamless.usgs.gov). 30-meter resolution data.
- DOT roads: Road conditions 2004 from NC DOT Highway Stormwater Program (HSP) geodatabase. This layer only includes NC DOT maintained roadways defined by interstates, US routes, NC routes, and secondary routes.
- Falls Lake Watershed boundary: The Upper Neuse Subbasin boundary was extracted from the NC basins layer in the HSP Geodatabase. This was used as the estimated Falls Lake Watershed boundary until a more detailed boundary is available from DWQ (Raj N.).

Methodology for preparing the LULC data

Summary: Create a slight buffer of the Falls Lake watershed and use it to clip the NLCD raster data before converting it into a polygon coverage.

Steps:

1. Load the Data sources into ArcMap and set the Display Coordinate system to be the same as the NLCD 2001 layer.
2. Buffer the Project Area (Upper Neuse Sub-basin boundary) by five km. This buffer area was chosen as a conservative buffer of the watershed area and hopefully should include the final watershed boundary used by DWQ.
3. Export the new project area buffer layer to a new layer that is in the same coordinate system as the Display (and NLCD layer).
4. Use the “Extract by Mask” tool to reduce the size of the NLCD raster dataset before converting it to a polygon layer from a raster dataset. Use the project area layer as the input mask and the NLCD raster layer as the input raster. The “Environment Settings->General Settings-> Output Extent” should be set to be the same as the polygon layer and the “Snap Raster” option should be set to snap to the NLCD layer.
5. Use the “Raster to Polygon” tool to convert the NLCD subset to a polygon layer making sure that the extents of the layers are aligned or the results will be shifted improperly. When using this tool the “Simplify Polygons” option should not be used (i.e. unchecked). . The “Environment Settings->General Settings-> Output Extent” should be set to be the same as the NLCD subset raster layer.
6. Join the NLCD code lookup table with descriptions of the NLCD codes to the new Falls Lake LULC polygon layer.
7. Project the new polygon layer to a projection desired by DWQ (i.e. NC State Plane, NAD83, meters).

Methodology for Preparing the DOT Road Data

Summary: In general, we will plan to use the NCDOT right of way (ROW) attribute where available, and where not available we will attempt to estimate the ROW from a combination of the surface width, left and right road shoulder widths, and median widths. In a few road segments (e.g. highway ramps) some or all of these fields may be blank or have out of acceptable range values. In these cases, the ROW will be estimated based on DOT expert opinion of the typical ROW dimensions for the particular road segments. These cases are a small percentage of the total road segments in the Falls Lake Watershed.

Once we have an actual or estimated ROW value for all of the road segments then we will use half of the ROW value for each individual road segment to create an individual buffer distance for that road segment. The buffer distance will then be used to create a buffer polygon layer from the road centerlines found with the DOT road conditions layer. Roads that may not have equal portions of the ROW width on both sides of the road center line (i.e. roads with medians) are buffered separately. These roads are buffered separately for the left side and the right side. The individual buffer distances are determined by using the median width and half of the surface width for the left side buffer and the right side buffer is the ROW width minus the right side buffer width.
Once all of the buffers have been created, they will be merged and dissolved to create a single layer of polygons representing the NC DOT right of way areas. A landuse code field will be added to the dissolved layer and assigned a code (29) for NC DOT right of ways.

Steps:

1. Clip NC DOT roads to the buffer of the watershed.
2. Add fields to hold the estimated ROW, buffer distance of both sides, left buffer distance, and right buffer distance.
3. Calculate the estimated ROW for each road segment in the following ways:
   - If the ROW is available, then calculate estimated ROW to ROW.
   - If the ROW is not available, surface width > 0, and median width < 100; then estimated ROW = surface width + median width +left shoulder width + right shoulder width.
   - If the ROW is not available, surface width > 0, and (median width > 100 or Median Type < 3); then estimated ROW = surface width +left shoulder width + right shoulder width.
   - If the ROW is not available and surface width = 0 then assume the segment is a ramp. Estimated ROW = 14'(surface width) +8' (left shoulder width) + 8'(right shoulder width) for a standard ramp.
4. Calculate the buffer distances for the different road segments. The buffer distance is the same for both sides of some road segments and for others a separate right side and left side buffer distances are calculated. These buffer distances are calculated in the following ways:
   - 'ROWNO <> 0 AND (MEDWIDTH = 0 OR MEDTYP < 3)' --> Both = ROW/2
   - 'ROWNO <> 0 AND MEDWIDTH > 0 AND MEDTYP > 2' --> Left = MedWidth + 1/2 Surfwidth, Right = ROW - Left

- 'ROW=0,SURF>0,RS, LS=0,MED>0, MEDTYP>2, MEDWID<100' --> Both = (SurfWidth+ MedianWidth)/2
- 'ROW=0,SURF>0,RS=0,LS=0,MED>0, (MEDTYP<3 OR MEDWID>100' --> Both = (SurfWidth)/2
- 'ROW=0;SURF>0;RS=0,LS=0, MED=0' --> Both = (SurfWidth)/2
- 'ROWNO = 0, SURFWID > 0, LSWIDTH > 0, RSWIDTH=LSWIDTH' --> Both = (Surfwidth + MedWidth + LSWidth + RSWidth) / 2
- ' ROWNO = 0, SURFWID > 0, RSWIDTH <> LSWIDTH' ---> Left = Medwith + 1/2 Surfwidth + Leftwidth, Right = 1/2 Surfwidth + Right width
- 'ROWNO = 0 AND SURFWID = 0' --> *Ramps - Assume Standard Ramp* -> Both = (8+14+8)/2

5. Buffer the different groups (i.e. both or left/right) of road segments separately.
6. Merge the three different buffers (both, left, right).
7. Add a GridCode field to the merged buffers layer and calculate it to equal the NCDOT code (29).
8. Dissolve the merged buffers on ID and GridCode.
9. Use the Update tool to integrate the Falls Lake NLCD with the dissolved road buffers.

<u>Methodology for Integrating the LULC data and DOT Road data</u>

Summary: Once the LULC and DOT roads data have been prepared, the LULC data is replaced with the DOT ROW road centerline buffers wherever they overlap. Lastly, clip the integrated LULC layer by the Falls Lake watershed boundary.

<u>Methodology for Calculating Sub-basin Average NC DOT Right of Way Percent Impervious (Paved) Area Factors</u>

Summary: First, intersect the NC DOT road segments with the sub-basin boundaries. Next, use the estimated ROW widths for each road segment and the length of the portion of the same road segment that falls within the Falls Lake watershed to calculate the ROW area for each road segment. Where the impervious area has already been calculated for each road segment, the portion of the road segment that falls within the Falls Lake watershed will be used to determine the impervious area. For the other road segments, (e.g. highway ramps), it will be calculated from the widths of the paved components (e.g. paved shoulders, medians, road surfaces). Lastly, total the ROW total area and impervious area by sub-basin, and then use the totals to calculate the average ROW percent impervious areas by sub-basin.

Steps To Determine NCDOT Fertilizer Application
(Extracted from DOT Application Estimate Spreadsheet)

1. Annual average of fertilizer application determined for each County based on DOT estimates (tons) for 2005-2007

2. Annual average of fertilizer application determined for area of each County area within the Falls Lake watershed by using a percent-of-area weighted approach
3. Annual average kg/ha of fertilizer determined for area of each County area within the Falls Lake watershed

4. Annual kg/ha of Ammonia (as N), Nitrate (as N), Phosphorus (as P), and Potassium (as K) determined using stoikiometry of fertilizer.

5. Fertilizer application methods (maintenance, wildflower beds, TIPs, etc) are factored into apportioning out the total load over the 12-month period.

6. Within each subwatershed (63 subwatershed) determine the area of DOT landuse

7. Assign each subwatershed to a County (based on the relative area of overlap) and determine the total DOT area for all subbasins in each County

8. Determine Monthly application rates for 10-20-20 fertilizer using application scheme on DOT_App sheet

9. Determine Monthly application rates for 18-9-9 fertilizer using application scheme on DOT_App sheet

10. Sum 10-20-20 and 18-9-9 application estimates to determine total monthly application for each constituent by subwatershed (63).

NCDOT Highway Stormwater PROGRAM

North Carolina
Department of Transportation
Highway Stormwater Program:

Summary of Atmospheric Deposition Data Available for Modeling Nutrients in the Falls Lake, North Carolina, Watershed

Draft Report

May 5, 2008

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List of Acronyms and Abbreviations

ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
CMAQ	Community Multiscale Air Quality
CASTNET	Clean Air Status and Trends Network
CSTR	Continuously Stirred Tank Reactor
EMC	Environmental Management Commission
GIS	Geographic Information System
HUC	Hydrologic Unit Code
ILWAS	Integrated Lake Watershed Acidification Model
NADP	National Atmospheric Deposition Program
NCDAQ	North Carolina Division of Air Quality
NCDOT	North Carolina Department of Transportation
NCDWQ	North Carolina Division of Water Quality
NEP	National Estuary Program
NOAA	National Oceanic and Atmospheric Administration
SWMM	Storage, Treatment, Overflow, Runoff Model
TAC	Technical Advisory Committee
USEPA	United States Environmental Protection Agency
WARMF	Watershed Analysis Risk Management Framework
WASP	Water Quality Analysis Simulation Program
WDT	Watershed Deposition Tool

Executive Summary

Atmospheric deposition is now recognized as a significant contributor to water quality problems, acidification of streams and lakes, and toxic contamination in fish. Several National Estuary Programs (NEPs) have calculated that atmospheric deposition of at least one pollutant is a significant portion of the total pollutant load to their estuaries (USEPA, 2001). Nitrogen inputs have been studied in several East and Gulf Coast estuaries because of concerns about eutrophication. Nitrogen from atmospheric deposition is estimated to be as high as 10% to 40% of the total input of nitrogen to many of these estuaries and perhaps higher in a few cases (Paerl, 2002).

Falls Lake, located near Raleigh, North Carolina, was constructed by the U.S. Army Corps of Engineers between 1978 and 1983 to control flooding and provide a source of drinking water for Raleigh and its surrounding communities. The lake also offers opportunities for recreation, fish and wildlife conservation and enhancement, and pollution abatement and water quality control through low-flow augmentation in the Neuse River. The North Carolina Division of Water Quality (NCDWQ) is in the process of developing watershed and lake models to address recent North Carolina legislation (S.L. 2005-190) related to eutrophication in the lake. As a member of the Falls Lake Technical Advisory Committee (TAC), the NCDOT has offered to support NCDWQ in model development.

The purpose of this report is to support the NCDWQ in the development of a Watershed Analysis Risk Management Framework (WARMF) model for Falls Lake by providing NCDWQ with information and data related to nutrient loading from atmospheric sources. This report includes a review of wet and dry nitrogen deposition data from stations in close proximity to the Falls Lake watershed, and a review of the Watershed Deposition Tool (WDT) developed by the United States Environmental Protection Agency (USEPA).

This review resulted in the following findings:

1. National Atmospheric Deposition Program (NADP) station NC41 (Finley Farms, Wake County, North Carolina) provides the best source of wet chemistry data necessary to support the WARMF model. NC41 data include weekly concentrations (mg/l) for ammonia, calcium, magnesium, potassium, sodium, sulfate, nitrate, and chloride during the 2004–2007 Falls Lake study period.

2. For dry chemistry inputs, Clean Air Status and Trends Network (CASTNET) station PED108 (Prince Edward, Prince Edward County, Virginia) was found to be the best available source of weekly average data for sulfate, SO_x, NO_x, nitrate and ammonium. The Prince Edward station is located approximately 65 miles north of the Falls Lake watershed in Prince Edward County, Virginia.

3. The WDT was found to be a useful tool in understanding deposition spatially on an annual scale; however, the information provided by the tool is incompatible with the

input requirements of WARMF. The WDT provides deposition estimates on an annual or seasonal basis. The WDT is valuable for comparing annual deposition estimates in the Falls Lake watershed to deposition estimates in watersheds in which other monitoring stations, including CASTNET Stations PED108 (Prince Edward, Virginia), CND125 (Candor, North Carolina), and NCDAQ Lenoir Community College are located. This evaluation found that, using the 2001 base Community Multiscale Air Quality (CMAQ) model data set, total nitrogen deposition estimates for the PED108 watershed/region are within 10% of annual estimates found in the Falls Lake watershed. In contrast, nitrogen estimates for the areas surrounding CND125 and Lenoir Community College stations resulted in area-averaged deposition values up to 207% and 316% higher, respectively, than annual estimates found in the Falls Lake watershed.

4. A summary list of recommended sources and data for use in supporting the Falls Lake WARMF model is provided in Table E-1. Raw data inputs are provided in Appendix B.

Table E-1 Recommended data and sources to support WARMF model air chemistry inputs

Resultant Parameter	WARMF Input Units		Monitoring Station Network, Station ID, and Lab Measurement for Falls Lake WARMF Model	
	Wet	Dry	Rain (Wet) Quality	Air (Dry) Quality
SO_x	µg/m^3	µg/m^3	Not Applicable	CASTNET, PED108, wso2
NO_x	µg/m^3	µg/m^3	Not Applicable	CASTNET, PED108, nhno3
Ammonium[a]	mg/l N	µg/m^3 N	NADP, NC41, nh4	CASTNET, PED108, tnh4
Ca	mg/l	µg/m^3	NADP, NC41, ca	Not Applicable
Mg	mg/l	µg/m^3	NADP, NC41, mg	Not Applicable
K	mg/l	µg/m^3	NADP, NC41, k	Not Applicable
Na	mg/l	µg/m^3	NADP, NC41, na	Not Applicable
SO_4[a]	mg/l S	µg/m^3 S	NADP, NC41, so4	CASTNET – PED108, nso4
NO_3[a]	mg/l N	µg/m^3 N	NADP, NC41, no3	CASTNET – PED108, tno3
Cl	mg/l	µg/m^3	NADP, NC41, cl	Not Applicable

[a] To obtain model inputs, data are translated to determine concentrations as S and N. For example, measurements for NO_3 are multiplied by the fraction 14.0067/(3*15.9994), where 14.0067 and 15.9994 are the atomic weights of nitrogen and oxygen, respectively.

1 Background

Falls Lake was constructed by the U.S. Army Corps of Engineers between 1978 and 1983 to control flooding and provide a source of drinking water for Raleigh and its surrounding communities. The lake also offers opportunities for recreation, fish and wildlife conservation and enhancement, pollution abatement, and water quality control through low-flow augmentation in the Neuse River.

The Falls Lake watershed is approximately 494,078 acres (772 square miles). At normal pool elevation the lake covers an area of about 11,310 acres from about 10 miles north of Raleigh, North Carolina to the confluence of the Eno and Flat Rivers.

In July 2005, NC Senate Bill 981 (S.L. 2005-190), also known as the Drinking Water Reservoir Protection Act, was passed by the NC General Assembly requiring the North Carolina Environmental Management Commission (EMC) to evaluate nutrients and adopt nutrient control criteria for a select group of NC reservoirs, including Falls Lake. To address the requirements of this legislation as well as ongoing eutrophication in the lake, the NCDWQ is collecting water quality data and developing watershed and lake models. As a member of the Falls Lake Technical Advisory Committee (TAC), the NCDOT has offered to support NCDWQ in model development as deemed appropriate by the two agencies.

The purpose of this report is to support NCDWQ in the development of a Falls Lake WARMF model by providing NCDWQ with information and data related to nutrient loading from atmospheric sources. Specifically, this report provides a review of

- Wet and dry nitrogen deposition data from stations in close proximity to the Falls Lake watershed, and
- USEPA's Watershed Deposition Tool (WDT).

The WDT was evaluated to determine whether the tool provides information that can be used as an input to the Falls Lake WARMF model, and if the information provided by the WDT is a better alternative to existing NADP and CASTNET data for estimating loads from atmospheric sources in the Falls Lake model. This report provides recommendations to NCDWQ and the Falls Lake TAC on atmospheric data available for use as input to the Falls Lake WARMF model.

2 WARMF Model Overview and Input Requirements

The WARMF model is a watershed modeling system that contains several embedded models adapted from the Integrated Lake Watershed Acidification Model (ILWAS), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), Storage, Treatment, Overflow, Runoff Model (SWMM), and Water Quality Analysis Simulation Program (WASP) and can be used to simulate loading from atmospheric, surface, and point sources. The algorithms used to represent chemical processes between the air (e.g., wet and dry deposition) and land/water surface in WARMF were derived from the ILWAS model but several improvements have been made in WARMF to take advantage of improved hydrologic information and dynamic routing capability. The processes and reactions used in ILWAS are outlined in detail in Gherini et al. (1985). This section provides a summary of the primary processes related to atmospheric deposition in WARMF described in Gherini et al. (1985) and Chen et al. (2001).

WARMF divides watersheds into land catchments, river segments, and reservoirs and uses the continuously stirred tank reactor (CSTR) model for flow routing and mass balance within a given soil layer or river segment. The hydraulic module simulates the processes of canopy interception, snow pack accumulation and snow melt, infiltration through soil layers, evapotranspiration from soil, ex-filtration of ground water to stream segments, kinematic wave routing of stream flows, and flow routing of the terminal reservoir. Water is routed from one compartment to another and concentrations of dissolved constituents are calculated by simulating the biogeochemical reactions taking place in each compartment. Along each flow path, the chemistry module performs mass balance and chemical equilibrium calculations to account for the processes of dry deposition to the canopy, nitrification of ammonia on the canopy, ion leaching from sap to the canopy surface, wash-off by throughfall, and ion leaching by snowmelt, as well as the soil processes, including, litter fall, litter breakdown, litter decay, nitrification, denitrification, cation exchange, anion adsorption, weathering, and nutrient uptake (Chen et al., 2001).

Deposition of wet and dry constituents occur on all surfaces (catchments, stream segments, and lake segments) represented in the model. In catchments, vegetation and the tree canopy enhance the accumulation of dry deposition (SO_2, NO_x, and particulates). The dry deposition collection rate for each chemical species is proportional to the leaf area index, ambient air quality, the species deposition velocity, and a collection efficiency. The foliar exudation rate is proportional to the chemical composition of the leaves, a chemical species amplification factor, and the leaf area index. SO_2 and NO_x deposited on the canopy are assumed to be rapidly converted to sulfate and nitrate. In the model, this occurs within one time step. Ammonia on the canopy is oxidized to nitrate at a temperature dependent rate proportional to the mass of ammonia present. This chemical reaction is assumed to follow the first order kinetic rate.

WARMF models the deposition of dry air particles onto land surfaces and vegetation using the following equation:

$$D_j = \frac{eV_dC_jLA}{1.0E6}$$

where

D_j = dry deposition rate of chemical species j on a land use

e = collection efficiency of canopy

V_d = deposition velocity in cm/s

C_j = ambient air concentration of chemical species j in meq/m^3

L = leaf area index of the canopy

A = area of the land use in cm^2

Dry deposition falling directly to the snowpack and soil surface is calculated by the same equation, with the values of e and L set to 1. The adsorption of gaseous SO_x and NO_x through stomata is modeled using the same equation except that V_d is the uptake velocity. Foliar uptake of SO_x and NO_x will reduce the amount of sulfur and nitrogen uptake by roots. This is because SO_x and NO_x absorbed by leaves go toward satisfying the plant's demand for nitrogen and sulfate and less nutrient uptake from the soil is needed to maintain plant growth. Dry deposition directly to the soil occurs when vegetation or foliage is absent. Since a catchment can include many land uses, each with its own vegetation characteristics, percent pervious area, and erosion coefficients, WARMF determines the concentrations of constituents associated with each compartment along the flow path.

WARMF tracks the mass of individual chemical constituents on the canopy due to dry deposition, foliar exudation, and water retained on the canopy. When rainfall occurs, the model mixes the precipitation water with the mass of chemical constituents on the canopy. The resulting concentrations are assigned to the throughfall as well as the water retained on the canopy for the next time step (Chen et al., 2001). For surface runoff, the water on the land surface is modeled as a CSTR. The model mixes the constituent in the surface water retained from the previous time step with the constituent associated with the new arrivals from throughfall, snowmelt, and direct wet deposition and dry deposition. The resulting concentration is the concentration for surface runoff, ground water infiltration and surface water retention for the next time step. The constituent contained in the surface runoff becomes the nonpoint source load from the catchment.

WARMF's data module includes inputs for air and rain chemistry data. Air quality data includes chemical constituent concentrations (mg/l) in precipitation and chemical constituent concentrations (µg/m^3) in the air. WARMF requires monthly or weekly average data inputs for both air quality and precipitation chemistry data. WARMF's user manual directs the user to acquire rain chemistry data from the NADP and air chemistry data from the CASTNET, both of which are accessed through the internet. The following sections discuss these and other sources of rain and air chemistry data that were evaluated in this project.

3 Atmospheric Nitrogen Deposition Composition and Data

Atmospheric deposition of nitrogen (N) can be a significant contributor to nitrogen enrichment in waterbodies downwind of anthropogenic sources (Paerl et al. 2002). Atmospheric deposition is a unique source of nitrogen because the airshed of a water body may exceed the watershed area by a factor of 10–20, and thus sources are often outside the boundary of the managed watershed area. For example, Figure 3-1 illustrates the difference in area of the airshed and watershed for the Pamlico River in North Carolina. It is reasonable to expect that the Falls Lake nitrogen airshed spans an area of similar size and proportion to the one identified in Figure 3-1.

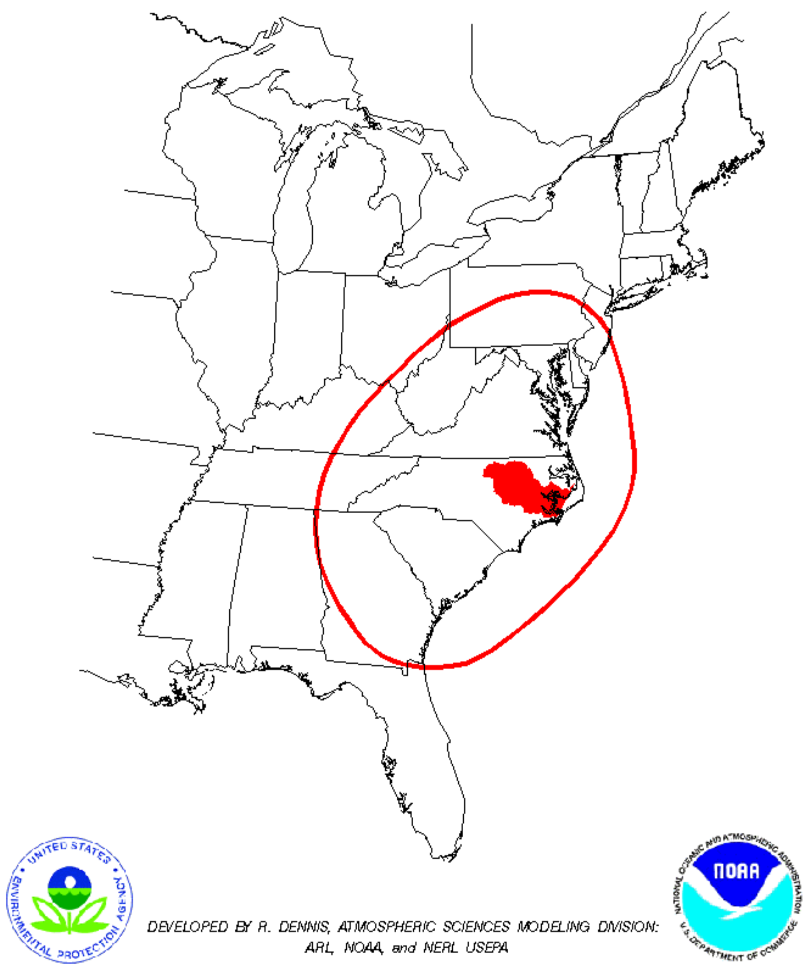

Figure 3-1 Principal oxidized nitrogen airshed for the Pamlico River watershed. Source: http://www.epa.gov/AMD/Multimedia/characteristicsTable.html

Atmospherically deposited N may be either wet in origin (when N is dissolved in precipitation) or dry (when N-containing particles and gases settle on land and water surfaces). For example, stomatal uptake is a component of dry deposition, and will influence the portion of dry-deposited N that is retained in vegetation (a sink in the cycle). Nitrogen in either form may be deposited directly or it may take an indirect route if it enters the water body via runoff and groundwater from the surrounding watershed. The majority of atmospheric N exists as inorganic N in two principal forms: oxidized and reduced (substantially in the forms of NO_x and NH_3, respectively).

All forms of inorganic N are very water soluble and wet deposit equally well. Dry deposition is significantly influenced by the form of the inorganic N and the physical characteristics of the surface onto which it is deposited. Dry deposition flux depends on both the ambient concentration and the chemical's affinity for deposition (Paerl, 2002).

In the United States, the majority of wet deposition data are collected through the NADP and the CASTNET monitoring programs. In North Carolina, the NCDAQ also maintains several stations, some of which include nitrogen deposition data. Dry deposition estimates tend to be derived from atmospheric modeling efforts, many of which are conducted through a partnership of the National Oceanic and Atmospheric Administration (NOAA) and the USEPA Atmospheric Sciences Modeling Division (<http://www.epa.gov/asmdnerl>).

Each of these data sources was consulted during the process of identifying appropriate dry and wet nitrogen concentration data for input to the Falls Lake WARMF model. Sites and data were assessed on the following selection criteria:

- The availability of data for the 2004–2007 period to be modeled using WARMF
- Proximity of the site to the Falls Lake watershed
- Characteristics of the station/site area, i.e., the intended purpose of the site (to characterize regional conditions or deposition from a single source), surrounding land uses, and regional airshed contributors to nitrogen deposition
- A comparison of deposition estimates (e.g., lb/acre/year) in the area surrounding the site to deposition estimates in the Falls Lake watershed using the WDT

The remainder of this section provides a summary of data available through each of the three monitoring networks mentioned.

3.1 National Atmospheric Deposition Program

The NADP is a cooperative effort among private, state, and federal organizations to investigate atmospheric deposition and support informed decisions on air quality issues related to precipitation chemistry (Lear, 1999). Data available through this program are accessible on the NADP website at <http://nadp.sws.uiuc.edu>. This program provides the following data and information:

- Weekly and daily precipitation chemistry data
- Monthly, seasonal, and annual precipitation-weighted mean concentrations
- Annual and seasonal deposition totals
- Mercury deposition data

- Daily precipitation totals
- Color isopleth maps of precipitation concentrations and wet deposition
- Site photos and information
- Quality assurance data and information

Table 3-1 provides a list and short description of NADP stations local to the Falls Lake watershed and throughout North Carolina. Figure 3-2 is a map of active and inactive NADP stations in and around North Carolina.

Table 3-1 Active NADP sites in North Carolina or in close proximity to the Falls Lake watershed

NADP Station Name	Station Number	County	Distance From Falls Lake (mi)[a]	Terrain and Land Use	Corresponding CASTNET Station
Finley Farm	NC41	Wake	15	Rolling, Urban	RTP101 (inactive)
Clinton Crops Research	NC35	Sampson	65	Flat, Animal Agriculture	None present
Jordan Creek	NC36	Scotland	80	Flat, Forest/Cleared	CND125
Piedmont Research	NC34	Rowan	105	Rolling, Agriculture	None present
Prince Edward (Virginia)	VA24	Prince Edward	110	Rolling, Forest	PED108
Lewiston	NC03	Bertie	120	Flat, Agriculture/Forest	None present
Hoffman Forest	NC29	Onslow	105	Flat, Forest	None present
Beaufort	NC06	Carteret	135	Flat, Agriculture	BFT142
Mt. Mitchell	NC45	Yancey	200	Mountaintop, Forest	PNF126
Coweeta	NC25	Macon	275	Complex, Forest	COW137

[a] Distances are approximate and were estimated using Google Earth (http://earth.google.com) mapping/measuring tools.

As evident in Table 3-1, NC41 is the closest station to Falls Lake. The second closest station, NC35, was strategically located in an area of southeast North Carolina to characterize deposition from animal agricultural sources.

Station NC41 is located on the campus of North Carolina State University in an environment classified as urban. Urban sites are defined as having 400 or more people per square km within a 15-km radius of the site (NADP, 2004). The area adjacent to the station includes animal agriculture, urban, and forested land uses, a mix of land uses similar to those in the Falls Lake watershed. Based on proximity of NC41 to the Falls Lake watershed, the similarity between land uses surrounding NC41 and those present in Falls Lake, and the availability of wet deposition chemistry data for the period of interest, NC41 provides the best option for wet deposition chemistry for the Falls Lake model.

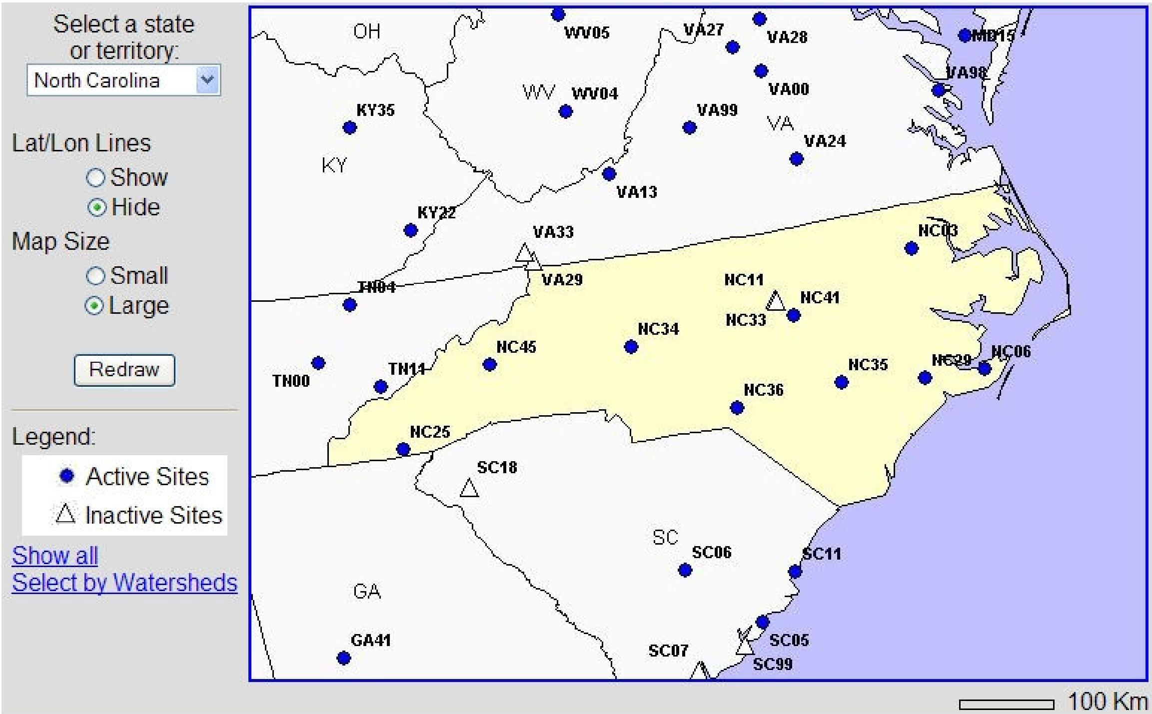

Figure 3-2 National Atmospheric Deposition Program active and inactive sites. Source: <http://nadp.sws.uiuc.edu/sites/sitemap.asp?state=nc>

3.2 Clean Air Status and Trends Network

CASTNET is considered the nation's primary source for atmospheric data used to estimate dry acidic deposition. Each CASTNET dry deposition site provides the following data:

- Weekly, average atmospheric concentrations ($\mu g/m^3$) of sulfate, nitrate, ammonium, sulfur dioxide, and nitric acid
- Hourly concentrations of ambient ozone levels
- Meteorological conditions required for calculating dry deposition rates

Dry deposition rates at CASTNET sites are calculated using atmospheric concentrations, meteorological data, and information on land use, vegetation, and surface conditions. CASTNET monitors atmospheric dry deposition using 3-stage filter packs. The filter pack contains a teflon filter which is for sampling particulate species (particulate NH_4^+, NO_3^-), a nylon filter for nitric acid (HNO_3) and a nylon filter including a potassium carbonate impregnated cellulose filter for sulfur dioxide (SO_2). Because of the interdependence of wet and dry deposition, wet deposition data for the NADP are collected at all CASTNET sites. Together, these two long-term databases provide the necessary data to estimate trends and spatial patterns in total atmospheric deposition.

Active CASTNET sites in North Carolina and southern Virginia are provided in Table 3-2 and shown in Figure 3-3. No CASTNET sites are located in the Falls Lake watershed. Of the available sites, PED108, in Prince Edward County, Virginia, is the closest at 65 miles from the upper watershed boundary. CND125, in Montgomery County, is the closest NC site to the lake at approximately 80 miles southwest. Based on distance from the Falls Lake watershed, terrain and land use, and intended purpose of the sites, PED108 and CND125 are very similar. Both sites are located in rural areas of rolling, forested terrain, and both were set up to characterize regional deposition. Given this, the WDT was used to further characterize and compare deposition in these watersheds to deposition in the Falls Lake watershed. Additional detail on this analysis using the WDT is provided in Section 5.

Table 3-2 CASTNET active sites in North Carolina and Southern Virginia

CASTNET Station Name	Station Number	County	Distance From Falls Lake (mi)[a]	Terrain/ Land Use	Corresponding NADP Station
Prince Edward (VA)	PED108	Prince Edward	65[b]	Rolling/ Forest	VA24
Candor	CND125	Montgomery	80	Rolling/ Forest	NC36
Beaufort	BFT142	Carteret	135	Flat/ Agriculture	NC06
Cranberry	PNF126	Avery	185	Mountaintop/ Forest	NC45
Coweeta	COW137	Macon	275	Complex/ Forest	NC25

[a] Distances are approximate and were determined using Google Earth (http://earth.google.com) mapping and measuring tools.

[b] Value reflects the distance between PED108 and the upper boundary of the Falls Lake watershed. The distance from PED108 to the outlet of Falls Lake is approximately 85 miles.

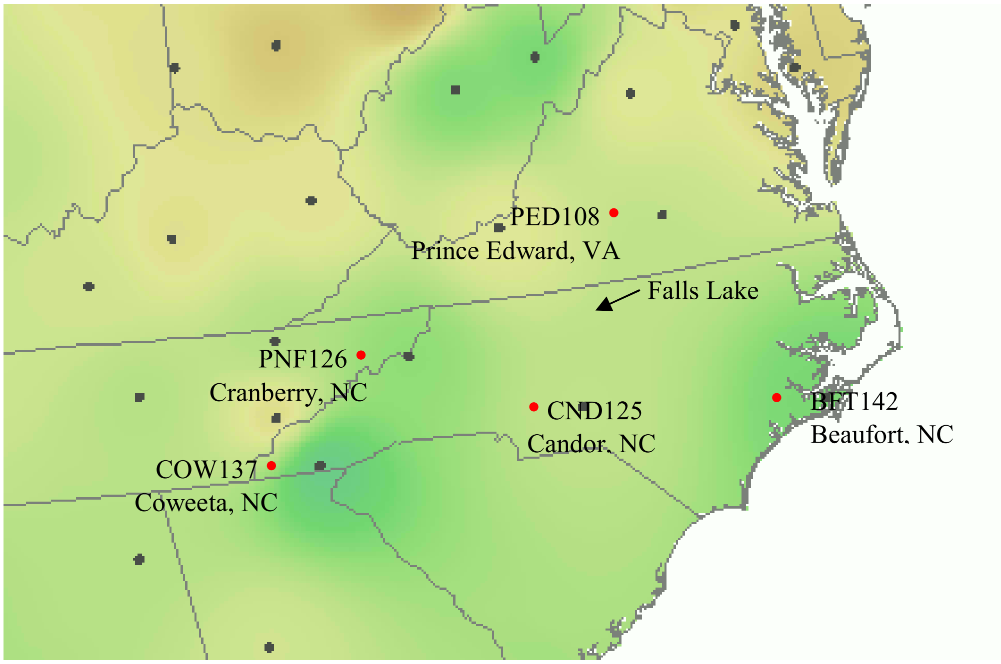

Figure 3-3 CASTNET active sites in North Carolina and southeastern Virginia. Adapted from <http://www.epa.gov/castnet/maps/0406/hno3_c-0406.gif>

3.3 Additional Sources of Air Data

In addition to wet deposition chemistry data from NADP and CASTNET, extensive ambient concentration data for NO_x and ammonia are available from other sites in North Carolina at <http://daq.state.nc.us/monitor> (Table 3-3 and Figure 3-4). The nearest representative sites for NO_x data are the Raleigh Millbrook Middle school (Wake County) and Clinton Crops Research stations (Sampson County), and for ammonia data are the Lenoir Community College (sometimes referred to as the Kinston site) and Clinton Crops Research stations.

Upon first glance, NO_x data from the Raleigh Millbrook Middle School station appear to be the best available dataset for WARMF. However, WARMF requires NO_x input as a concentration of nitric acid (HNO_3); an end product of NO_x. Mono-nitrogen oxides eventually form nitric acid when dissolved in atmospheric moisture. Given this model requirement, both the Raleigh Millbrook Middle School and Clinton Crops Research stations were excluded as options for NO_x input into WARMF.

Both the Clinton Crops Research Station and Lenoir Community College site provide ammonia data that are in the appropriate format and units for WARMF. Of the two stations, the Clinton Crops Research Station is the least fitted to provide data for the Falls WARMF model because it is located in an area heavily influenced by animal agriculture; a land use very different from that of Falls Lake watershed and one from which we would expect high ammonia concentrations. The Lenoir Community College site is located in an area less dominated by animal agriculture nitrogen and thus poses as a potential source of ammonia. To evaluate conditions surrounding the Lenoir Community College site and determine if the ammonia data collected at this site are appropriate for use in the Falls Lake model the site was evaluated using EPA's Watershed Deposition Tool. Analysis and discussion of the tool for the Lenoir Community College site is provided in Section 4 of this report.

Table 3-3 Active ambient air quality data for stations maintained by the NCDAQ

Site Name	County	Distance from Falls Lake (mi)[a]	Nitrogen or Sulfur Measurements	Units[b]
Millbrook	Wake	6	Reactive Nitrogen Oxides, Sulfur Dioxide	PPB
Pittsboro	Chatham	30	Sulfur Dioxide	PPM
Clinton Crops Research Station	Sampson	65	Reactive Nitrogen Oxides, Ammonia	PPB
Lenoir Community College	Lenoir	75	Ammonia	PPB
Jamesville	Martin	95	Ammonia	PPB
Rockwell	Rowan	100	Reactive Nitrogen Oxides	PPB
Aurora PCS Phosphate	Beaufort	110	Sulfur Dioxide	PPM
Wilmington Highway 421	New Hanover	120	Sulfur Dioxide	PPM

Source: <http://www.ncair.org/monitor>

[a] Distances are approximate and were determined using Google Earth (http://earth.google.com) mapping and measuring tools.

[b] PPB = parts per billion and PPM = parts per million

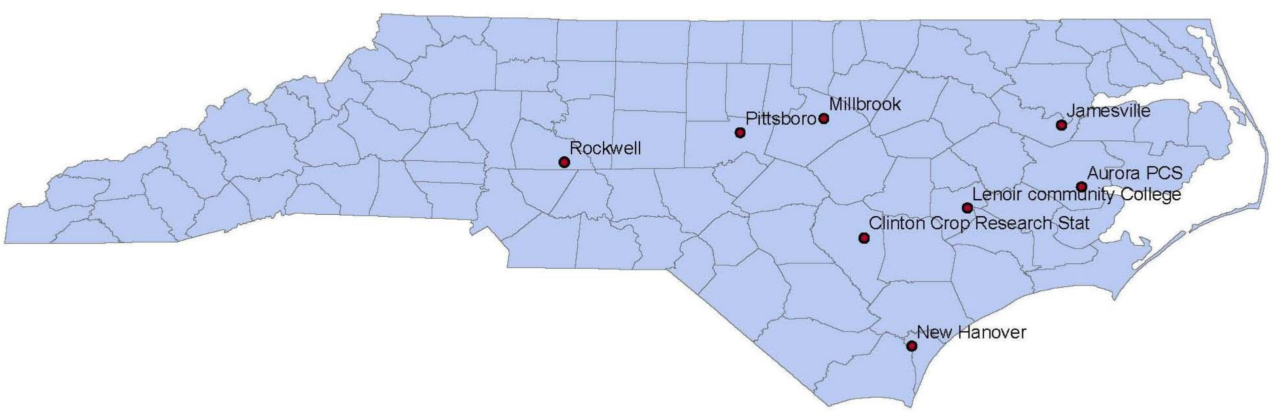

Figure 3-4 Map of select ambient NCDAQ air quality stations listed in Table 3-3.

4 Watershed Deposition Tool

The Watershed Deposition Tool was developed by Argonne National Laboratory and USEPA's Atmospheric Modeling Division to provide a linkage between NOAA-USEPA's regional-scale, multi-pollutant Community Multiscale Air Quality (CMAQ) model and water quality models. The WDT uses gridded deposition output from CMAQ to estimate deposition at the 8-digit hydrologic unit code (HUC) watershed scale. Using CMAQ output, the WDT calculates a weighted average of deposition (wet, dry, and wet + dry) across a selected HUC or set of selected HUCs for a given simulation scenario on a seasonal or annual basis. The WDT can also be used to evaluate changes in deposition as various air-emission controls become effective (USEPA, 2008). For example, USEPA provides scenarios for years 2010 and 2020 on the WDT website to serve as a comparison against the 2001 "base" condition. The WDT provides deposition estimates for wet or dry nitrogen and oxidized or reduced fractions of nitrogen, sulfur, and mercury, as identified in Table 4-1.

Table 4-1 Resultant deposition parameters from the Watershed Deposition Tool

Nitrogen	Sulfur	Mercury
Dry Oxidized	Total Dry	Total Dry
Dry Reduced	Total Wet	Total Wet
Total Dry (Oxidized + Reduced)	Total (Dry + Wet)	Total (Dry + Wet)
Wet Oxidized		
Wet Reduced		
Total Wet (Oxidized + Reduced)		
Total Oxidized (Dry + Wet)		
Total Reduced (Dry + Wet)		
Total (Oxidized + Reduced)		

Deposition estimates provided on USEPA's website and used in this analysis are based on CMAQ version 4.5 at a grid resolution of 36 kilometers. The CMAQ 2001 base condition (<http://www.epa.gov/AMD/Multimedia/depositionMapping.html>) is a result of modeling three years of data (2001–2003): one year of greater than average precipitation, one year of below average precipitation, and one year of average precipitation.

Resultant deposition estimates from the WDT are provided as "total deposition" and "average deposition" in the watershed area. The total deposition for each resultant is provided in mass units as kilogram, gram, pound, or microgram. The average deposition for the watershed is provided in mass/area units, where the mass units are the same as those available for total deposition and the area units include acre, hectare, square meter, or square kilometer. Note that these units differ considerably from the concentration units (mg/l and $\mu g/m^3$) necessary to support the existing WARMF input file. Regardless of this disparity, the WDT (v1.4.10) was reviewed to determine whether it provides information to support WARMF modeling or related technical and policy decisions.

The WDT provides total and average deposition for a given watershed area based on the users' selection of the following criteria:

1. CMAQ model result file(s). Annual and seasonal CMAQ output files for the years 2001, 2010, or 2020 are provided on the USEPA WDT website as input into the WDT.
2. Resultant deposition parameter. A list of resultants is provided in Table 4-1 of this report.
3. Watershed polygon shapefile. The WDT provides 8-digit HUCs for the entire United States as the default watershed area for analysis. The user may choose to generate and import personalized polygon shapefiles.

The Falls Lake watershed (772 square miles) lies within a portion of the Upper Neuse Basin (HUC 03020201, 2,383 square miles). ArcGIS 9.1 was used to create a Falls Lake boundary shapefile that is compatible with the WDT (containing fields and projection units required in the WDT). The WDT was then used to generate annual loads for the Falls Lake watershed under scenarios for 2001 (base conditions), 2010, and 2020. The results of this analysis are presented in Table 4-2. Total nitrogen deposition figures for the 2001, 2010, and 2020 scenarios are provided in Appendix A.

Table 4-2 Annual nitrogen deposition estimates for the Falls Lake watershed based on CMAQ model runs

Nitrogen Resultant Deposition Totals	2001			2010			2020		
	Total 1,000 lb[a]	Average lb/acre	% of Total-N	Total 1,000 lb[a]	Average lb/acre	% of Total-N	Total 1,000 lb[a]	Average lb/acre	% of Total-N
Dry Oxidized	2,276	4.7	44%	1,303	2.7	33%	897	1.8	24%
Dry Reduced	675	1.4	13%	895	1.8	22%	1,151	2.4	31%
Total Dry N	2,952	6.0	57%	2,197	4.5	55%	2,048	4.2	56%
Wet Oxidized	1,051	2.2	20%	607	1.2	15%	428	0.9	12%
Wet Reduced	1,157	2.4	22%	1,184	2.4	30%	1,192	2.4	33%
Total Wet N	2,208	4.5	43%	1,791	3.7	45%	1,620	3.3	44%
Total Oxidized	3,328	6.8	64%	1,909	3.9	48%	1,325	2.7	36%
Total Reduced	1,832	3.7	36%	2,079	4.3	52%	2,343	4.8	64%
Total Nitrogen	5,160	10.6	100%	3,988	8.2	100%	3,668	7.5	100%

[a] Total pounds presented are in thousands.

When evaluating wet and dry deposition loads, it is important that these loads be considered within the context of the complex reactions and processes that occur on the landscape, particularly within the tree canopy and soil layers. In terms of nutrient fate, transport, and the potential to cause eutrophication in downstream waterbodies, annual deposition loads, such as those presented in Table 4-2, are considered distinctly different than unit area loads from land uses and other traditional nonpoint sources.

Table 4-2 presents several interesting findings on the change of oxidized vs. reduced and wet vs. dry nitrogen fraction of the total amount of nitrogen deposited in the Falls Lake watershed, as well as the changes in these relationships that can be expected over the next several years (2010 and 2020 scenarios). The 2001 average estimates of total nitrogen show total oxidized nitrogen (6.8 lb/acre/yr) to be about twice as high as the total reduced fraction (3.74 lb/acre/yr). This relationship changes in the 2010 scenario based on an anticipated large reduction in total oxidized nitrogen (from 6.8 to 3.9 lb/acre/yr) and an increase in total reduced nitrogen (from 3.74 to 4.25 lb/acre/yr). As a result, in the 2010 scenario, more than one-half of the total nitrogen is accounted for in the reduced fraction. Under the 2020 scenario, reduced nitrogen has increased (4.79 lb/acre/yr) while oxidized nitrogen has decreased (2.71 lb/acre/yr), resulting in a situation where the reduced fraction is twice as large as the oxidized fraction.

While significant changes in the proportions of oxidized and reduced nitrogen fractions occur among the 2001, 2010, and 2020 scenarios, both wet and dry deposition totals are estimated to decline over time. Wet deposition is expected to decline by 19% between the 2001 and 2010 scenarios and 27% between the 2001 and 2020 scenarios. Dry deposition is expected to decline by 26% between the 2001 and 2010 scenarios and 31% between the 2001 and 2020 scenarios. In all three scenarios, dry deposition accounts for 55–57% of the total deposition, whereas, wet deposition accounts for 43–45% of the total deposition.

As previously discussed, WDT deposition loading estimates are not of direct use as input in the Falls Lake WARMF model which requires estimates of pollutant concentration (not load). However, the WDT was used to evaluate deposition in areas where dry deposition data (CASTNET and NCDAQ data) are present. The purpose of this evaluation was to identify a primary station or source of dry deposition data for WARMF. As mentioned in Section 3.3, the NCDAQ station at Millbrook (Wake County) provides the best available data for reactive nitrogen oxides and sulfur dioxide. The remaining model input needs include dry deposition concentrations for nitrate, ammonia, and sulfate. Two CASTNET stations (CND125 and PED108) and one NCDAQ station (Lenoir Community College) were identified as active stations that are available to fulfill these information needs. The CASTNET stations provide estimates (modeled) for dry deposition of nitrate, ammonia, and sulfate, whereas, the NCDAQ station provides measured ambient data for ammonia only.

To compare deposition between the Falls Lake and three air stations, the WDT was used to identify HUC-8 watersheds in which the three stations are located and to provide estimates of annual deposition rates (lb/acre/year) in those watersheds. Figure 4-1 is a map of the watershed areas selected for this analysis. It should be noted that the watershed areas vary in size and were selected primarily on the basis of the location of the air stations. Hence, comparisons were based on a unit area deposition rate (lb/acre/year) in each watershed, thus reducing the relative importance of comparing watersheds of the same size. Watershed size is an important factor when deposition concentrations vary considerably throughout the watershed. In the case of the two CASTNET sites very little evidence of deposition variability within the watersheds was evident. However, 2001 deposition estimates in the Lenoir Community College HUC-8 showed significant variability, primarily in reduced-N totals. In general, western portions of the watershed had higher deposition concentrations than the eastern portions. Because the NCDAQ site is located close to the middle of this HUC, the information provided by the WDT for the NCDAQ watershed area remains useful and relevant to this discussion. However, caution should be taken when using the data for purposes other than a general comparison.

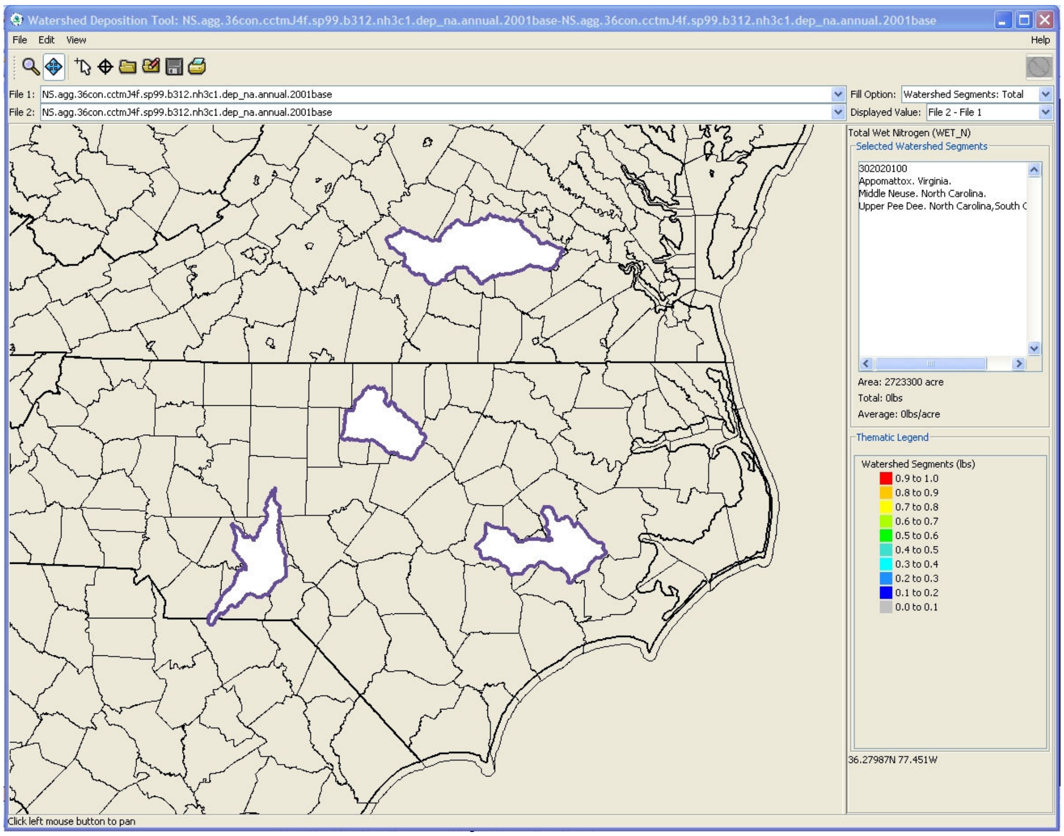

Figure 4-1 Watersheds selected to compare dry deposition of nitrate, ammonia, sulfate, and SO_x in the Falls Lake watershed with deposition in watersheds in which select CASTNET and NCDAQ stations are located

Table 4-3 provides a summary of WDT 2001 deposition estimates for N and S in the Falls Lake watershed and three air station watersheds as well as a comparison of estimates at each watershed to Falls Lake estimates. Of the three, the Appomattox Watershed, in which the Prince William Station is located, is the station that most closely matches deposition estimates in the Falls Lake watershed. With the exception of total dry sulfide, all resultant deposition totals estimated in the Appomattox watershed were within 10% of the values estimated in Falls Lake. Of most importance to obtaining WARMF inputs, dry deposition estimates in the Appomattox watershed were found to be only 9% higher for dry oxidized N and less than 1% lower than dry reduced N than estimates in Falls Lake. In comparison, the concentration of dry reduced nitrogen in the Upper Pee Dee and Middle Neuse watersheds was found to be 207% and 316%

higher, respectively, than the concentration in the Falls Lake watershed. Dry oxidized nitrogen estimates in the Falls Lake watershed were also more similar to estimates in the Appomattox watershed than to estimates in the Upper Pee Dee and Middle Neuse.

Table 4-3 Average nitrogen deposition estimates as determined by the WDT for Falls Lake, Upper Pee Dee, Appomattox, and Middle Neuse watersheds based on 2001 CMAQ model runs

	Average Annual Deposition and Percent Relative to Deposition in the Falls Lake Watershed using 2001 CMAQ Deposition Estimates						
Station/Location	**Falls Lake, NC**	**CASTNET, CND125, Candor, NC**		**CASTNET, PED108, Prince Edward, VA**		**NCDAQ, Lenoir Community College, Kinston, NC**	
Watershed	**Upper Neuse**	**Upper Pee Dee**		**Appomattox**		**Middle Neuse**	
Units	**lb/acre**	**lb/acre**	**% Diff.**	**lb/acre**	**% Diff**	**lb/acre**	**% Diff**
Dry Oxidized N	4.7	3.4	27%	5.1	9%	2.9	37%
Dry Reduced N	1.4	4.2	207%	1.4	1%	5.7	316%
Total Dry N	6.0	7.7	27%	6.4	7%	8.7	44%
Wet Oxidized N	2.1	2.1	1%	2.4	10%	1.7	23%
Wet Reduced N	2.4	3.7	55%	2.2	9%	4.2	76%
Total Wet N	4.5	5.8	29%	4.5	0%	5.8	29%
Total Oxidized N	6.8	5.6	18%	7.4	9%	4.6	33%
Total Reduced N	3.7	7.9	111%	3.5	6%	9.9	164%
Total Nitrogen	10.5	13.5	28%	11.0	4%	14.5	37%
Total Dry S	5.1	3.7	27%	6.0	17%	3.4	33%
Total Wet S	6.3	6.5	4%	6.6	5%	5.6	11%
Total Sulfur	11.4	10.3	10%	12.6	10%	9.0	21%

5 Data Availability and Gaps

Per NCDWQ, the Falls Lake WARMF model will be calibrated using 2005-2006 data and validated using 2007 data. Data from 2004 will be used as a model "start-up" period to allow the model to self-adjust to various model inputs and reactions. WARMF requires that the atmospheric chemistry file be complete and contain no missing data. In general, weekly data are available at NC41 and PED108 for most of the 2005-2007 study period, however, a portion of the data during this period are missing. NC41 is missing a total of 49 weeks of information. The majority of missing data occur between June 2007 and December 2007; a period for which information is not yet available. At PED108, 27 weeks of data are missing. Twenty-six of the 27 missing weeks (June 2007 - December 2007) are not yet available to the general public. Information at both the NC41 and PED108 sites for the later months of 2007 is expected to become available in May or June 2008 (personal communication with Brian Lee, USEPA).

CASTNET data is also unavailable for January 2004 through July 2004. Though 2004 data are less critical to the development of the model, inquiries were made with USEPA and their contractors to try to obtain more information on this gap. In a conversation between URS and USEPA on April 1, 2008, USEPA stated that they would try to find out specifically what had happened to the data. USEPA suggested that, in the absence of the data, weekly averages of data available for similar calendar weeks in the years prior to and after 2004 be used to estimate data for the missing period. In the event that the January-July 2004 data is located and provided to URS, it will be promptly provided to NCDWQ.

A variety of approaches have been used in modeling to estimate data for missing time periods and no single approach is appropriate under all circumstances or for all datasets. These approaches include, but are not limited to, simple approaches that rely on an average of data available before and after the missing date or an average based on a defined period of data (e.g. month or seasonal average) as a substitute for the missing period. These approaches are common and have been used in previous WARMF applications in North Carolina. Another simple approach used in a previous North Carolina WARMF application was to duplicate an entire year of data for the missing period. More complex approaches include those in which randomly selected values are drawn from a hypothesized parametric distribution of the available dataset.

The NC41 and PED108 datasets were evaluated to determine the presence of seasonality and other temporal trends with the purpose of determining a applicable approach to estimating missing values. In general, dry deposition data showed strong seasonal trends while wet deposition showed little to no seasonal trend. Based on these findings, and USEPA's direction, two approaches were used to estimate values for NC41 and PED108. In cases where only one or two values are missing out of a large period of available data, the missing value was estimated as the average of data available immediately before and after the missing period. In cases where long periods of information are missing (for example, more than two weeks at a time), weekly estimates were based on the average of data collected during the same calendar week in the 2000-2007 period. Using this approach, the estimated dataset maintained any inherent seasonal trend and the potential for very high or low outlier values was reduced. Appendix B includes the resulting model input dataset for WARMF and identifies data that are estimated using the two approaches.

6 Conclusions

The purpose of this report is to support the development of a Falls Lake WARMF model by providing NCDWQ with information and data related to nutrient loading from atmospheric sources. Specifically, this report provides a review of wet and dry nitrogen deposition data from stations in close proximity to the Falls Lake watershed, and an evaluation of USEPA's WDT.

The primary findings of this report are as follows:

1. NADP station NC41 (Finley Farms, Wake County, North Carolina) provides the best source of wet chemistry data necessary to support the WARMF model. NC41 data

include weekly concentrations for ammonia, calcium, magnesium, potassium, sodium, sulfate, nitrate, and chloride during the 2004–2007 study period. NC41 is located approximately 15 miles south of the lake and is maintained by North Carolina State University.

2. For dry chemistry inputs, CASTNET station PED108 (Prince Edward, Prince Edward County, Virginia) was found to be the best available source of weekly average data for sulfate, SO_x, NO_x, nitrate, and ammonia. The Prince Edward station is located approximately 65 miles north of the Falls Lake watershed in Prince Edward County, Virginia.

3. USEPA's WDT was used to evaluate seasonal and annual deposition of nitrogen in the Falls Lake watershed. The WDT was found to be a useful tool in understanding deposition spatially on an annual scale; however, the information provided by the tool is incompatible with the input requirements of WARMF. The WDT provides deposition estimates on an annual or seasonal basis (mass/year in the entire watershed and mass/unit area of the watershed). The WDT is valuable for comparing annual deposition estimates in the Falls Lake watershed to deposition estimates in watersheds in which other monitoring stations are located, including CASTNET Stations PED108 (Prince Edward, Virginia) and CND125 (Candor, North Carolina), and NCDAQ's Lenoir Community College. This evaluation found that, using the 2001 base CMAQ data set, all nitrogen deposition estimates for the PED108 watershed/region are within 10% of annual estimates found in the Falls Lake watershed. In contrast, Table 4-3 outlines a much greater divergence in nitrogen deposition estimates for the areas surrounding the CND125 and Lenoir Community College stations as compared to the WDT estimates for the Falls Lake watershed.

4. A summary list of recommended sources and data for use in supporting the Falls Lake WARMF model is provided in Table 6-1. Raw data inputs are provided in Appendix B.

Table 6-1 Recommended data and sources to support WARMF model rain and air chemistry inputs

Resultant Parameter	WARMF Input Units		Monitoring Station Network, Station ID, and Lab Measurement for Falls Lake WARMF Model	
	Wet	Dry	Rain (Wet) Quality	Air (Dry) Quality
SO_x	µg/m^3	µg/m^3	Not Applicable	CASTNET, PED108, wso2
NO_x	µg/m^3	µg/m^3	Not Applicable	CASTNET, PED108, nhno3
Ammonium[a]	mg/l N	µg/m^3 N	NADP, NC41, nh4	CASTNET, PED108, tnh4
Ca	mg/l	µg/m^3	NADP, NC41, ca	Not Applicable
Mg	mg/l	µg/m^3	NADP, NC41, mg	Not Applicable
K	mg/l	µg/m^3	NADP, NC41, k	Not Applicable
Na	mg/l	µg/m^3	NADP, NC41, na	Not Applicable
SO_4[a]	mg/l S	µg/m^3 S	NADP, NC41, so4	CASTNET – PED108, nso4
NO_3[a]	mg/l N	µg/m^3 N	NADP, NC41, no3	CASTNET – PED108, tno3
Cl	mg/l	µg/m^3	NADP, NC41, cl	Not Applicable

[a] To obtain model inputs, data are translated to determine concentrations as S and N. For example, measurements for NO_3 are multiplied by the fraction 14.0067/(3*15.9994), where 14.0067 and 15.9994 are the atomic weights of nitrogen and oxygen, respectively.

7 References

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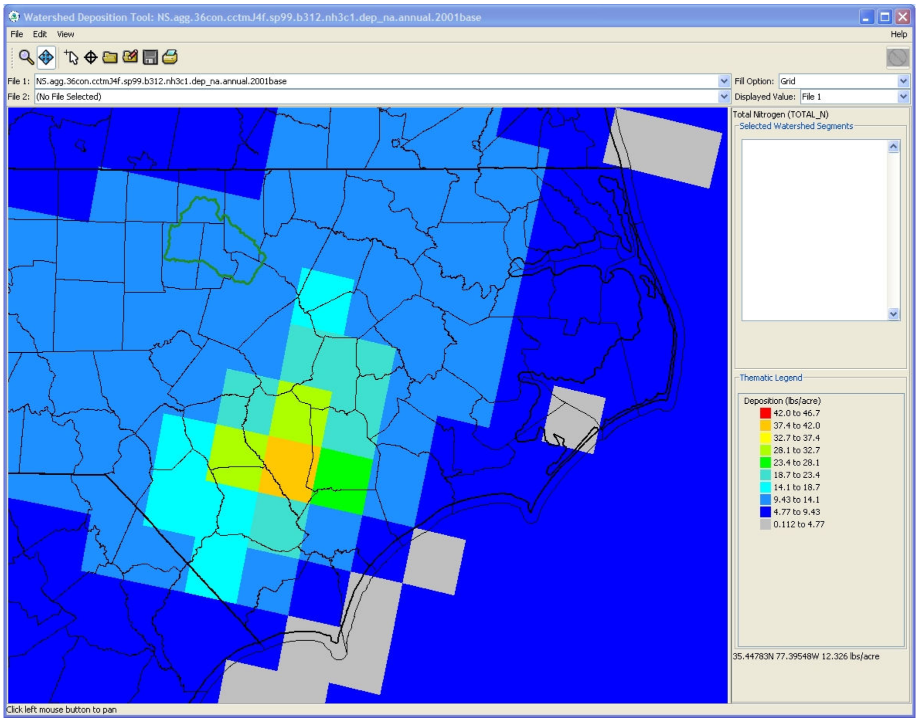
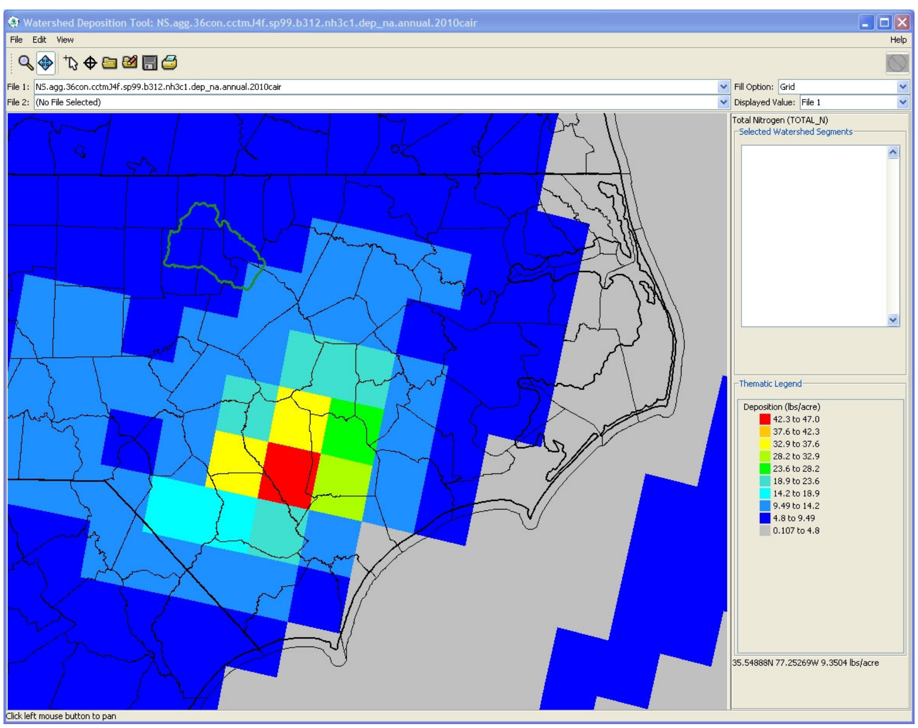
Appendix A

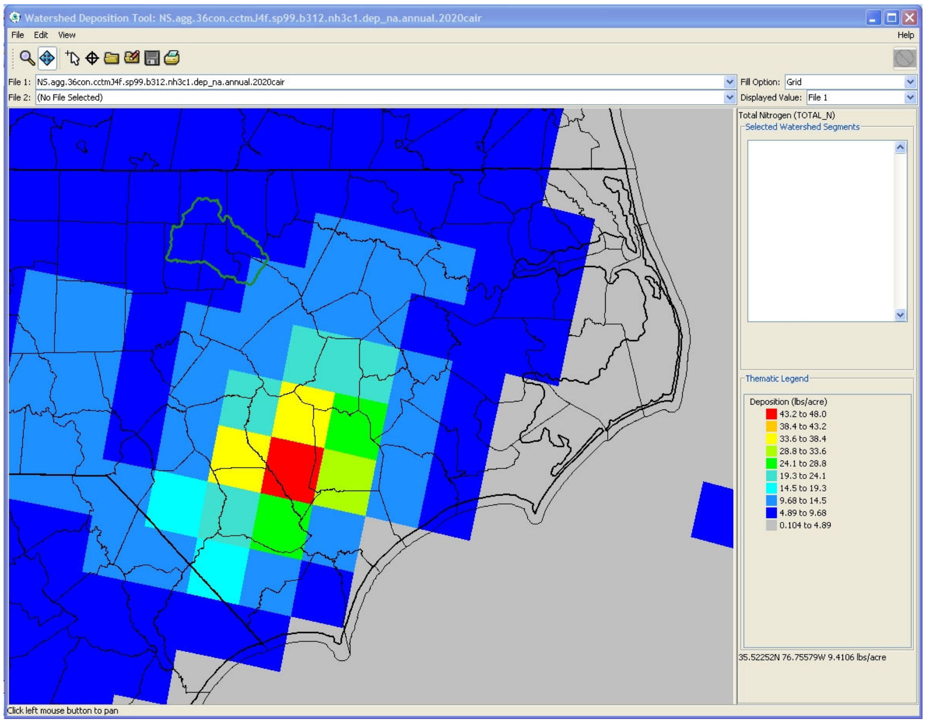
N-Deposition in Falls Lake Watershed as Estimated using the Watershed Deposition Tool



Watershed Deposition Tool estimate for Total Nitrogen Deposition in Central and Eastern North Carolina using the CMAQ 2001 data set.



Watershed Deposition Tool estimate for Total Nitrogen Deposition in Central and Eastern North Carolina using the CMAQ 2010 data set.



Watershed Deposition Tool estimate for Total Nitrogen Deposition in Central and Eastern North Carolina using the CMAQ 2020 data set.

Appendix B

Air Chemistry Data for the Falls Lake WARMF Model

Summary of Air Chemistry Data for Use in the Falls Lake WARMF Model

Information provided in this Appendix includes data from CASTNET and NADP stations. Cells that are not highlighted are weekly average measurements or model estimates (in the case of CASTNET data). Cells that are highlighted tan or green are dates on which no data are available. Data in Tan-colored cells were estimated using weekly average data from the weeks prior to and after the period of missing information. Data in Green-colored cells were estimated using the average of data available during the same month and week during 2000-2007 for the respective CASTNET and NADP stations. NADP Data after 10/30/2007 and PED108 data after 6/19/2007 have not been released. If this information becomes available in time to be used in the WARMF model, URS will supply an updated dataset. In the interim, estimates are provided.

Last Updated: April 4, 2008

Input	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Air	Air	Air	Air	Air
Station ID	NC41	NC41	NC41	NC41	NC41	NC41	NC41	NC41	PED108	PED108	PED108	PED108	PED108
Parameter	Ca	Mg	K	Na	NH4 as N	NO3 as N	Cl	SO4 as S	NO3 as N	NH4 as N	SO4 as S	SOx as SO2	NOx as NO2
Date/Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
12/30/2003	0.04	0.01	0.01	0.05	0.13	0.08	0.12	0.17	0.09	0.52	0.30	6.89	1.12
1/6/2004	0.05	0.00	0.00	0.02	0.17	0.39	0.07	0.09	0.29	0.73	0.32	11.64	1.13
1/13/2004	0.06	0.03	0.02	0.30	0.23	0.29	0.65	0.61	0.13	0.71	0.39	6.70	1.13
1/20/2004	0.06	0.06	0.03	0.50	0.17	0.21	1.00	0.43	0.22	0.81	0.37	10.24	1.38
1/28/2004	0.05	0.08	0.04	0.70	0.12	0.12	1.35	0.25	0.15	0.65	0.29	7.88	1.08
2/3/2004	0.06	0.05	0.03	0.46	0.26	0.13	0.77	0.34	0.14	0.74	0.31	6.53	1.28
2/10/2004	0.05	0.01	0.01	0.07	0.23	0.30	0.16	0.54	0.14	0.77	0.20	8.40	1.44
2/17/2004	0.13	0.04	0.04	0.31	0.78	0.44	0.43	0.99	0.11	0.80	0.23	6.15	1.17
2/24/2004	0.06	0.01	0.01	0.14	0.17	0.22	0.23	0.23	0.10	0.82	0.22	5.42	1.34
3/2/2004	0.22	0.05	0.06	0.25	0.65	0.46	0.54	0.74	0.09	0.73	0.16	7.02	1.27
3/9/2004	0.16	0.06	0.04	0.41	0.44	0.62	0.72	0.96	0.13	0.81	0.16	6.70	1.50
3/16/2004	0.12	0.02	0.03	0.03	0.50	0.45	0.10	0.84	0.13	0.83	0.18	4.75	1.22
3/23/2004	0.87	0.23	0.17	1.30	1.65	3.27	1.88	3.37	0.14	1.00	0.20	4.78	1.51
3/30/2004	0.07	0.02	0.02	0.09	0.17	0.32	0.17	0.34	0.05	0.89	0.24	4.60	1.46
4/6/2004	0.12	0.05	0.05	0.36	0.67	0.40	0.60	0.82	0.06	0.87	0.23	3.98	1.52
4/13/2004	0.06	0.02	0.05	0.13	0.12	0.17	0.24	0.26	0.09	0.78	0.25	2.89	1.10
4/20/2004	0.06	0.02	0.01	0.09	0.18	0.18	0.16	0.41	0.10	0.84	0.25	2.92	1.12
4/27/2004	0.03	0.01	0.02	0.11	0.20	0.13	0.20	0.20	0.05	0.84	0.19	2.85	1.22
5/4/2004	0.15	0.05	0.01	0.29	0.28	0.37	0.52	0.39	0.08	1.16	0.23	3.41	1.48
5/11/2004	0.26	0.08	0.01	0.47	0.36	0.62	0.85	0.58	0.04	1.03	0.21	2.50	1.04
5/18/2004	0.06	0.01	0.02	0.07	0.28	0.20	0.13	0.65	0.04	1.19	0.21	1.95	1.05
5/25/2004	0.03	0.01	0.03	0.09	0.15	0.11	0.16	0.32	0.05	1.03	0.23	1.88	0.90
6/1/2004	0.06	0.01	0.02	0.04	0.30	0.33	0.11	0.47	0.03	1.21	0.25	1.51	0.82
6/8/2004	0.07	0.03	0.02	0.21	0.30	0.26	0.41	0.58	0.02	1.20	0.21	1.82	0.92
6/15/2004	0.16	0.09	0.11	0.68	0.44	0.42	1.33	0.89	0.03	2.56	0.30	4.20	1.89
6/22/2004	0.05	0.01	0.01	0.04	0.17	0.24	0.10	0.46	0.02	1.42	0.28	2.26	1.09
6/29/2004	0.05	0.02	0.07	0.04	0.47	0.18	0.10	1.03	0.02	1.33	0.22	1.94	0.87
7/6/2004	0.14	0.02	0.03	0.03	0.68	0.39	0.12	0.79	0.01	1.82	0.25	2.23	0.92
7/13/2004	0.07	0.02	0.02	0.08	0.29	0.27	0.18	0.63	0.01	1.07	0.25	1.77	0.77
7/20/2004	0.09	0.01	0.02	0.01	0.56	0.43	0.12	1.41	0.03	2.17	0.31	1.03	0.54
7/27/2004	0.03	0.02	0.30	0.18	0.26	0.10	0.33	0.12	0.02	0.75	0.17	0.34	0.35
8/3/2004	0.02	0.00	0.00	0.00	0.11	0.09	0.05	0.37	0.01	1.87	0.32	1.82	0.54
8/10/2004	0.05	0.02	0.20	0.03	0.39	0.07	0.08	0.18	0.02	1.70	0.28	1.48	0.56
8/17/2004	0.02	0.00	0.00	0.01	0.08	0.09	0.04	0.28	0.01	2.12	0.36	2.19	0.84
8/24/2004	0.02	0.01	0.01	0.14	0.21	0.06	0.25	0.18	0.03	1.44	0.22	0.97	0.57

Input	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Air	Air	Air	Air	Air
Station ID	NC41	NC41	NC41	NC41	NC41	NC41	NC41	NC41	PED108	PED108	PED108	PED108	PED108
Parameter	Ca	Mg	K	Na	NH4 as N	NO3 as N	Cl	SO4 as S	NO3 as N	NH4 as N	SO4 as S	SOx as SO2	NOx as NO2
Date/Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
8/31/2004	0.03	0.01	0.05	0.05	0.09	0.12	0.11	0.22	0.05	1.72	0.28	1.61	0.58
9/7/2004	0.05	0.05	0.03	0.45	0.30	0.13	0.76	0.25	0.02	1.51	0.18	0.90	0.43
9/14/2004	0.04	0.03	0.03	0.19	0.16	0.12	0.33	0.22	0.02	0.87	0.21	0.59	0.46
9/21/2004	0.08	0.11	0.06	0.96	0.33	0.12	1.69	0.31	0.06	1.24	0.25	1.64	0.62
9/28/2004	0.07	0.02	0.02	0.20	0.49	0.34	0.32	0.72	0.03	2.24	0.22	0.93	0.74
10/5/2004	0.07	0.05	0.21	0.15	0.94	0.25	0.24	0.61	0.03	1.19	0.22	2.95	0.87
10/12/2004	0.06	0.07	0.40	0.10	1.39	0.15	0.16	0.50	0.02	0.72	0.24	1.99	0.84
10/19/2004	0.06	0.02	0.03	0.11	0.28	0.60	0.26	0.89	0.21	1.11	0.18	1.48	0.34
10/26/2004	0.08	0.03	0.03	0.23	0.40	0.55	0.40	0.91	0.03	1.58	0.34	5.92	1.40
11/2/2004	0.10	0.05	0.03	0.35	0.53	0.51	0.55	0.94	0.04	0.58	0.34	5.26	0.74
11/9/2004	0.02	0.02	0.01	0.18	0.14	0.08	0.34	0.14	0.07	0.44	0.27	3.93	0.66
11/16/2004	0.04	0.00	0.01	0.02	0.34	0.17	0.05	0.39	0.16	1.29	0.24	3.89	0.80
11/23/2004	0.04	0.01	0.01	0.12	0.17	0.09	0.22	0.24	0.04	0.63	0.26	2.04	0.45
11/30/2004	0.03	0.01	0.01	0.11	0.13	0.13	0.20	0.38	0.09	0.59	0.30	5.83	0.90
12/7/2004	0.04	0.01	0.02	0.14	0.16	0.13	0.22	0.33	0.02	0.65	0.24	2.96	0.60
12/14/2004	0.25	0.02	0.04	0.03	0.56	1.18	0.28	0.57	0.14	0.56	0.26	11.31	1.16
12/21/2004	0.04	0.04	0.04	0.37	0.13	0.10	0.65	0.22	0.14	0.69	0.21	12.64	0.96
12/28/2004	0.13	0.04	0.04	0.28	0.38	0.73	0.52	0.51	0.16	0.93	0.28	12.25	1.70
1/4/2005	0.13	0.04	0.04	0.28	0.38	0.73	0.52	0.51	0.09	0.97	0.25	6.46	1.00
1/11/2005	0.02	0.02	0.01	0.18	0.05	0.02	0.32	0.05	0.17	0.72	0.30	7.21	1.22
1/18/2005	0.21	0.06	0.06	0.53	0.80	1.64	0.81	1.21	0.35	0.81	0.44	11.35	1.38
1/25/2005	0.02	0.00	0.01	0.08	0.08	0.07	0.15	0.17	0.38	0.93	0.31	9.36	1.16
2/1/2005	0.03	0.01	0.01	0.10	0.14	0.13	0.17	0.42	0.38	1.08	0.41	11.67	2.00
2/8/2005	0.18	0.04	0.07	0.26	0.90	0.57	0.41	1.00	0.19	0.73	0.23	6.43	0.96
2/15/2005	0.08	0.01	0.02	0.05	0.66	0.32	0.09	0.77	0.23	1.01	0.23	7.01	0.95
2/22/2005	0.03	0.01	0.01	0.08	0.22	0.19	0.16	0.44	0.06	1.38	0.24	9.36	1.95
3/1/2005	0.05	0.01	0.01	0.04	0.21	0.12	0.06	0.30	0.04	0.84	0.25	7.86	1.50
3/8/2005	0.31	0.03	0.05	0.11	0.55	0.47	0.18	0.89	0.09	0.79	0.21	6.43	1.51
3/15/2005	0.03	0.00	0.01	0.01	0.30	0.22	0.03	0.57	0.35	1.91	0.39	6.40	2.42
3/22/2005	0.08	0.05	0.10	0.40	0.36	0.17	0.70	0.41	0.15	1.64	0.28	6.75	2.47
3/29/2005	0.13	0.01	0.03	0.05	0.29	0.26	0.13	0.48	0.02	0.86	0.33	3.79	1.36
4/5/2005	0.16	0.03	0.03	0.14	0.36	0.36	0.29	0.64	0.10	0.73	0.29	4.06	1.93
4/12/2005	0.18	0.05	0.10	0.27	0.35	0.34	0.45	0.65	0.23	0.65	0.34	4.96	1.45
4/19/2005	0.25	0.04	0.02	0.08	0.55	0.49	0.17	1.01	0.05	1.55	0.34	3.18	1.70
4/26/2005	0.10	0.01	0.02	0.04	0.23	0.24	0.11	0.49	0.04	0.97	0.32	2.16	1.10
5/3/2005	0.05	0.01	0.01	0.03	0.13	0.11	0.07	0.21	0.04	1.55	0.34	4.11	2.08
5/10/2005	0.18	0.02	0.02	0.04	0.61	0.57	0.13	1.26	0.03	1.51	0.37	2.42	1.52
5/17/2005	0.13	0.04	0.03	0.22	0.55	0.42	0.35	0.92	0.02	1.83	0.33	1.91	1.34
5/24/2005	0.07	0.02	0.02	0.13	0.57	0.28	0.21	0.57	0.02	1.22	0.36	2.30	1.05
5/31/2005	0.01	0.00	0.01	0.04	0.59	0.15	0.07	0.21	0.01	1.65	0.31	1.19	0.84
6/7/2005	0.06	0.01	0.01	0.05	0.52	0.34	0.12	0.80	0.02	0.83	0.31	2.30	0.84
6/14/2005	0.50	0.09	0.15	0.15	1.52	1.26	0.56	2.98	0.02	1.19	0.29	1.08	0.78
6/21/2005	0.27	0.05	0.10	0.09	0.94	0.68	0.33	1.64	0.01	1.79	0.35	1.86	1.29
6/28/2005	0.03	0.01	0.05	0.03	0.35	0.10	0.09	0.29	0.03	2.11	0.34	2.41	1.01
7/5/2005	0.08	0.02	0.01	0.09	0.17	0.13	0.16	0.36	0.01	2.35	0.36	1.51	0.88
7/12/2005	0.04	0.01	0.01	0.03	0.20	0.20	0.13	1.01	0.01	1.45	0.52	3.31	0.90
7/19/2005	0.07	0.01	0.01	0.03	0.21	0.30	0.09	0.78	0.01	1.94	0.32	1.90	0.90
7/26/2005	0.05	0.01	0.01	0.03	0.45	0.37	0.09	0.44	0.01	1.95	0.30	1.67	0.91
8/2/2005	0.08	0.02	0.05	0.06	0.20	0.21	0.14	0.40	0.01	2.72	0.29	2.37	1.07
8/9/2005	0.07	0.01	0.03	0.03	0.19	0.21	0.12	0.48	0.01	2.54	0.47	2.84	1.12
8/16/2005	0.07	0.01	0.01	0.01	0.18	0.22	0.10	0.56	0.01	1.74	0.27	1.35	0.81
8/23/2005	0.10	0.02	0.04	0.07	0.41	0.35	0.17	0.78	0.01	1.40	0.19	1.11	0.96
8/30/2005	0.03	0.01	0.01	0.04	0.15	0.16	0.10	0.27	0.02	1.48	0.25	1.84	0.77
9/6/2005	0.09	0.03	0.04	0.21	0.47	0.21	0.43	0.49	0.02	1.03	0.25	2.52	1.06

Input	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Air	Air	Air	Air	Air
Station ID	NC41	NC41	NC41	NC41	NC41	NC41	NC41	NC41	PED108	PED108	PED108	PED108	PED108
Parameter	Ca	Mg	K	Na	NH4 as N	NO3 as N	Cl	SO4 as S	NO3 as N	NH4 as N	SO4 as S	SOx as SO2	NOx as NO2
Date/Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
9/13/2005	0.24	0.22	0.09	1.89	0.47	0.43	2.96	1.12	0.02	1.50	0.31	1.94	1.12
9/20/2005	0.05	0.01	0.01	0.05	0.26	0.15	0.10	0.59	0.02	1.94	0.36	3.10	1.33
9/27/2005	0.03	0.01	0.01	0.10	0.23	0.11	0.19	0.40	0.03	0.80	0.30	3.17	1.06
10/4/2005	0.02	0.02	0.01	0.14	0.20	0.07	0.27	0.21	0.08	0.51	0.23	2.37	0.33
10/11/2005	0.09	0.04	0.16	0.12	0.43	0.25	0.29	0.76	0.02	1.01	0.37	2.42	0.70
10/18/2005	0.16	0.06	0.31	0.10	0.66	0.44	0.30	1.31	0.10	1.13	0.28	2.92	1.11
10/25/2005	0.16	0.04	0.13	0.11	0.49	0.31	0.24	0.79	0.02	0.76	0.31	4.41	0.83
11/1/2005	0.16	0.04	0.13	0.11	0.49	0.31	0.24	0.79	0.03	1.10	0.39	7.15	1.61
11/8/2005	0.35	0.04	0.03	0.10	0.65	0.47	0.15	0.91	0.12	0.80	0.39	5.66	1.18
11/15/2005	0.04	0.02	0.01	0.13	0.20	0.09	0.23	0.19	0.14	0.60	0.37	3.97	0.66
11/22/2005	0.04	0.07	0.02	0.64	0.14	0.06	1.17	0.20	0.13	0.43	0.23	4.67	0.84
11/29/2005	0.04	0.01	0.01	0.07	0.17	0.11	0.14	0.32	0.11	0.81	0.38	8.52	0.88
12/5/2005	0.03	0.01	0.01	0.07	0.22	0.13	0.13	0.34	0.05	0.78	0.33	9.09	1.50
12/13/2005	0.03	0.01	0.01	0.07	0.27	0.15	0.11	0.36	0.11	0.60	0.31	8.37	1.41
12/20/2005	0.07	0.09	0.08	0.76	0.51	0.26	1.38	0.57	0.05	0.53	0.25	11.67	1.91
12/27/2005	0.10	0.01	0.02	0.09	0.24	0.16	0.17	0.35	0.09	0.68	0.25	5.56	0.79
1/3/2006	0.23	0.02	0.03	0.03	1.06	1.68	0.22	1.43	0.04	0.75	0.32	6.89	1.42
1/10/2006	0.09	0.03	0.02	0.24	0.14	0.12	0.42	0.25	0.10	0.67	0.38	6.08	1.47
1/17/2006	0.06	0.03	0.02	0.26	0.21	0.11	0.46	0.37	0.09	0.56	0.35	7.83	1.15
1/24/2006	0.05	0.01	0.03	0.03	0.20	0.48	0.08	0.43	0.07	0.46	0.27	5.59	1.03
1/31/2006	0.10	0.06	0.03	0.47	0.21	0.12	0.83	0.27	0.02	0.81	0.30	5.00	1.19
2/7/2006	0.08	0.01	0.02	0.05	0.66	0.37	0.19	0.84	0.12	0.91	0.39	9.98	1.84
2/14/2006	0.27	0.04	0.12	0.16	0.38	0.39	0.34	1.21	0.14	0.76	0.26	8.96	1.62
2/21/2006	0.05	0.01	0.04	0.02	0.37	0.26	0.07	0.51	0.09	0.79	0.26	6.13	1.66
2/28/2006	0.16	0.02	0.06	0.03	0.82	1.13	0.31	1.25	0.22	0.94	0.31	13.49	1.86
3/7/2006	0.18	0.05	0.05	0.38	0.29	0.22	0.57	0.63	0.16	0.67	0.30	7.12	1.67
3/14/2006	0.06	0.01	0.01	0.01	0.21	0.14	0.06	0.38	0.11	0.58	0.17	7.25	1.03
3/21/2006	0.21	0.04	0.07	0.17	0.35	0.32	0.27	0.61	0.22	1.38	0.34	6.30	1.49
3/28/2006	0.21	0.04	0.07	0.17	0.35	0.32	0.27	0.61	0.02	1.74	0.35	5.69	2.38
4/4/2006	0.28	0.02	0.03	0.05	0.47	0.52	0.13	0.71	0.06	0.67	0.20	4.85	1.14
4/11/2006	0.32	0.07	0.18	0.26	0.44	0.42	0.31	0.73	0.10	0.87	0.28	3.59	1.27
4/18/2006	0.09	0.02	0.02	0.08	0.18	0.12	0.13	0.29	0.04	0.89	0.41	2.58	1.34
4/25/2006	0.17	0.03	0.21	0.06	1.00	0.24	0.15	0.67	0.06	0.63	0.27	3.66	1.32
5/2/2006	0.12	0.04	0.28	0.05	0.38	0.23	0.14	0.78	0.06	1.11	0.30	2.75	0.93
5/9/2006	0.08	0.01	0.02	0.01	0.30	0.13	0.05	0.45	0.03	1.10	0.25	2.10	0.88
5/16/2006	0.46	0.05	0.04	0.02	0.88	0.44	0.08	0.79	0.03	0.92	0.20	1.73	0.73
5/23/2006	0.40	0.04	0.07	0.06	0.49	0.37	0.12	0.62	0.01	1.44	0.34	3.28	1.13
5/30/2006	0.14	0.04	0.06	0.16	0.62	0.38	0.31	1.06	0.01	1.79	0.42	2.51	1.19
6/6/2006	0.01	0.00	0.00	0.01	0.06	0.02	0.02	0.04	0.01	1.41	0.21	1.64	0.89
6/13/2006	0.17	0.02	0.05	0.01	0.61	0.31	0.11	0.81	0.02	1.80	0.42	3.55	1.23
6/20/2006	0.10	0.03	0.03	0.20	0.56	0.31	0.39	0.52	0.02	1.09	0.23	1.17	0.87
6/27/2006	0.06	0.02	0.03	0.18	0.06	0.17	0.34	0.09	0.01	1.59	0.25	2.25	0.92
7/4/2006	0.06	0.01	0.02	0.04	0.29	0.15	0.09	0.62	0.01	1.64	0.41	4.22	1.04
7/11/2006	0.16	0.04	0.04	0.28	0.30	0.40	0.43	0.55	0.01	1.30	0.36	2.30	0.82
7/18/2006	0.15	0.02	0.05	0.03	0.35	0.39	0.14	0.88	0.01	1.61	0.41	3.03	0.86
7/25/2006	0.04	0.01	0.01	0.01	0.29	0.21	0.07	0.51	0.01	1.78	0.26	2.00	0.83
8/1/2006	0.22	0.03	0.04	0.10	0.40	0.67	0.25	1.40	0.01	1.99	0.32	1.84	0.96
8/8/2006	0.35	0.04	0.04	0.06	0.51	0.78	0.25	1.92	0.02	1.89	0.41	3.77	1.26
8/15/2006	0.51	0.11	0.09	0.22	0.69	0.74	0.49	1.40	0.01	1.21	0.29	1.76	0.92
8/22/2006	0.10	0.03	0.11	0.02	0.44	0.27	0.09	0.64	0.02	2.01	0.34	2.63	1.18
8/29/2006	0.02	0.00	0.00	0.03	0.14	0.09	0.05	0.20	0.01	0.78	0.25	1.28	0.45
9/5/2006	0.16	0.02	0.01	0.04	0.54	0.29	0.16	0.80	0.01	1.50	0.20	1.45	0.75
9/12/2006	0.04	0.03	0.07	0.25	0.26	0.08	0.46	0.19	0.01	1.34	0.23	2.13	0.75
9/19/2006	0.08	0.02	0.02	0.08	0.27	0.15	0.14	0.57	0.01	1.18	0.26	2.81	0.74

Input	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Air	Air	Air	Air	Air
Station ID	NC41	NC41	NC41	NC41	NC41	NC41	NC41	NC41	PED108	PED108	PED108	PED108	PED108
Parameter	Ca	Mg	K	Na	NH4 as N	NO3 as N	Cl	SO4 as S	NO3 as N	NH4 as N	SO4 as S	SOx as SO2	NOx as NO2
Date/Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
9/26/2006	0.07	0.01	0.01	0.03	0.17	0.14	0.06	0.41	0.01	1.13	0.22	2.26	0.70
10/3/2006	0.05	0.04	0.02	0.28	0.28	0.23	0.51	0.56	0.03	0.84	0.25	2.37	0.86
10/10/2006	0.06	0.02	0.01	0.17	0.21	0.21	0.27	0.49	0.06	0.60	0.19	2.10	0.70
10/17/2006	0.06	0.05	0.03	0.45	0.30	0.21	0.78	0.53	0.02	1.01	0.19	1.55	0.65
10/24/2006	0.03	0.01	0.01	0.06	0.22	0.14	0.14	0.35	0.02	0.61	0.20	2.50	0.74
10/31/2006	0.02	0.01	0.01	0.16	0.11	0.03	0.29	0.06	0.12	0.81	0.52	6.44	1.12
11/8/2006	0.02	0.00	0.01	0.02	0.09	0.10	0.05	0.32	0.05	0.88	0.55	2.72	0.96
11/14/2006	0.03	0.02	0.01	0.21	0.10	0.09	0.37	0.24	0.05	0.57	0.48	4.97	1.05
11/21/2006	0.03	0.02	0.01	0.23	0.09	0.07	0.40	0.22	0.05	0.42	0.64	5.50	1.36
11/28/2006	0.03	0.02	0.01	0.25	0.08	0.06	0.43	0.21	0.15	0.49	0.19	6.02	0.71
12/5/2006	0.04	0.05	0.03	0.50	0.18	0.08	0.87	0.26	0.13	0.43	0.22	9.50	1.89
12/12/2006	0.04	0.05	0.03	0.50	0.18	0.08	0.87	0.26	0.05	0.53	0.25	5.76	1.42
12/19/2006	0.02	0.01	0.02	0.13	0.13	0.05	0.23	0.16	0.13	0.55	0.30	6.90	0.98
12/26/2006	0.09	0.15	0.07	1.38	0.40	0.13	2.43	0.44	0.15	0.90	0.53	4.47	0.78
1/2/2007	0.03	0.02	0.01	0.17	0.12	0.06	0.30	0.21	0.11	0.47	0.61	2.31	0.62
1/9/2007	0.03	0.02	0.01	0.18	0.15	0.09	0.33	0.31	0.27	0.47	0.54	8.64	0.92
1/16/2007	0.03	0.02	0.01	0.18	0.18	0.12	0.36	0.40	0.09	0.51	0.54	4.65	0.67
1/23/2007	0.04	0.01	0.01	0.10	0.18	0.11	0.20	0.29	0.04	0.71	0.43	7.65	1.42
1/30/2007	0.05	0.00	0.01	0.01	0.17	0.09	0.04	0.17	0.21	0.79	0.55	5.14	1.25
2/6/2007	0.09	0.02	0.03	0.17	0.23	0.16	0.32	0.40	0.28	0.77	0.34	14.36	1.46
2/13/2007	0.13	0.04	0.05	0.33	0.29	0.22	0.61	0.62	0.17	0.69	0.60	7.88	1.22
2/20/2007	0.08	0.03	0.03	0.27	0.23	0.14	0.48	0.39	0.14	0.73	0.55	4.49	1.07
2/27/2007	0.04	0.02	0.02	0.20	0.17	0.06	0.35	0.16	0.09	0.76	0.21	5.13	1.18
3/6/2007	0.03	0.01	0.01	0.15	0.16	0.07	0.27	0.16	0.23	0.95	0.22	10.44	1.94
3/13/2007	0.02	0.01	0.01	0.10	0.15	0.09	0.19	0.15	0.06	1.03	0.22	6.24	1.45
3/20/2007	0.07	0.03	0.08	0.18	0.29	0.20	0.31	0.34	0.22	0.96	0.27	6.30	2.13
3/27/2007	0.07	0.03	0.08	0.18	0.29	0.20	0.31	0.34	0.07	0.83	0.30	7.06	1.64
4/3/2007	0.10	0.03	0.06	0.12	0.35	0.50	0.20	0.65	0.05	1.07	0.44	2.79	1.09
4/10/2007	0.13	0.07	0.24	0.34	0.49	0.14	0.59	0.41	0.03	1.13	0.44	1.83	0.90
4/17/2007	0.77	0.09	0.05	0.06	1.33	1.42	0.23	2.81	0.04	0.79	0.53	3.54	1.28
4/24/2007	0.15	0.06	0.04	0.49	0.28	0.18	0.81	0.46	0.05	1.04	0.26	2.54	1.50
5/1/2007	0.11	0.04	0.04	0.32	0.43	0.23	0.51	0.58	0.10	0.75	0.45	2.53	1.26
5/8/2007	0.07	0.02	0.03	0.14	0.58	0.29	0.22	0.71	0.03	0.80	0.44	1.29	0.82
5/15/2007	0.55	0.26	0.16	1.76	2.17	1.24	2.16	3.58	0.05	1.08	0.45	3.09	1.19
5/22/2007	0.28	0.13	0.08	0.92	1.18	0.65	1.16	1.83	0.12	1.03	0.41	1.90	1.17
5/29/2007	0.02	0.01	0.01	0.09	0.19	0.06	0.16	0.07	0.05	1.01	0.50	1.44	1.10
6/5/2007	0.19	0.03	0.03	0.03	0.54	0.31	0.11	1.26	0.01	1.34	0.43	1.25	1.17
6/12/2007	0.06	0.01	0.01	0.04	0.27	0.28	0.10	0.37	0.01	1.71	0.44	1.03	1.13
6/19/2007	0.16	0.04	0.06	0.18	0.52	0.44	0.40	0.96	0.01	1.50	0.45	2.65	0.98
6/26/2007	0.07	0.01	0.02	0.07	0.35	0.32	0.17	0.60	0.02	1.33	0.22	1.94	0.87
7/3/2007	0.05	0.01	0.03	0.06	0.22	0.16	0.13	0.41	0.01	1.82	0.25	2.23	0.92
7/10/2007	0.06	0.01	0.04	0.02	0.48	0.38	0.11	0.65	0.01	1.07	0.25	1.77	0.77
7/17/2007	0.02	0.00	0.01	0.01	0.09	0.09	0.03	0.19	0.02	2.12	0.34	2.42	1.22
7/24/2007	0.08	0.01	0.12	0.03	0.66	0.42	0.14	0.74	0.02	1.13	0.20	1.35	0.70
7/31/2007	0.04	0.01	0.07	0.05	0.35	0.28	0.12	0.47	0.01	1.59	0.28	1.96	0.90
8/7/2007	0.09	0.01	0.03	0.05	0.23	0.30	0.13	0.69	0.01	1.79	0.25	1.83	0.88
8/14/2007	0.17	0.02	0.07	0.05	0.39	0.45	0.15	0.96	0.01	1.53	0.23	1.57	0.80
8/21/2007	0.24	0.04	0.04	0.09	0.61	0.39	0.20	1.17	0.02	1.56	0.29	2.01	1.01
8/28/2007	0.10	0.02	0.04	0.07	0.41	0.35	0.17	0.78	0.03	1.15	0.21	1.24	0.58
9/4/2007	0.03	0.01	0.01	0.04	0.15	0.16	0.10	0.27	0.04	1.06	0.17	1.40	0.73
9/11/2007	0.02	0.00	0.01	0.04	0.22	0.10	0.08	0.16	0.04	1.19	0.28	2.14	0.78
9/18/2007	0.06	0.01	0.06	0.11	0.40	0.12	0.20	0.21	0.02	1.34	0.21	2.16	0.83
9/25/2007	0.05	0.02	0.09	0.17	0.41	0.11	0.30	0.15	0.04	0.91	0.21	1.84	0.71
10/2/2007	0.05	0.02	0.11	0.22	0.43	0.10	0.41	0.09	0.07	1.01	0.22	2.17	0.80

Input	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Rain	Air	Air	Air	Air	Air
Station ID	NC41	NC41	NC41	NC41	NC41	NC41	NC41	NC41	PED108	PED108	PED108	PED108	PED108
Parameter	Ca	Mg	K	Na	NH4 as N	NO3 as N	Cl	SO4 as S	NO3 as N	NH4 as N	SO4 as S	SOx as SO2	NOx as NO2
Date/Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
10/9/2007	0.04	0.02	0.03	0.16	0.28	0.13	0.31	0.31	0.05	0.78	0.20	2.37	0.73
10/16/2007	0.04	0.03	0.09	0.15	0.42	0.15	0.26	0.37	0.07	0.92	0.19	2.56	0.77
10/23/2007	0.02	0.01	0.01	0.10	0.10	0.04	0.20	0.08	0.05	0.93	0.29	4.28	0.95
10/30/2007	0.02	0.01	0.01	0.06	0.19	0.18	0.13	0.38	0.07	0.71	0.28	4.44	0.91
11/6/2007	0.04	0.02	0.02	0.15	0.32	0.37	0.26	0.53	0.09	0.70	0.25	4.51	0.96
11/13/2007	0.09	0.02	0.01	0.08	0.25	0.19	0.16	0.43	0.09	0.65	0.26	4.32	0.88
11/20/2007	0.03	0.02	0.01	0.14	0.18	0.12	0.26	0.26	0.13	0.61	0.20	4.65	0.74
11/27/2007	0.03	0.03	0.02	0.24	0.15	0.07	0.43	0.21	0.08	0.62	0.23	6.81	1.06
12/4/2007	0.05	0.01	0.01	0.10	0.22	0.30	0.21	0.35	0.14	0.72	0.23	6.12	1.06
12/11/2007	0.03	0.02	0.01	0.17	0.17	0.16	0.34	0.40	0.09	0.61	0.24	7.40	0.98
12/18/2007	0.08	0.03	0.02	0.28	0.26	0.33	0.54	0.42	0.12	0.60	0.24	7.11	0.88
12/25/2007	0.04	0.03	0.03	0.28	0.24	0.15	0.53	0.34	0.13	0.58	0.22	6.90	0.92

Appendix C: Ammonia, Nitrate, and TKN Calibration and Validation Plots:

Knap of Reeds Creek
Flat River – Above Lake Michie
Flat River – Below Lake Michie
Little River – Above Little River Reservoir
Little River – Below Little River Reservoir
Eno River
Ellerbe Creek

Knap of Reeds Creek

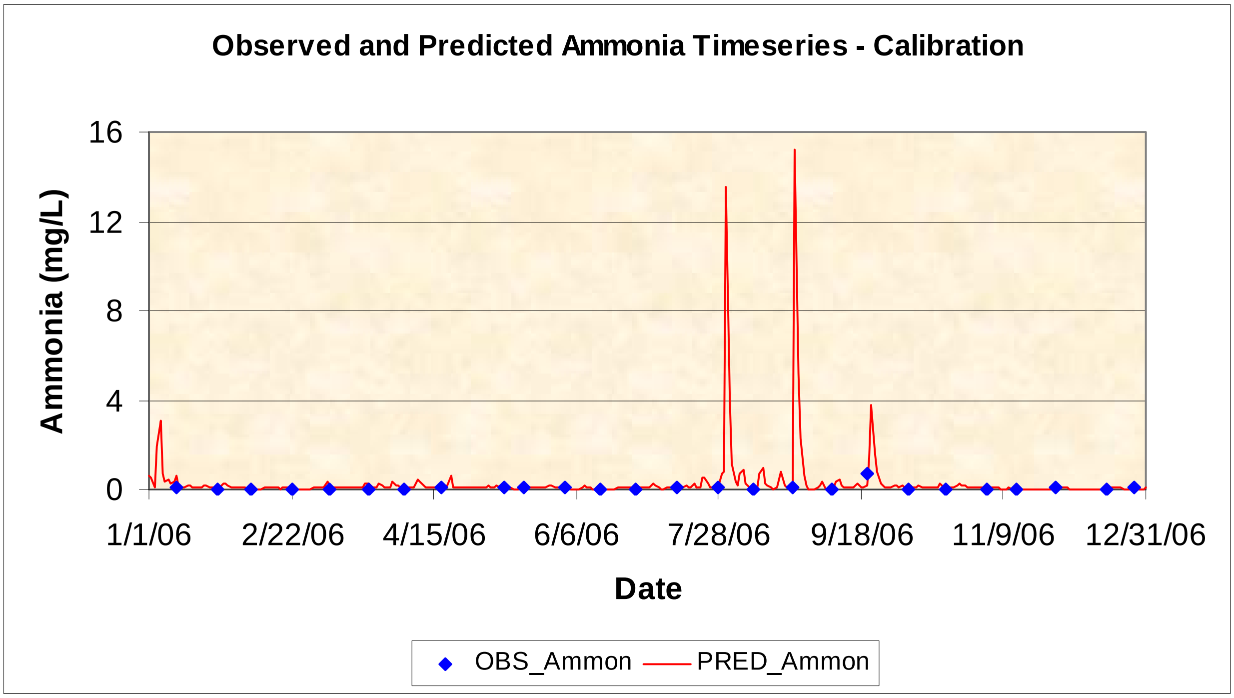


Figure KOR-C1. Calibration – Knap of Reeds Creek Ammonia concentrations daily time series.

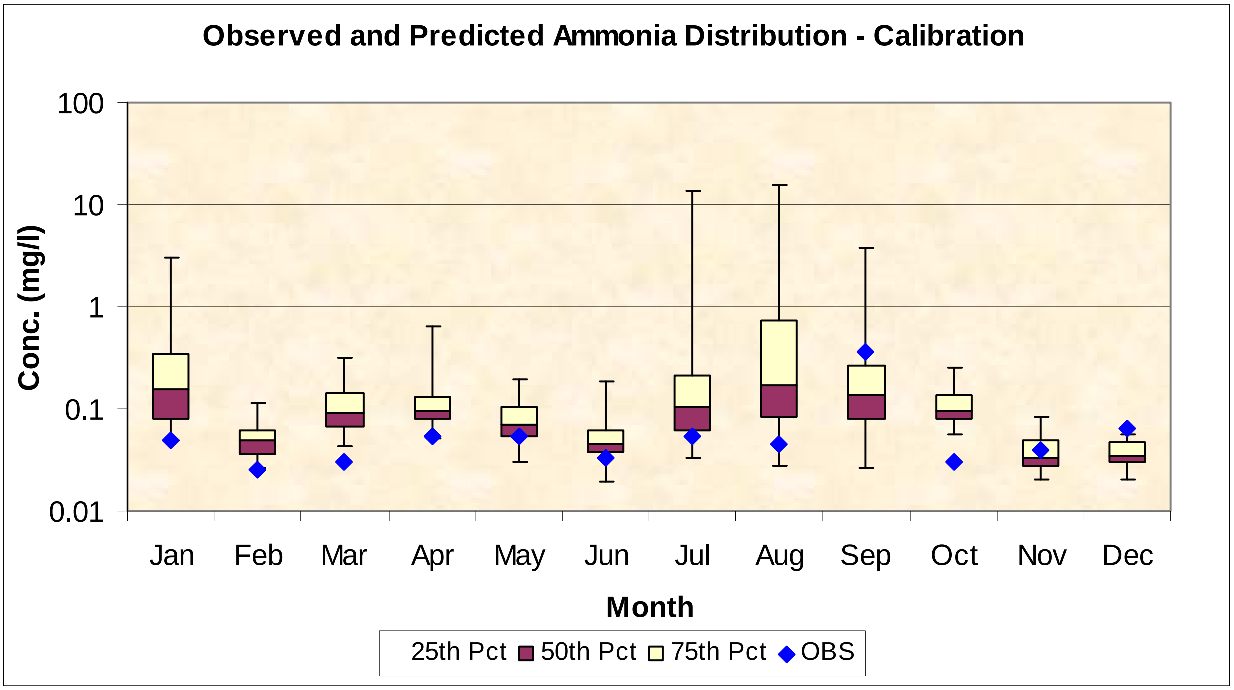


Figure KOR-C2. Calibration - Observed versus predicted Ammonia concentrations for Knap of Reeds Creek (shown in log scale).

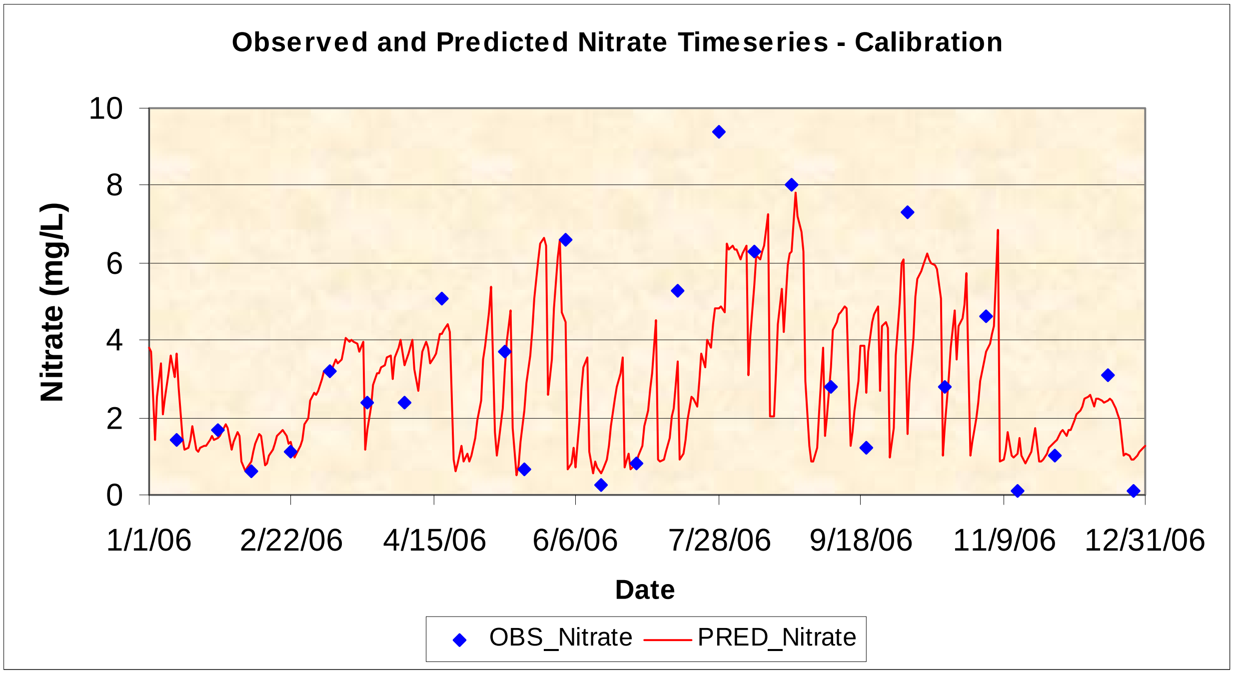


Figure KOR-C3. Calibration – Knap of Reeds Creek Nitrate concentrations daily time series.

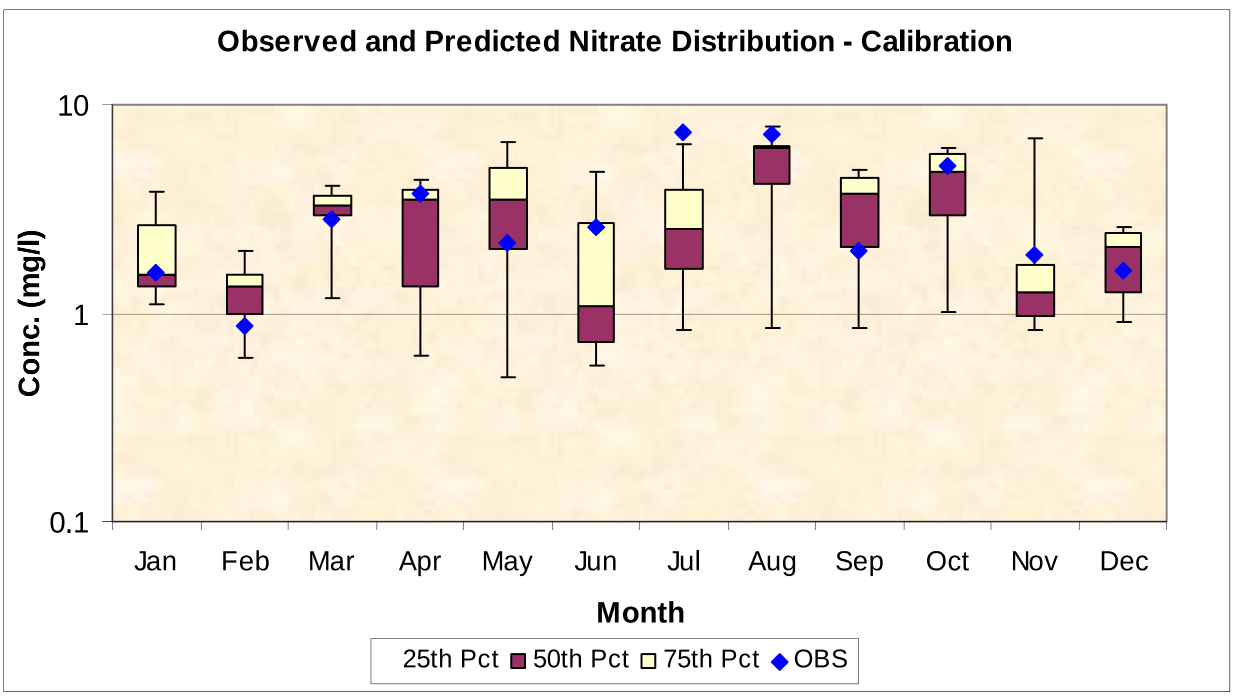


Figure KOR-C4. Calibration - Observed versus predicted Nitrate concentrations for Knap of Reeds Creek (shown in log scale).

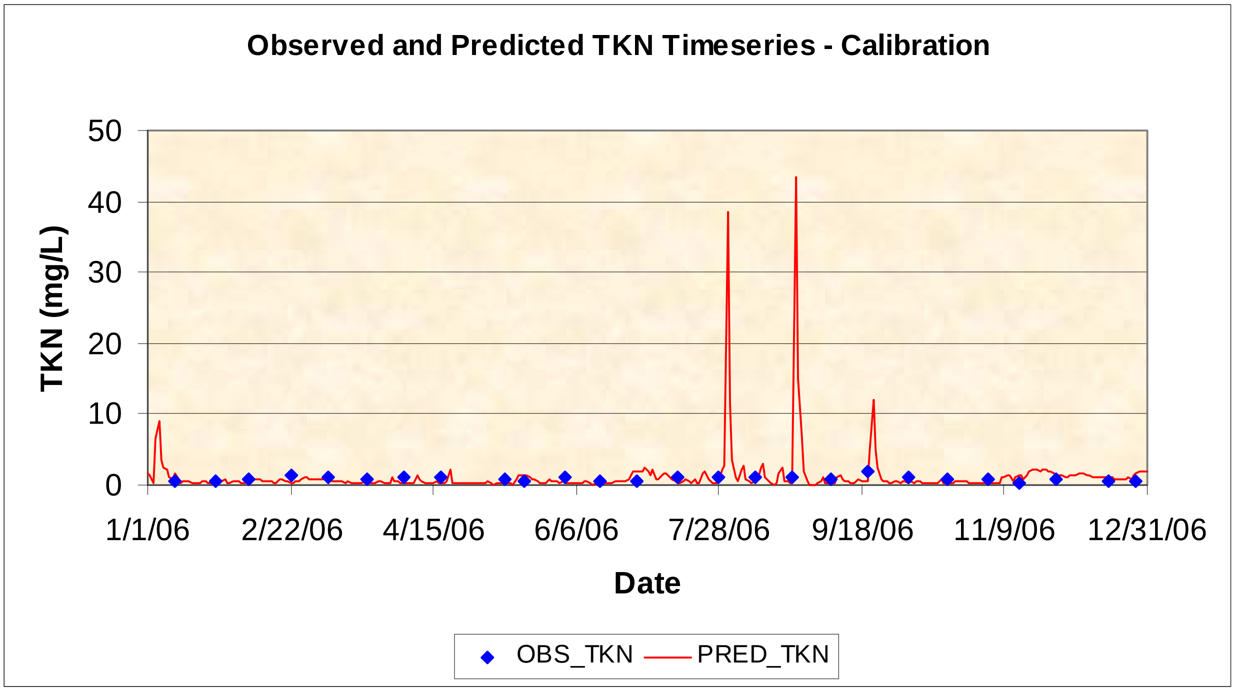


Figure KOR-C5. Calibration – Knap of Reeds Creek TKN concentrations daily time series.

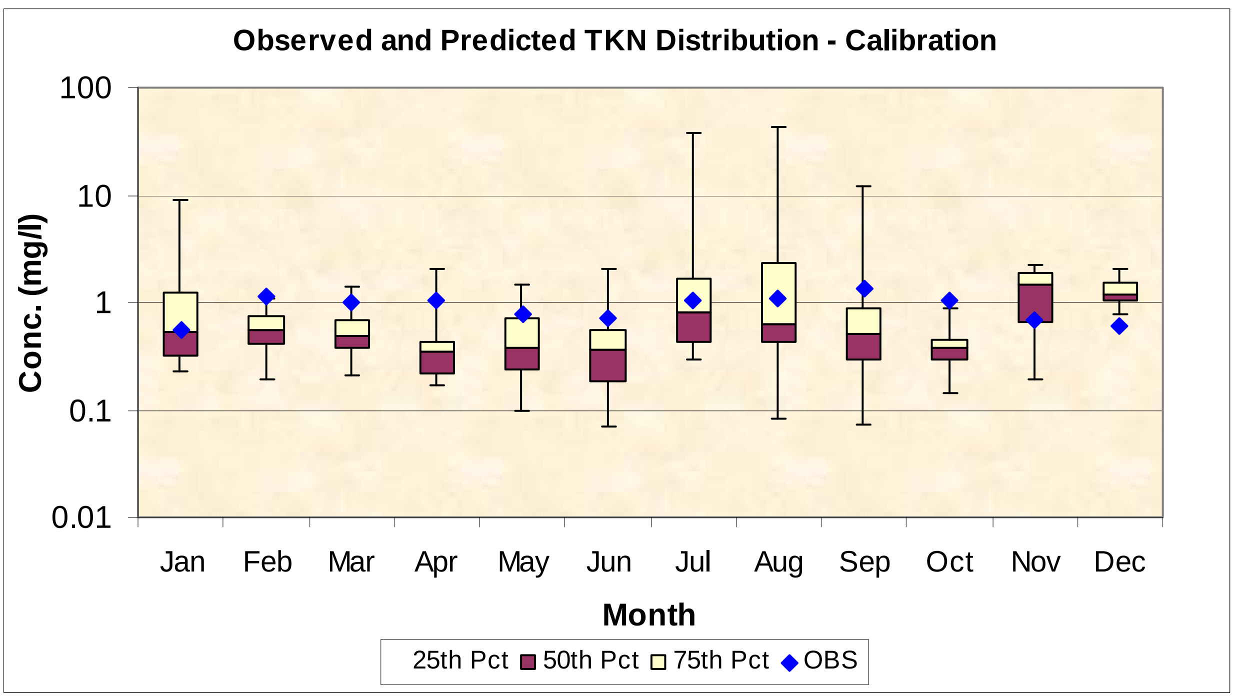


Figure KOR-C6. Calibration - Observed versus predicted TKN concentrations for Knap of Reeds Creek (shown in log scale).

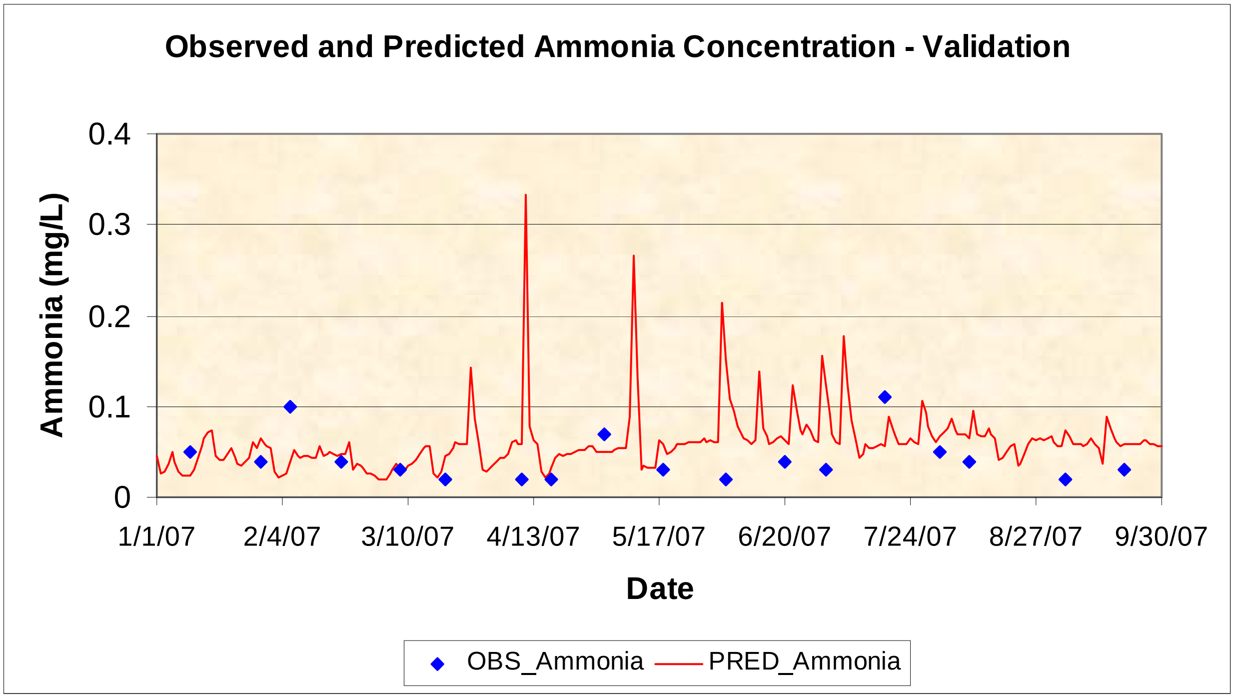


Figure KOR-C7. Validation – Knap of Reeds Creek Ammonia concentrations daily time series.

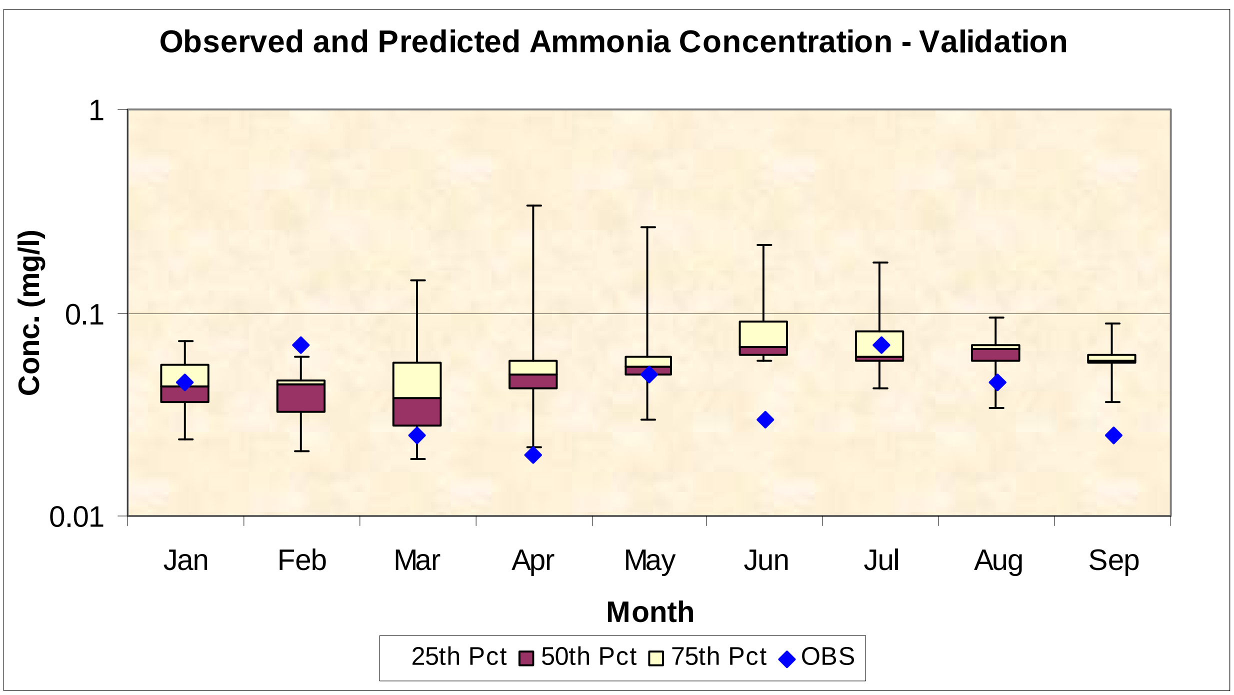


Figure KOR-C8. Validation - Observed versus predicted Ammonia concentrations for Knap of Reeds Creek (shown in log scale).

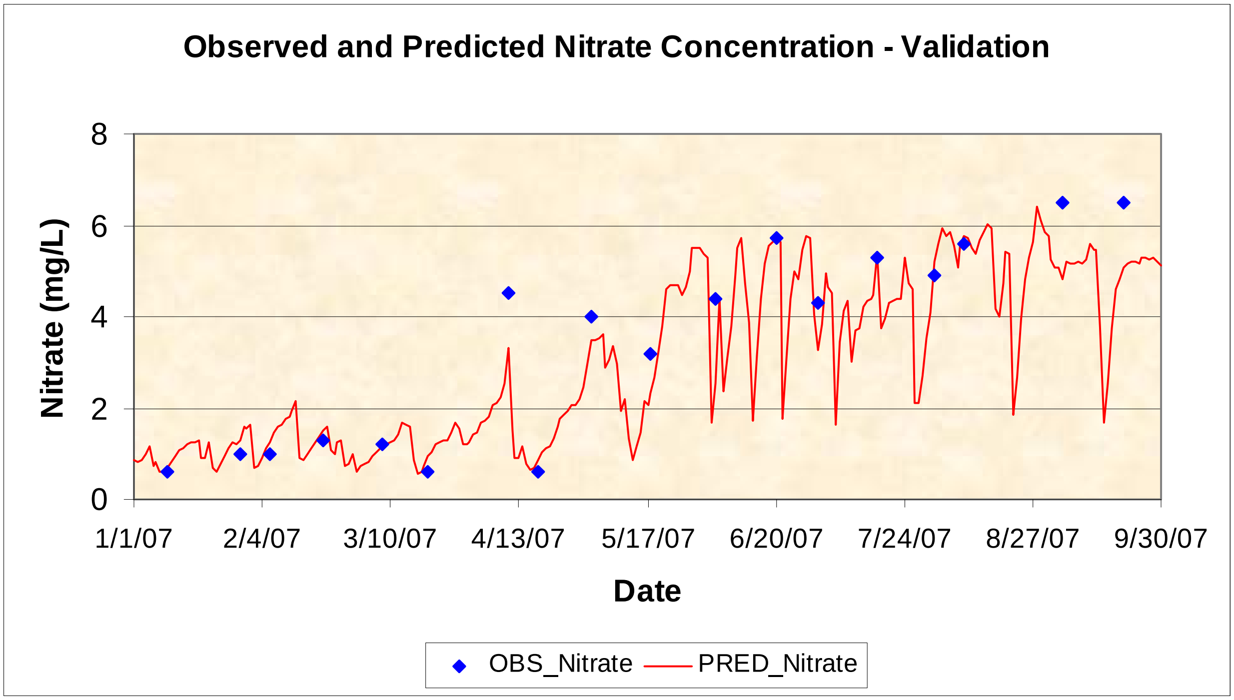


Figure KOR-C9. Validation – Knap of Reeds Creek Nitrate concentrations daily time series.

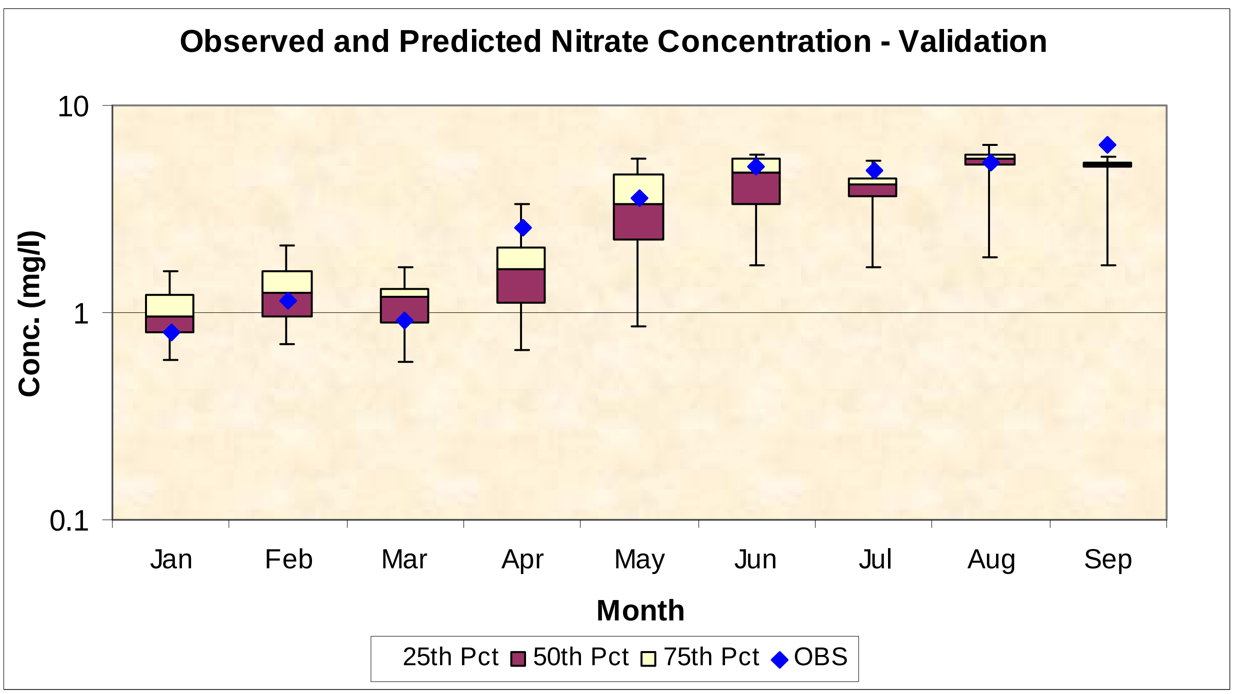


Figure KOR-C10. Validation - Observed versus predicted Nitrate concentrations for Knap of Reeds Creek (shown in log scale).

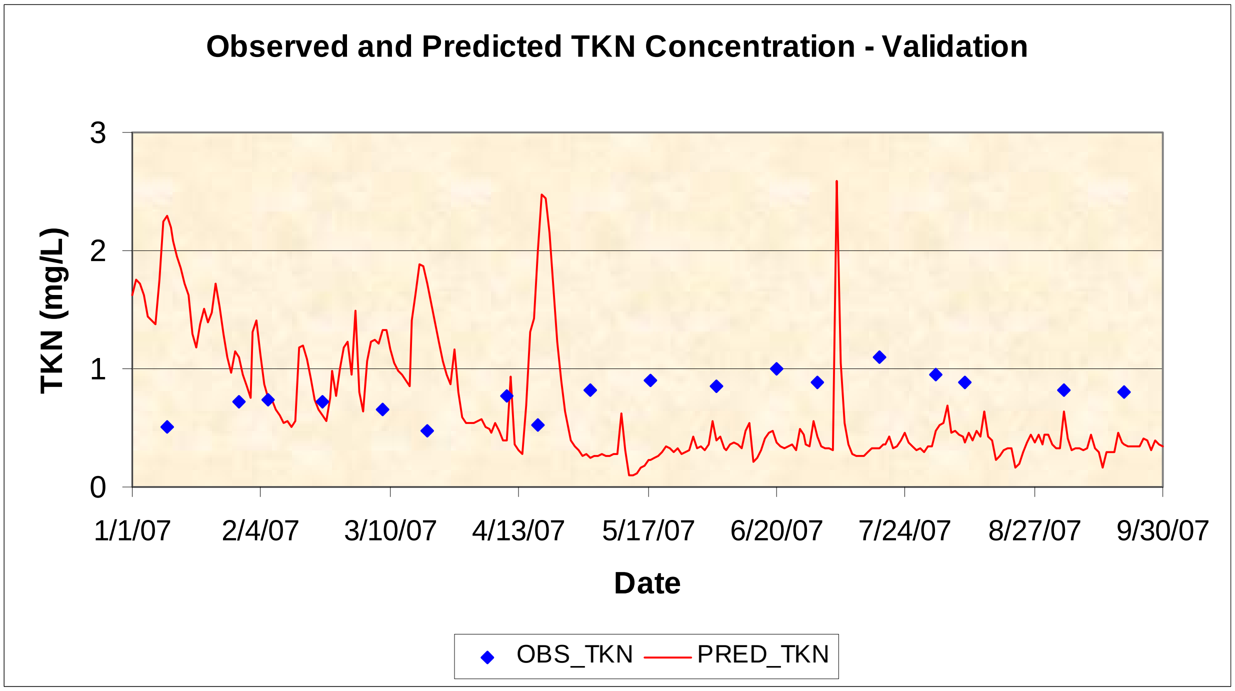


Figure KOR-C11. Validation – Knap of Reeds Creek TKN concentrations daily time series.

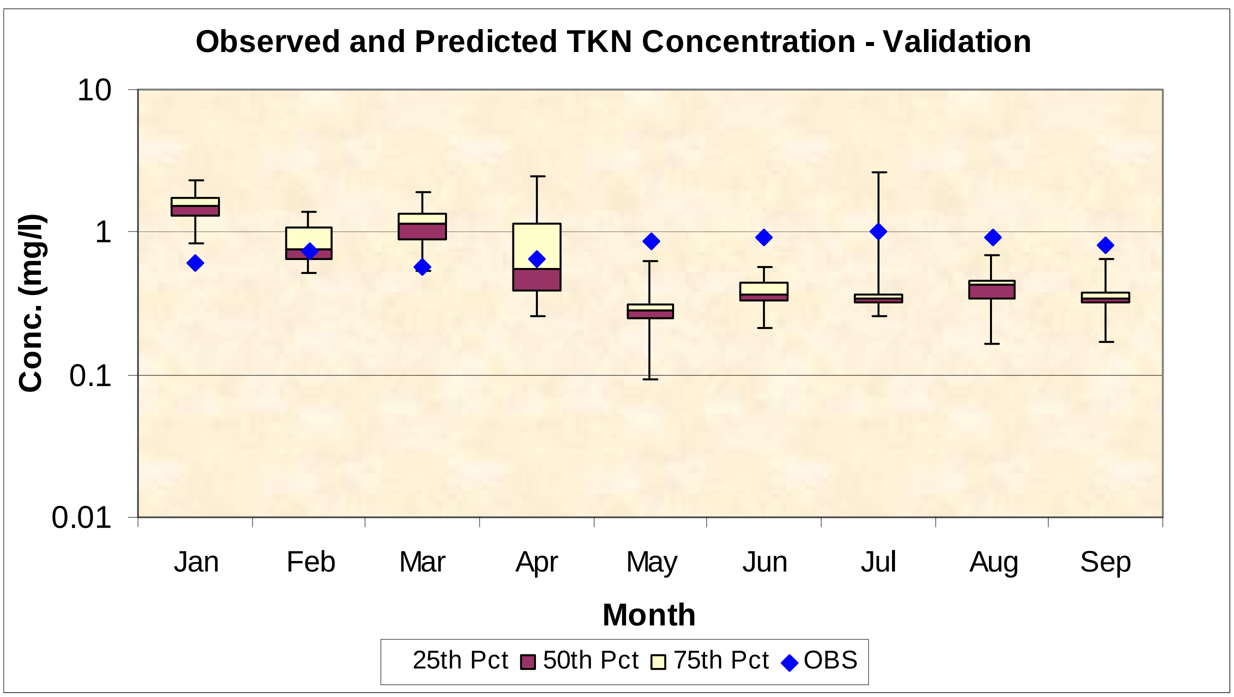


Figure KOR-C12. Validation - Observed versus predicted TKN concentrations for Knap of Reeds Creek (shown in log scale)

Flat River – Above Lake Michie

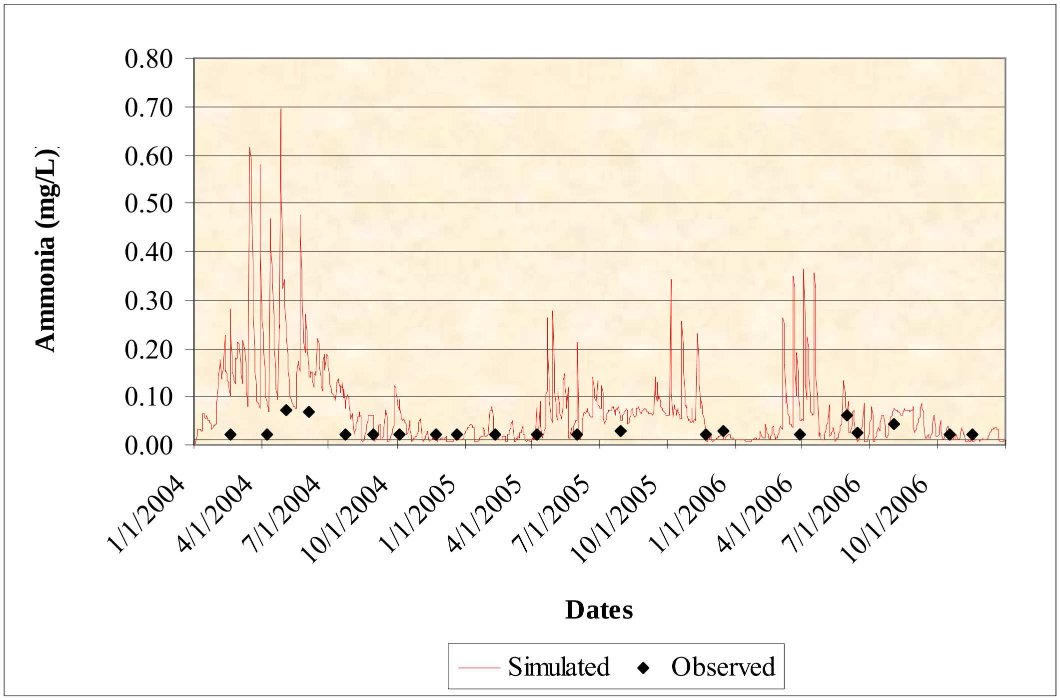


Figure FlatCalA_C1. Time series distribution of predicted and observed ammonia in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation periods are 2004 through 2006.

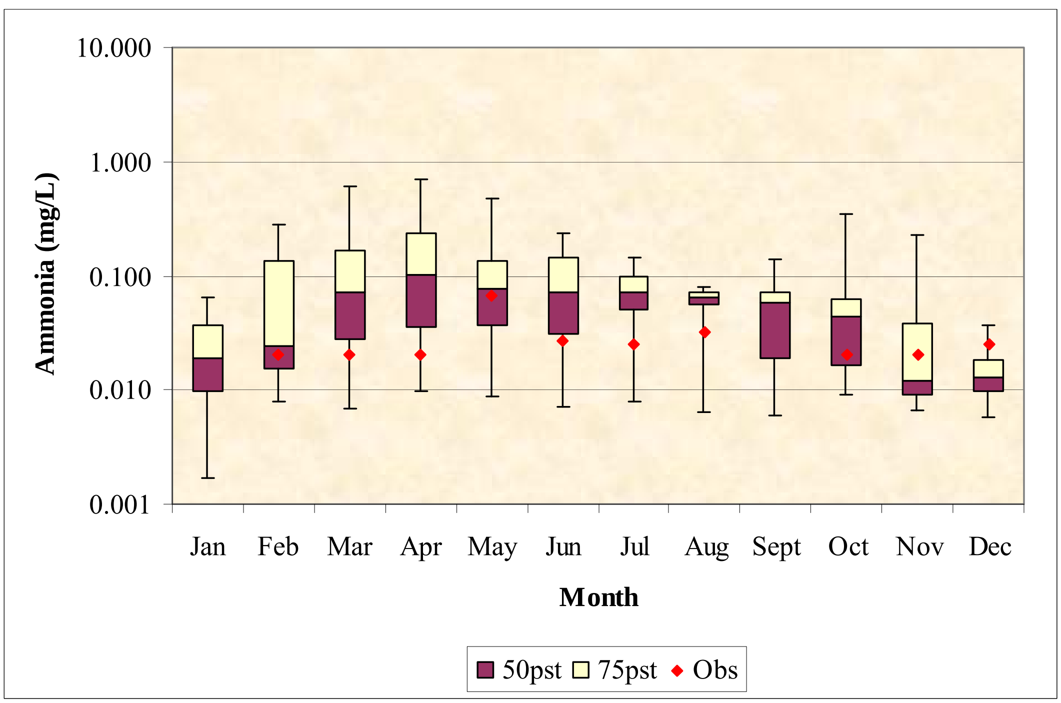


Figure FlatCalA_C2. Monthly observed concentration of ammonia vs. quantile distribution of predicted daily NH_4 in Flat River Watershed at USGS 02085500, above Lake Michie.

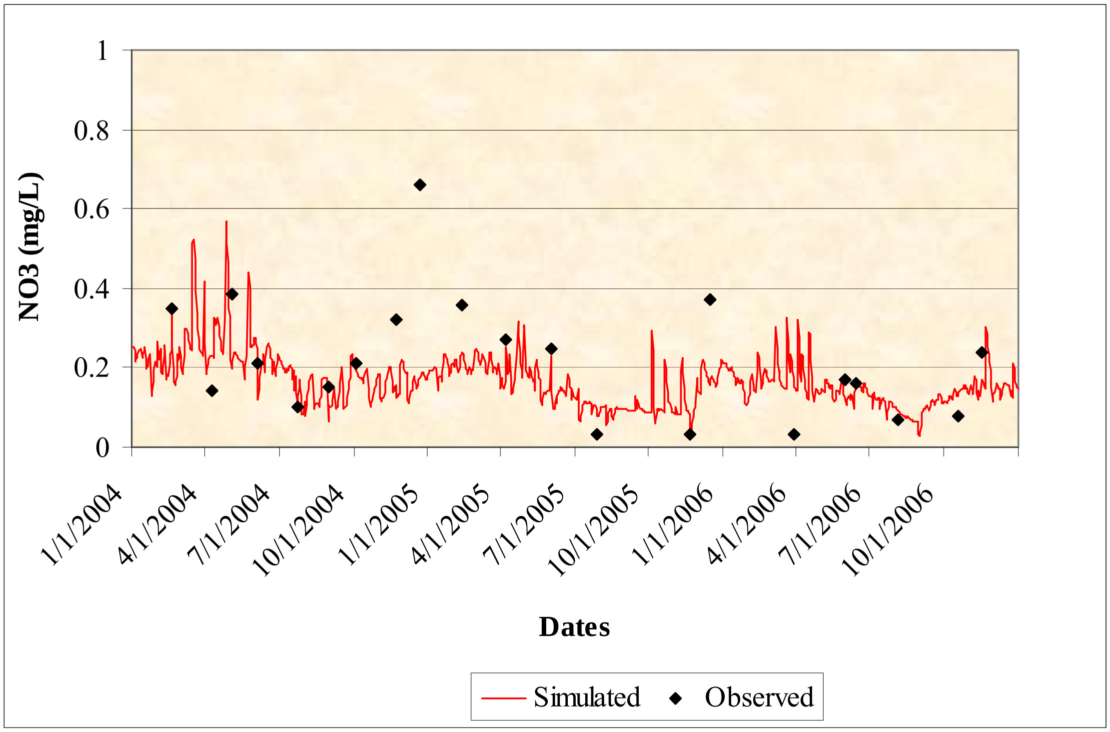


Figure FlatCalA_C3 Time series distribution of predicted and observed nitrate (NO_3) in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation periods are 2004 through 2006

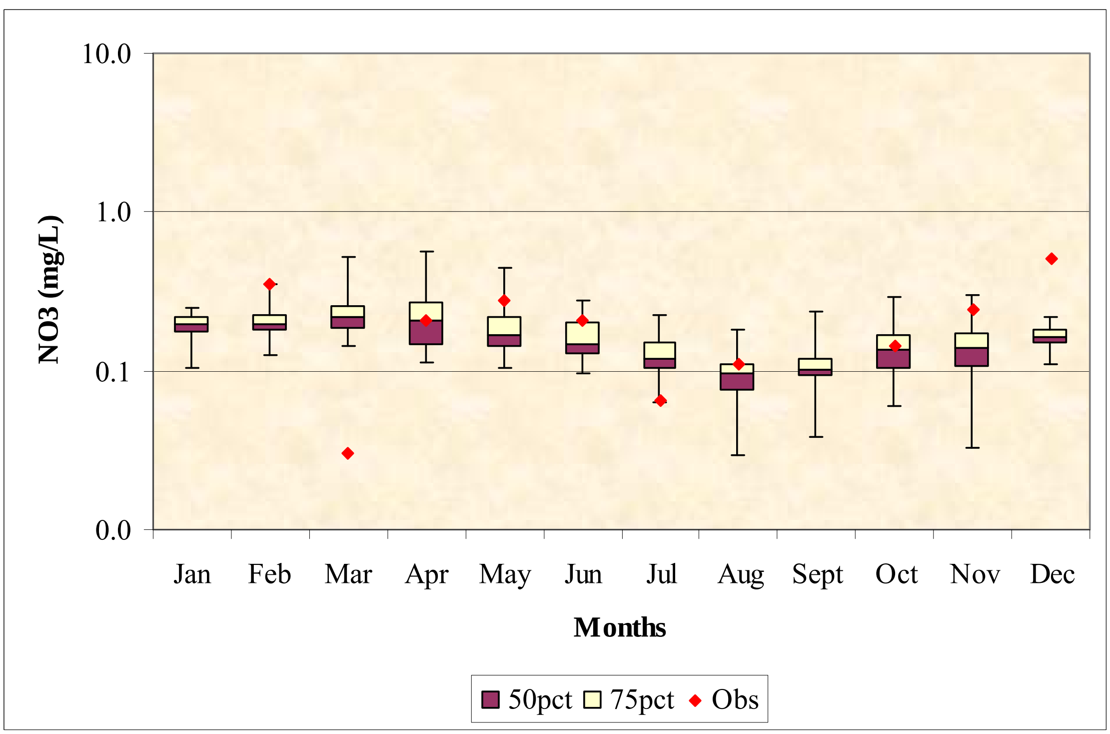


Figure FlatCalA_C4 Monthly observed concentration of nitrate (NO_3) vs. quantile distribution of predicted daily NO_3 in Flat River Watershed at USGS 02085500, above Lake Michie.

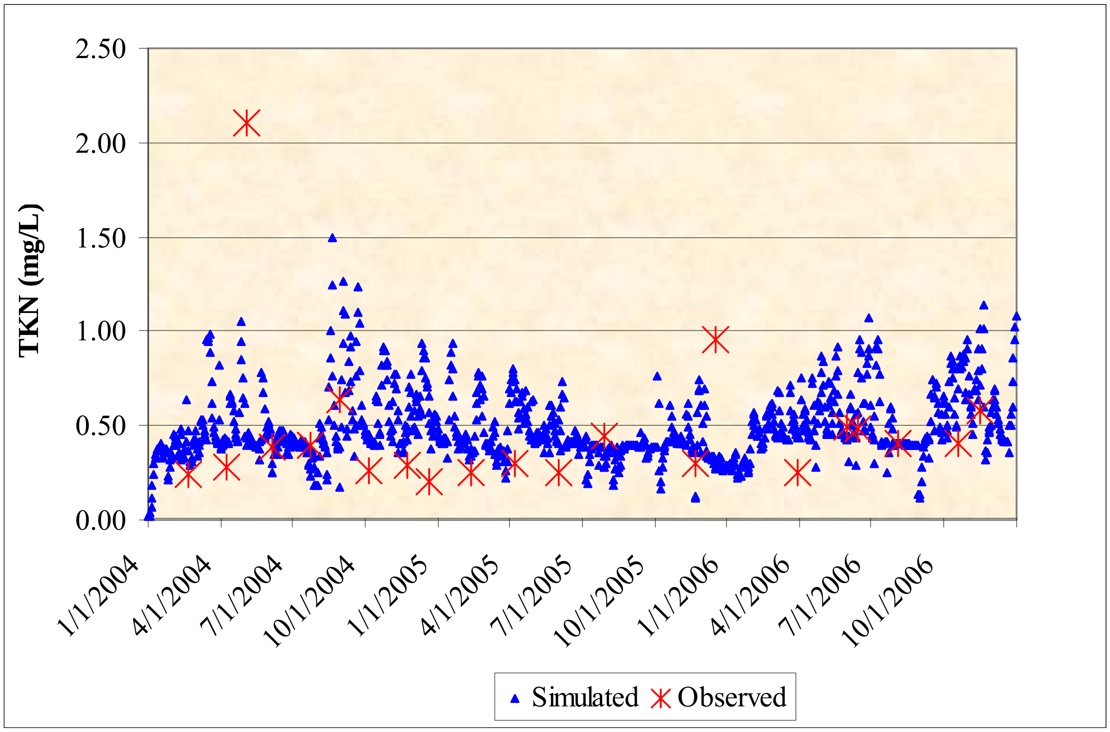


Figure FlatCalA_C5. Time series distribution of predicted and observed total kjeldahl nitrogen (TKN) in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation periods are 2004 through 2006.

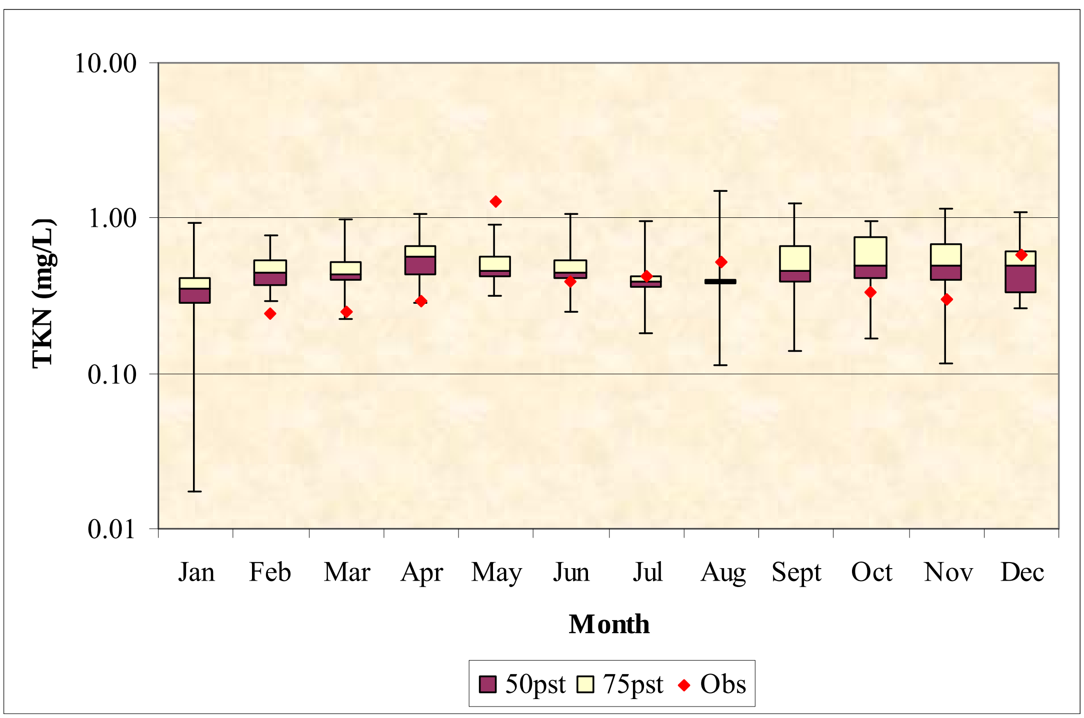


Figure FlatCalA_C6 Monthly observed concentration of total kjeldahl nitrogen (TKN) vs. quantile distribution of predicted daily TKN in Flat River Watershed at USGS 02085500, above Lake Michie.

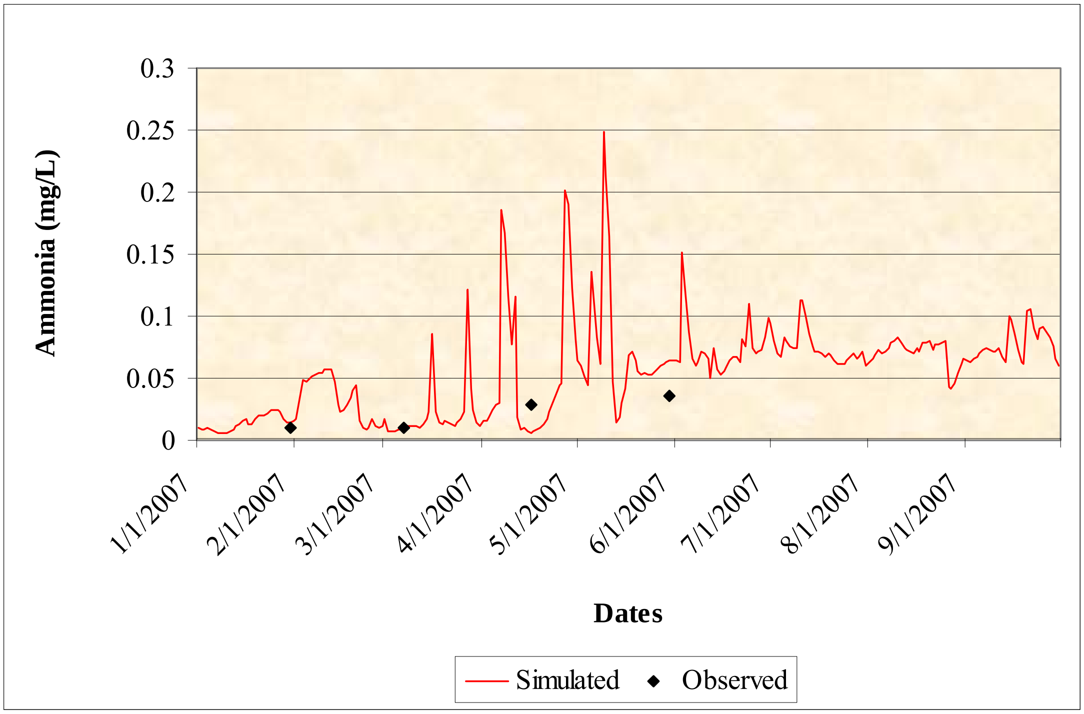


Figure FlatValA_C1. Time series distribution of predicted and observed ammonia in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation period is 2007.

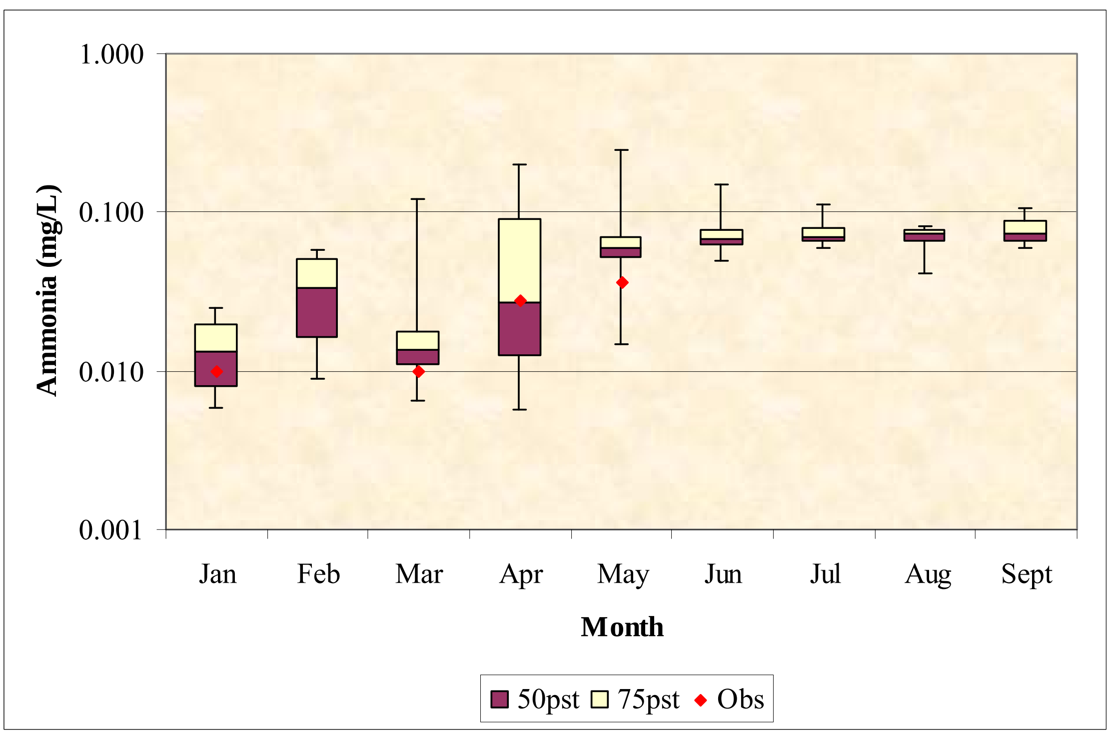


Figure FlatValA_C2. Monthly observed concentration of ammonia vs. quantile distribution of predicted daily NH_4 in Flat River Watershed at USGS 02085500, above Lake Michie.

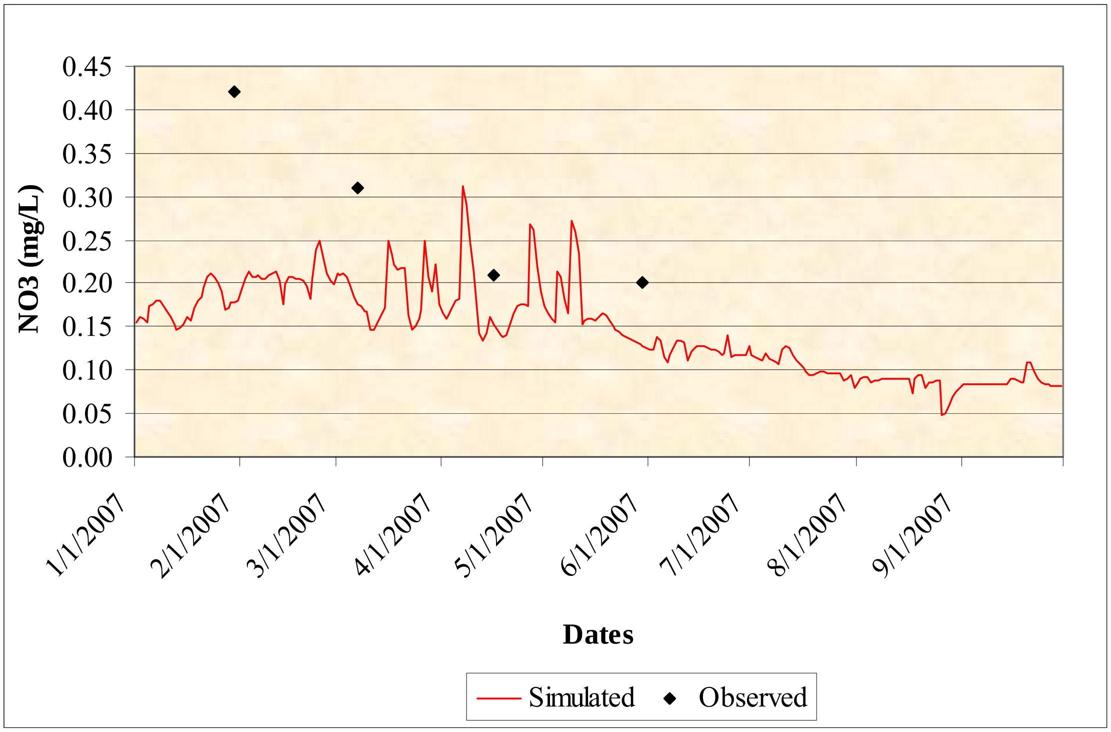


Figure FlatValA_C3. Time series distribution of predicted and observed nitrate (NO_3) in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation period is 2007.

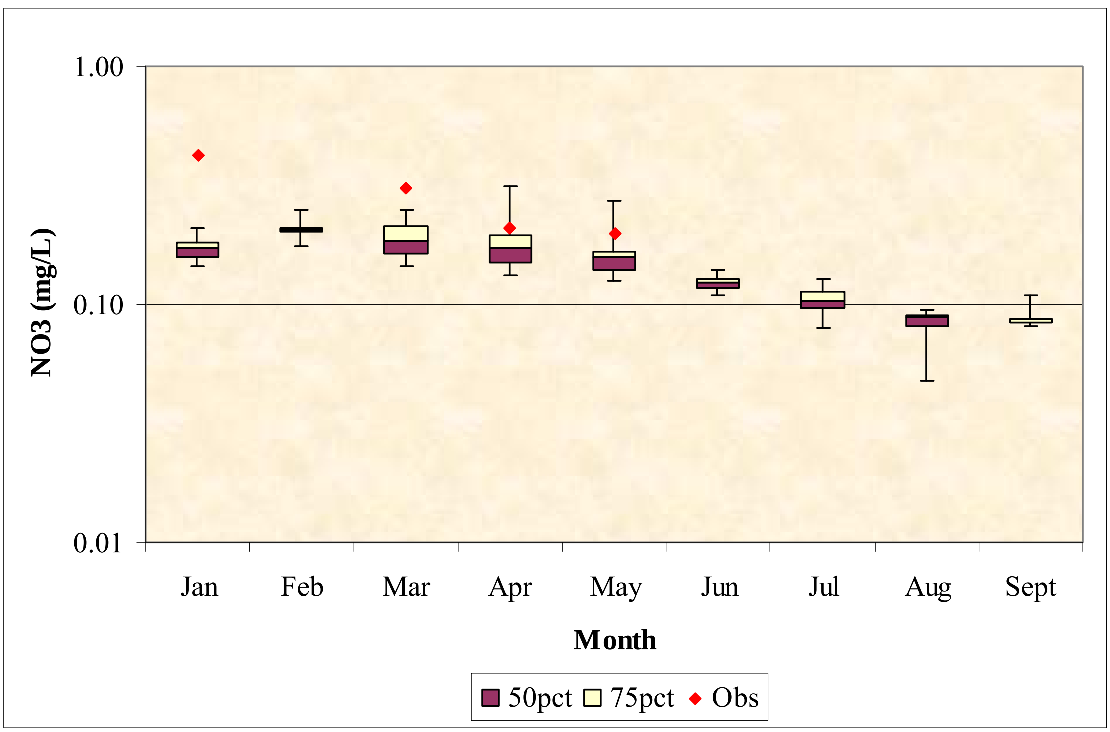


Figure FlatValA_C4. Monthly observed concentration of nitrate (NO_3) vs. quantile distribution of predicted daily NO_3 in Flat River Watershed at USGS 02085500, above Lake Michie.

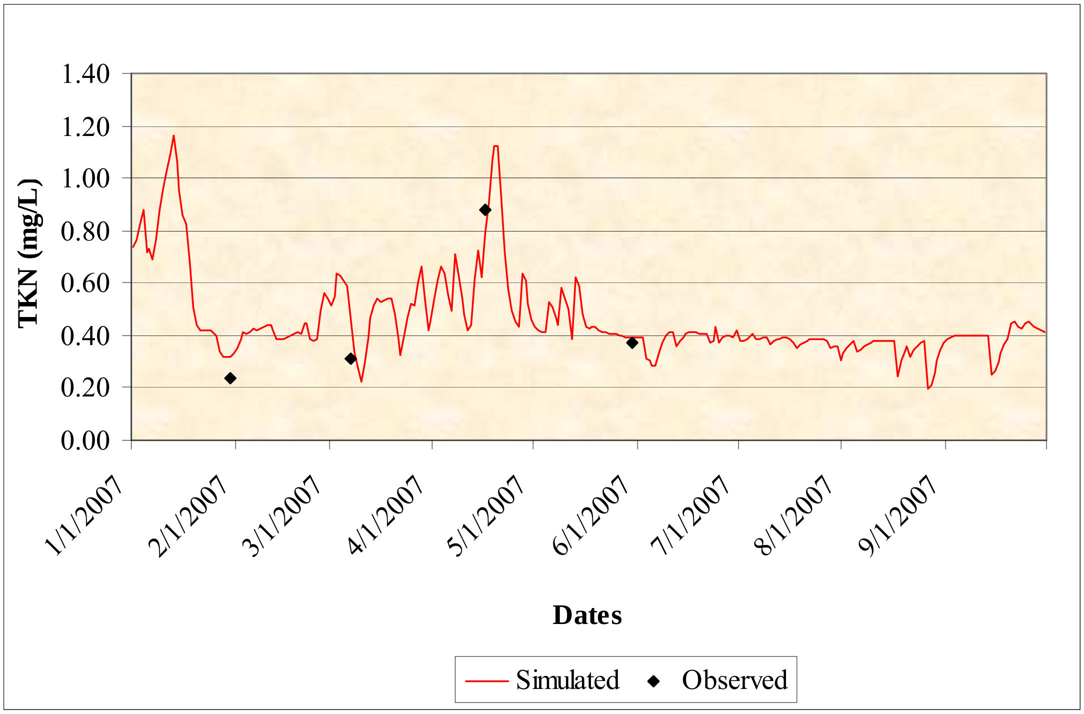


Figure FlatValA_C5. Time series distribution of predicted and observed total kjeldahl nitrogen (TKN) in Flat River Watershed at USGS 02085500, above Lake Michie. Model simulation period is 2007.

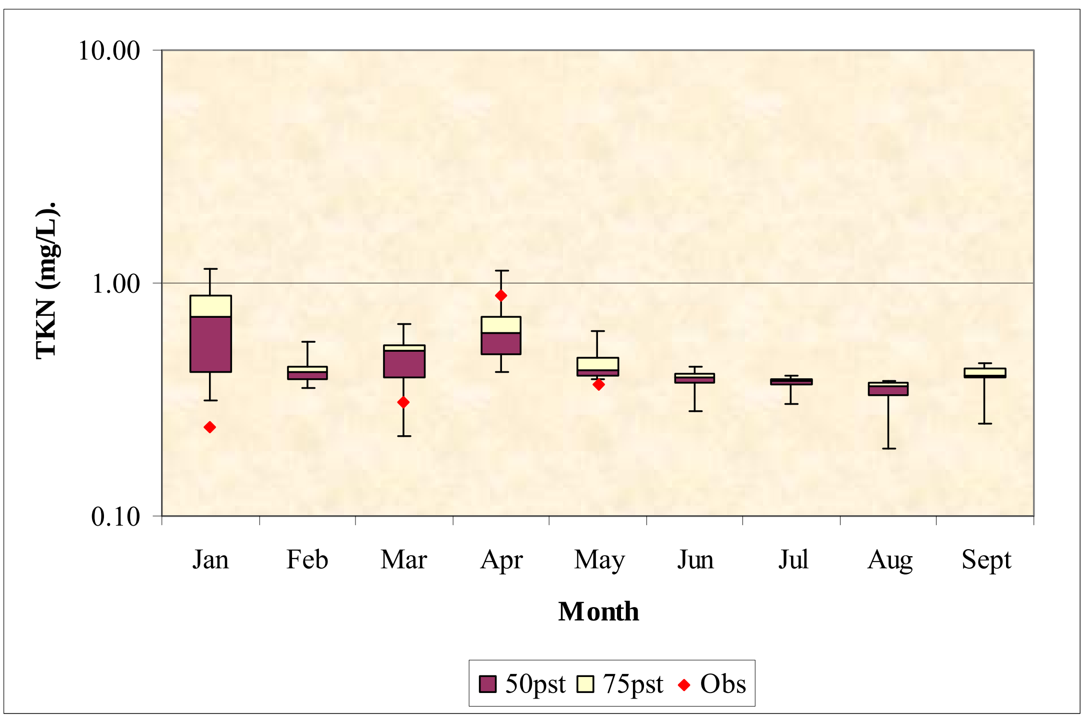


Figure FlatValA_C6. Monthly observed concentration of total kjeldahl nitrogen (TKN) vs. quantile distribution of predicted daily TKN in Flat River Watershed at USGS 02085500, above Lake Michie.

Flat River – Below Lake Michie

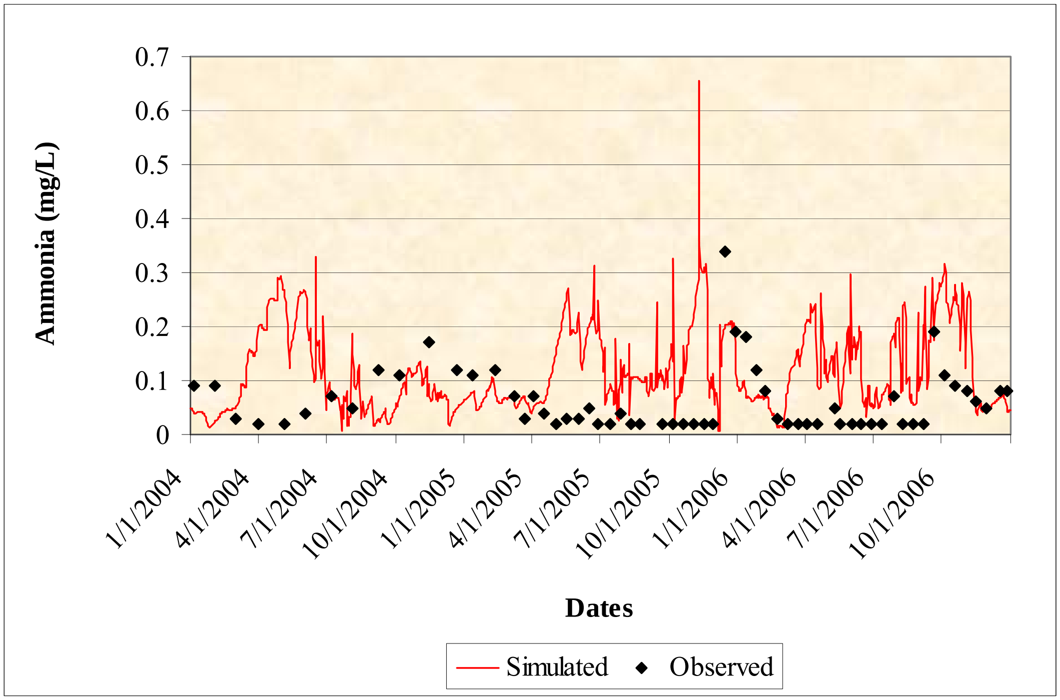


Figure FlatCalB_C1. Time series distribution of predicted and observed ammonia in Flat River Watershed at the ambient station J1100000, below Lake Michie.

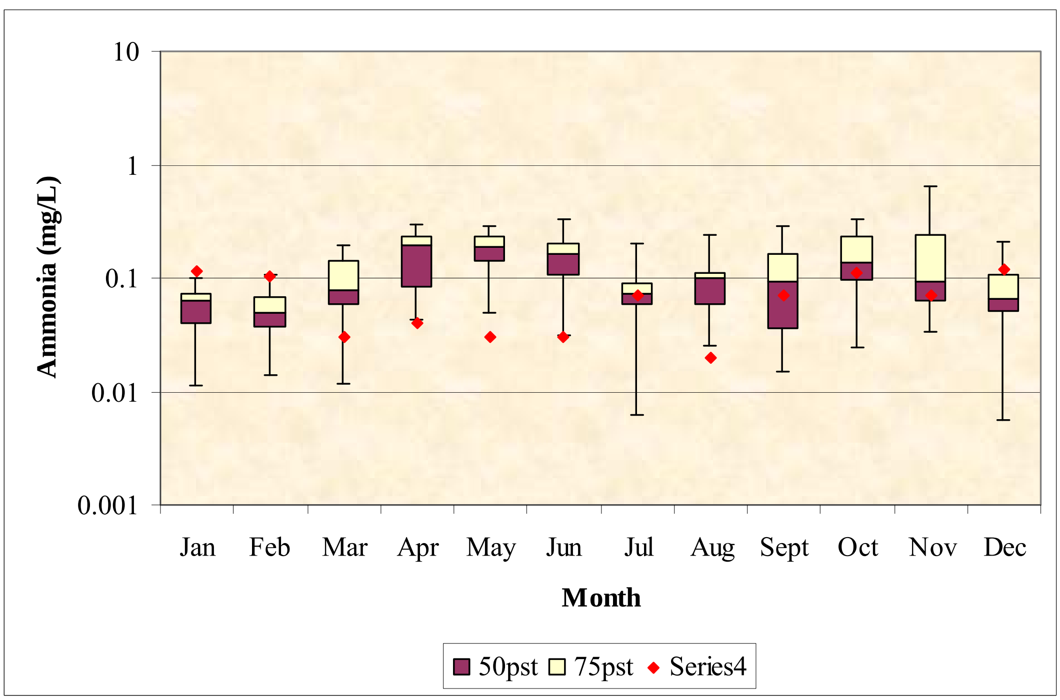


Figure FlatCalB_C2. Monthly-observed concentration of ammonia vs. quantile distribution of predicted daily NH_4 in Flat River Watershed at the ambient station J1100000, below Lake Michie.

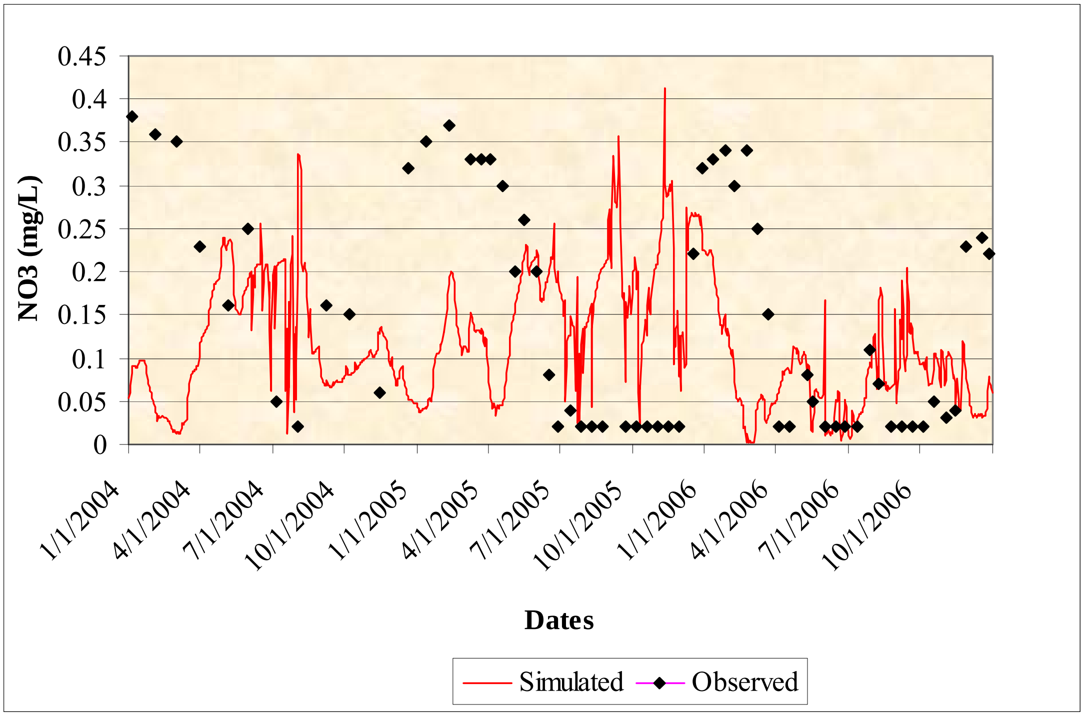


Figure FlatCalB_C3 Time series distribution of predicted and observed nitrate (NO_3) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation periods are 2004 through 2006

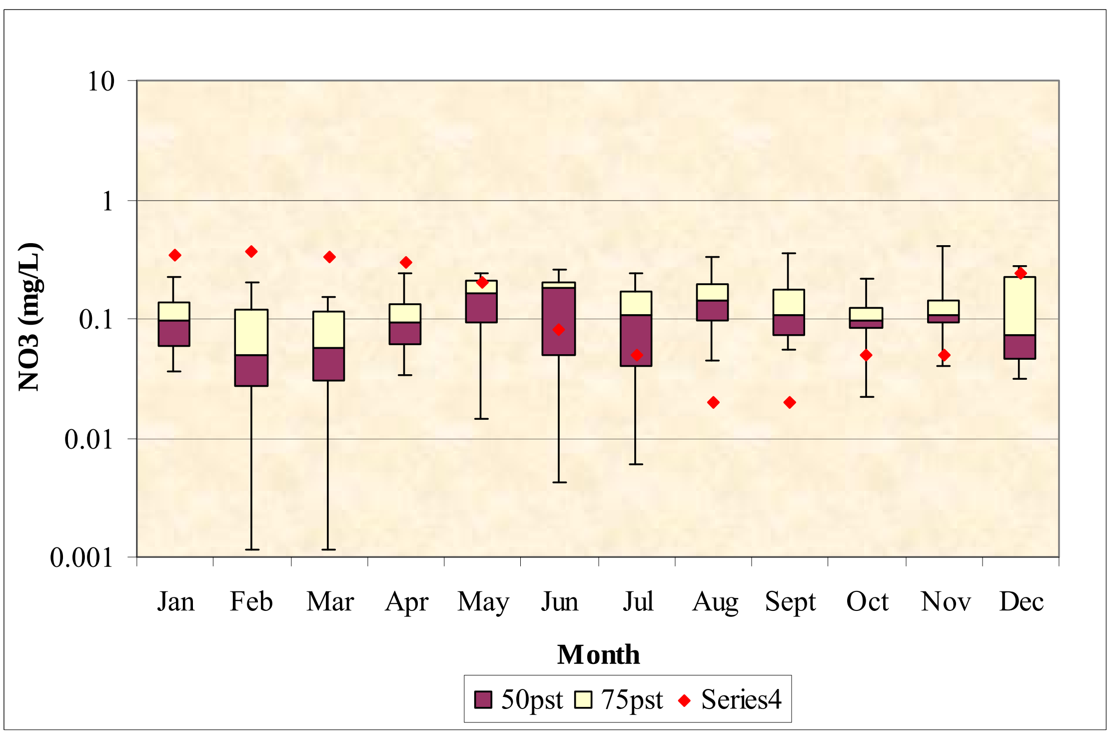


Figure FlatCalB_C4 Monthly observed concentration of nitrate (NO_3) vs. quantile distribution of predicted daily NO_3 in Flat River Watershed at the ambient station J1100000, below Lake Michie.

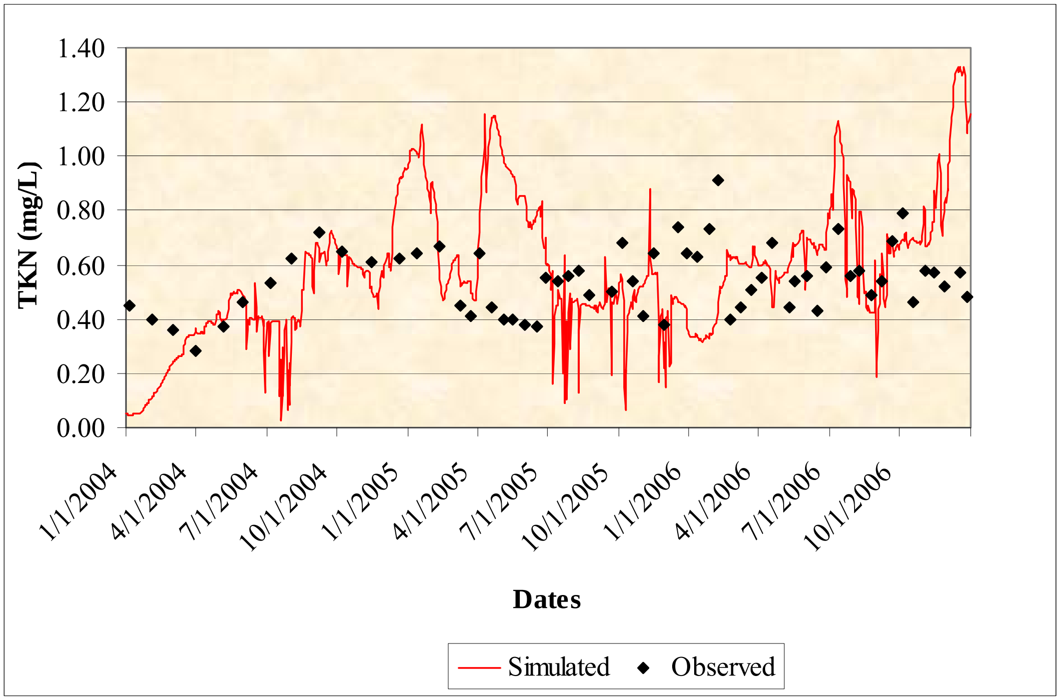


Figure FlatCalB_C5. Time series distribution of predicted and observed total kjeldahl nitrogen (TKN) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation periods are 2004 through 2006.

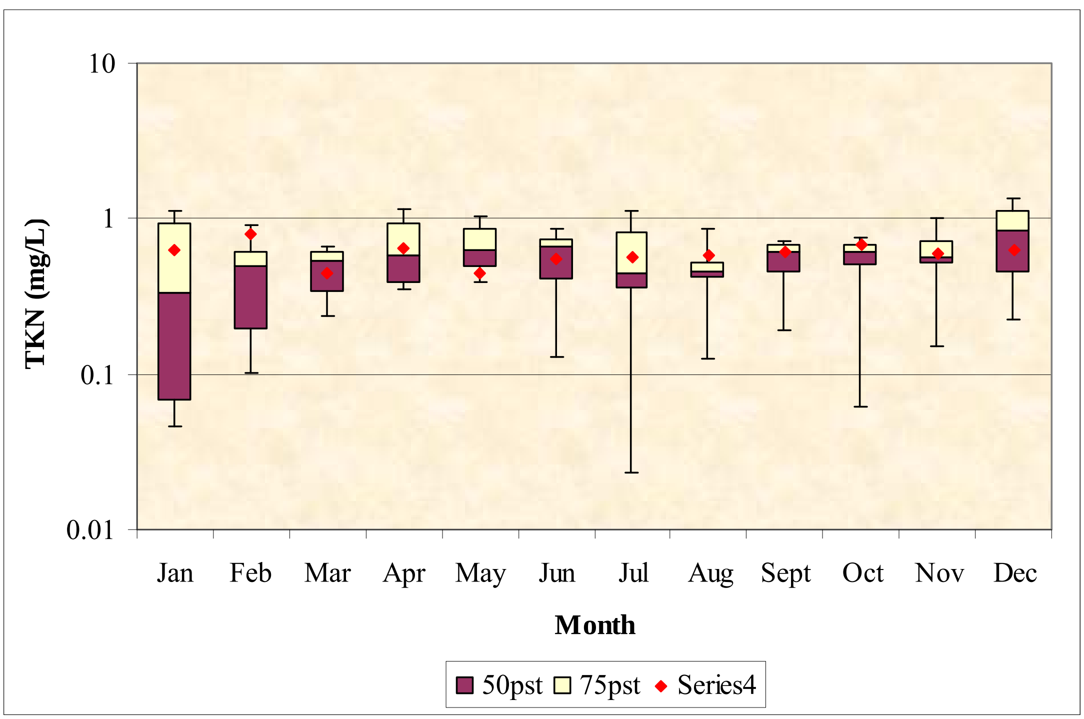


Figure FlatCalB_C6. Monthly-observed concentration of total kjeldahl nitrogen (TKN) vs. quantile distribution of predicted daily TKN in Flat River Watershed at the ambient station J1100000, below Lake Michie.

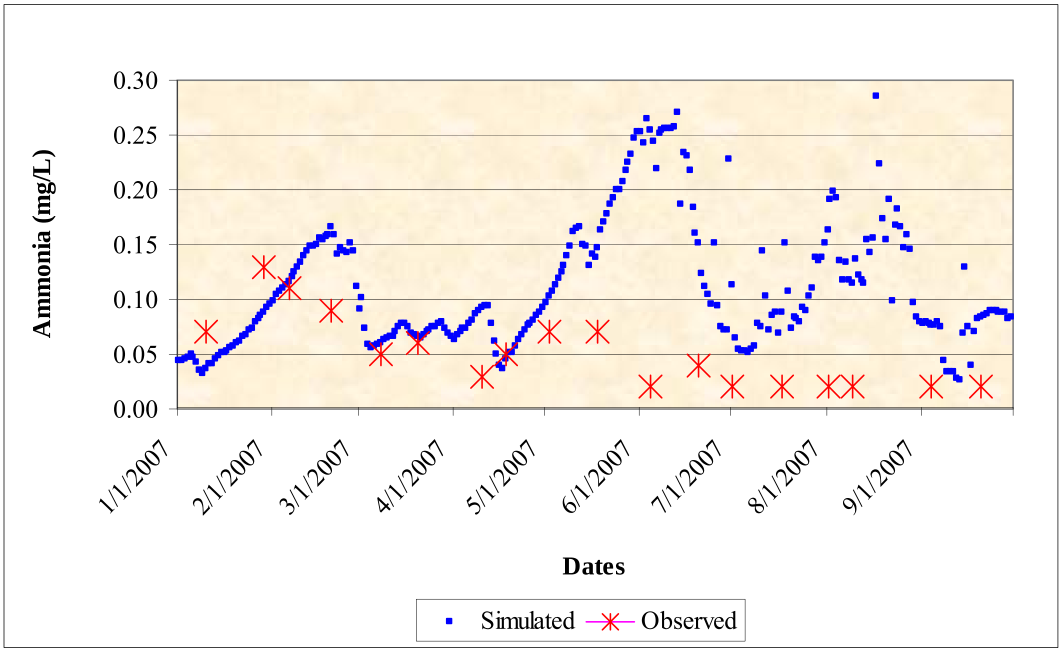


Figure FlatValB_C1. Time series distribution of predicted and observed ammonia in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation period is 2007.

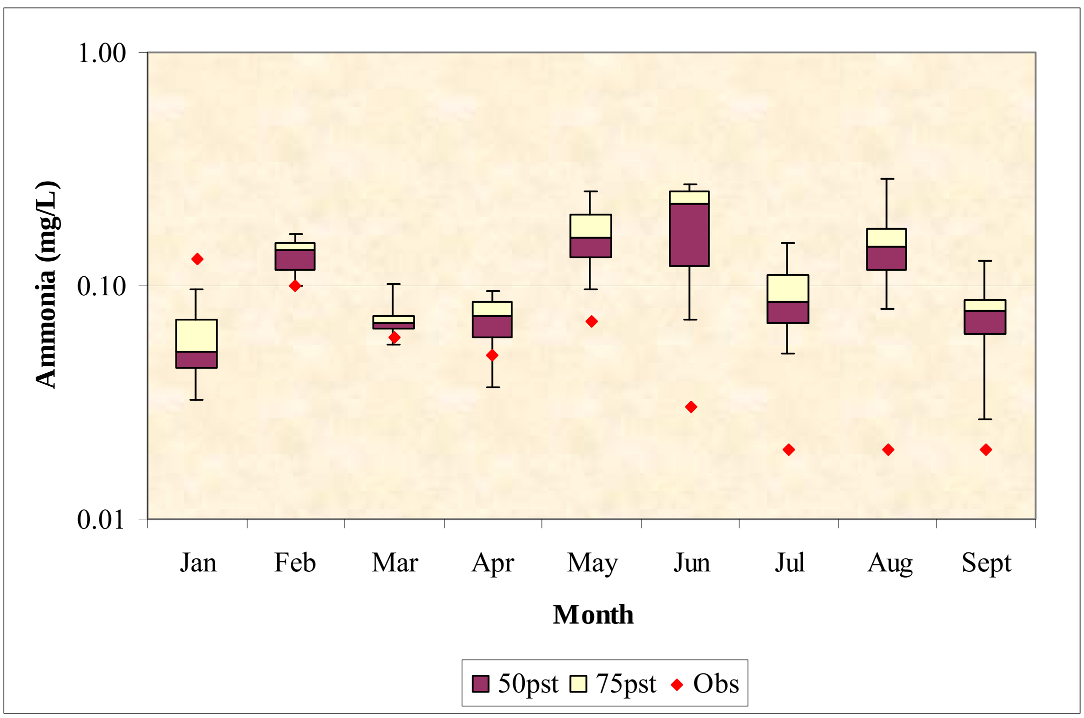


Figure FlatValB_C2. Monthly-observed concentration of ammonia vs. quantile distribution of predicted daily NH_4 in Flat River Watershed at the ambient station J1100000, below Lake Michie.

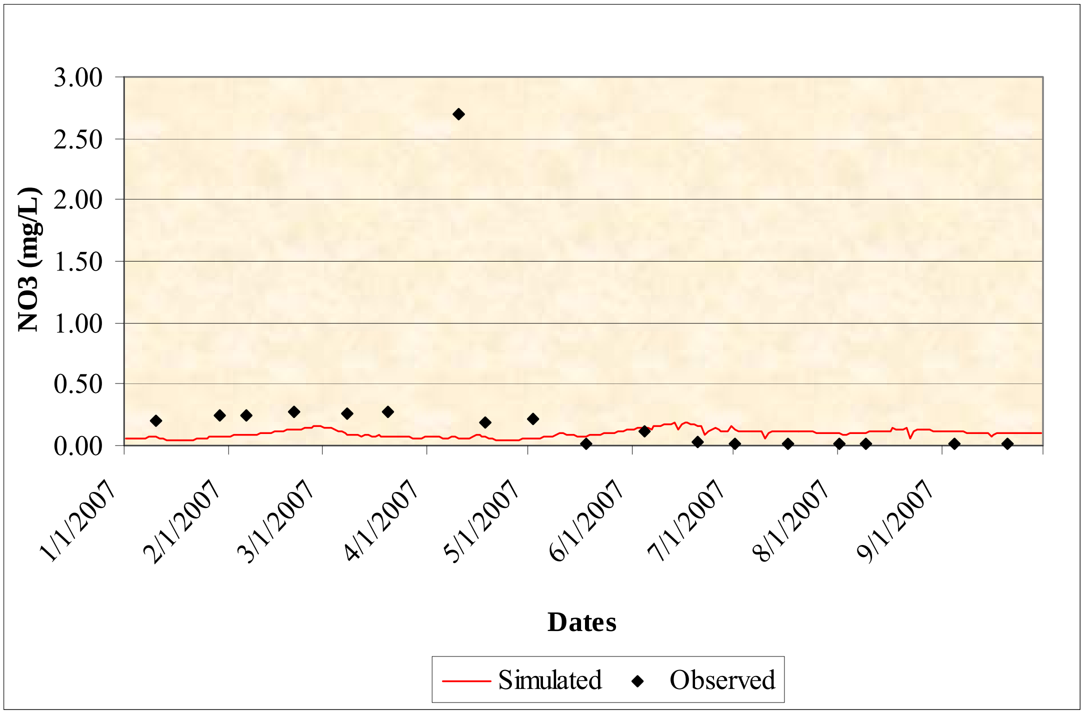


Figure FlatValB_C3. Time series distribution of predicted and observed nitrate (NO_3) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation period is 2007.

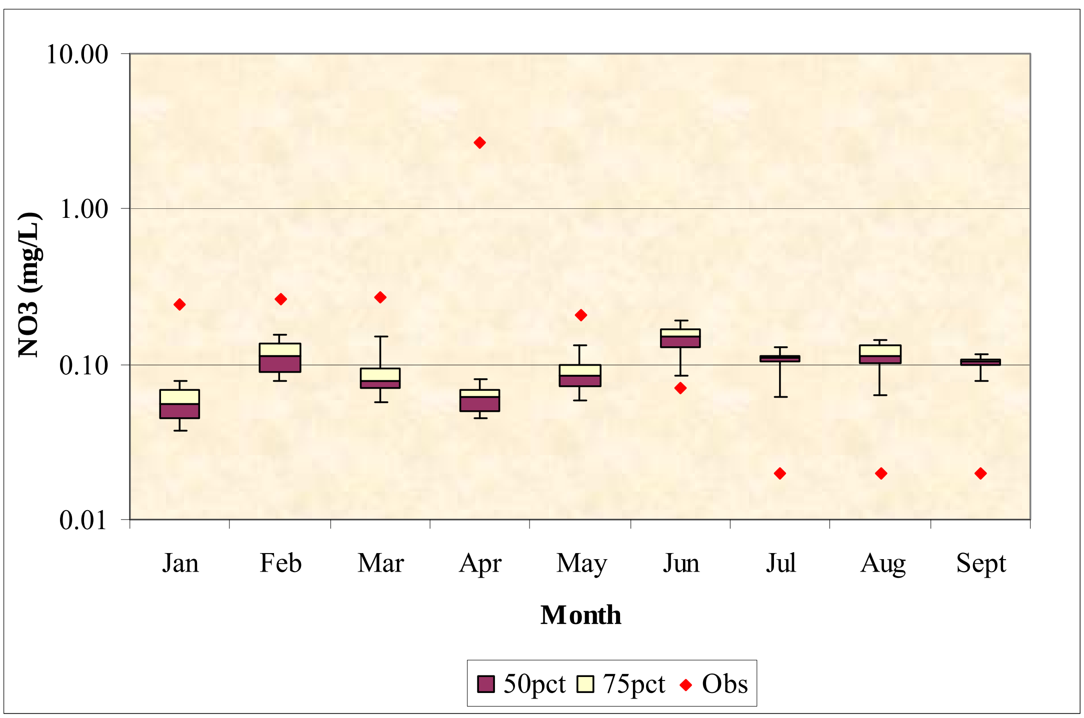


Figure FlatValB_C4. Monthly-observed concentration of nitrate (NO_3) vs. quantile distribution of predicted daily NO_3 in Flat River Watershed at the ambient station J1100000, below Lake Michie.

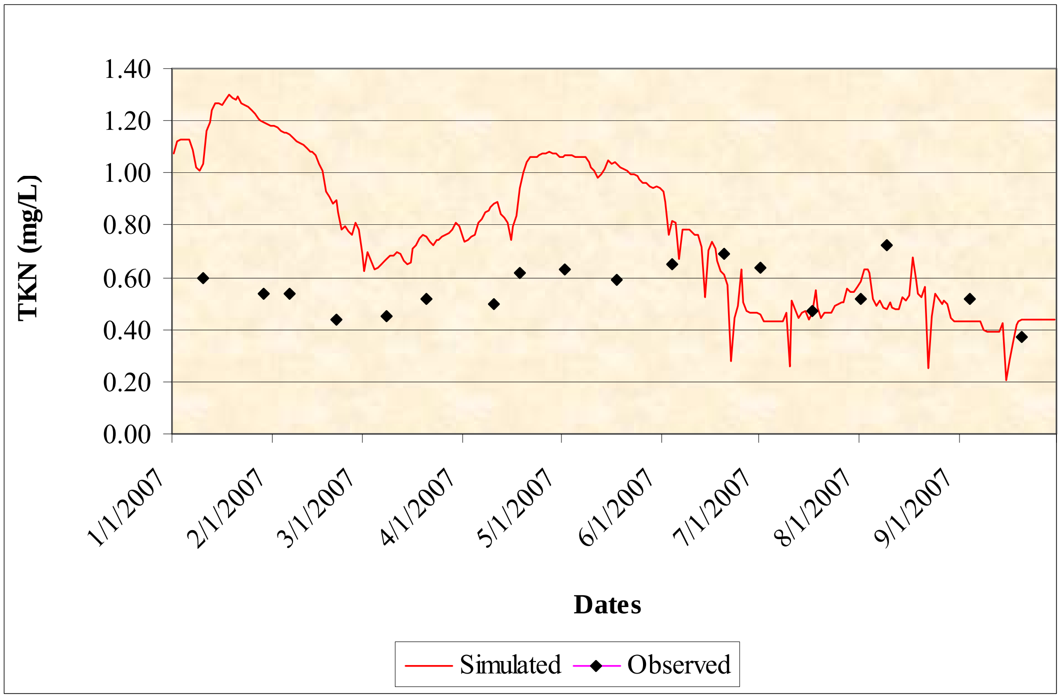


Figure FlatValB_C5. Time series distribution of predicted and observed total kjeldahl nitrogen (TKN) in Flat River Watershed at the ambient station J1100000, below Lake Michie. Model simulation period is 2007.

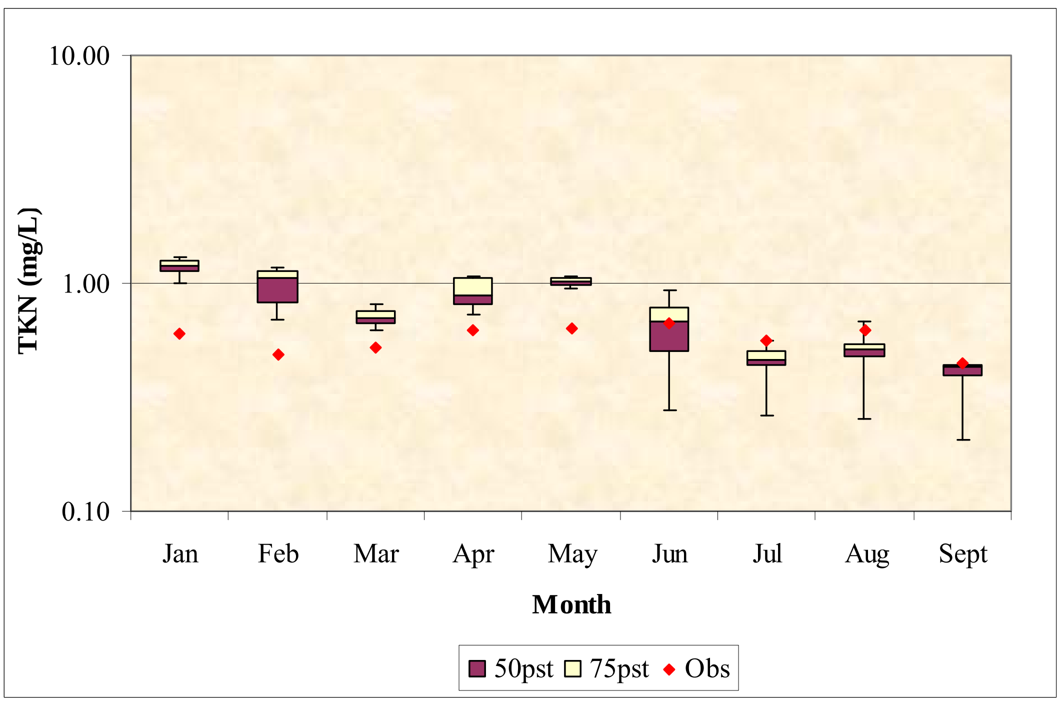


Figure FlatValB_C6. Monthly-observed concentration of total kjeldahl nitrogen (TKN) vs. quantile distribution of predicted daily TKN in Flat River Watershed at the ambient station J1100000, below Lake Michie.

Little River – Above Little River Reservoir

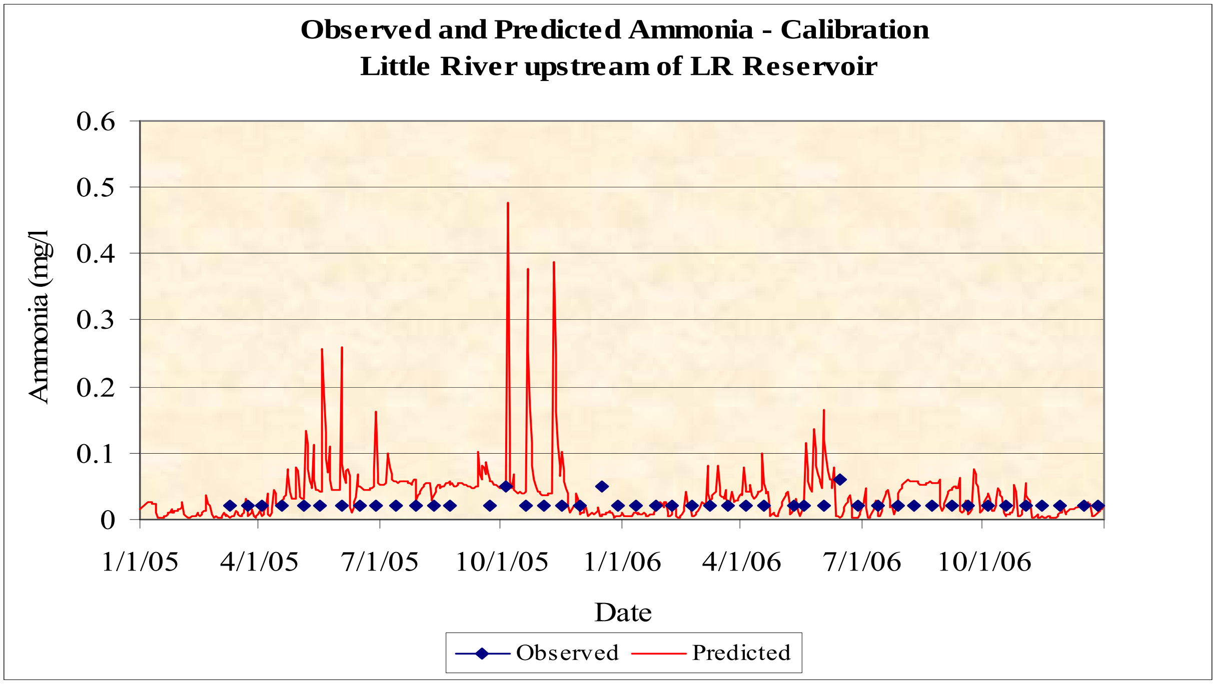


Figure LRA-C1. Time series plots of observed and simulated ammonia concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

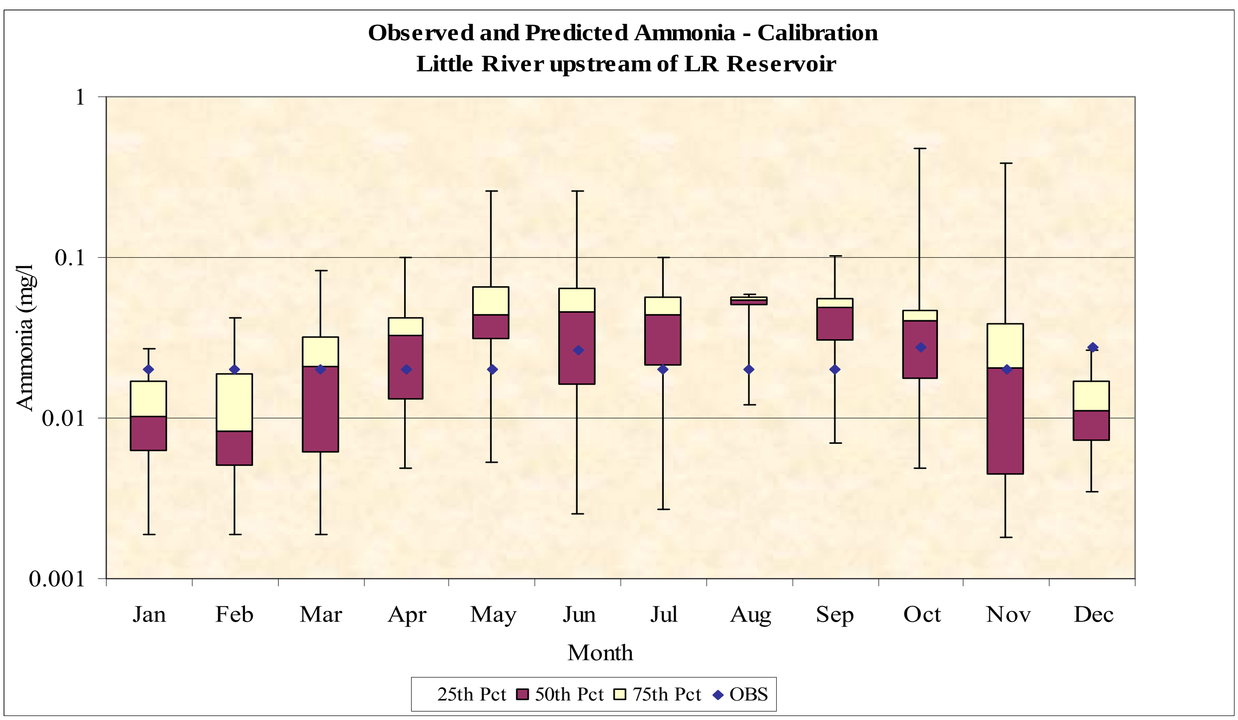


Figure LRA-C2. Seasonal distribution of observed and simulated ammonia concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

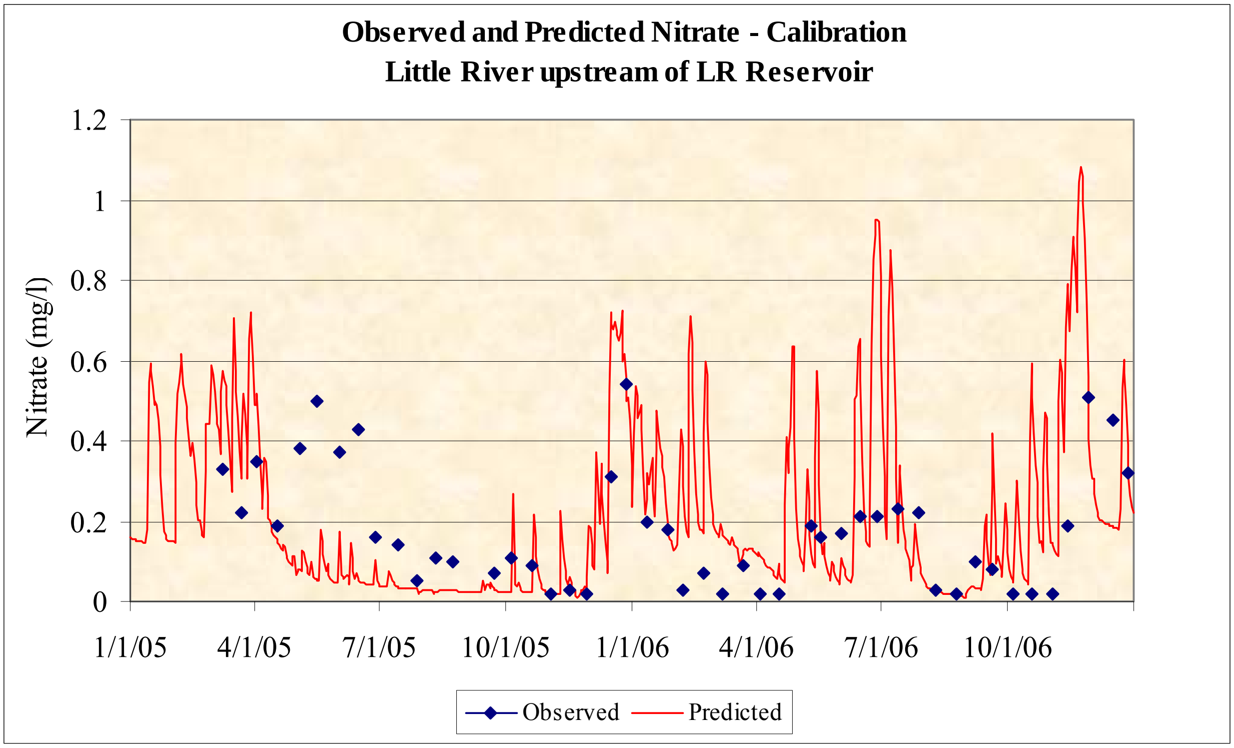


Figure LRA-C3. Time series plots of observed and simulated nitrate concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

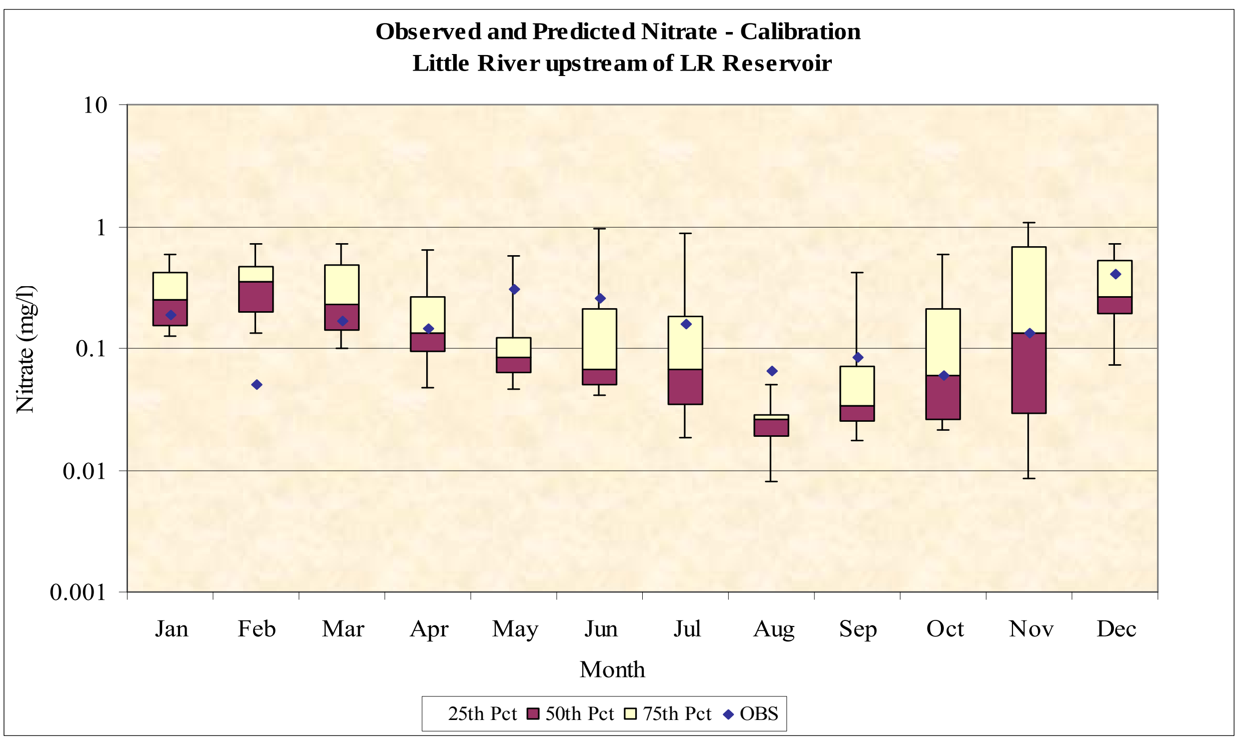


Figure LRA-C4. Seasonal distribution of observed and simulated nitrate concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

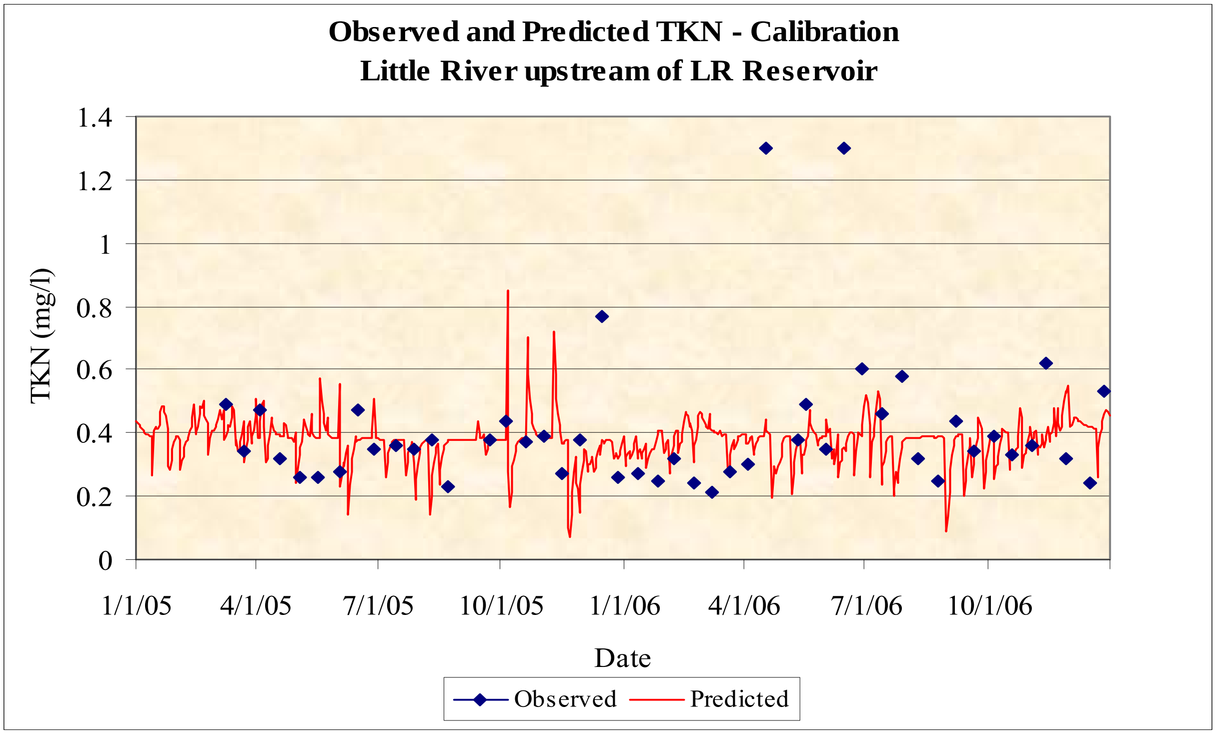


Figure LRA-C5. Time series plots of observed and simulated TKN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

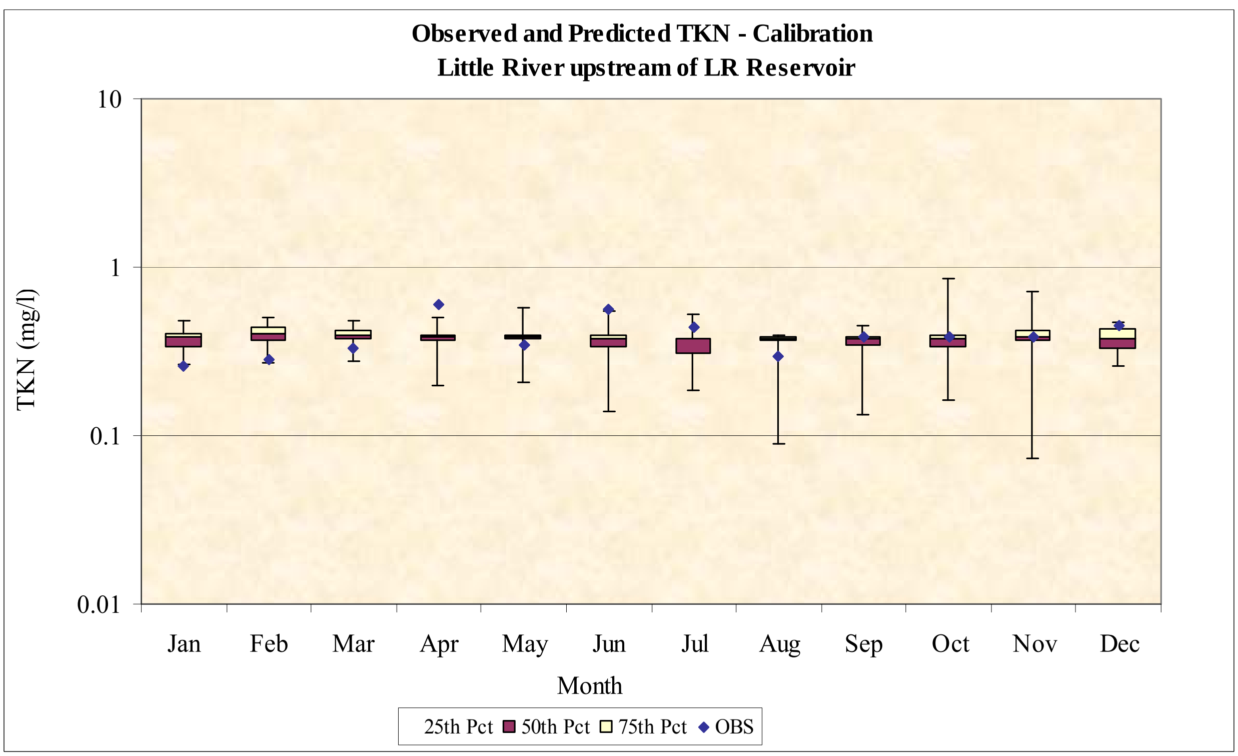


Figure LRA-C6. Seasonal distribution of observed and simulated TKN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

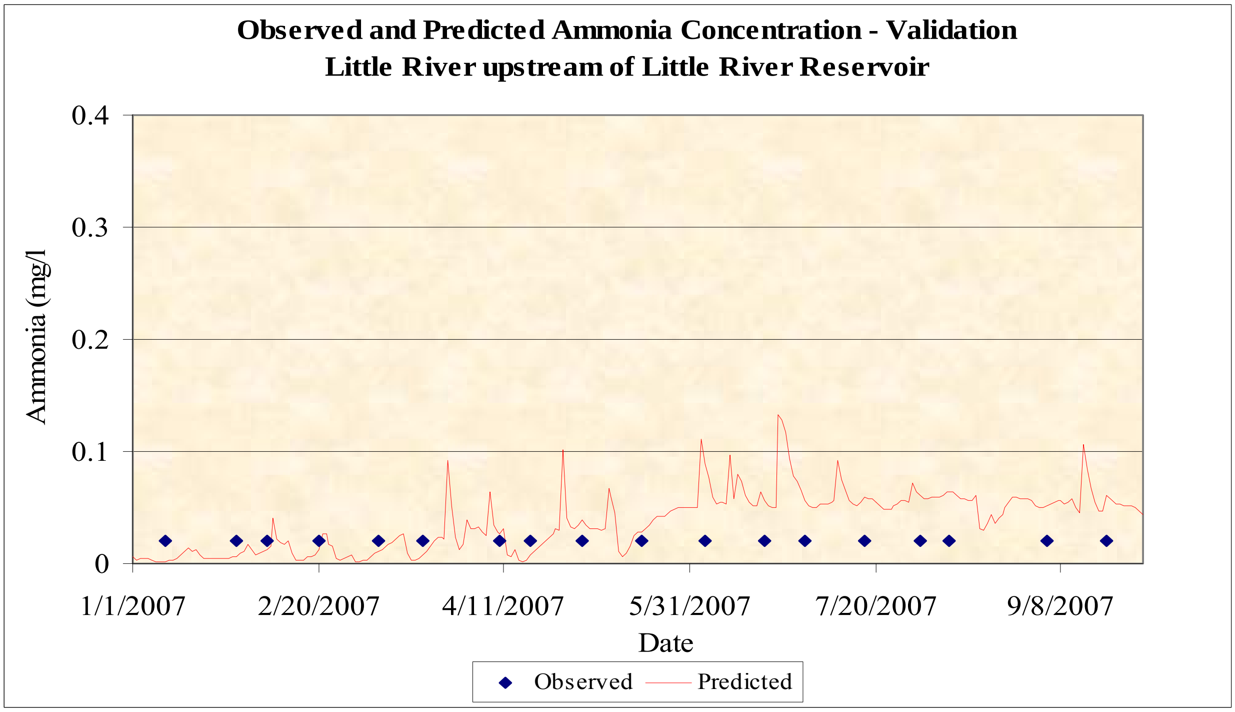


Figure LRA-C7. Time series plots of observed and simulated ammonia concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

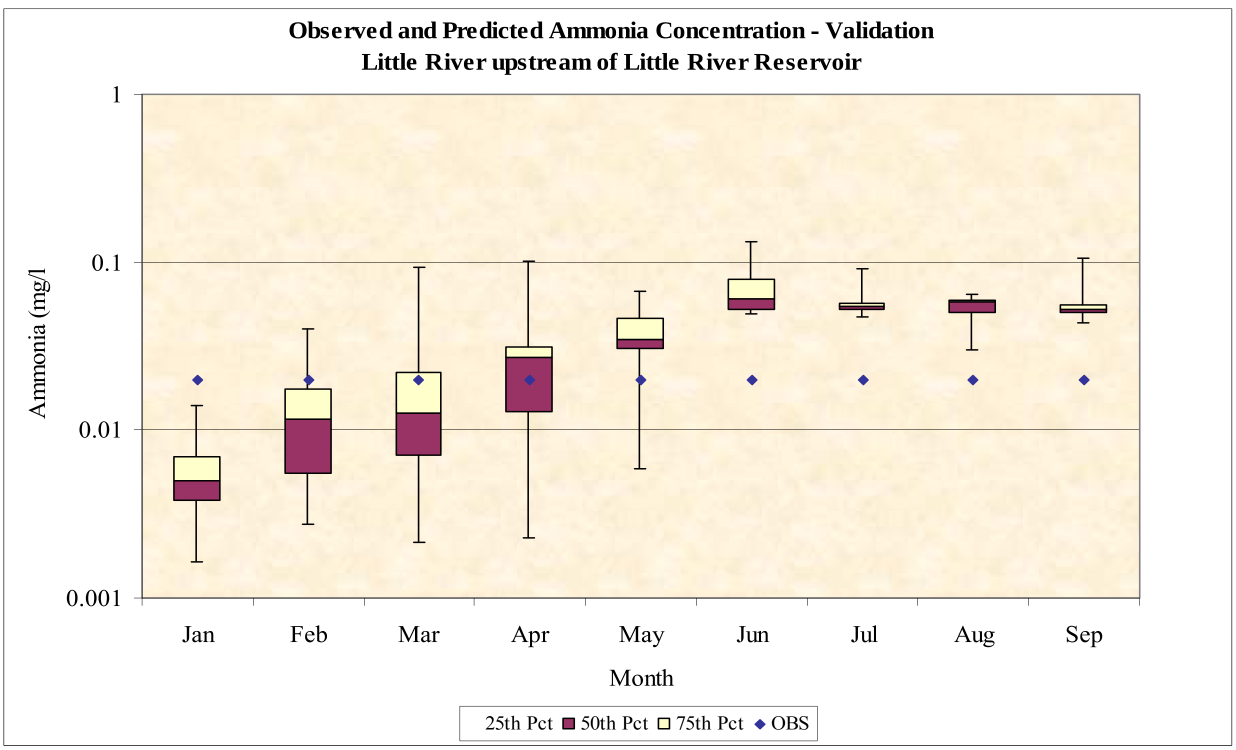


Figure LRA-C8. Seasonal distribution of observed and simulated ammonia concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

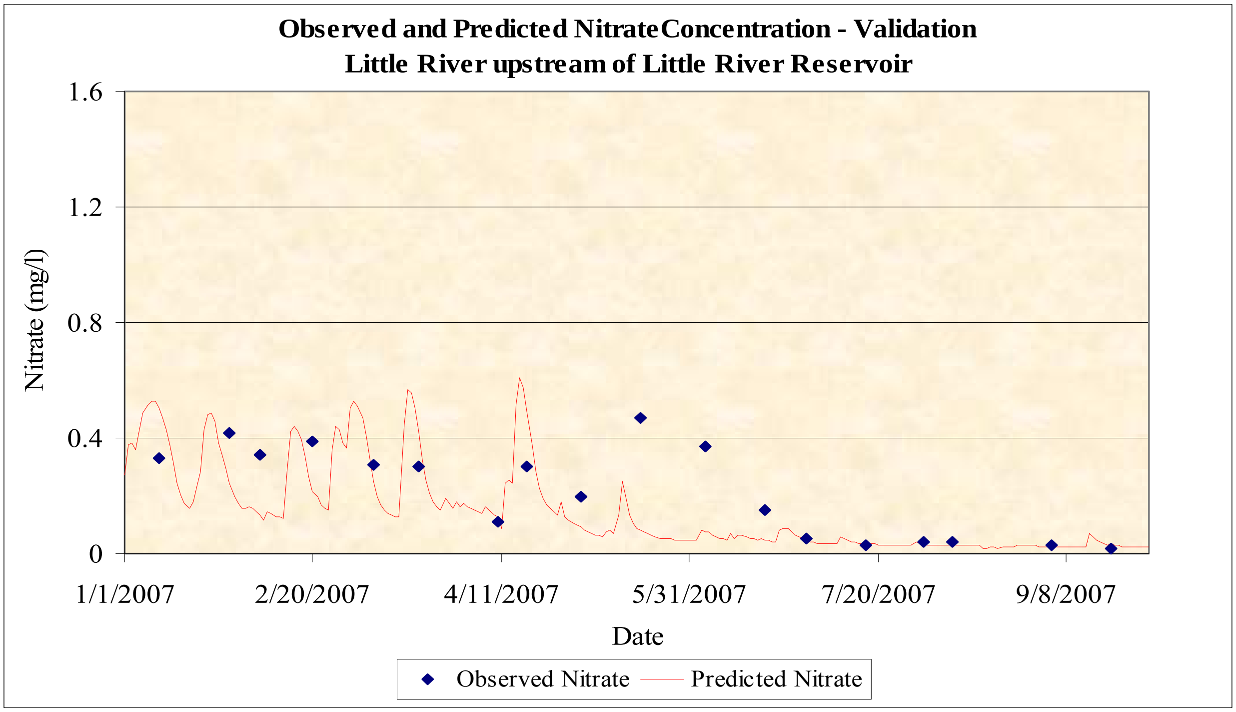


Figure LRA-C9. Time series plots of observed and simulated nitrate concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

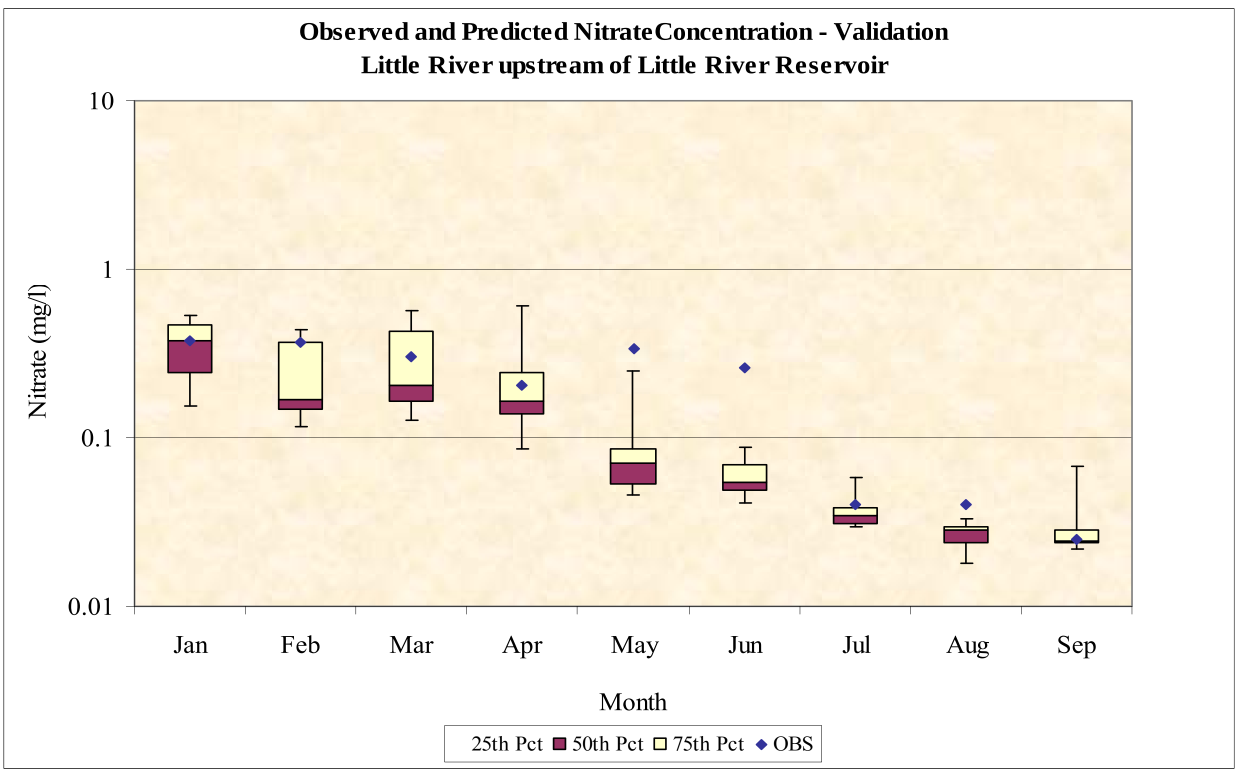


Figure LRA-C10. Seasonal distribution of observed and simulated nitrate concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

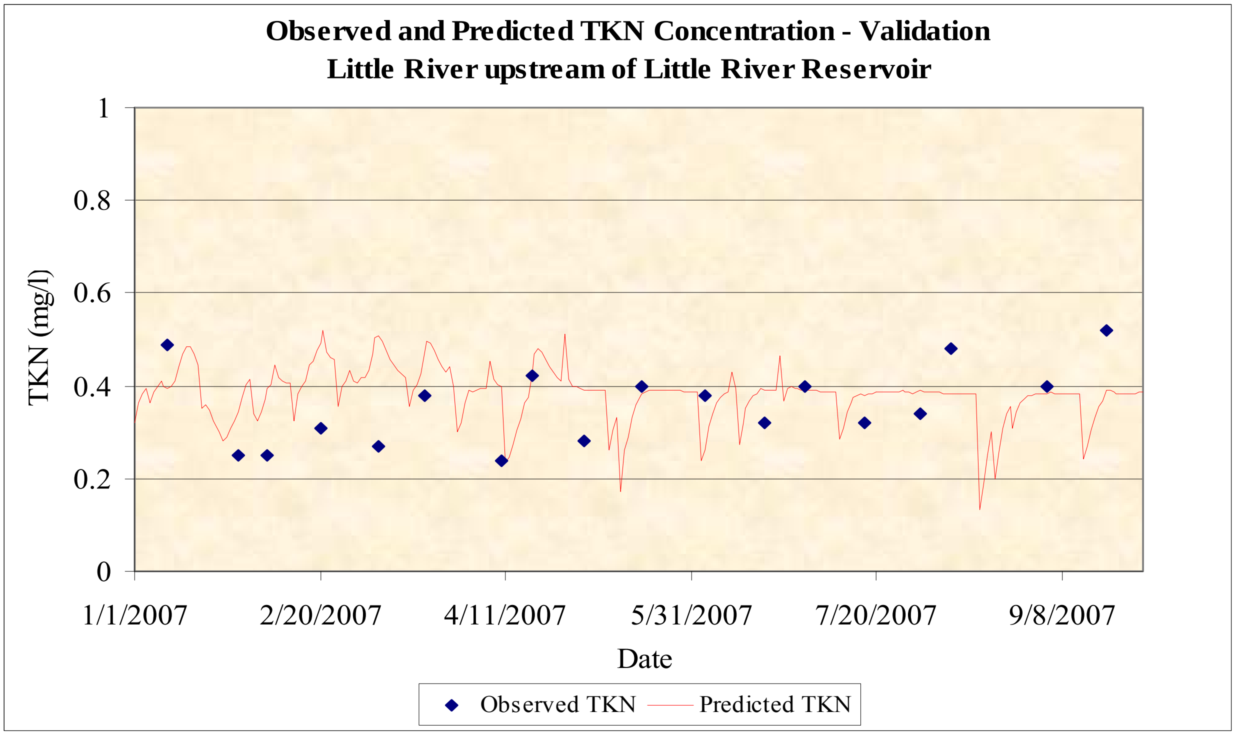


Figure LRA-C11. Time series plots of observed and simulated TKN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

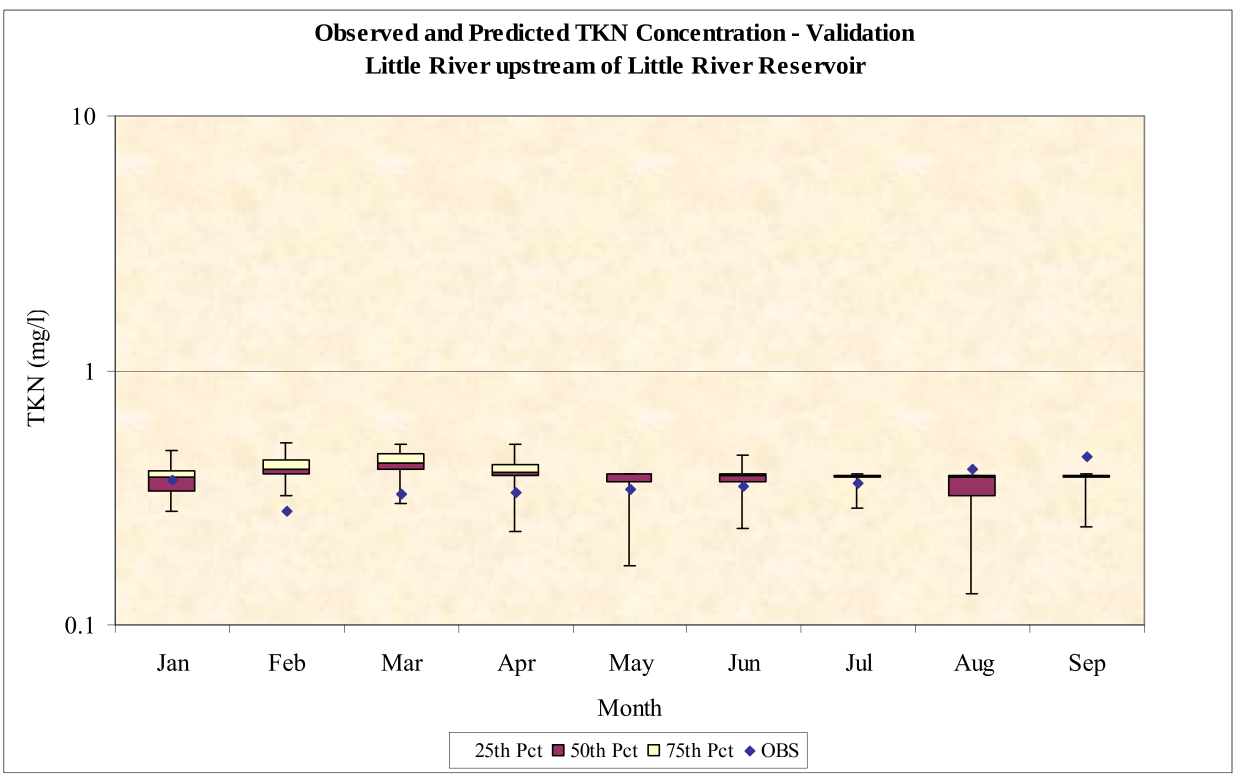


Figure LRA-C12. Seasonal distribution of observed and simulated TKN concentration at Little River DWQ monitoring station at SR 1461 near Orange Factory.

Little River Below Little River Reservoir

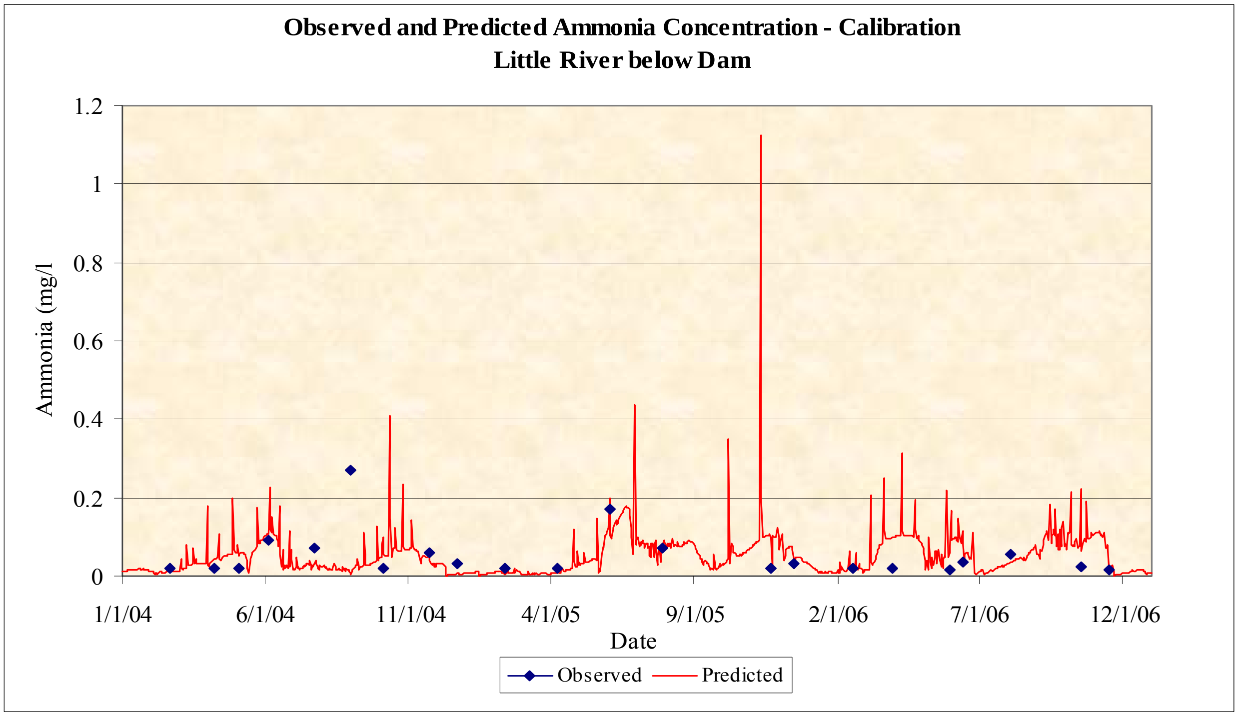


Figure LRB-C1. Time series plots of observed and simulated ammonia concentration at Little River USGS station below Little River tributary at Fairntosh.

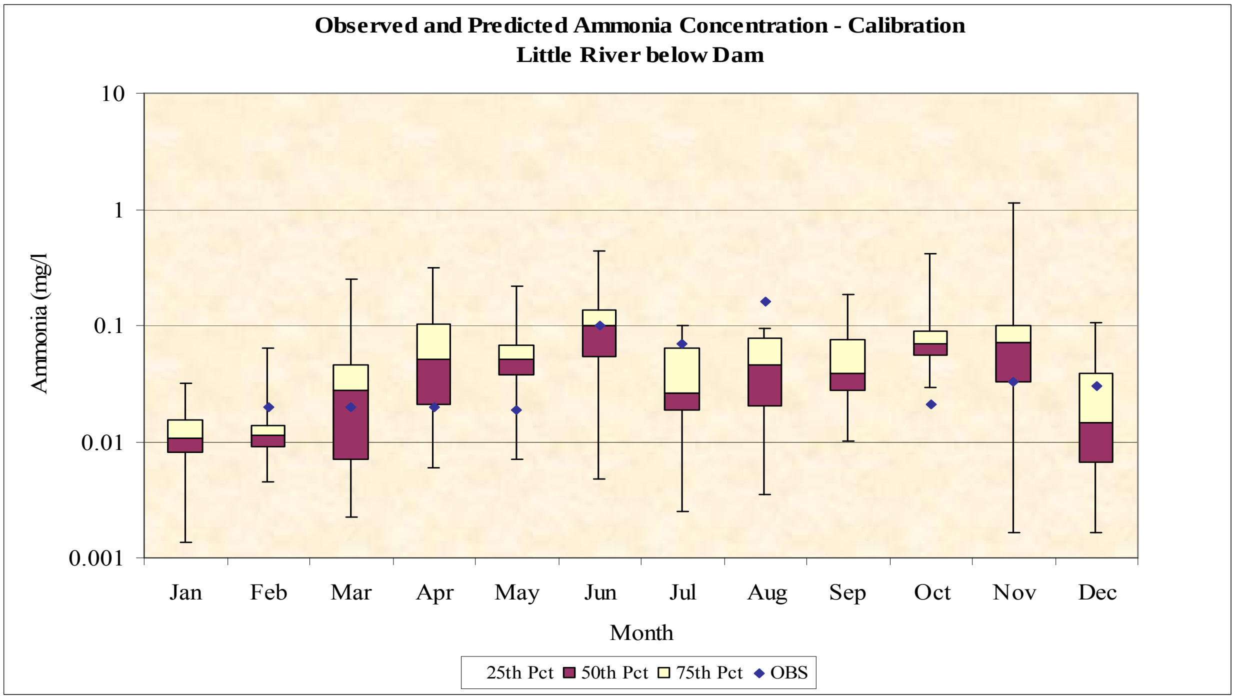


Figure LRB-C2. Seasonal distribution of observed and simulated ammonia concentration at Little River USGS station below Little River tributary at Fairntosh.

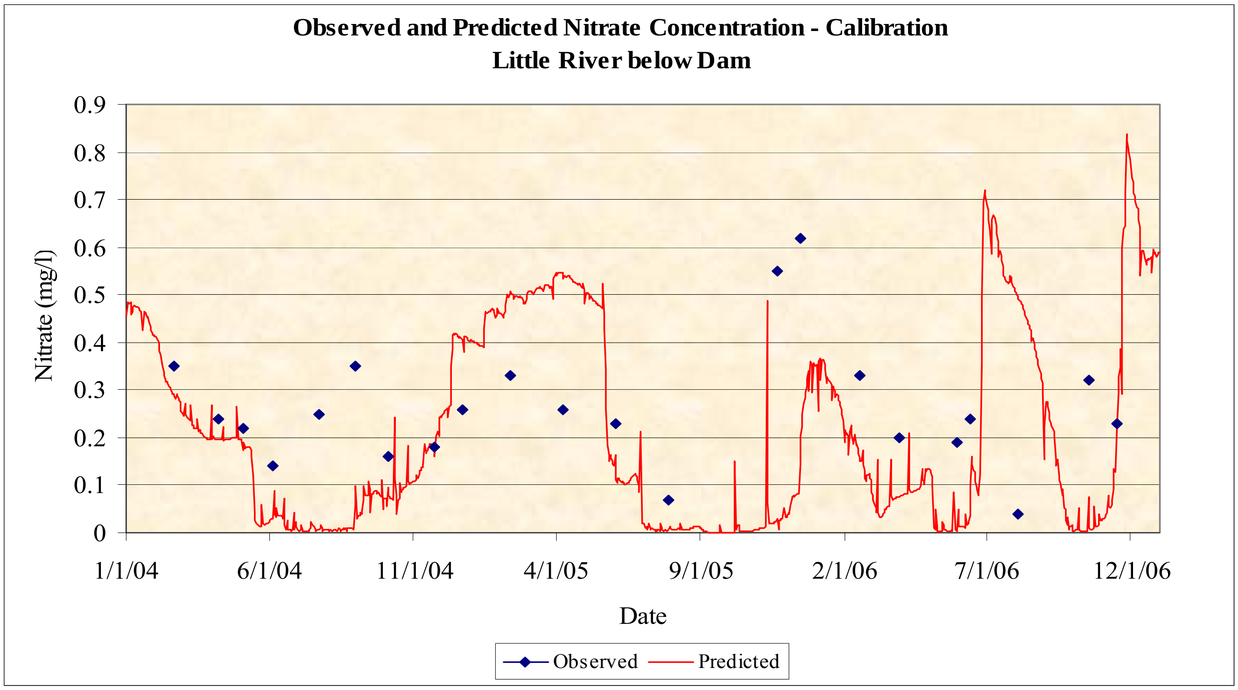


Figure LRB-C3. Time series plots of observed and simulated nitrate concentration at Little River USGS station below Little River tributary at Fairntosh.

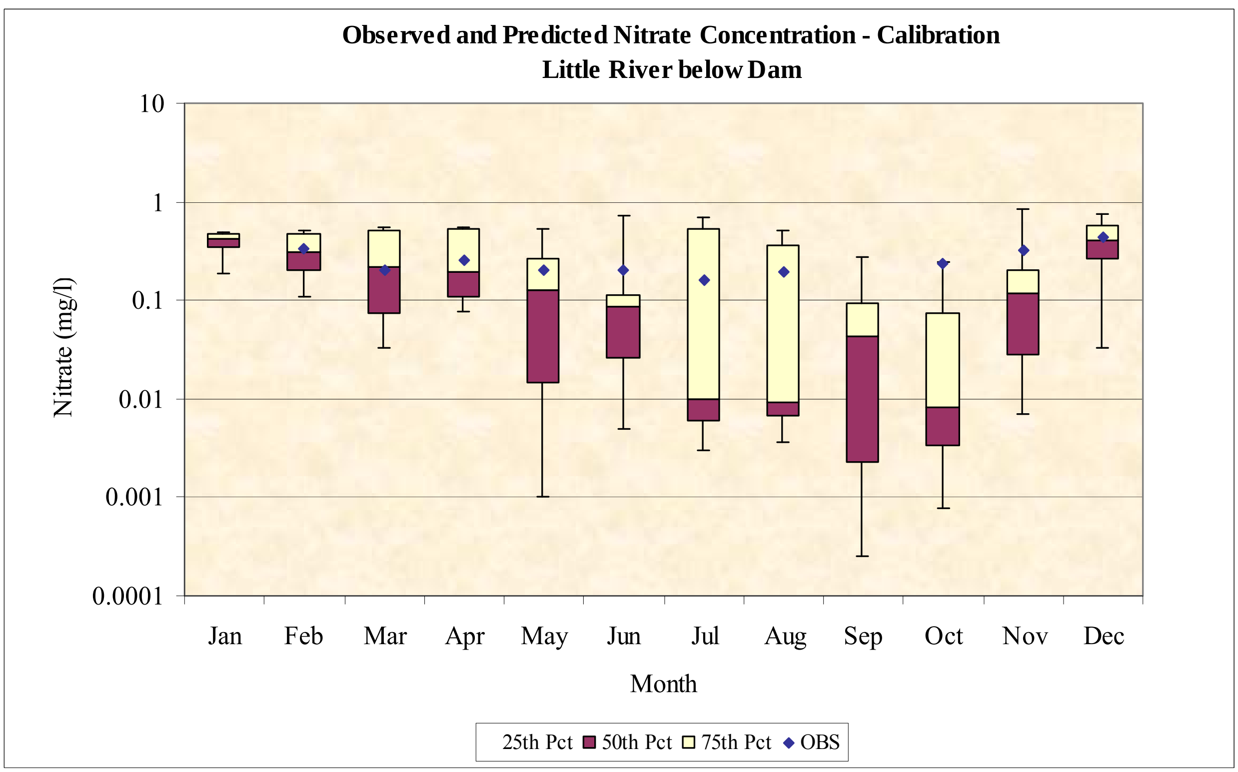


Figure LRB-C4. Seasonal distribution of observed and simulated nitrate concentration at Little River USGS station below Little River tributary at Fairntosh.

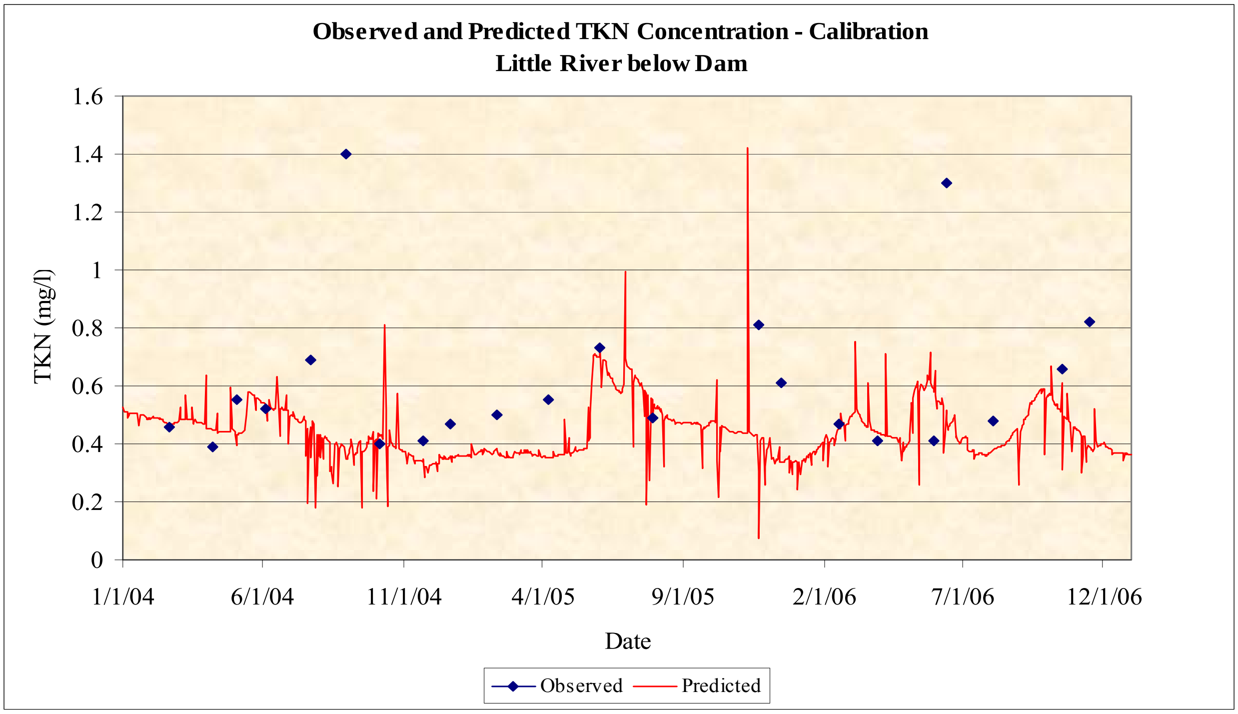


Figure LRB-C5. Time series plots of observed and simulated TKN concentration at Little River USGS station below Little River tributary at Fairntosh.

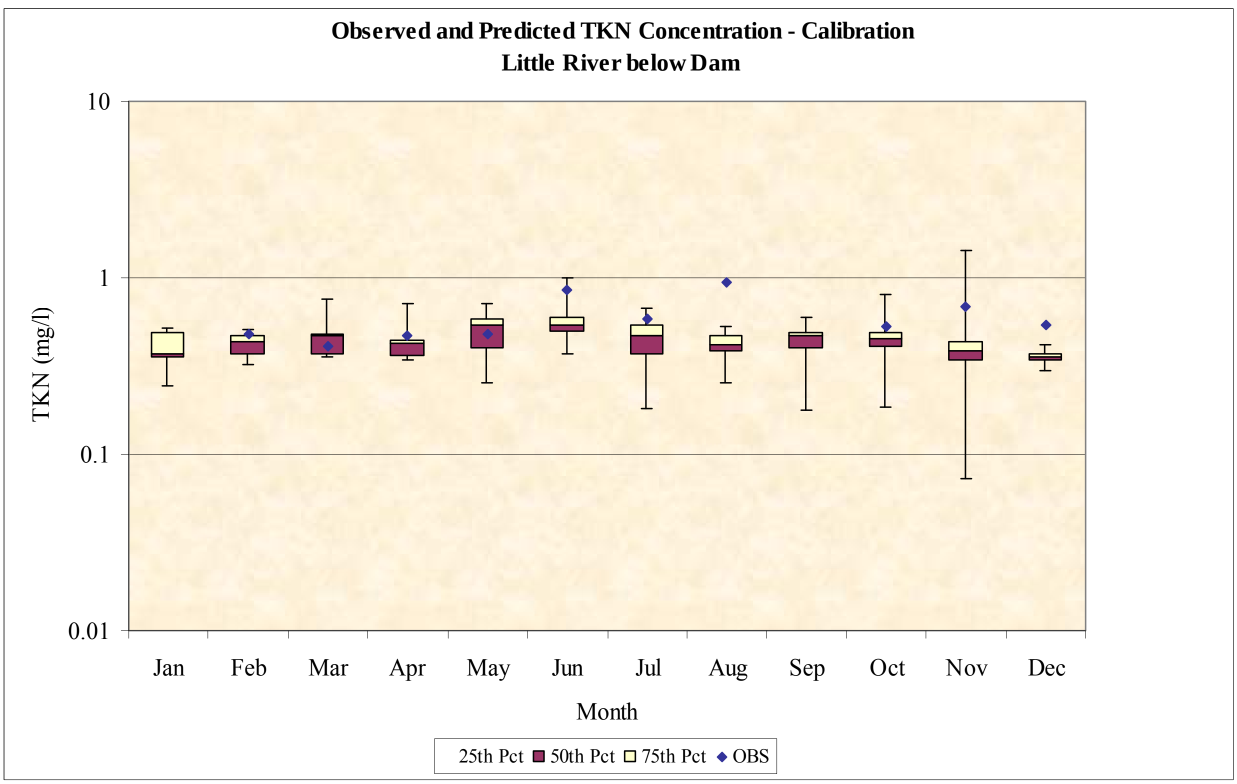


Figure LRB-C6. Seasonal distribution of observed and simulated TKN concentration at Little River USGS station below Little River tributary at Fairntosh.

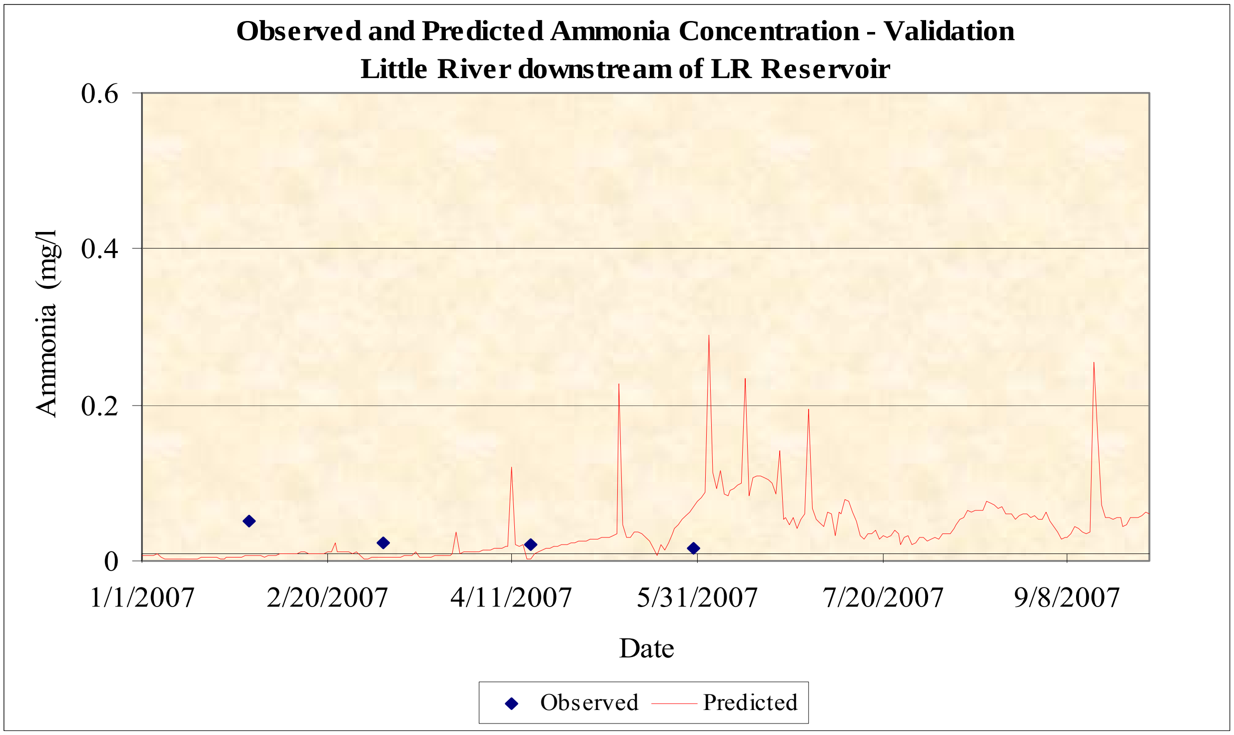


Figure LRB-C7. Time series plots of observed and simulated ammonia concentration at Little River USGS station below Little River tributary at Fairntosh.

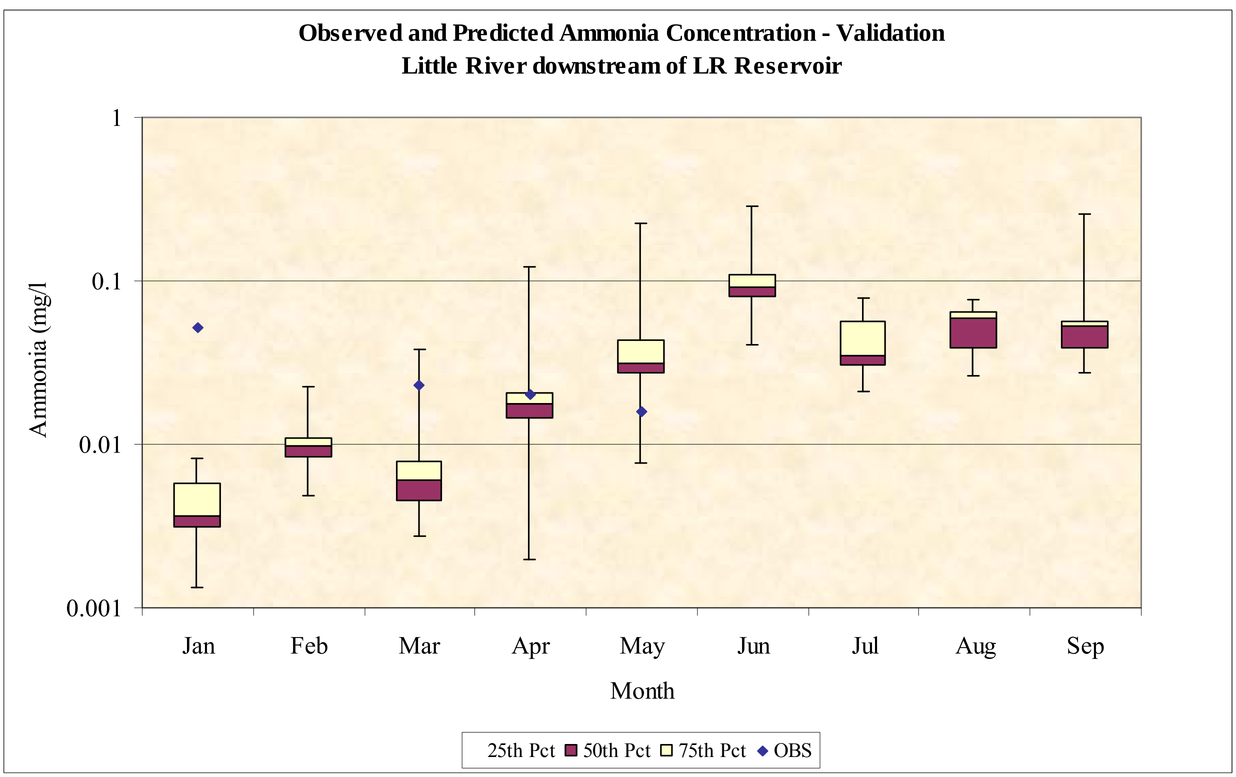


Figure LRB-C8. Seasonal distribution of observed and simulated ammonia concentration at Little River USGS station below Little River tributary at Fairntosh.

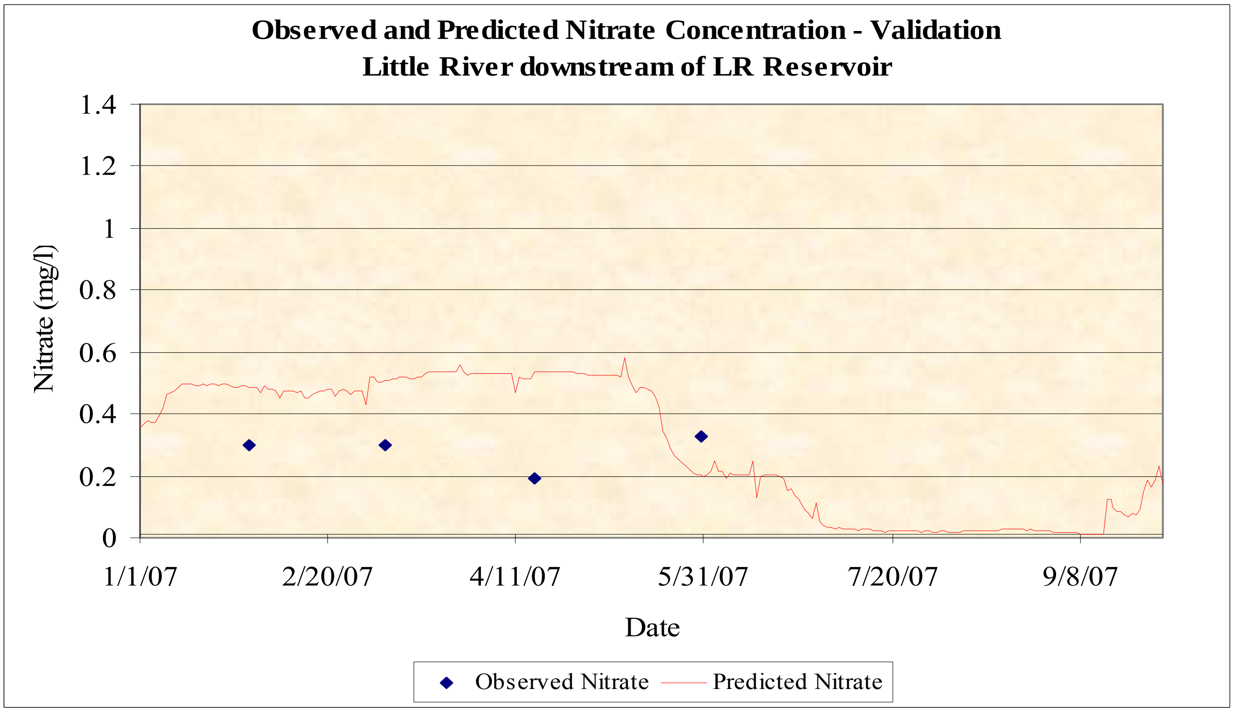


Figure LRB-C9. Time series plots of observed and simulated nitrate concentration at Little River USGS station below Little River tributary at Fairntosh.

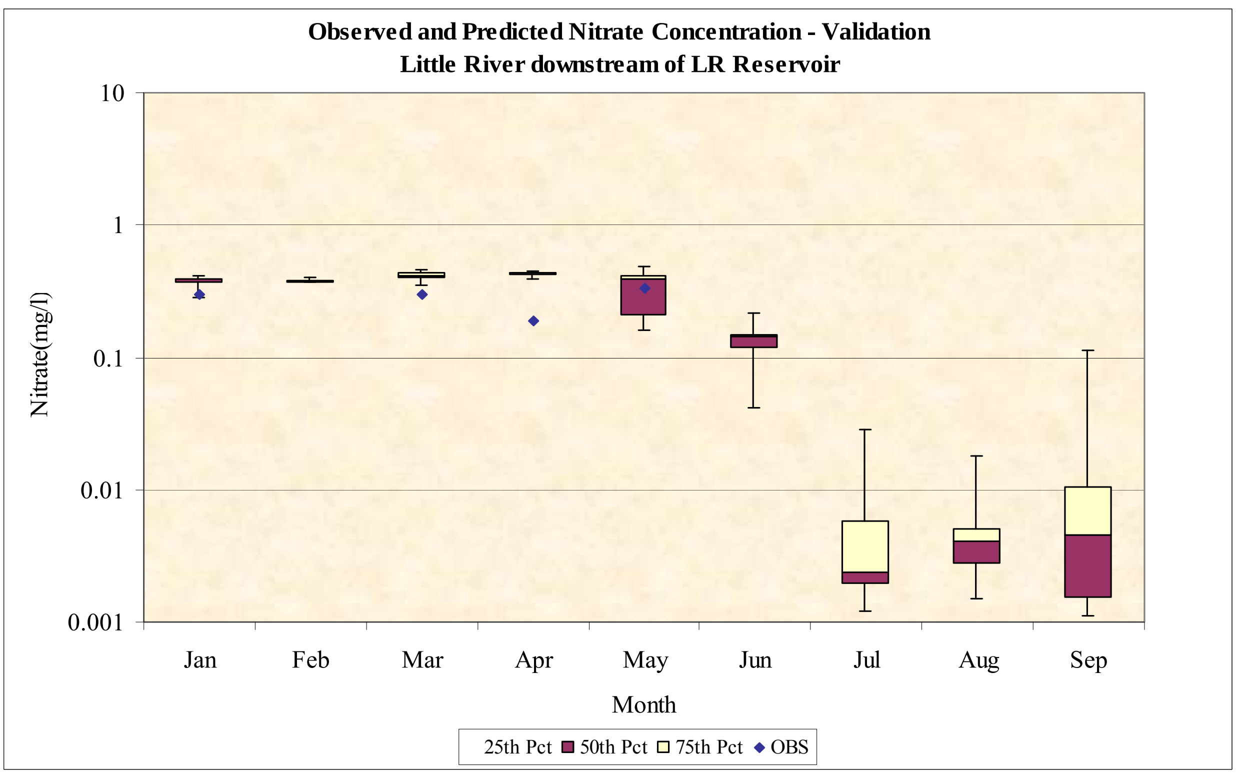


Figure LRB-C10. Seasonal distribution of observed and simulated nitrate concentration at Little River USGS station below Little River tributary at Fairntosh.

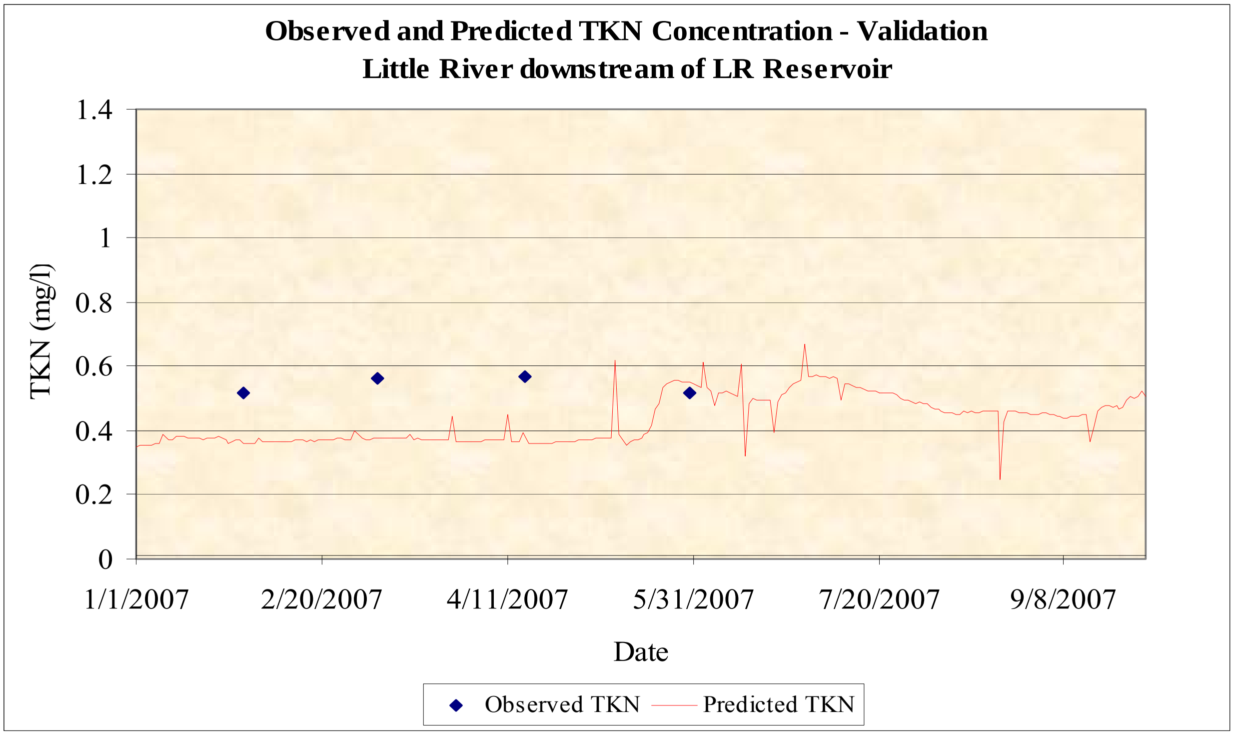


Figure LRB-C11. Time series plots of observed and simulated TKN concentration at Little River USGS station below Little River tributary at Fairntosh.

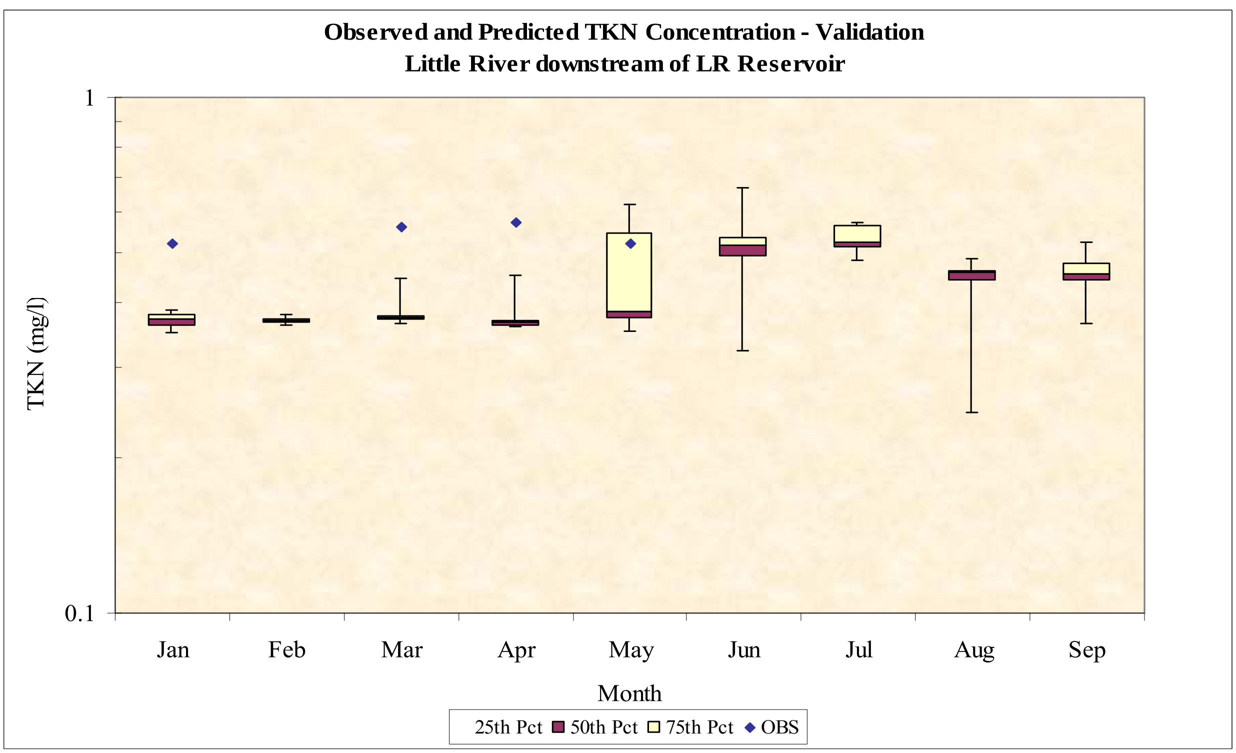


Figure LRB-C12. Seasonal distribution of observed and simulated TKN concentration at Little River USGS station below Little River tributary at Fairntosh.

Eno River

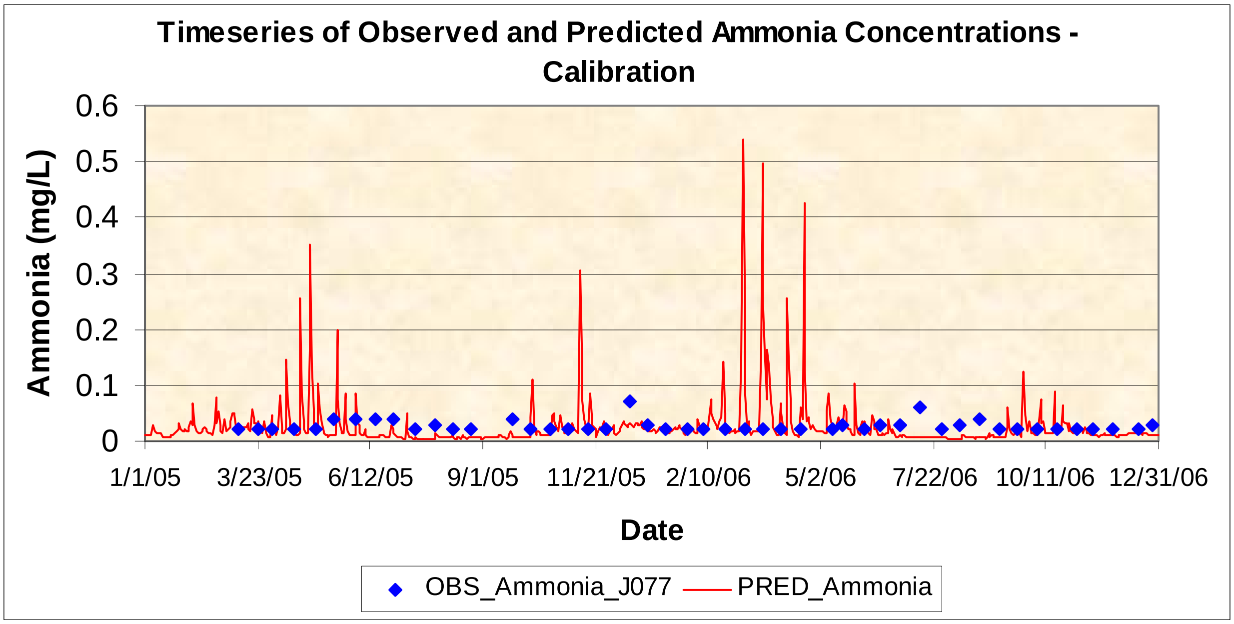


Figure Eno-C1. Calibration – Eno River (at Ambient Monitoring Station J0770000) Ammonia concentrations daily time series.

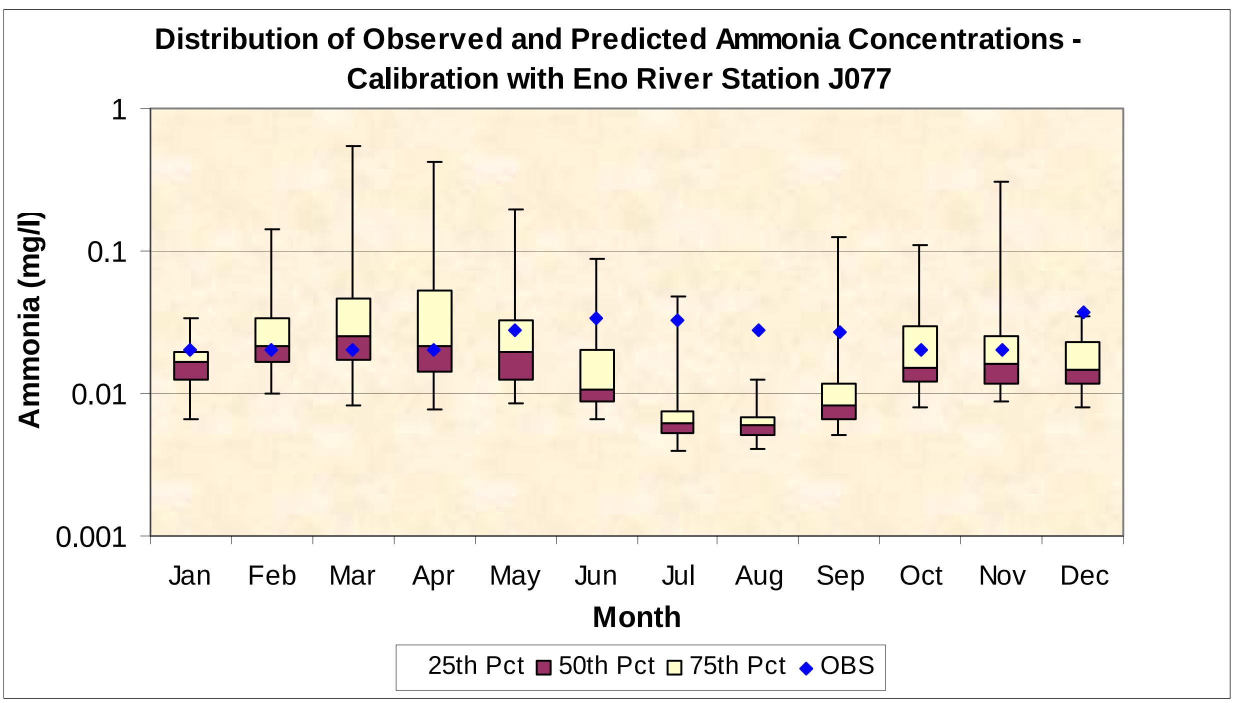


Figure Eno-C2. Calibration - Observed versus predicted Ammonia concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

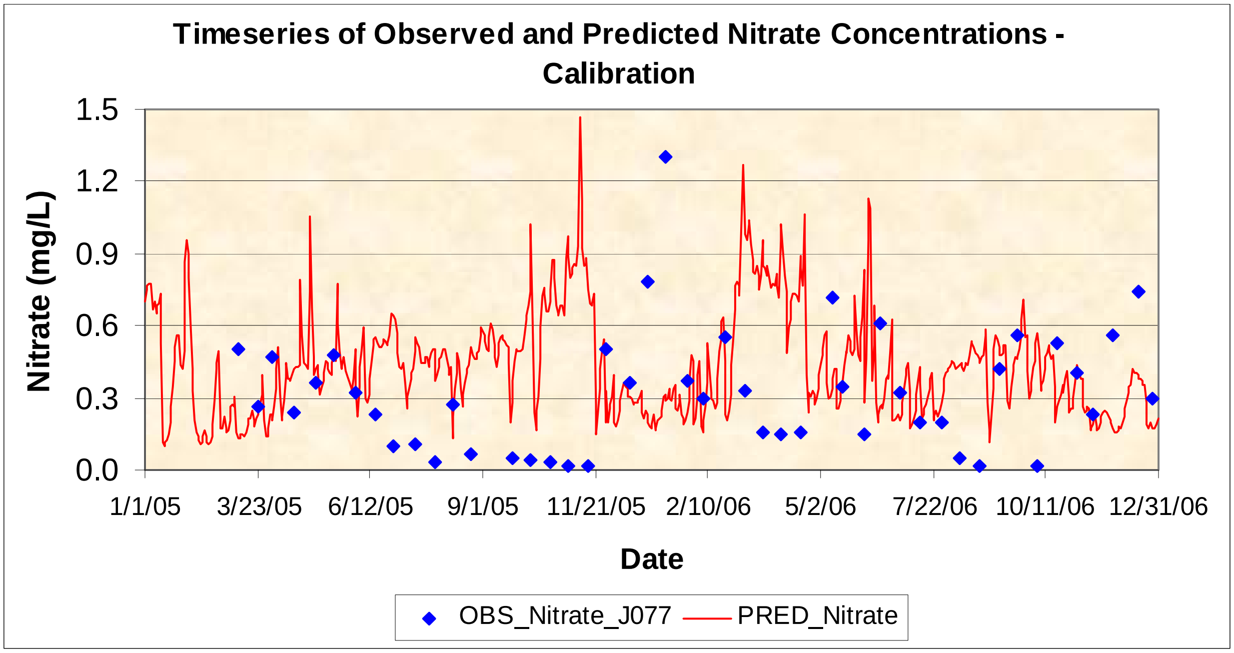


Figure Eno-C3. Calibration – Eno River (at Ambient Monitoring Station J0770000) Nitrate concentrations daily time series.

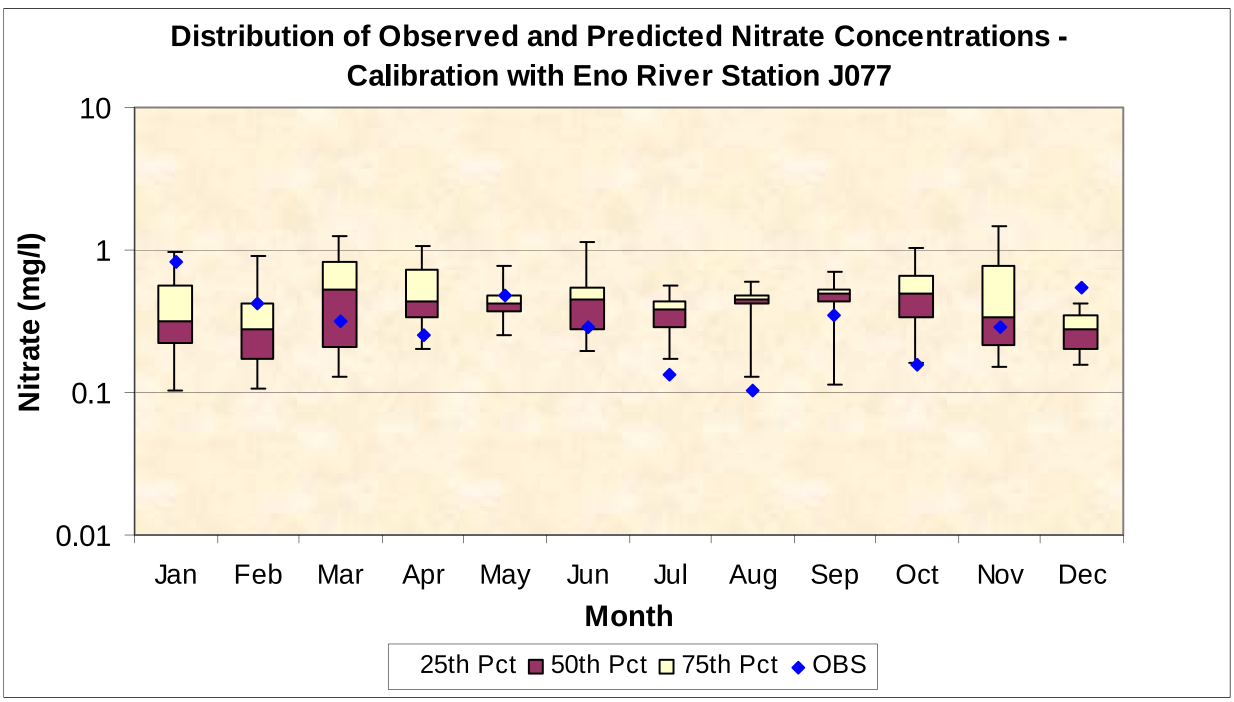


Figure Eno-C4. Calibration - Observed versus predicted Nitrate concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

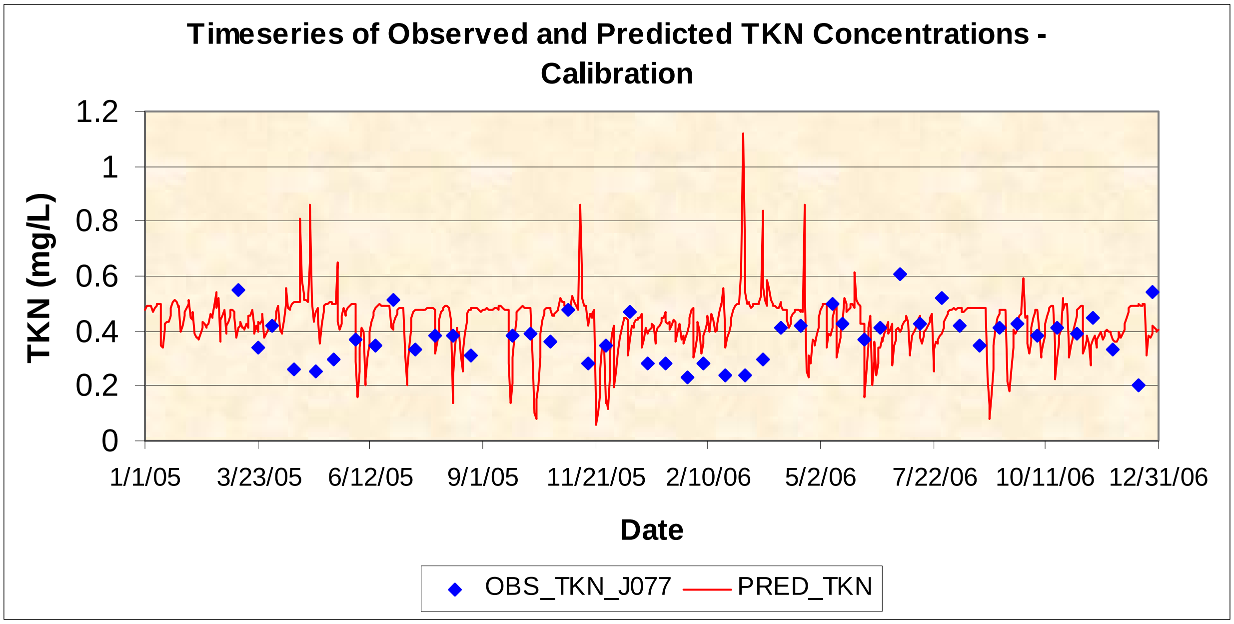


Figure Eno-C5. Calibration – Eno River (at Ambient Monitoring Station J0770000) TKN concentrations daily time series.

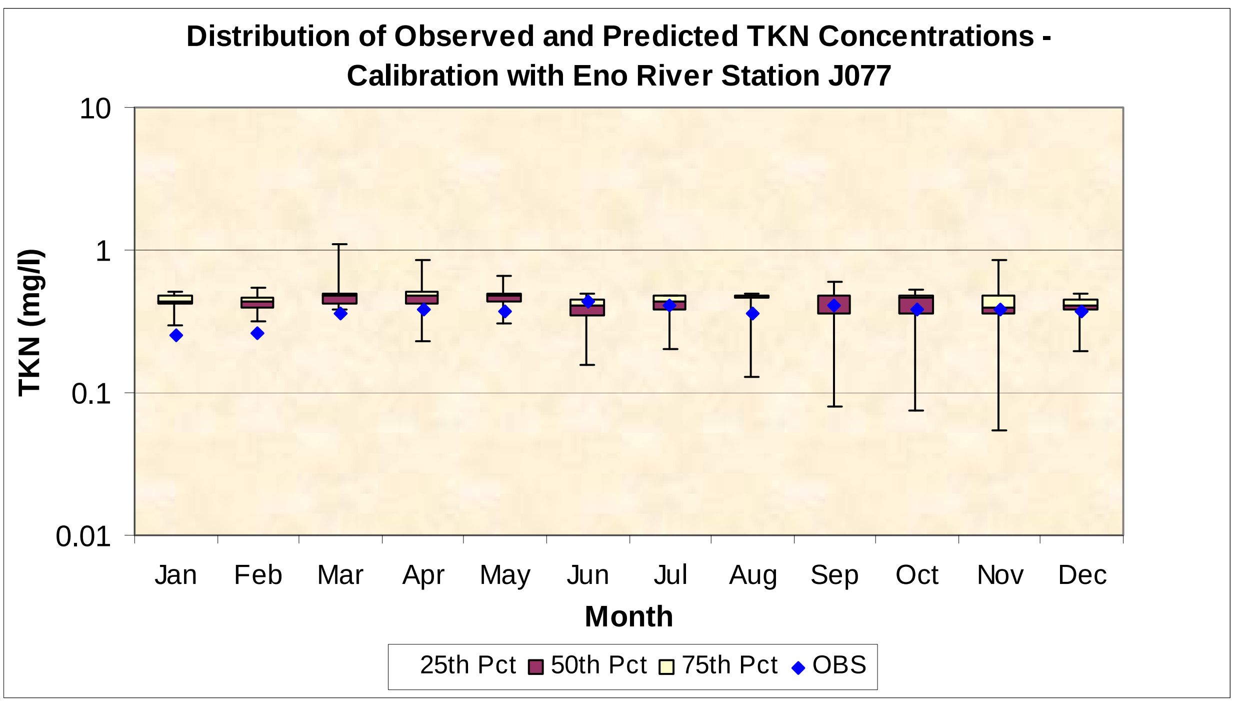


Figure Eno-C6. Calibration - Observed versus predicted TKN concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

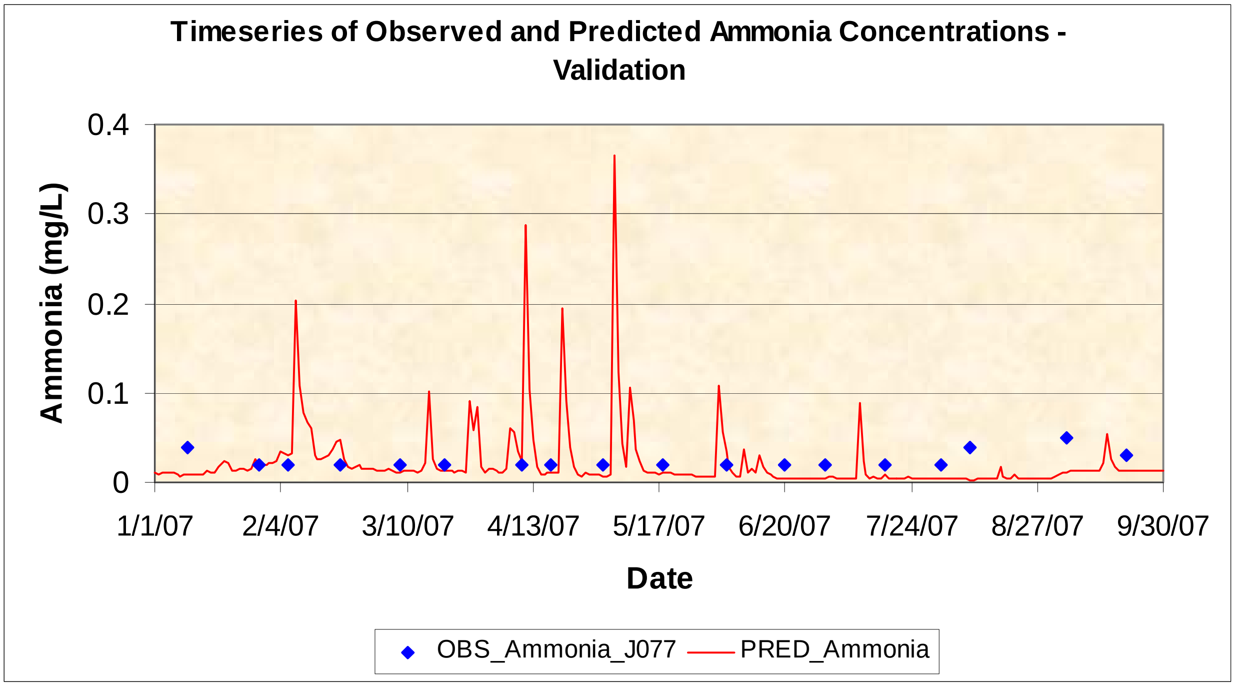


Figure Eno-C7. Validation – Eno River (at Ambient Monitoring Station J0770000) Ammonia concentrations daily time series.

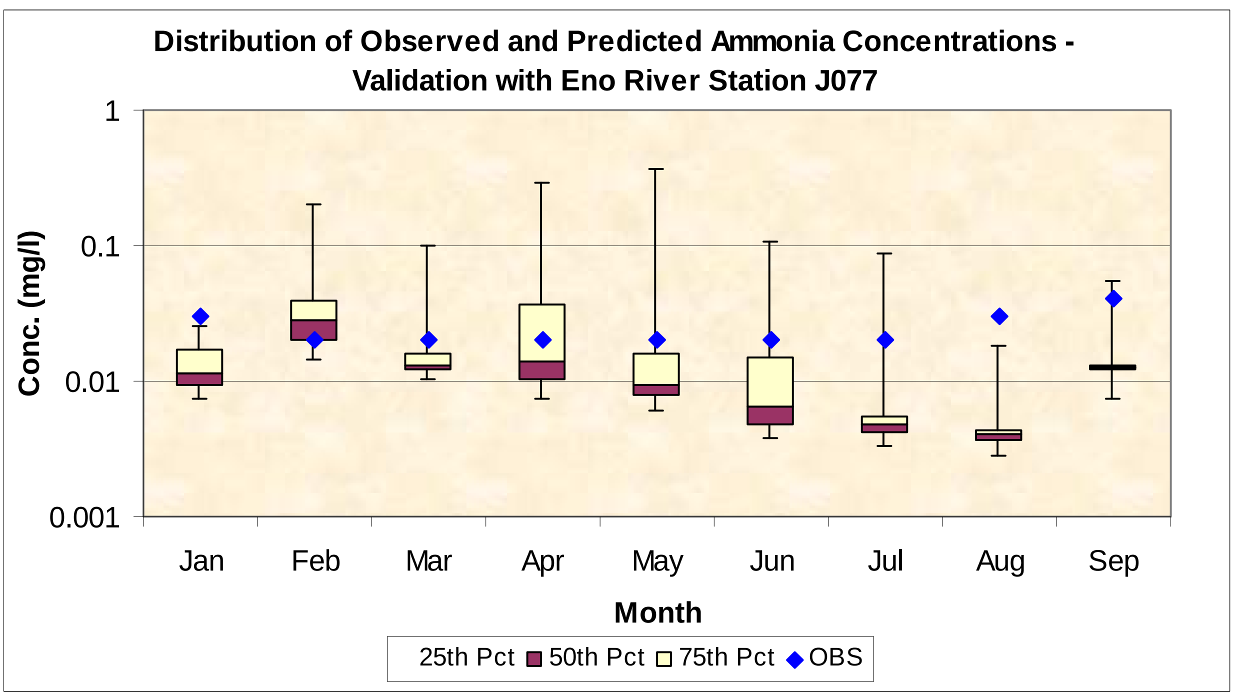


Figure Eno-C8. Validation - Observed versus predicted Ammonia concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

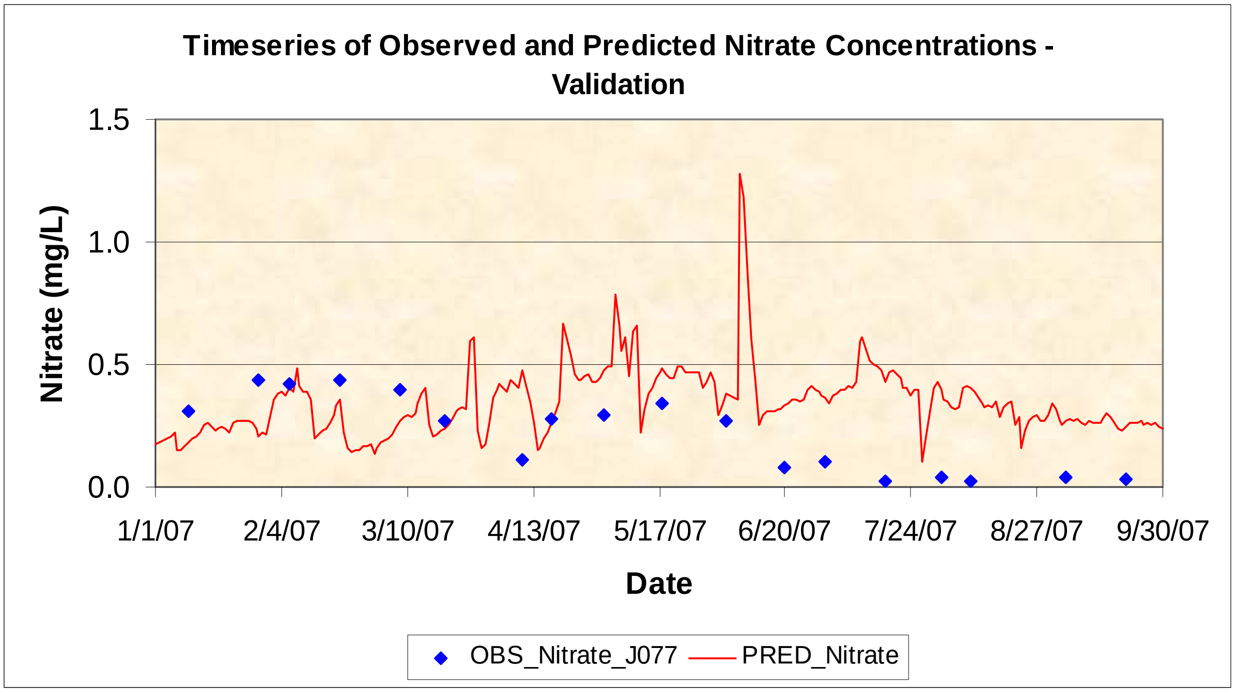


Figure Eno-C9. Validation – Eno River (at Ambient Monitoring Station J0770000) Nitrate concentrations daily time series.

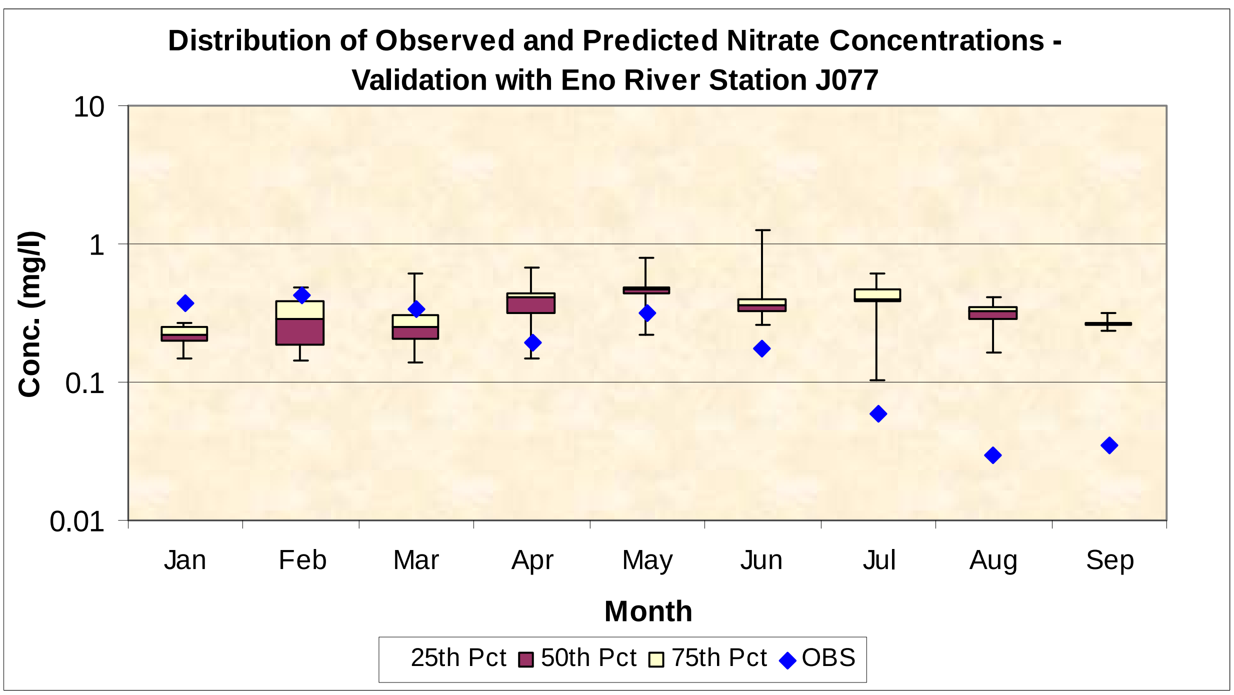


Figure Eno-C10. Validation - Observed versus predicted Nitrate concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

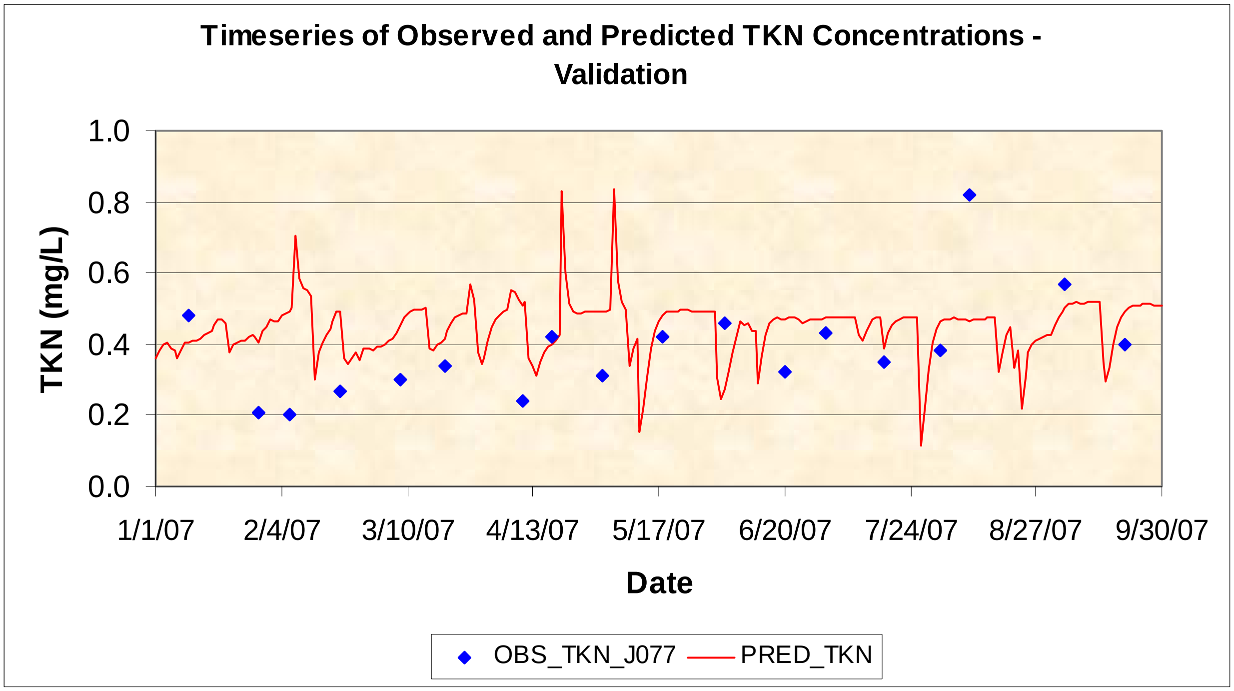


Figure Eno-C11. Validation – Eno River (at Ambient Monitoring Station J0770000) TKN concentrations daily time series.

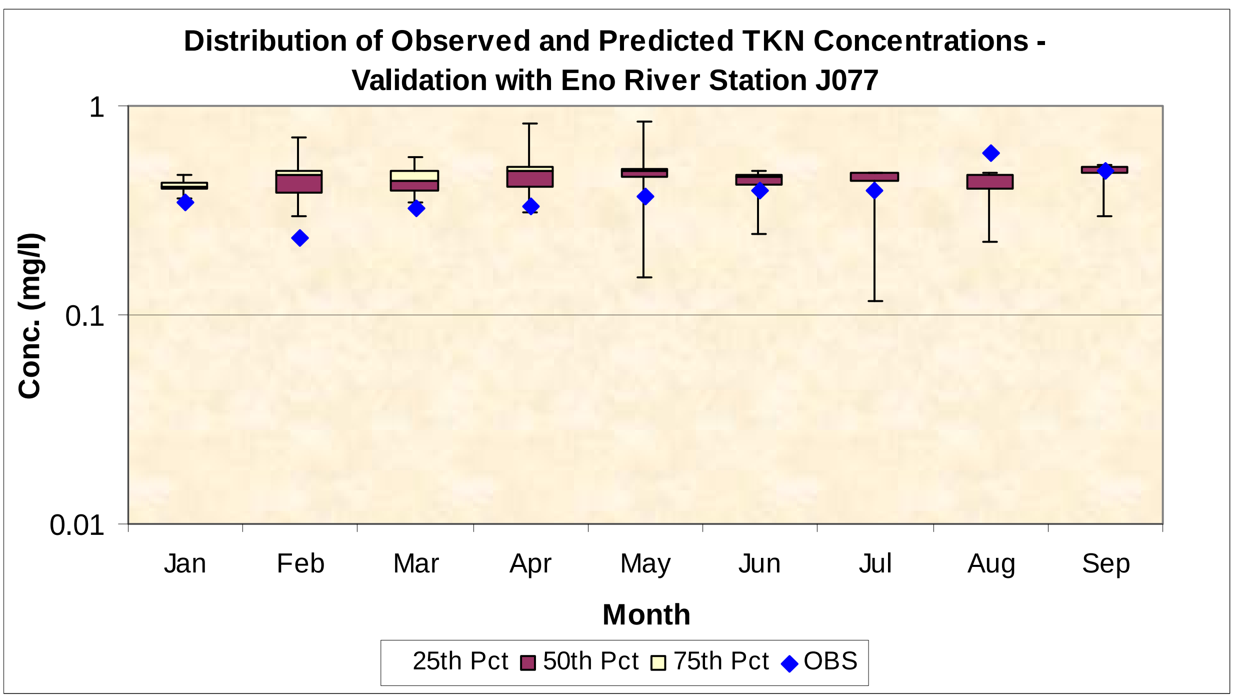


Figure Eno-C12. Validation - Observed versus predicted TKN concentrations for Eno River at Ambient Monitoring Station J0770000 (shown in log scale).

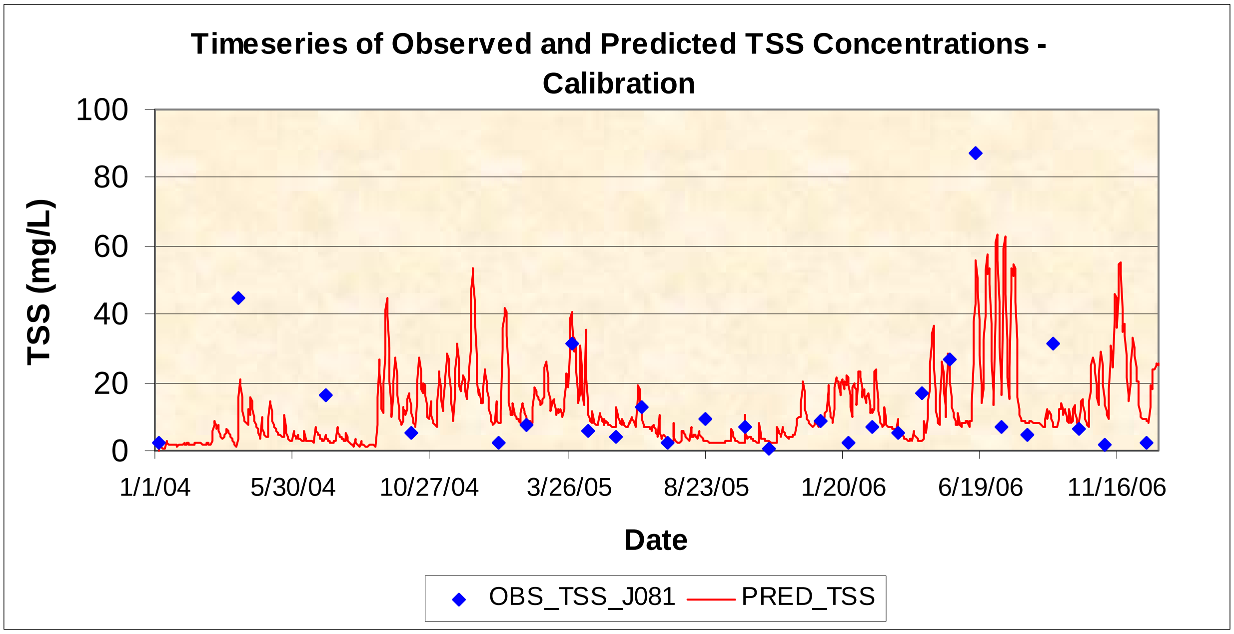


Figure Eno-C13. Calibration – Eno River (at Ambient Monitoring Station J0810000) TSS concentrations daily time series.

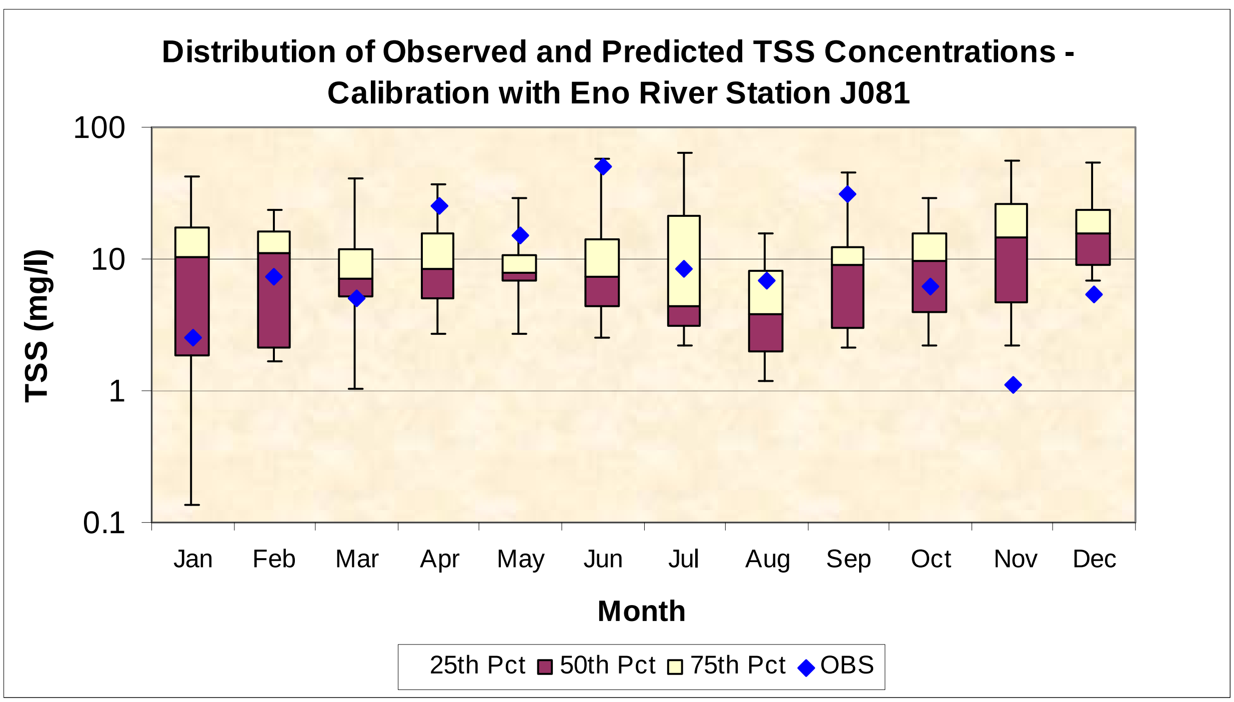


Figure Eno-C14. Calibration - Observed versus predicted TSS concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

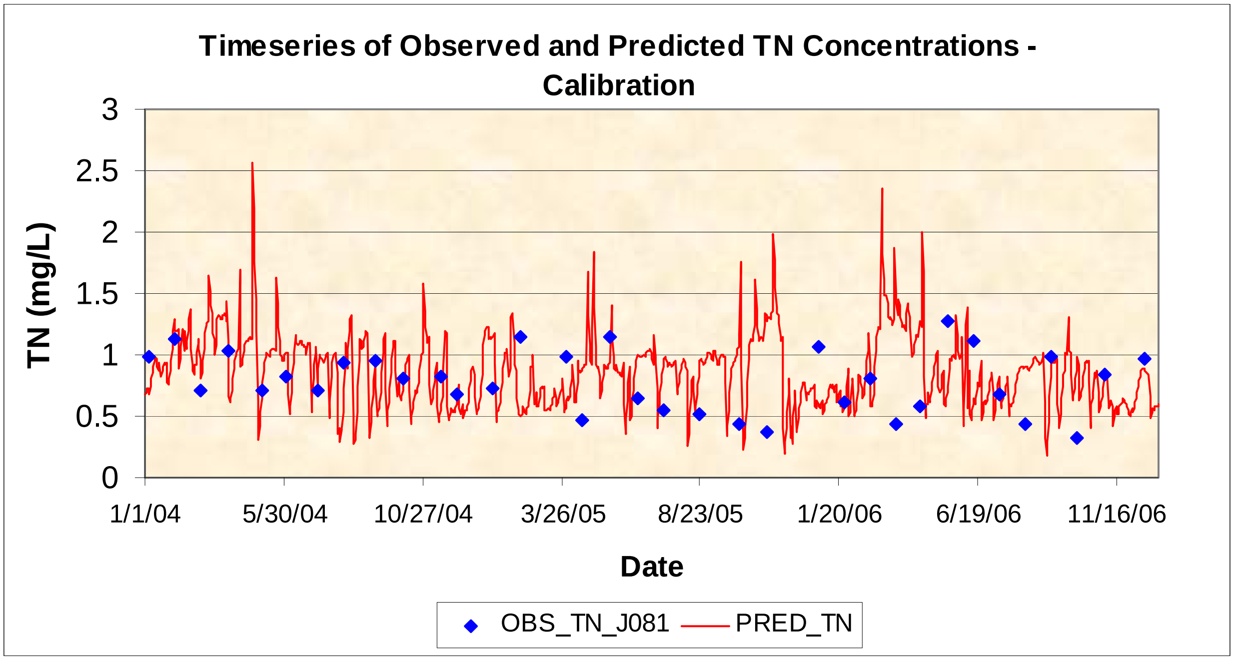


Figure Eno-C15. Calibration – Eno River (at Ambient Monitoring Station J0810000) TN concentrations daily time series.

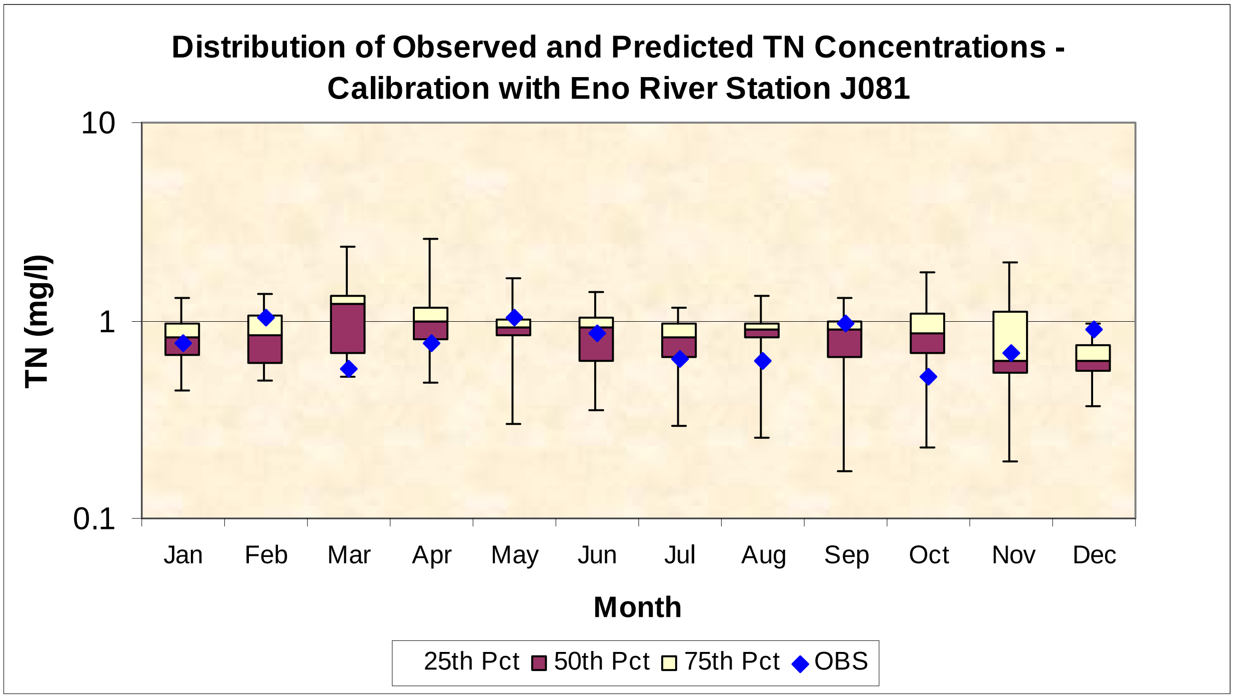


Figure Eno-C16. Calibration - Observed versus predicted TN concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

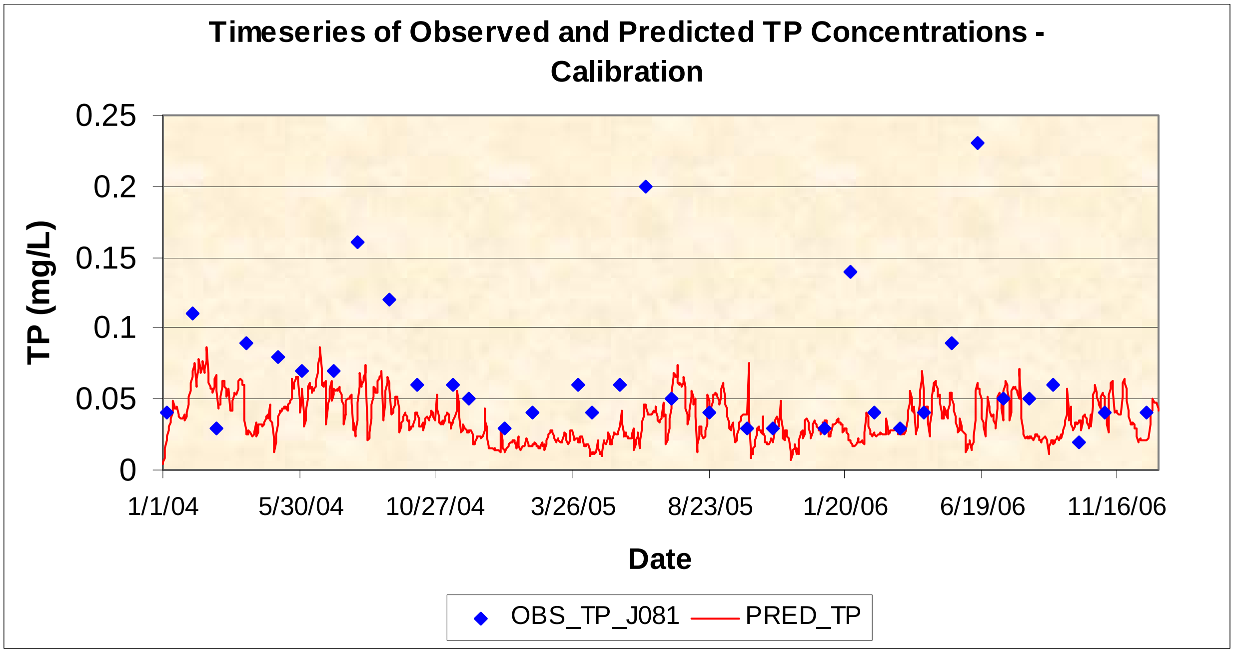


Figure Eno-C17. Calibration – Eno River (at Ambient Monitoring Station J0810000) TP concentrations daily time series.

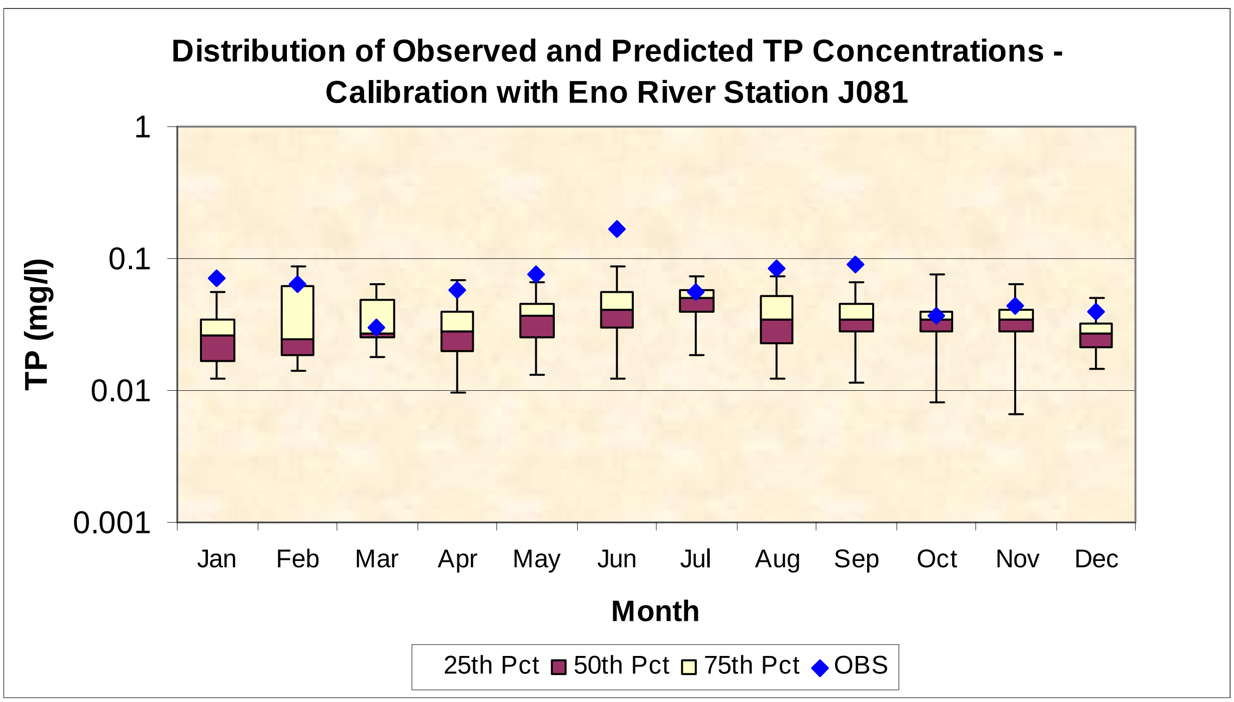


Figure Eno-C18. Calibration - Observed versus predicted TP concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

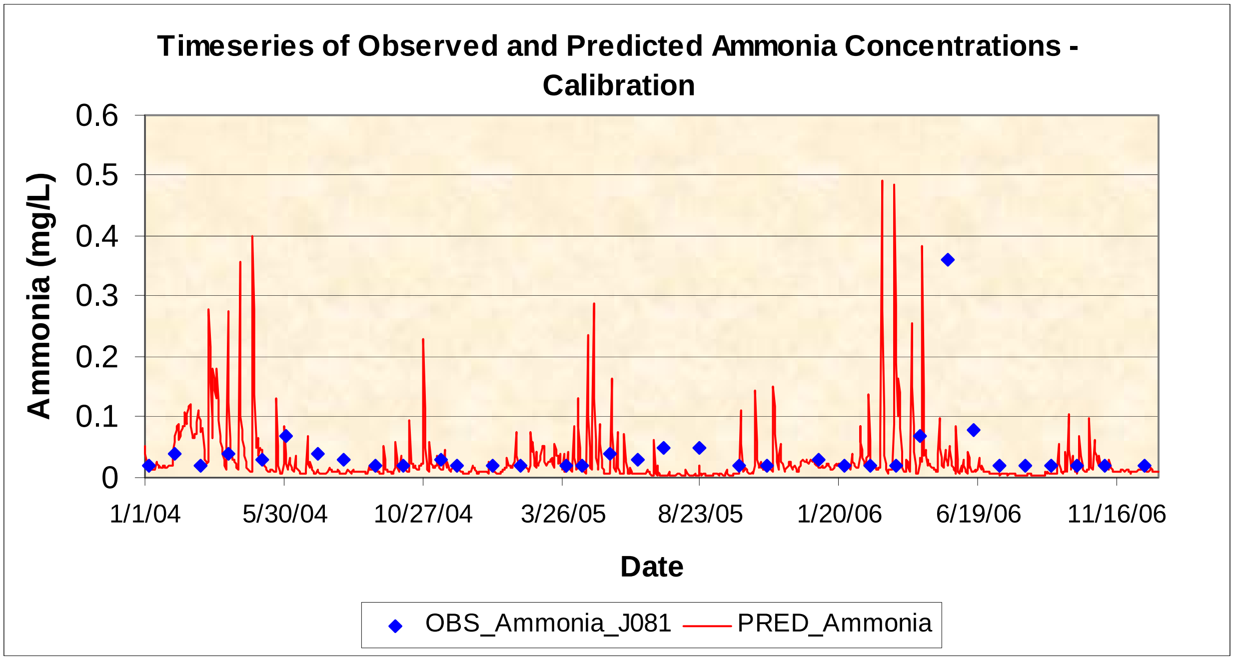


Figure Eno-C19. Calibration – Eno River (at Ambient Monitoring Station J0810000) Ammonia concentrations daily time series.

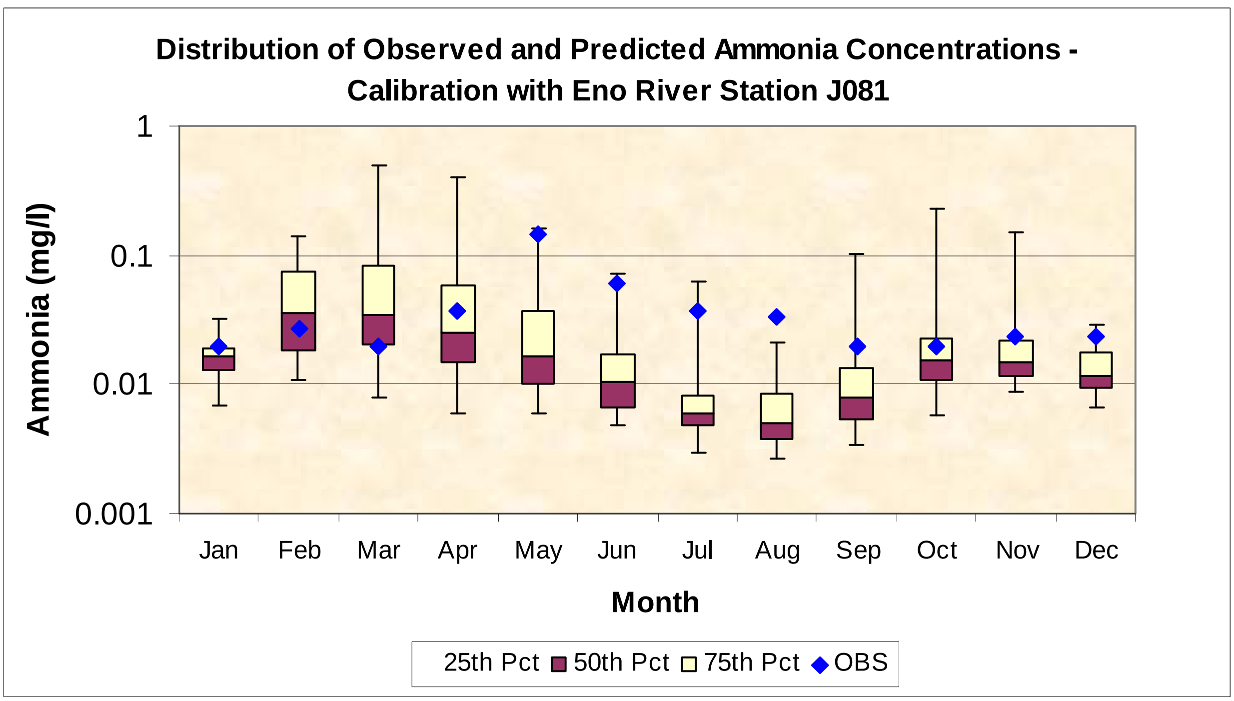


Figure Eno-C20. Calibration - Observed versus predicted Ammonia concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

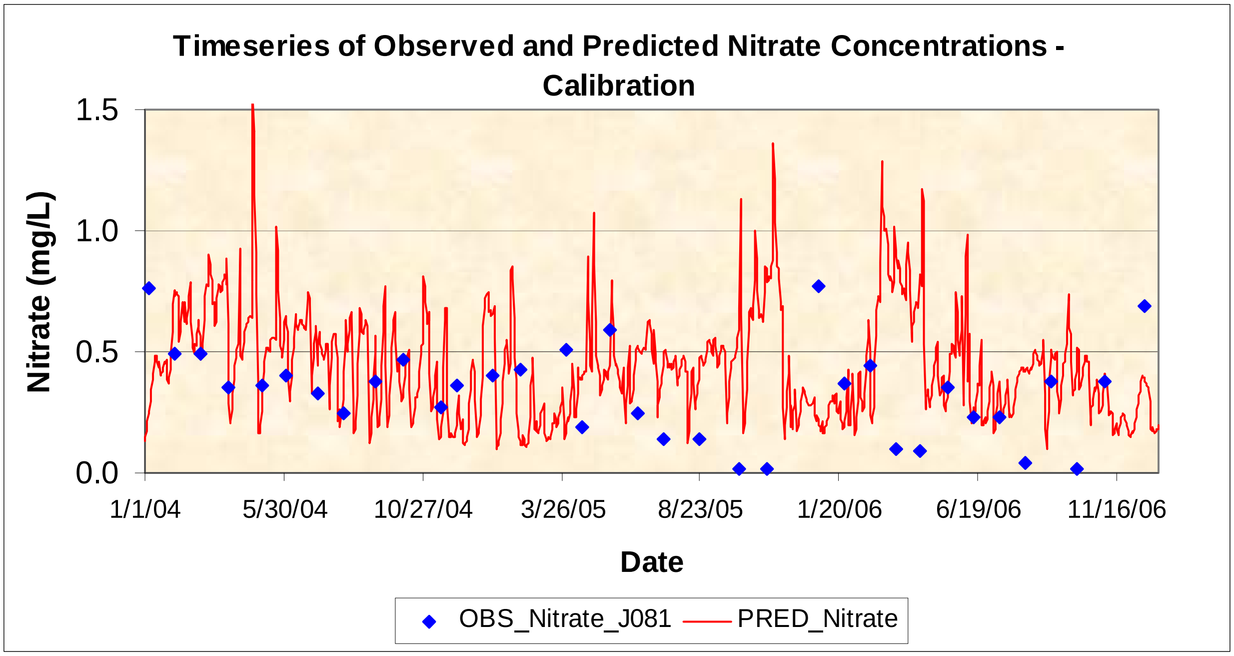


Figure Eno-C21. Calibration – Eno River (at Ambient Monitoring Station J0810000) Nitrate concentrations daily time series.

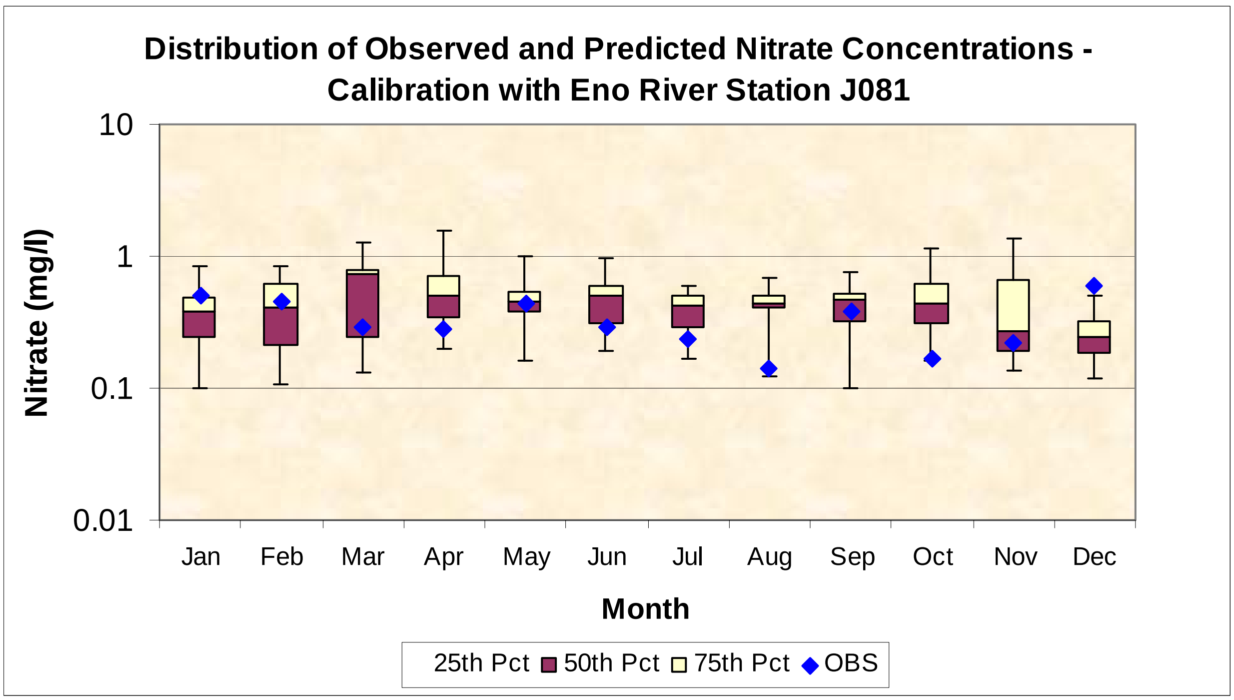


Figure Eno-C22. Calibration - Observed versus predicted Nitrate concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

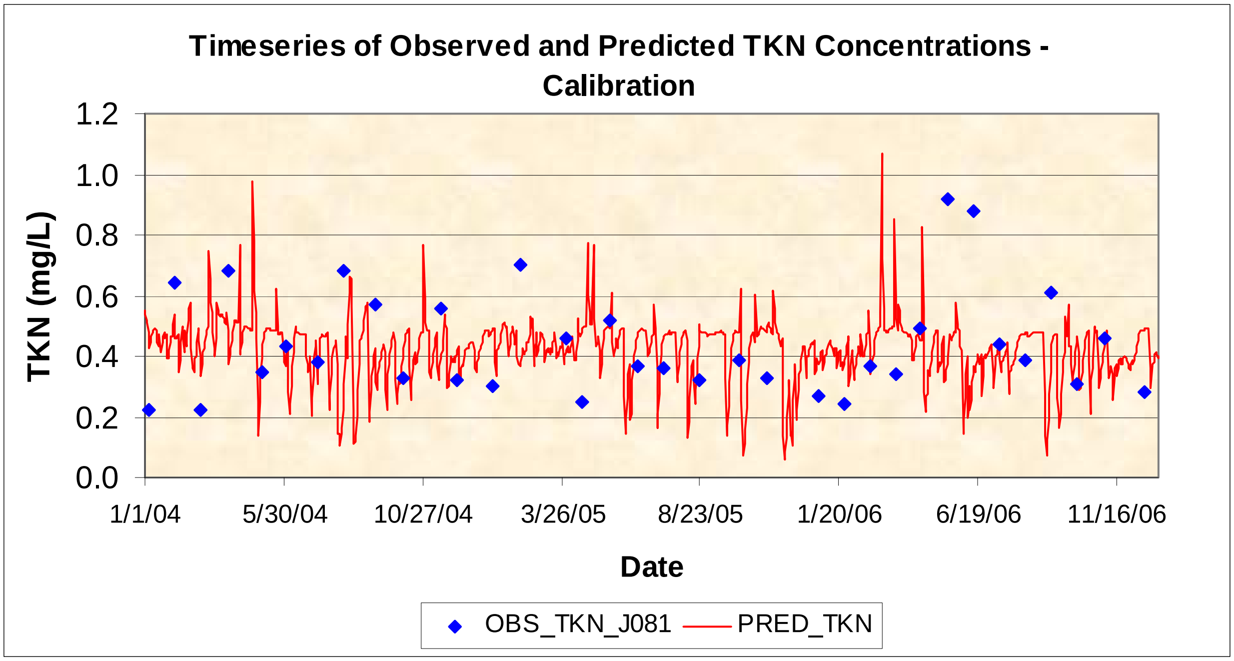


Figure Eno-C23. Calibration – Eno River (at Ambient Monitoring Station J0810000) TKN concentrations daily time series.

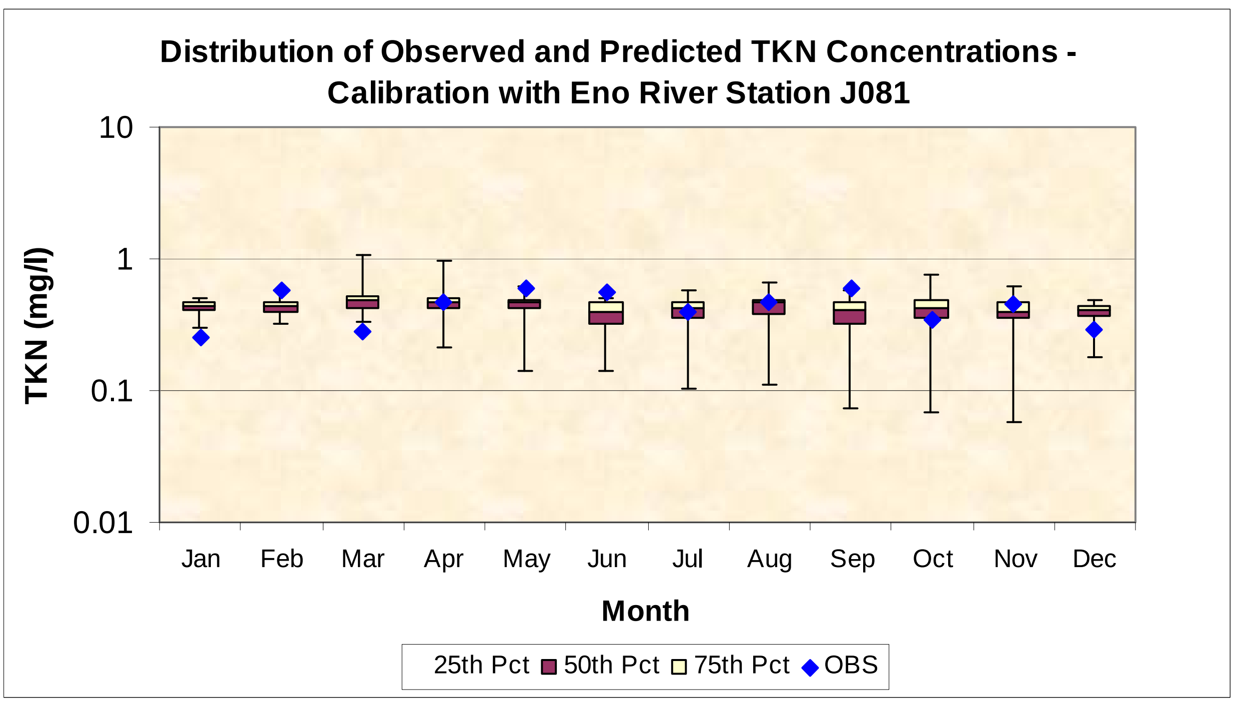


Figure Eno-C24. Calibration - Observed versus predicted TKN concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

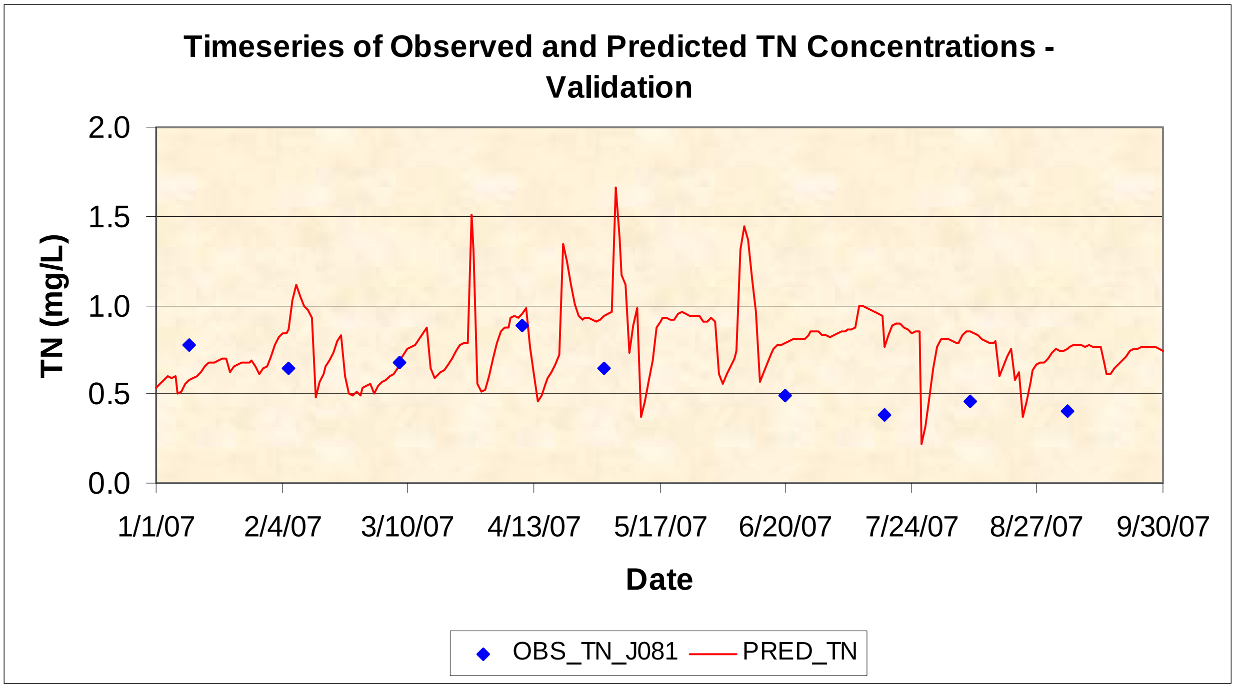


Figure Eno-C25. Validation – Eno River (at Ambient Monitoring Station J0810000) TN concentrations daily time series.

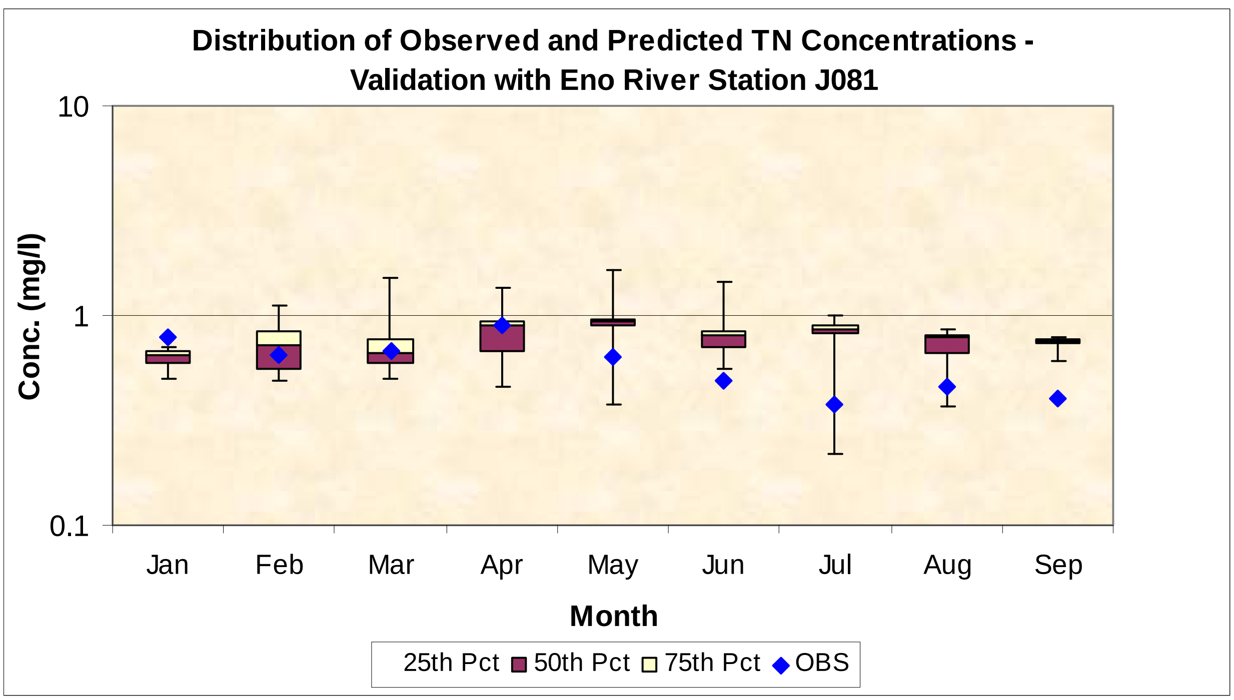


Figure Eno-C26. Validation - Observed versus predicted TN concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

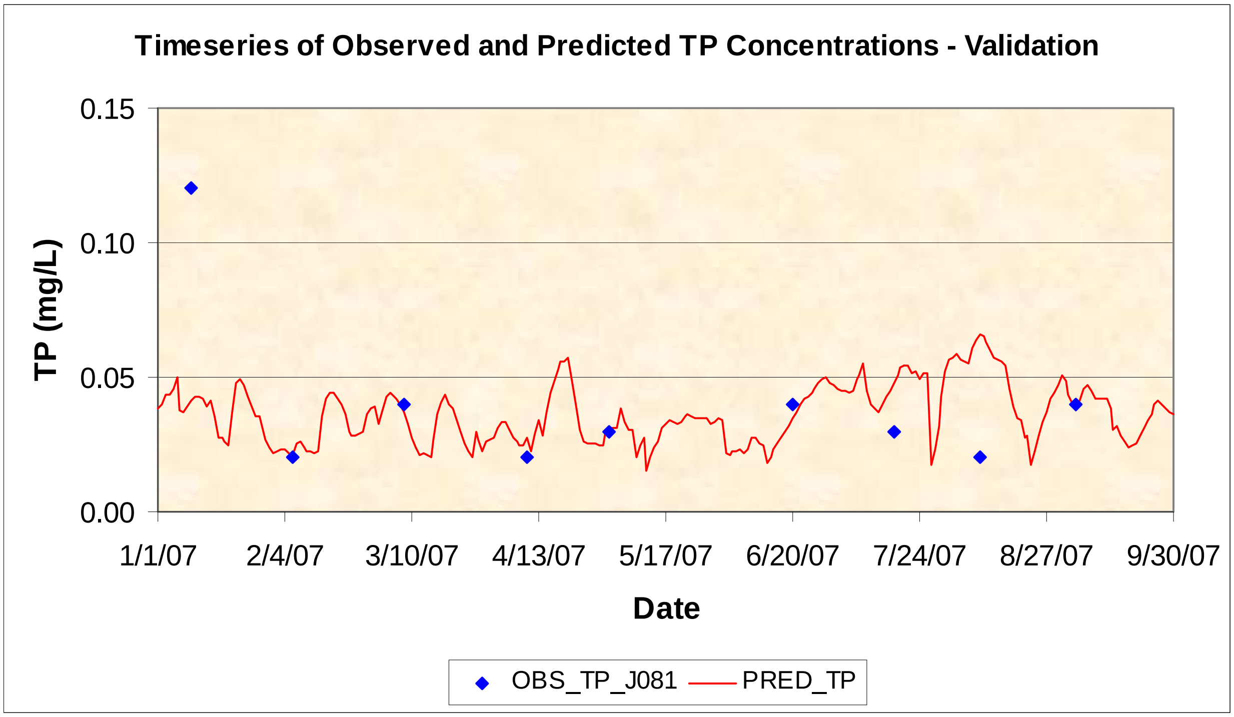


Figure Eno-C27. Validation – Eno River (at Ambient Monitoring Station J0810000) TP concentrations daily time series.

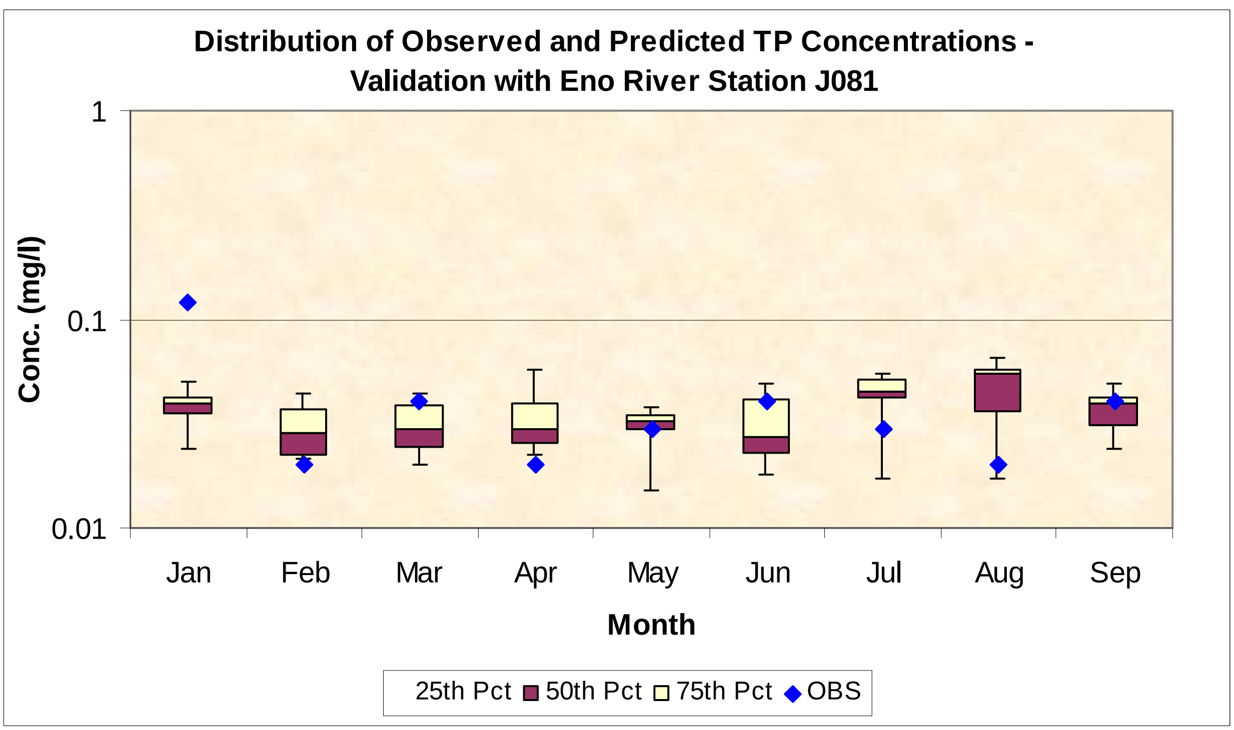


Figure Eno-C28. Validation - Observed versus predicted TP concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

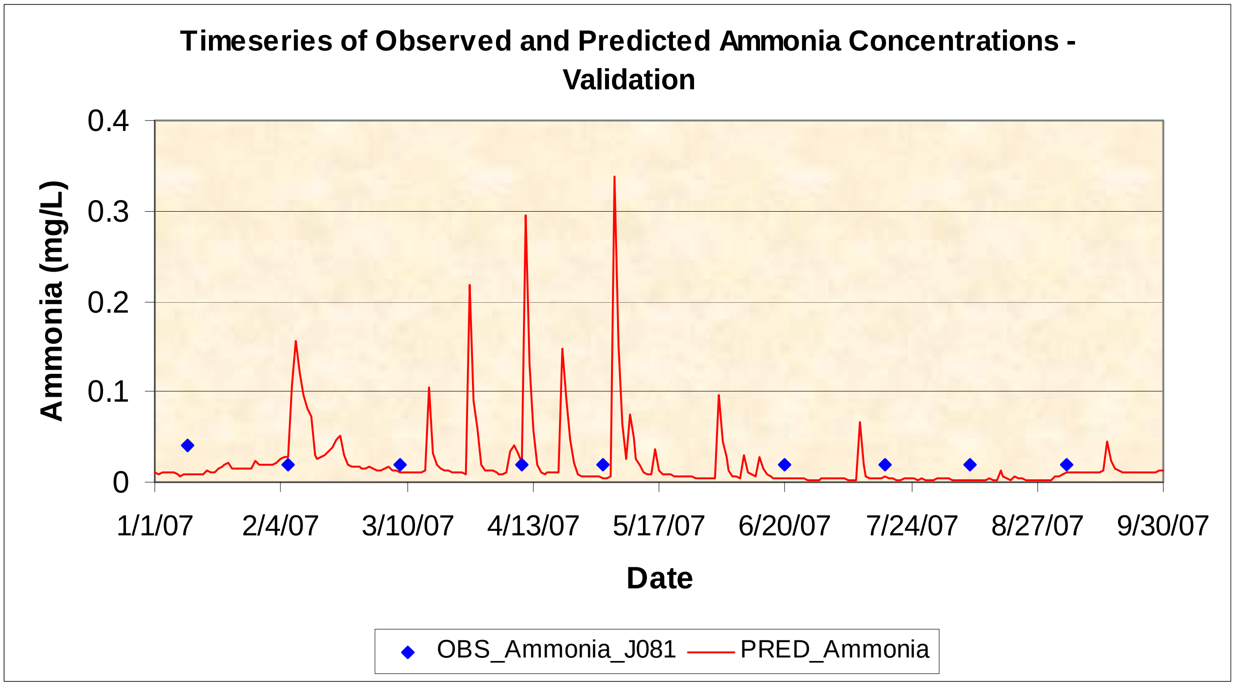


Figure Eno-C29. Validation – Eno River (at Ambient Monitoring Station J0810000) Ammonia concentrations daily time series.

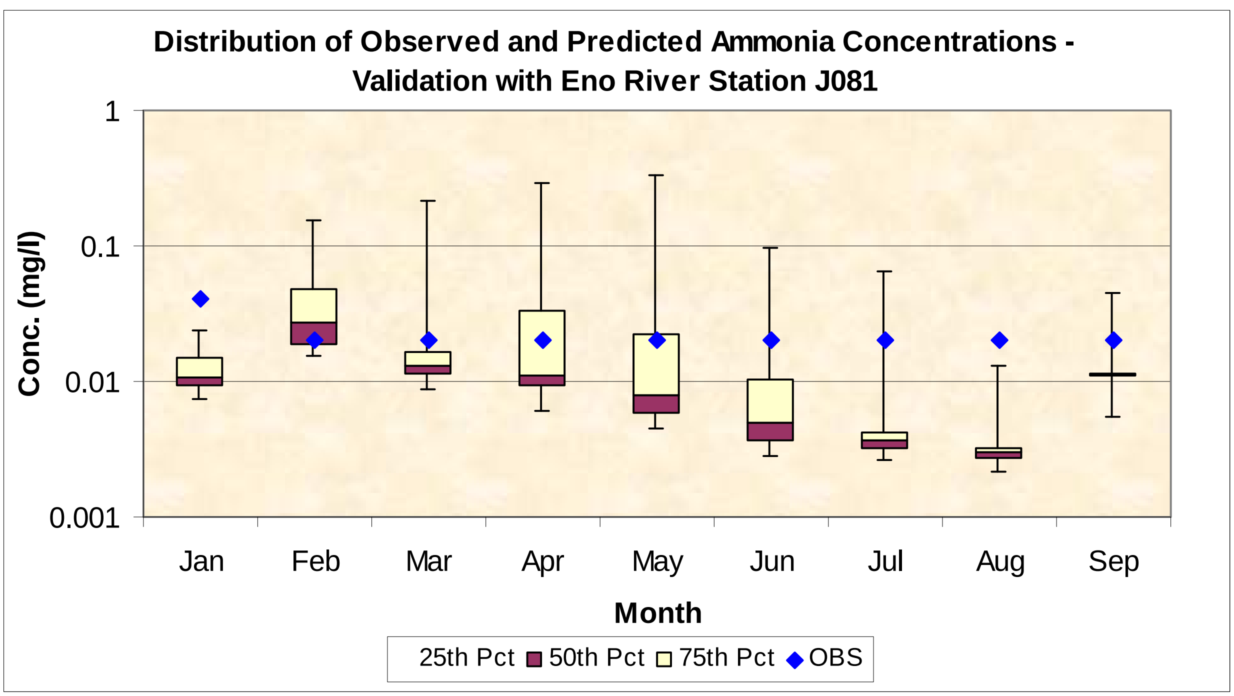


Figure Eno-C30. Validation - Observed versus predicted Ammonia concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

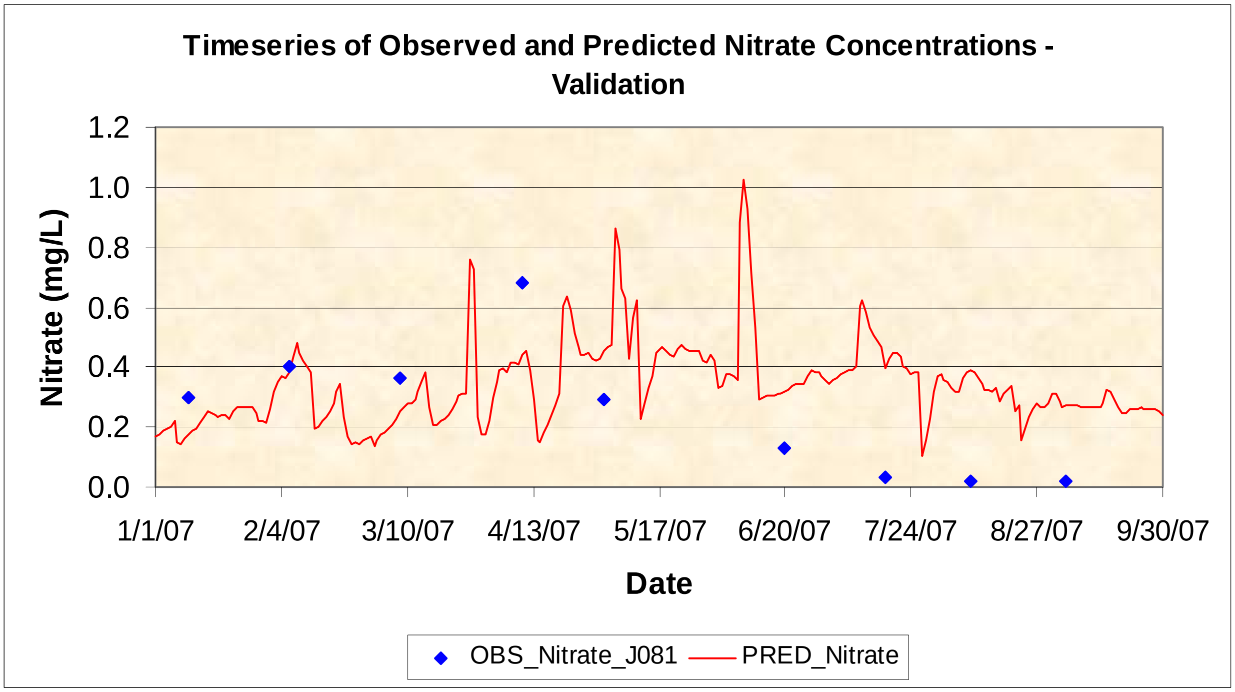


Figure Eno-C31. Validation – Eno River (at Ambient Monitoring Station J0810000) Nitrate concentrations daily time series.

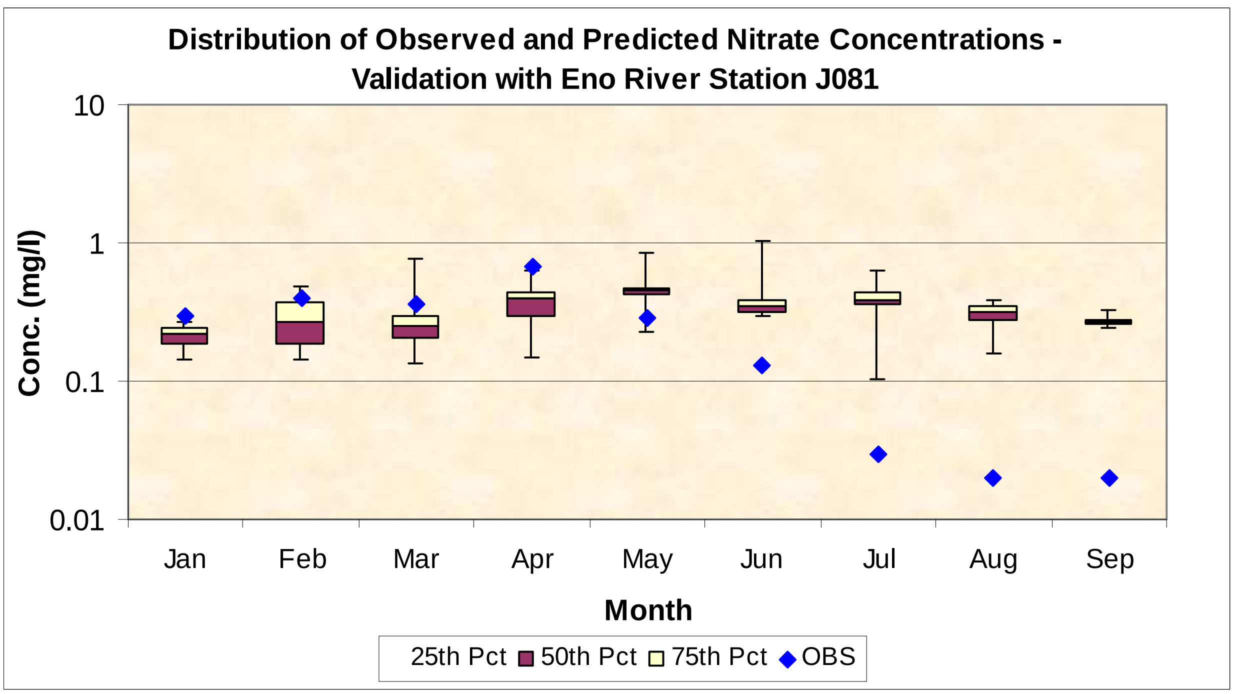


Figure Eno-C32. Validation - Observed versus predicted Nitrate concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

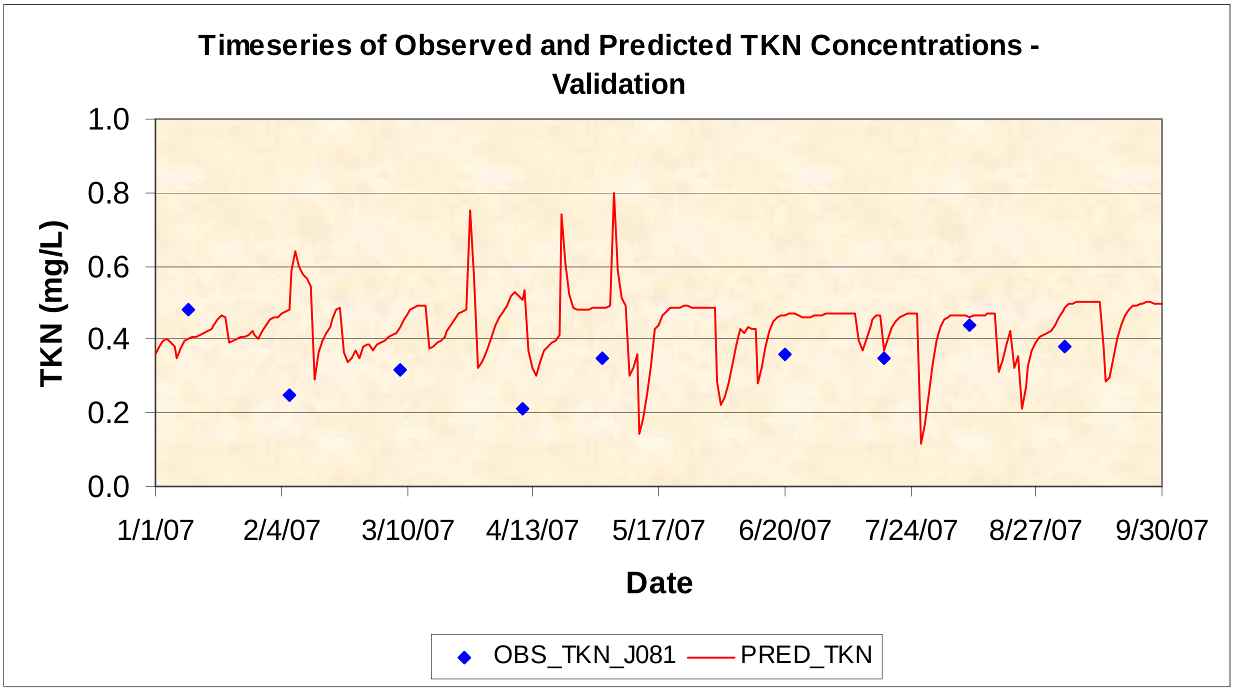


Figure Eno-C33. Validation – Eno River (at Ambient Monitoring Station J0810000) TKN concentrations daily time series.

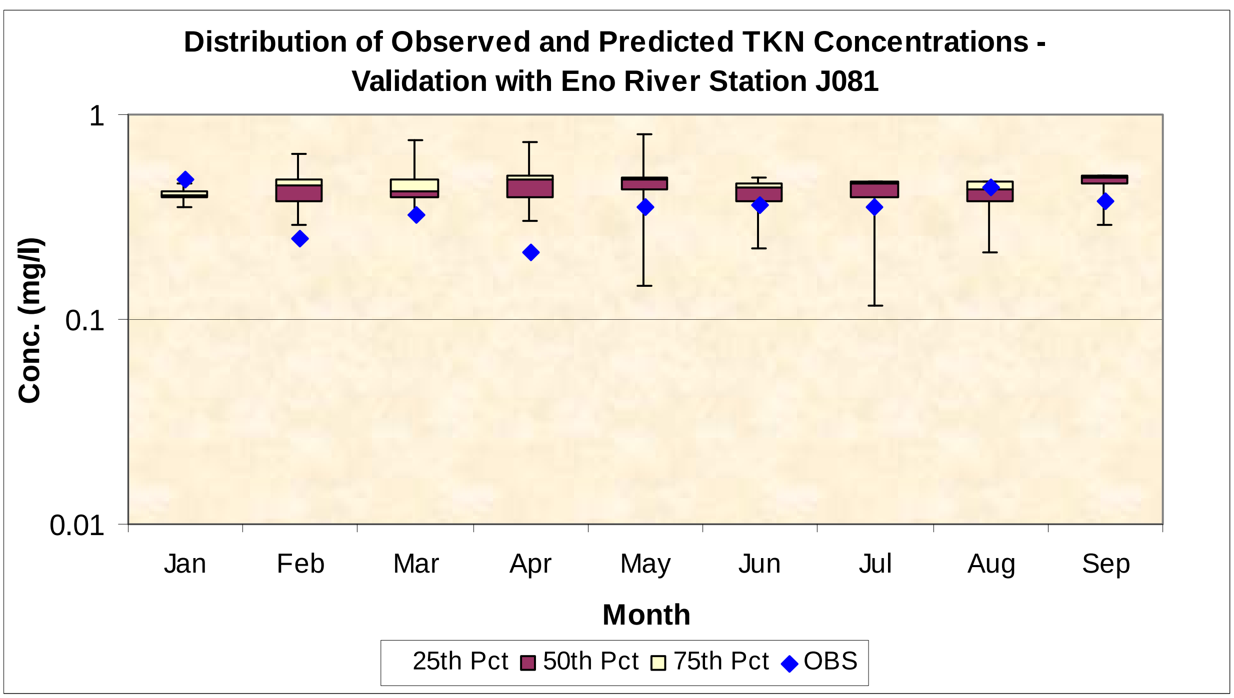


Figure Eno-C34. Validation - Observed versus predicted TKN concentrations for Eno River at Ambient Monitoring Station J0810000 (shown in log scale).

Ellerbe Creek

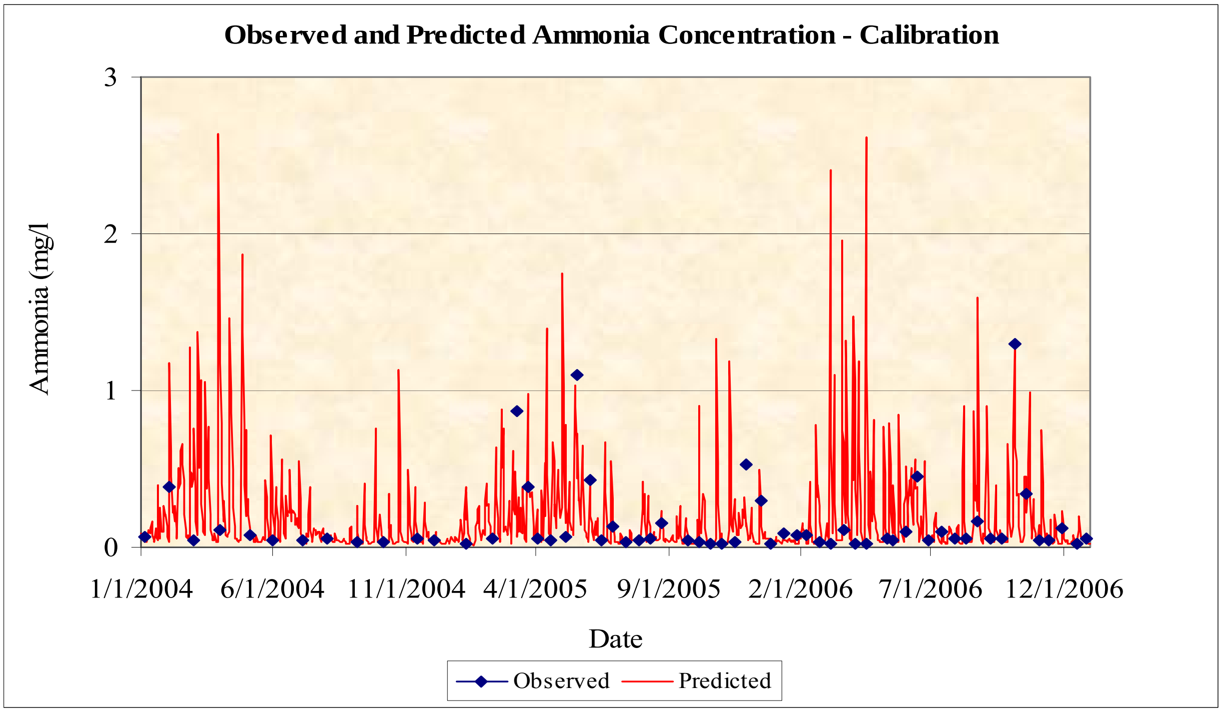


Figure ELL-C1. Time series plots of observed and simulated ammonia concentrations for the calibration period at the Ellerbe Creek monitoring station.

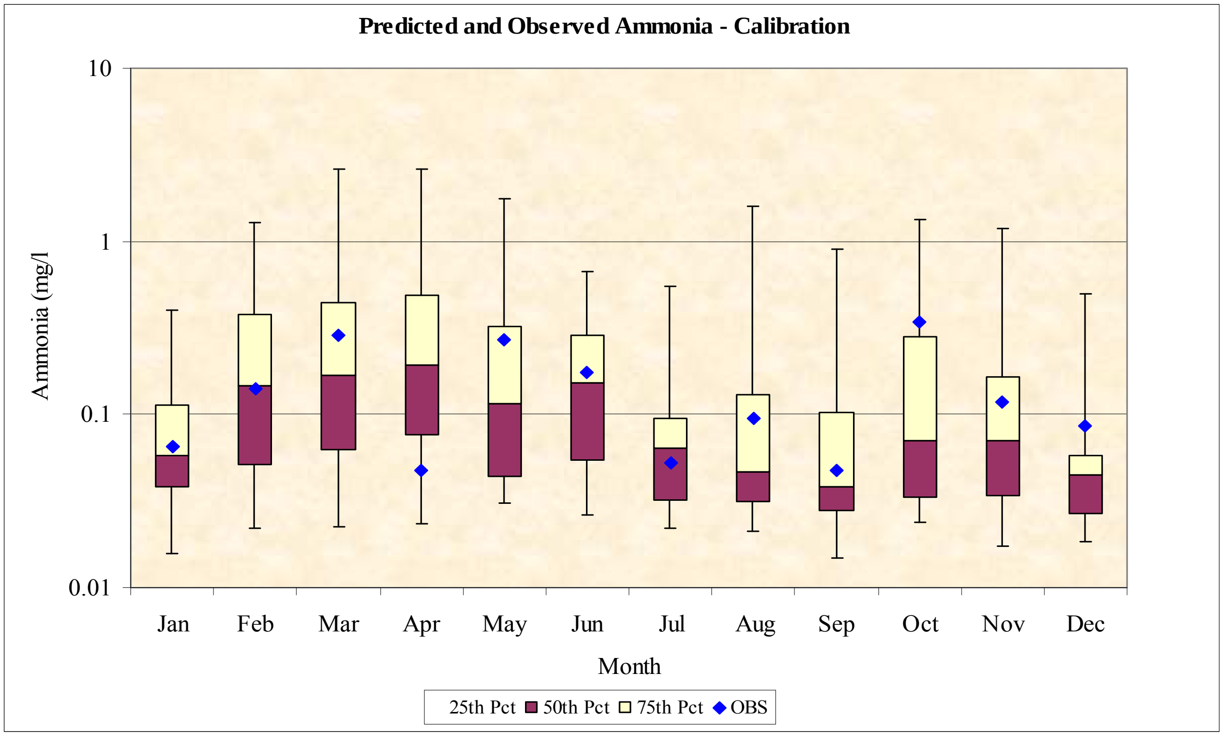


Figure ELL-C2. Seasonal distribution of observed and simulated ammonia concentration for the calibration period at the Ellerbe Creek DWQ station

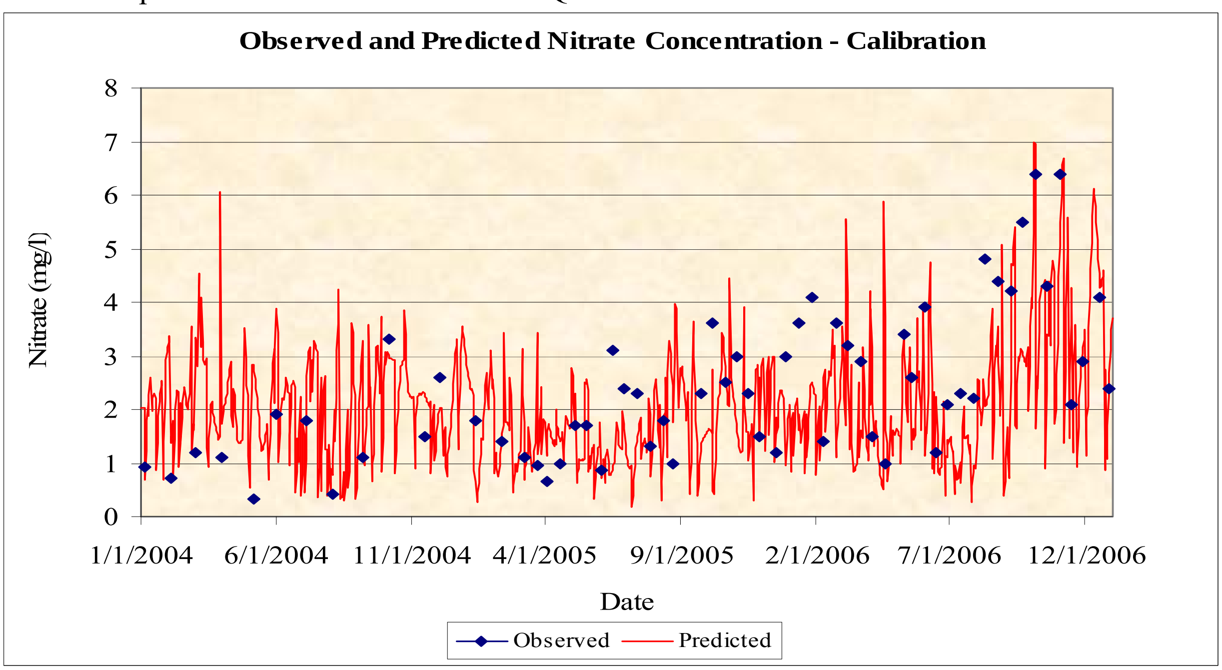


Figure ELL-C3. Time series plots of observed and simulated nitrate concentration for the calibration period at Ellerbe Creek DWQ monitoring station.

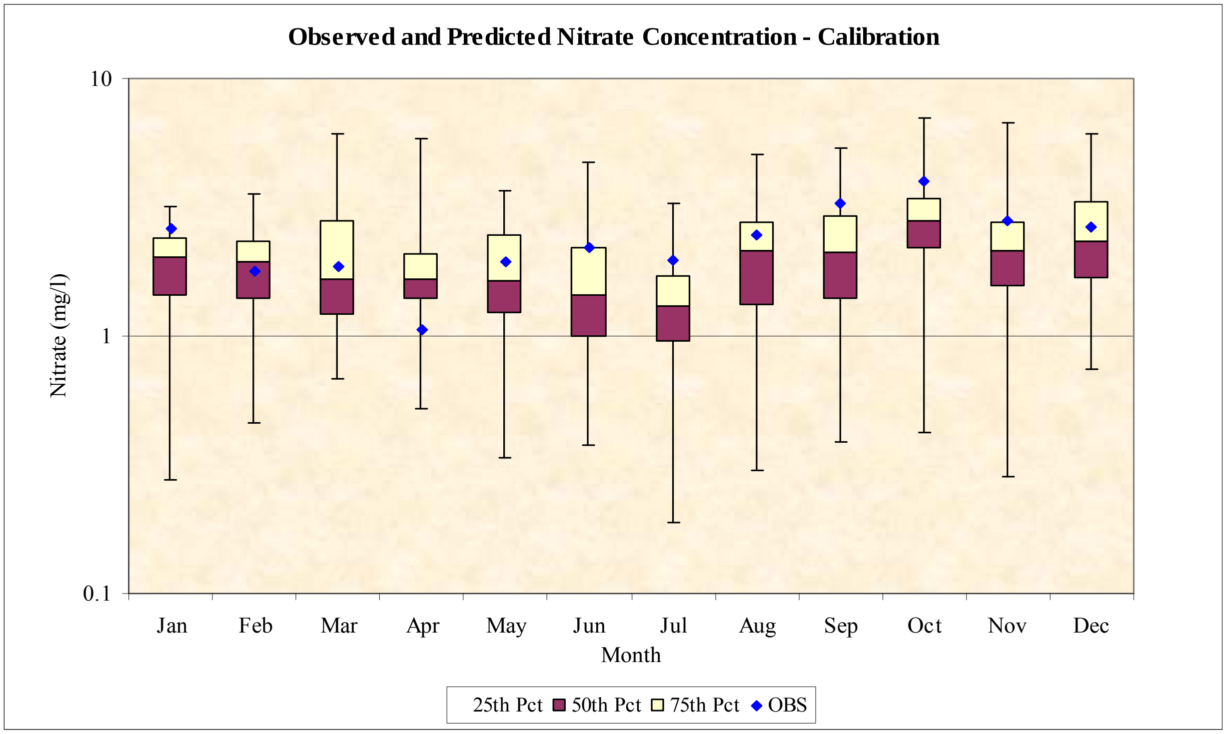


Figure ELL-C4. Seasonal distribution of observed and simulated nitrate concentration for the calibration period at Ellerbe Creek USGS gage station.

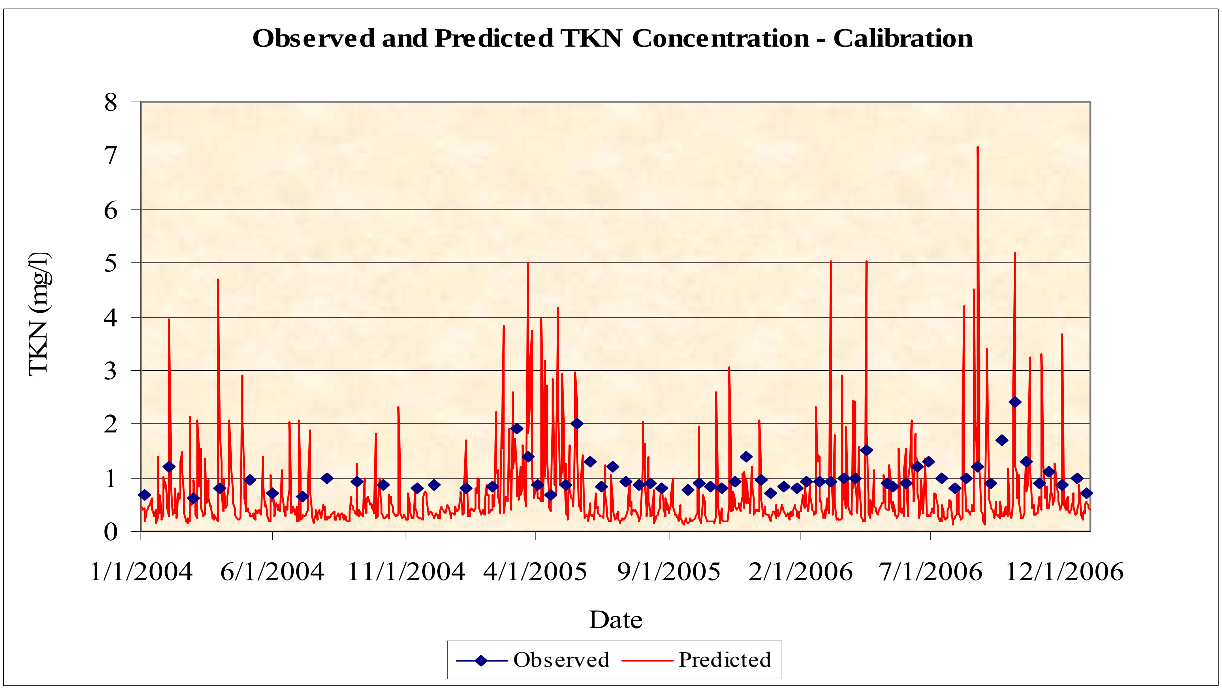


Figure ELL-C5. Time series plots of observed and simulated TKN concentration for the calibration period at Ellerbe Creek DWQ monitoring station.

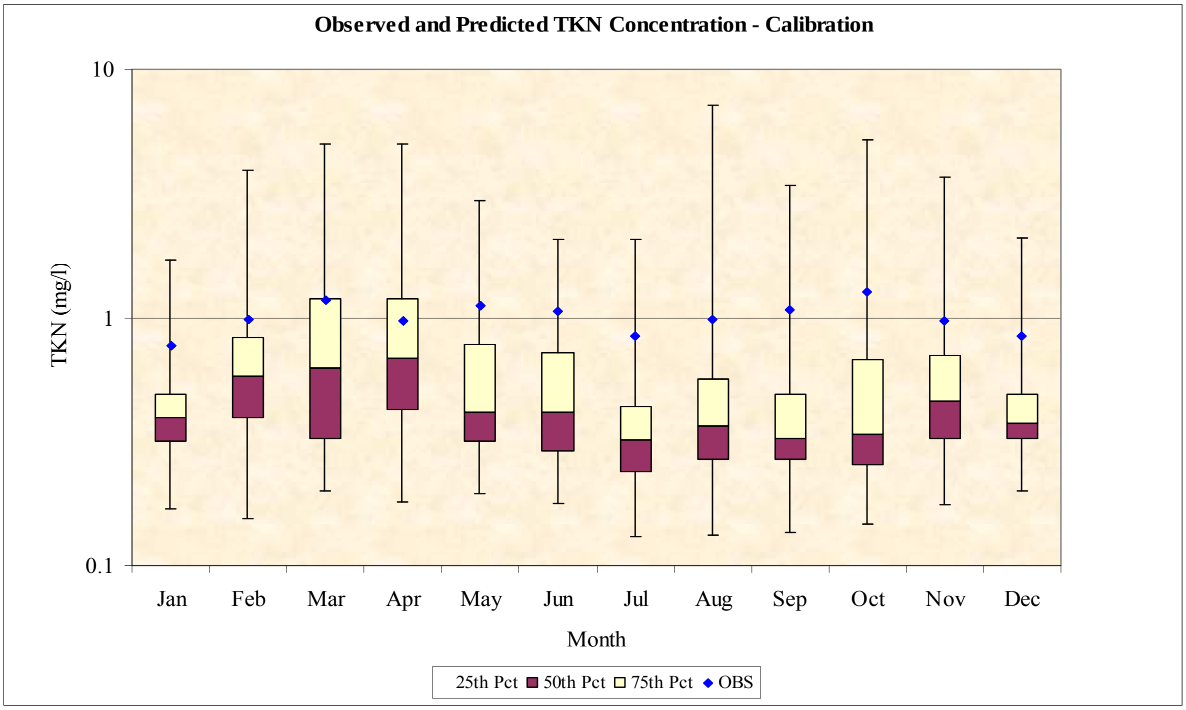


Figure ELL-C6. Seasonal distribution of observed and simulated TKN concentration for the calibration period at Ellerbe Creek DWQ monitoring station.

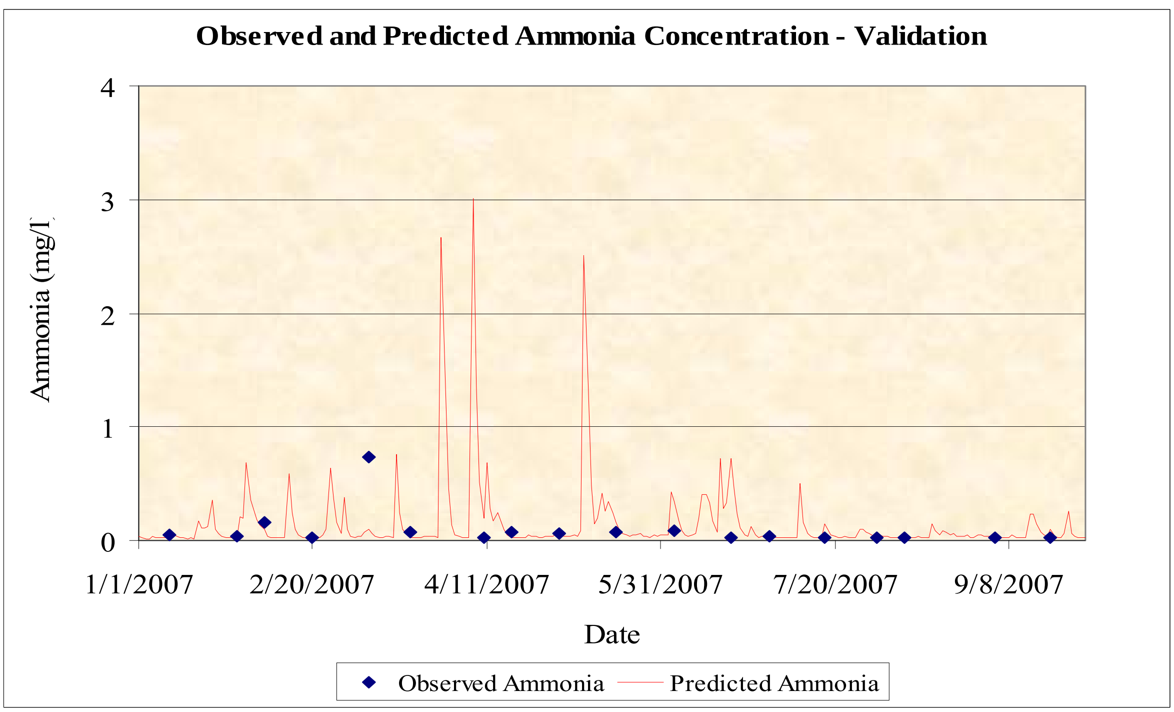


Figure ELL-C7. Time series plots of observed and simulated ammonia concentration validation at Ellerbe Creek DWQ monitoring station.

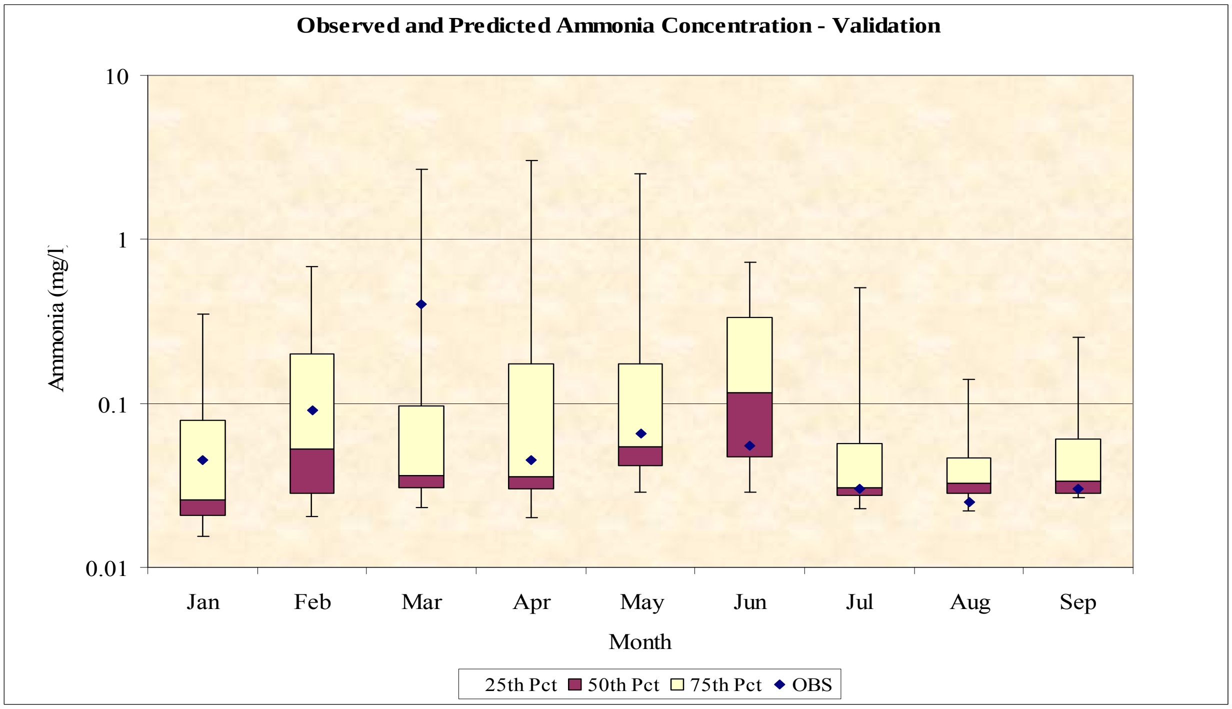


Figure ELL-C8. Seasonal distribution of observed and simulated ammonia concentration for the validation period at Ellerbe Creek DWQ monitoring station.

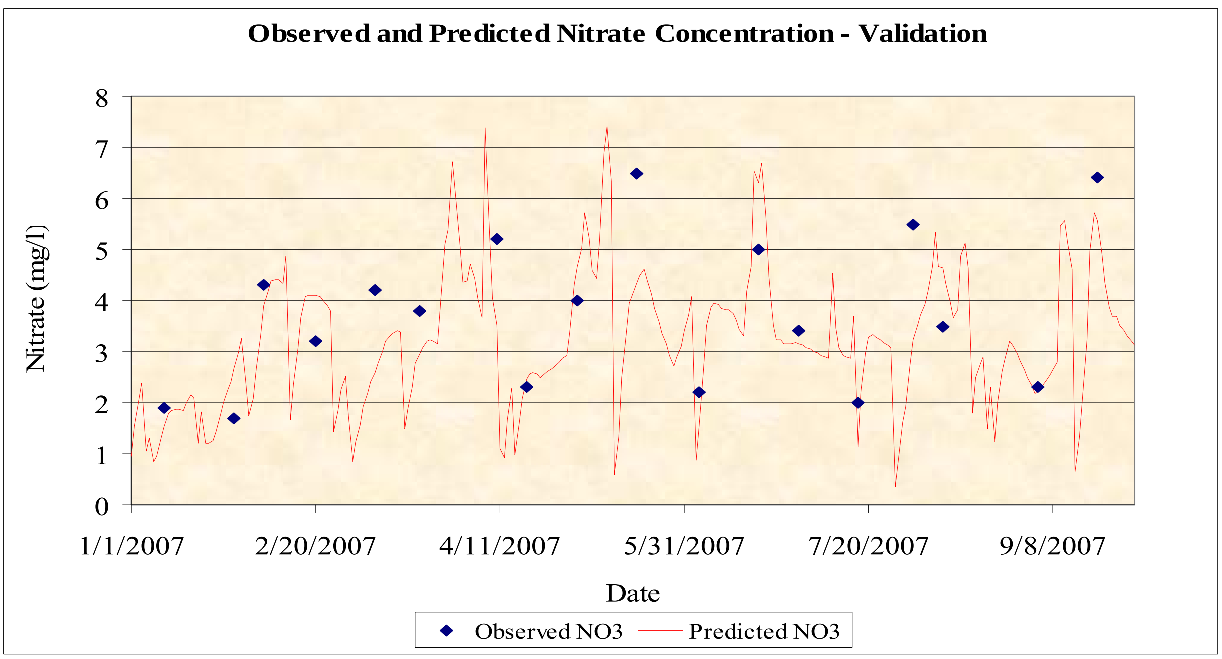


Figure ELL-C9. Time series plots of observed and simulated nitrate concentration for the validation period at Ellerbe Creek DWQ monitoring station.

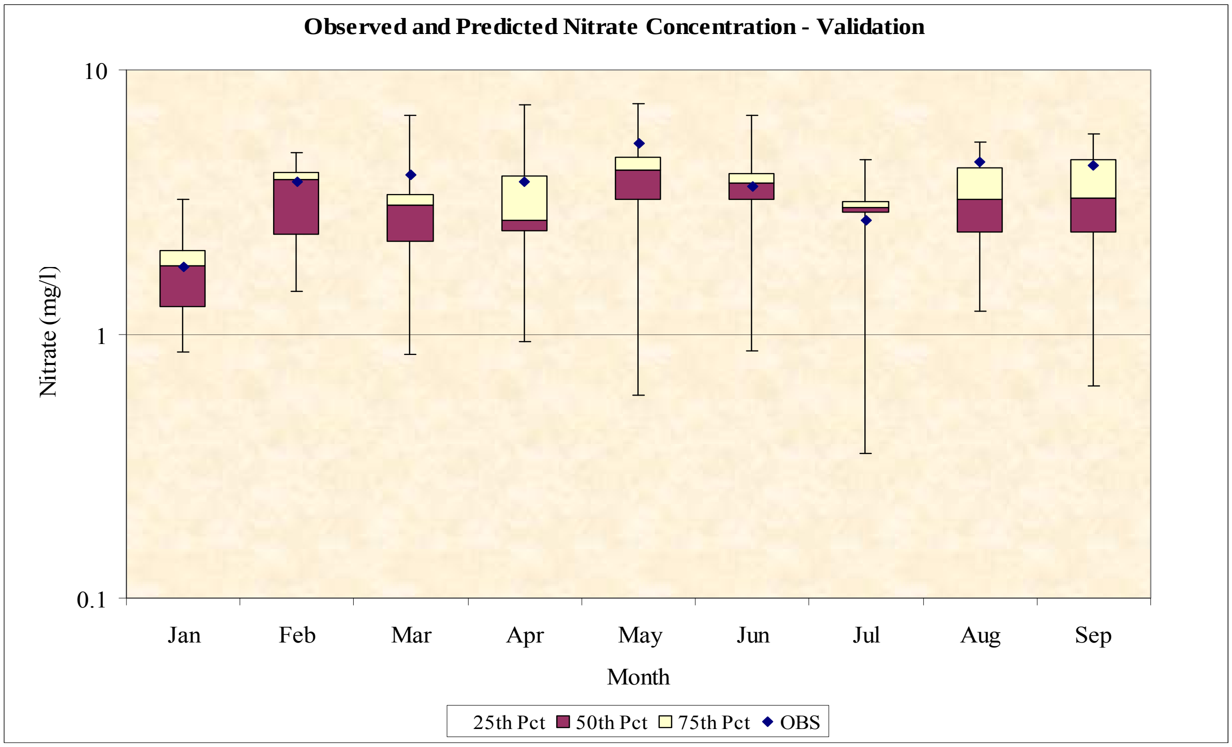


Figure ELL-C10. Seasonal distribution of observed and simulated nitrate concentration for the validation period at Ellerbe Creek DWQ monitoring station.

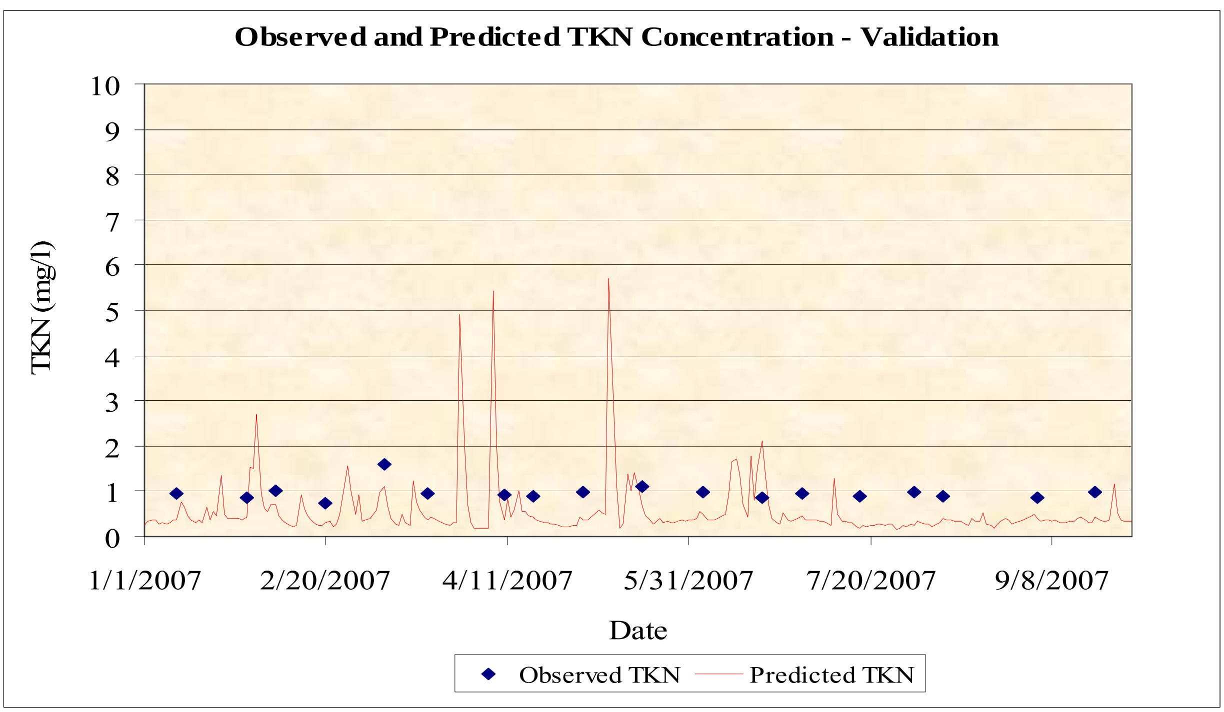


Figure ELL-C11. Time series plots of observed and simulated TKN concentration for the validation period at Ellerbe Creek DWQ monitoring station.

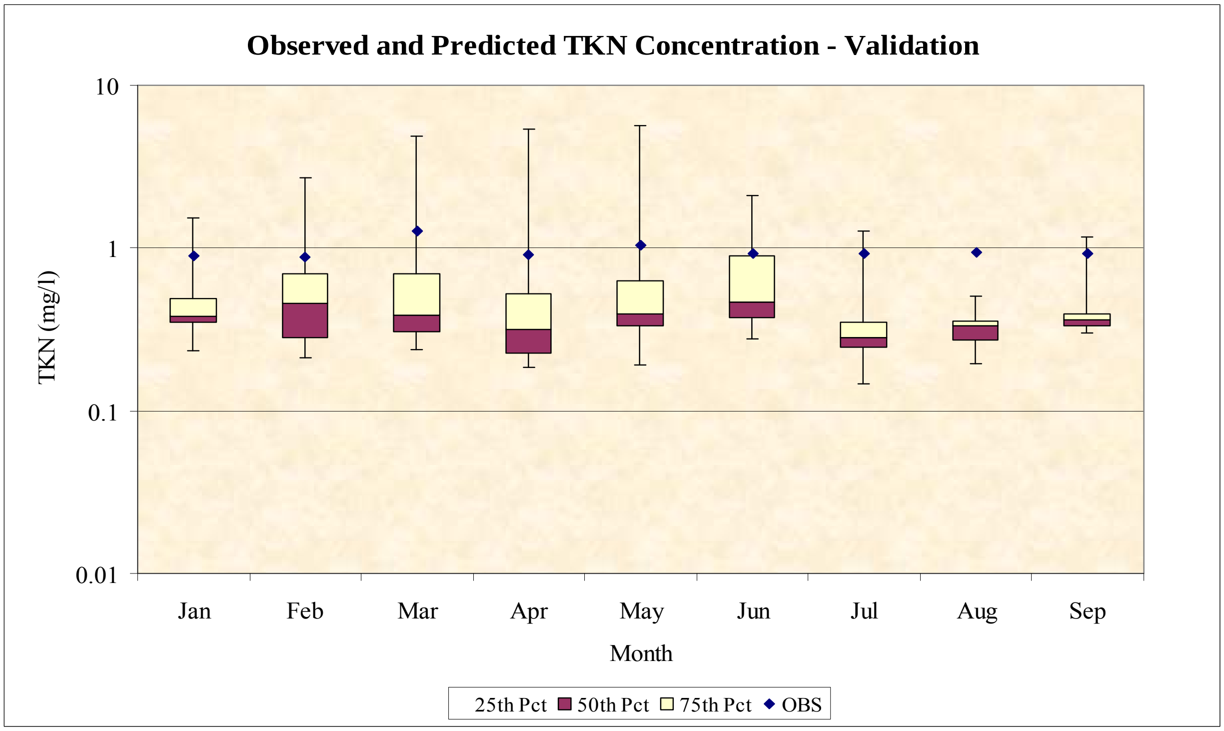


Figure ELL-C12. Seasonal distribution of observed and simulated TKN concentration for the calibration period at Ellerbe Creek DWQ monitoring station.