# WARMF Technical Support Report for the Catawba Basin Phosphorus TMDLs

For

South Carolina Department of Health & Environmental Control

Prepared by

Joel Herr
Carl Chen
Systech Engineering, Inc.
San Ramon, CA 94583

October 30, 2007

# TABLE OF CONTENTS

## List of Figures



## List of Tables

# 1 INTRODUCTION

## Introduction

The Catawba River, which enters South Carolina at Lake Wylie, has four impoundments within the state: Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, and Lake Wateree. All these reservoirs are listed on the South Carolina's 303(d) list of impaired waters for aquatic life. Total phosphorus is a pollutant causing the impairment.

Phosphorus has complex transport and fate characteristics in the environment. Loading to surface waters typically comes from both point sources and nonpoint sources. It readily adsorbs to sediment, which serves both as a means of transporting phosphorus to water bodies through soil erosion and a means of removing phosphorus from the water column by settling. Phosphorus is an important nutrient for algae. Excessive phosphorus, however, can cause algal bloom, which is bad for the clarity of water and for a balanced aquatic ecosystem. Determining the sources of phosphorus, the means of its transport, and its availability to algae requires a rigorous scientific model. The model can then determine the Total Maximum Daily Load (TMDL) of phosphorus and test various implementation plans.

To accomplish these tasks, the South Carolina Department of Health & Environmental Control (SCDHEC) is using the Watershed Analysis Risk Management Framework (WARMF). An application of WARMF to the Catawba River watershed was created in a previous project funded by Duke Energy and the Electric Power Research Institute. The purpose of the previous project was to promote watershed stewardship. The WARMF model has been made available to stakeholders in the region including the states of North and South Carolina for use in calculating TMDLs. WARMF is a public domain model available for download from EPA web site (http://www.epa.gov/athens/wwqtsc/). WARMF is a decision support system that has an Engineering module to perform scientific calculations and a Consensus Module to facilitate stakeholder processes in deciding how to manage the watershed under environmental constraints. WARMF also has a TMDL Module to calculate loading reduction necessary to meet the water quality criteria for beneficial uses.

# 2 WATERSHED MODEL (WARMF)

## Overview of WARMF

Watershed Analysis Risk Management Framework (WARMF) is a decision support system for the watershed approach and TMDL calculations. It integrates simulation of land catchment, river, and lake processes into one seamless model. WARMF is built with a user-friendly graphical user interface (GUI) to facilitate modeling and bridge the gap between modelers and stakeholders. Interaction with the model is done by point-and-click on a watershed map. WARMF is a public domain model distributed by the EPA from its Watershed and Water Quality Modeling Technical Support Center. WARMF has undergone peer reviews following EPA guidelines. WARMF includes a User's Guide (Herr, Weintraub, and Chen 2001), Technical Documentation (Chen, Herr, and Weintraub 2001) and a built-in context sensitive help system.

## Hydrology

WARMF simulates hydrology based on water balance and physics of flow. It begins with precipitation falling on the land surface as shown in Figure 1. Precipitation is divided into rainfall and/or snowfall based on temperature. Snow accumulates on top of the soil. Rain, snow melt, and irrigation water can percolate into the soil. Within the soil, water first goes to increase the moisture in each soil layer up to field capacity. Above field capacity, water percolates down to the water table, where it flows laterally out of the land catchment according to Darcy's Law.

Water on the soil or within the soil is subject to evapotranspiration. Evapotranspiration is calculated as a function of temperature and relative humidity, which can vary seasonally. The amount of water entering and leaving each soil layer is tracked. If more water enters the soil than leaves it, the water table rises. If the water table reaches the surface, the soil is saturated and overland flow occurs. The overland flow is calculated by Manning's equation.

Rivers accept the subsurface and overland flows from catchments linked to them. They also receive point source discharges and flow from upstream river segments. Diversion flows are removed from river segments. The remaining water in the river is routed downstream using the kinematic wave algorithm. The channel geometry, Manning's roughness coefficient, and bed slope are used to calculate depth, velocity, and flow. A thorough description of the processes simulated by WARMF is in the WARMF Technical Documentation (Chen, Herr, and Weintraub 2001).

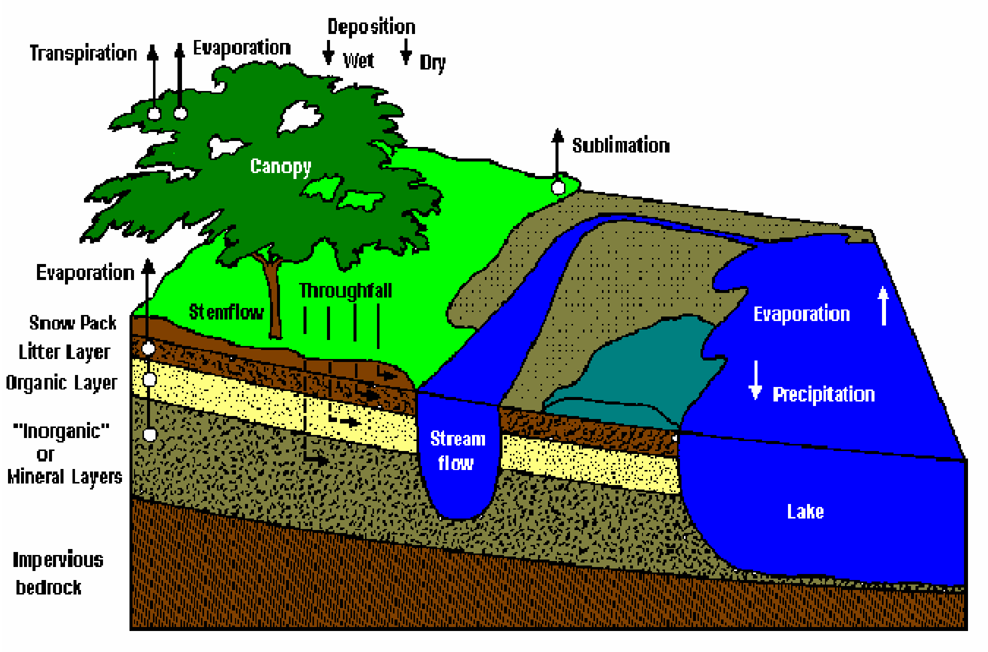


**Figure 1 Watershed Processes considered in WARMF.**

## Water Quality

Many chemical and physical processes are simulated. The chemical parameters simulated include ammonia, nitrate, phosphate, dissolved oxygen, pathogens, major cations and anions, pH, three classes of sediment, floating algae (phytoplankton) and attached algae (periphyton). A complete mass balance of each chemical constituent is maintained throughout the model for every time step. Water quality simulation starts with dry and wet atmospheric deposition falling on the vegetation canopy, land surface, and lake surface. The land is divided into many natural and human influenced land uses. In each land use, there is cycling of organic matter and nutrients between soil, biomass, and leaf litter. Chemical constituents then percolate into the soil with precipitation.

Within the soil, chemical constituents adsorb to soil particles. Cation adsorption is calculated using competitive cation exchange with available sites while anion adsorption is calculated using adsorption isotherms. Chemical reactions like nitrification and organic matter decay occur in the soil based on a first order expression. As water flows laterally out of the soil, it carries the dissolved chemical constituents in the pore water. When there is overland flow, sediment is eroded and with it those chemical constituents adsorbed to it.

In surface waters, sediment is subject to settling to and resuspension from river beds. Chemical reactions occur in the water column as in the soil and chemicals are transported downstream with flow. Periphyton growth is simulated, taking up nutrients from the water column and releasing organic matter. Lakes are simulated with multiple layers. Incoming flows penetrate to the level of equal density. Stratification of lakes is governed by wind and density gradient diffusion coefficients. Algal processes simulated include growth, respiration, mortality, and settling for three types of floating algae.

# 3 CATAWBA RIVER MODEL

The Catawba River application of WARMF includes the entire watershed of the Catawba River from the Blue Ridge mountains of North Carolina to the dam of Lake Wateree in South Carolina. There are a total of 11 reservoirs on the main stem of the Catawba River. For the purposes of SCDHEC, only the 4 reservoirs in South Carolina need to be modeled. The outflow from Lake Wylie near Fort Mill, South Carolina is used as the upstream boundary of the area simulated by SCDHEC. The entire Catawba River model in WARMF is shown in Figure 2; the portion simulated by SCDHEC is shown in Figure 3.

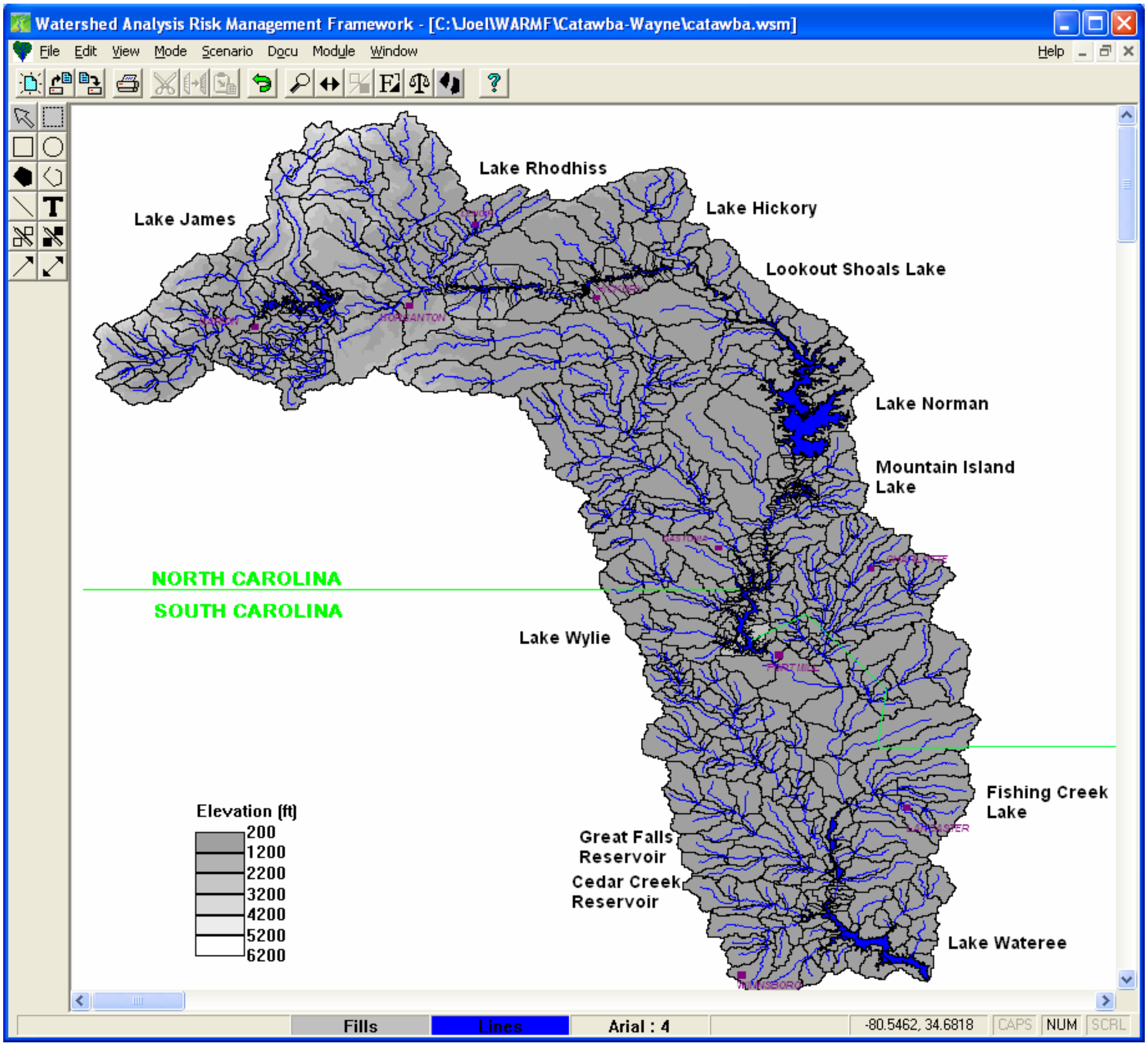


**Figure 2 Basin Map of the entire Catawba River Watershed in WARMF**

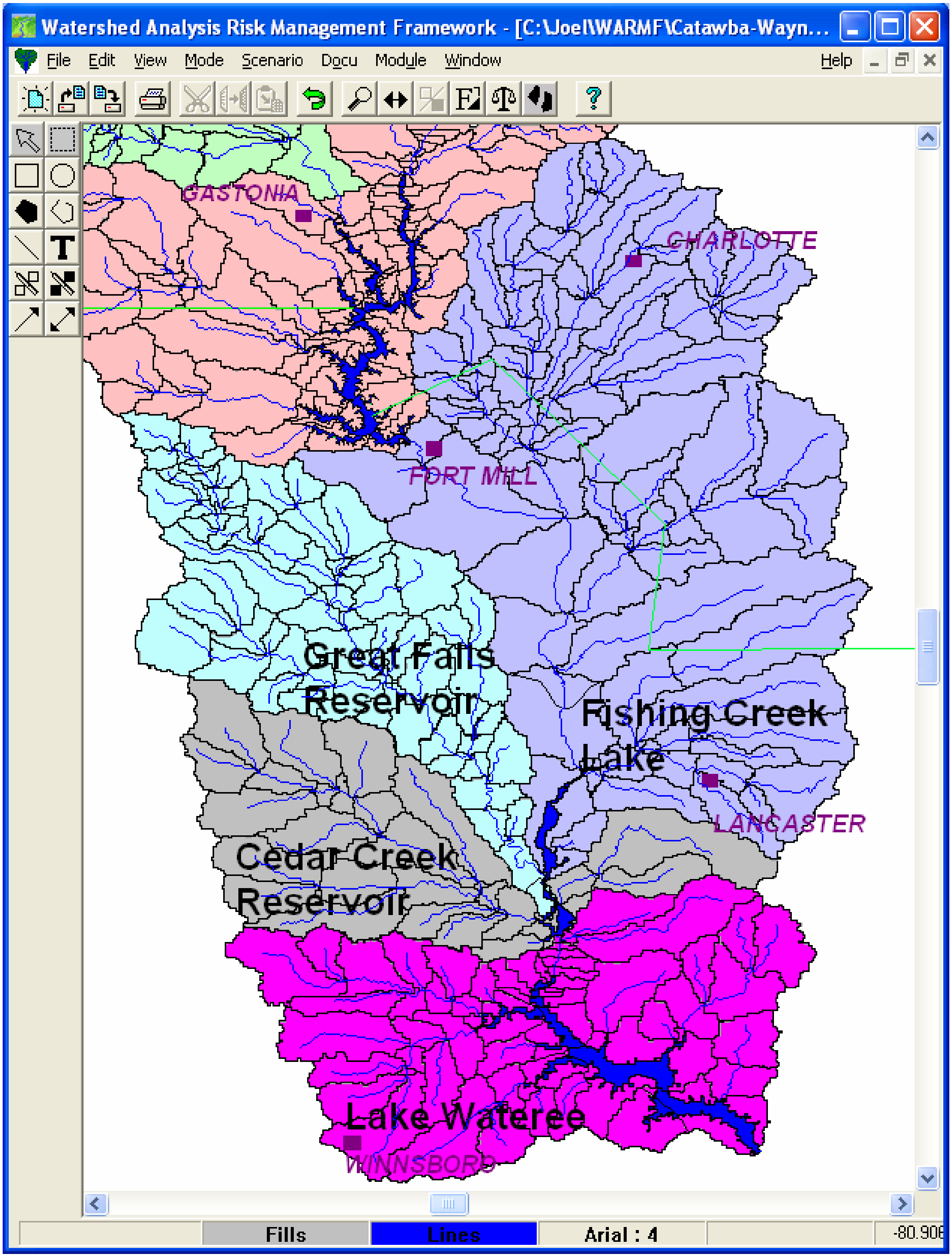


**Figure 3 Watersheds of the four Catawba River reservoirs in South Carolina**

Figure 3 shows the local watersheds for each of the reservoirs: Fishing Creek Reservoir in steel blue, Great Falls Reservoir in turquoise, Cedar Creek Reservoir in gray, and Lake Wateree in magenta. The watershed of Fishing Creek Reservoir includes Sugar Creek, which drains from the city of Charlotte North Carolina. .

# 4 TECHNICAL SUPPORT TASKS

SCDHEC is performing the model application in house. It only seeks technical support from Systech Engineering, Inc. SCDHEC identified six tasks for Systech Engineering to perform in support of the phosphorus TMDL study. Below are the descriptions of those tasks.

## Task 1: Land Use

### *SCDHEC Task Description*

Systech Engineering will provide assistance importing developed land use shape files into WARMF. Recommendations will be made regarding necessary parameter adjustments, such as land application rates, to include any new land use categories.

### *Systech Engineering Task Report*

SCDHEC provided a land use shapefile for the South Carolina portion of the watershed. Figure 4 shows the land use shapefile . WARMF has a utility to import a land use shapefile, overlay the shapefile with catchment boundaries, and calculate the percent of each land use in each catchment.

WARMF has its own land use categories, so each of the land uses in the shapefile must be assigned to land uses in WARMF. Table 1 shows how the land uses were assigned. As shown, the match between the land use categories of SCDHEC and the land use categories of WARMF are almost identical.

After importing the land use, a WARMF simulation was performed successfully, ensuring the model worked properly with the new land use.

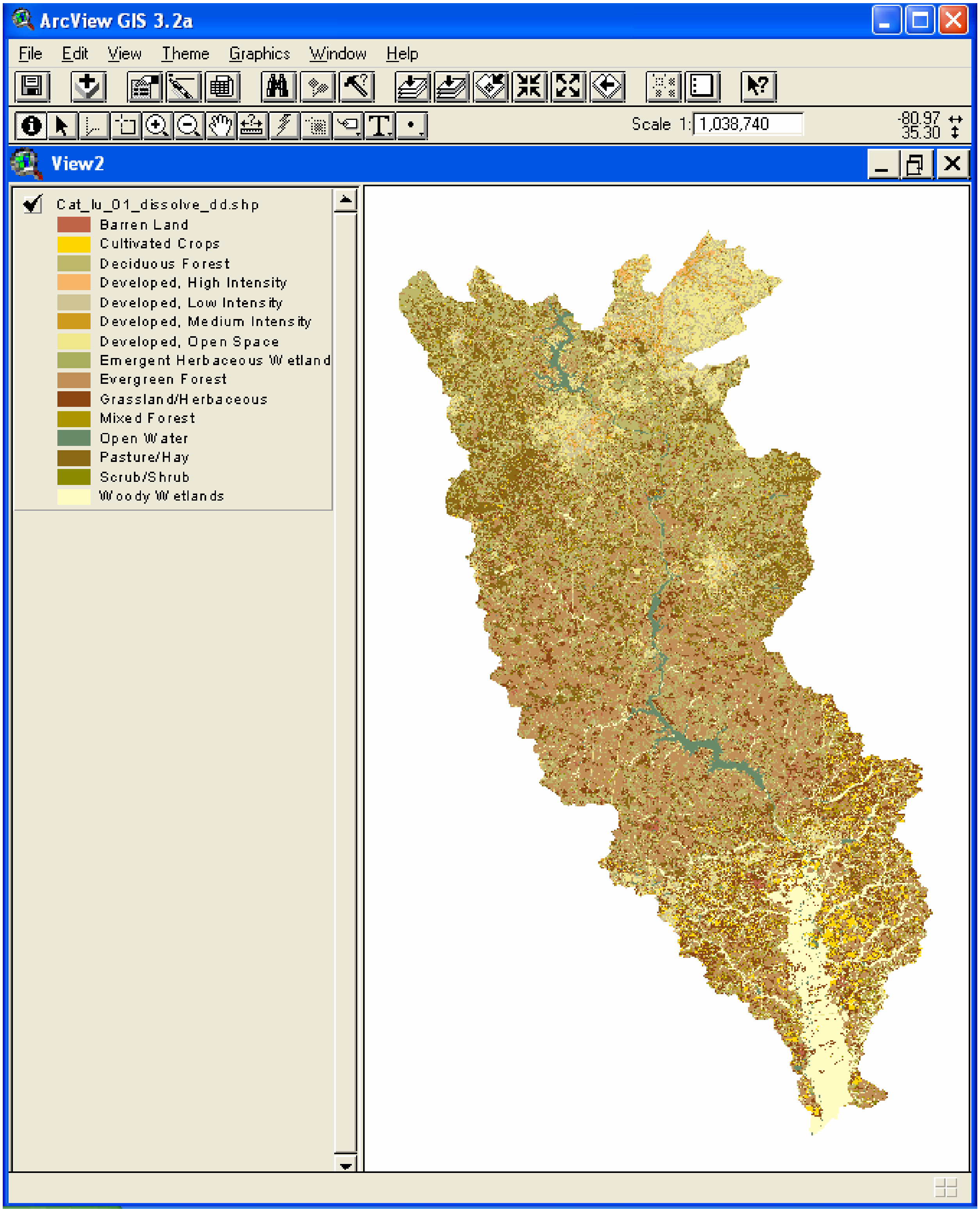


**Figure 4: Land use shapefile provided by SCDHEC**

**Table 1: Translation of SCDHEC Land Use to WARMF Land Use**

| SCDHEC Land Use | WARMF Land Use |
|---|---|
| Barren Land | Barren |
| Cultivated Crops | Cultivated |
| Deciduous Forest | Deciduous Forest |
| Developed, High Intensity | High Intensity Development |
| Developed, Low Intensity | Low Intensity Development |
| Developed, Medium Intensity | Medium Intensity Development |
| Developed, Open Space | Recreational Grasses |
| Emergent Herbaceous Wetland | Herbaceous Wetlands |
| Evergreen Forest | Evergreen Forest |
| Grassland/Herbaceous | Grassland |
| Mixed Forest | Mixed Forest |
| Open Water | Water |
| Pasture/Hay | Pasture |
| Scrub/Shrub | Scrub/Shrub |
| Woody Wetlands | Wetlands |

## Task 2: Fishing Creek Reservoir Temperature

### ***SCDHEC Task Description***

Determine cause and reduce temperature over predictions in Fishing Creek Reservoir simulation during late summer and early fall when the dam is spilling water and there is little or no generation flow.

### ***Systech Engineering Task Report***

Systech performed simulations of Fishing Creek Reservoir to ascertain and minimize the reported temperature anomalies. SCDHEC reported anomalies in late summers of 2004 and 2005 where simulated lake surface temperature would briefly rise to 50 degrees C.

Systech simulations did not duplicate these anomalies. The model showed one temperature spike to 36 degrees C occurring from September 1315, 2004. The new land use may have had an impact on the results for Fishing Creek Reservoir. Systech also fixed problems with the structure of the WARMF coefficient file provided by SCDHEC, and that may have helped reduce the temperature anomalies.

Figure 5 shows the simulation results of surface temperature for Fishing Creek Reservoir (in blue). Measured temperature is shown with black circles.

The simulated peak temperatures in the summer were 30 to 31 degrees Celsius, very close to the observed peak temperatures of 30 to 32 degrees Celsius. There was one temperature anomaly of 36 degrees Celsius in the simulated peak temperature in the summer of 2004. This anomaly is small and of short duration so it does not have a significant impact upon other simulation results.

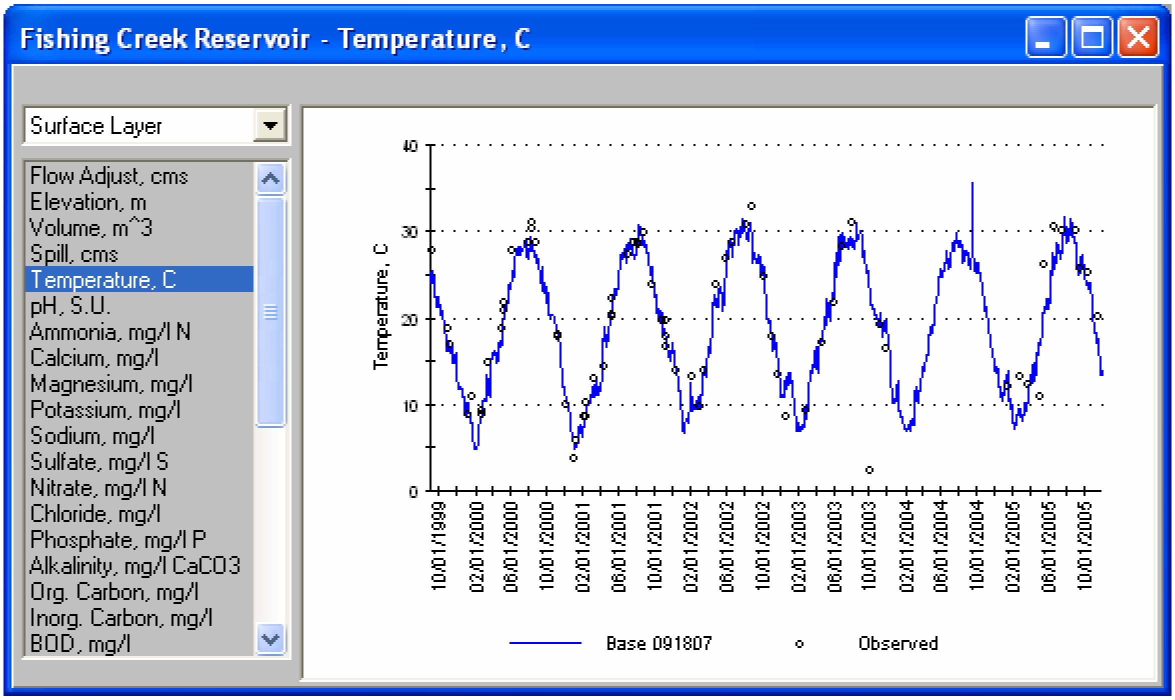


**Figure 5: Simulated surface temperature of Fishing Creek Reservoir**

## Task 3: Periphyton Modeling

### ***SCDHEC Task Description***

Systech Engineering will investigate and troubleshoot problems related to modeling periphyton on the Catawba River. Systech will review current input model files, test scenarios and debug as necessary. Systech will recommend values or range of values for specific model parameters and run test simulations.

### ***Systech Engineering Task Report***

Systech Engineering duplicated the unrealistic results reported by SCDHEC, including extremely high concentrations of nutrients and sulfate. The problem was caused by an incorrect setting of a parameter for periphyton. Conventional simulated parameters move with water, but periphyton remains fixed in its location while water flows past.

The parameter to set this characteristic is located in the WARMF system coefficients, Parameters tab, and Physical Data category. Scrolling to the right in the spreadsheet, the Advected column should be unchecked for periphyton.

Figure 6 shows the simulated total phosphorus concentration with the incorrect setting of the advection parameter with very unrealistic concentration of phosphorus. Figure 7 shows the total phosphorus concentration after the advection parameter was unchecked in WARMF. The simulation with periphyton now produces results similar to those simulations without periphyton.

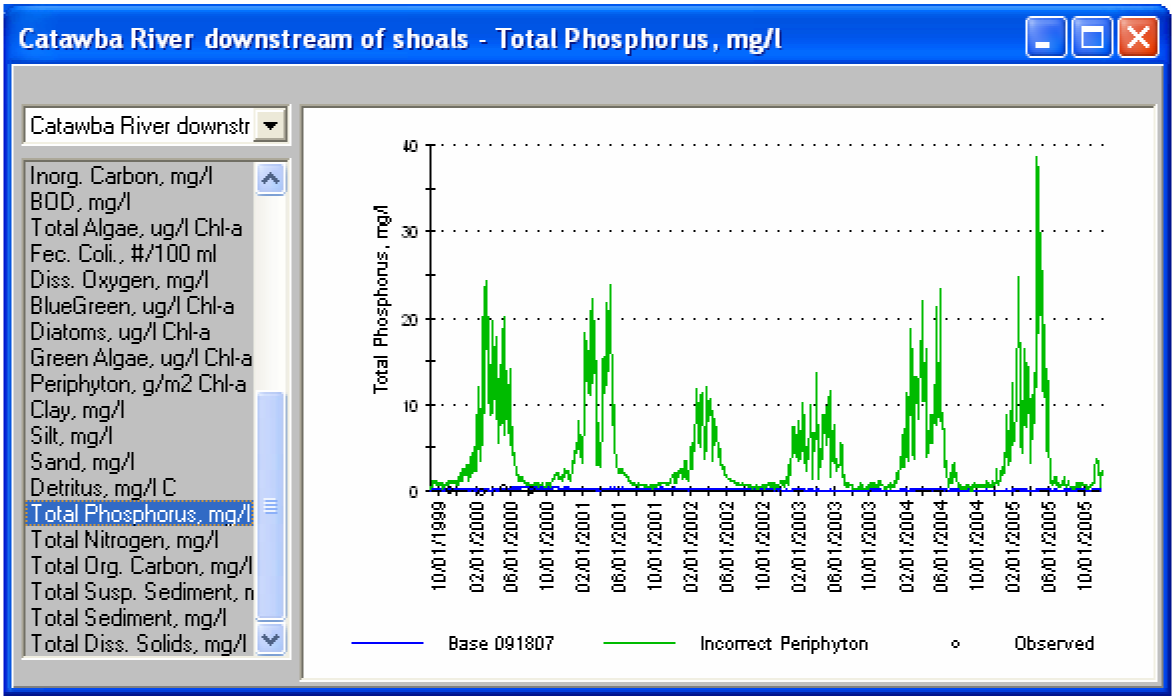


**Figure 6: Simulated total phosphorus of Fishing Creek Reservoir before the correction for the advection parameter of periphyton**

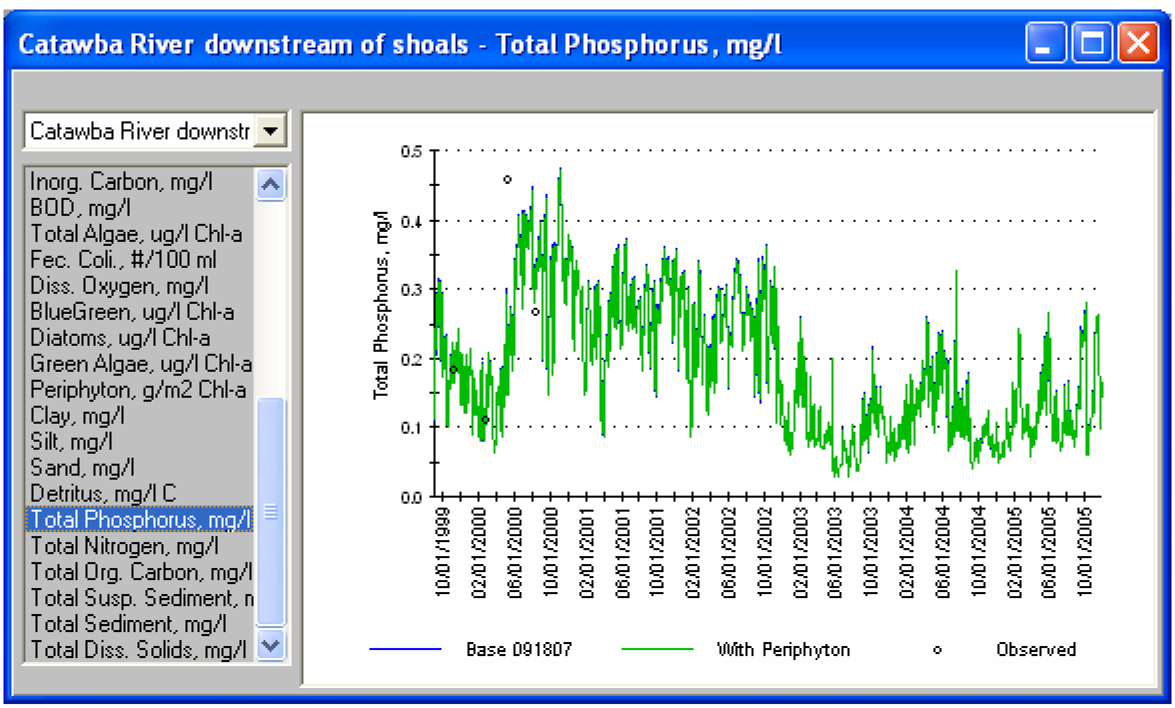


**Figure 7: Simulated total phosphorus of Fishing Creek Reservoir after the correction for the advection parameter of periphyton**

# Task 4: Assistance with Phosphorus Calibration

## *SCDHEC Task Description*

Systech Engineering will review model input files and model output file. Systech will make recommendations for adjustments to calibration coefficients and run test calibration runs. Recommendations and test runs will include specific coefficients and values.

## *Systech Engineering Task Report*

Systech Engineering made several changes to improve the model simulation of phosphorus for the Catawba River reservoirs. There are three recommended parameter changes described below, followed by the simulation results brought about by each of those changes.

### *Parameter Changes*

#### *Diffusion Coefficients of Lake Wateree*

The vertical circulation of reservoirs has a significant effect upon algae growth and settling of algae, detritus, and sediment. To determine if WARMF was simulating the vertical circulation of the reservoirs properly, vertical profiles of temperature were examined for each of the reservoirs. Fishing Creek Reservoir, Great Falls Reservoir, and Cedar Creek Reservoir all showed little summer stratification in either observed data or simulation results. Lake Wateree, however, showed thermal stratification of up to 11 $^{o}$C due to its greater depth.

In WARMF, the vertical stratification is governed by diffusion coefficients which account for vertical mixing in reservoirs caused by either wind or a vertical density gradient. The vertical profile of Lake Wateree was calibrated by modifying these coefficients, which are described in the WARMF Technical Documentation. Table 2 shows the recommended changes to the diffusion coefficients to be applied to all segments of Lake Wateree. In WARMF, these coefficients are found under the Diffusion tab of the reservoir segment input dialog.

**Table 2 Calibrated Lake Wateree Diffusion Coefficients**

| | Original Value | Recommended Value |
|---|---|---|
| **Wind Mixing Coefficients** | | |
| Minimum Diffusion Coefficient, $m^2/s$ | $5 \times 10^{-5}$ | 0 |
| A1 | $4 \times 10^{-4}$ | $1 \times 10^{-5}$ |
| A2 | 4.6 | 4.6 |
| Maximum Diffusion Coefficient, $m^2/s$ | 0.001 | $5 \times 10^{-5}$ |
| **Density Gradient Coefficients** | | |
| Critical Density Gradient, 1/m | $1 \times 10^{-6}$ | $5 \times 10^{-6}$ |
| Maximum Diffusion Coefficient, $m^2/s$ | $5 \times 10^{-4}$ | $5 \times 10^{-5}$ |
| Diffusion Attenuation Exponent | -0.7 | -0.7 |

The changes improved the match between the simulated and observed temperature profiles. Figure 8 shows an example temperature profile for Segment 2 of Lake Wateree, which is 12 km upstream of the dam. Figure 9 shows a temperature profile for Segment 3 of Lake Wateree, which is at the dam. In both figures, the original simulation results are in blue, the calibrated results are in green, and observed data is shown in black circles. The simulated temperature profiles with new diffusion coefficients are shown to match the observed data better than the original simulation.

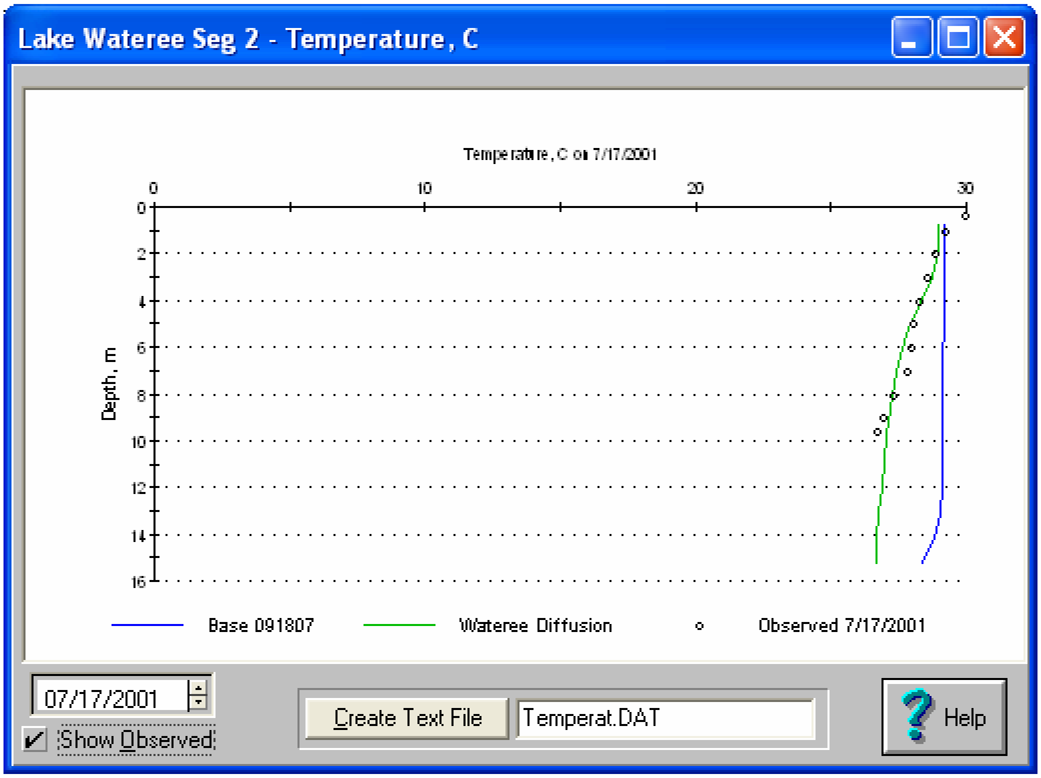


**Figure 8: Simulated and observed temperature profile, Lake Wateree Segment 2**

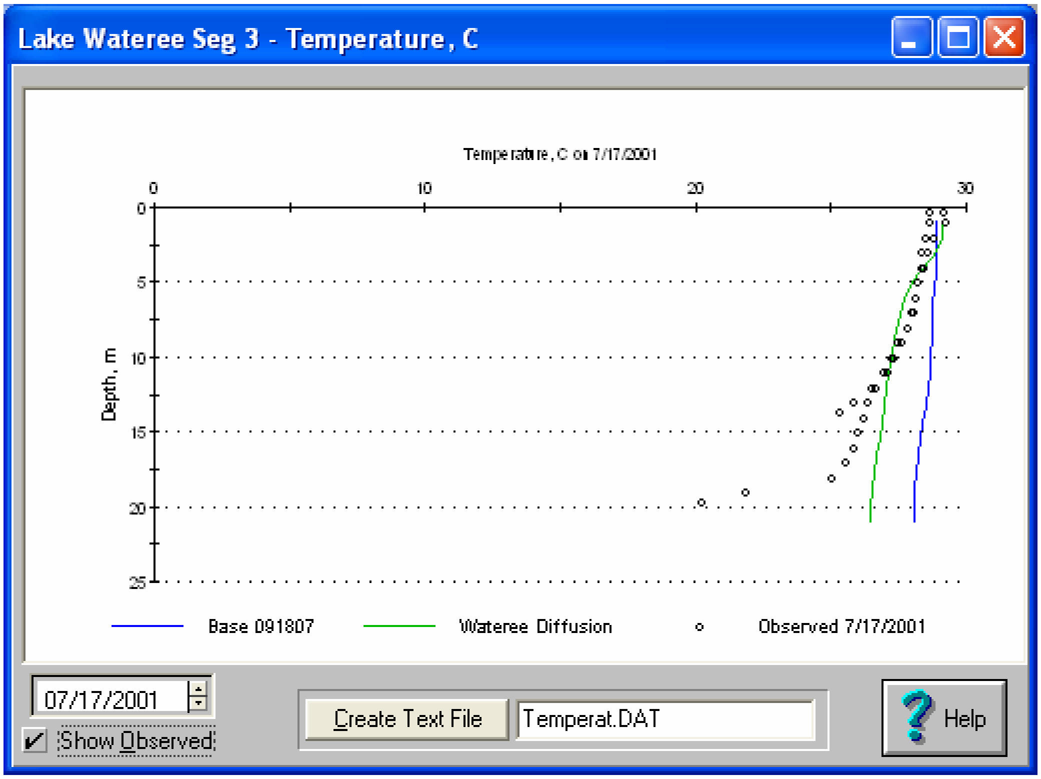


**Figure 9: Simulated and observed temperature profile, Lake Wateree Segment 3**

### *Algae and Detritus Settling Rates*

In examining the simulation results compared to observed data, it was apparent that there was significant removal of phosphorus occurring over the length of Lake Wateree. The mechanisms of removal are from settling of sediment with adsorbed phosphate and the settling of organic matter containing phosphorus.

WARMF simulates three types of algae: blue-greens, diatoms, and green algae. The specific settling rates of algae in the Catawba River reservoirs are not known, so the algal settling rate becomes part of calibration. The settling rates for detritus and all three algae types were increased to 0.5 m/d from the original values of 0.1-0.2 m/d. The coefficients were changed in the reservoir segment input dialog of WARMF, Reactions tab, on the lines in the spreadsheet for algae and detritus settling. These coefficients were applied to all the reservoir segments of Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, and Lake Wateree.

### *Dry Deposition of Phosphate*

WARMF simulates the wet deposition of chemical constituents in precipitation and the dry deposition of chemical constituents in the aironto the vegetation canopy, land surface, and lake surface. The deposition is a function of air concentration of chemical constituents, deposition velocity, and other factors. The concentration of chemical constituents in precipitation and in air is specified by a time series of measured or estimated data. The air concentration of phosphate is 25 µg/m$^3$, which is unually high and an order of magnitude greater than ammonia and sulfate concentrations.

Systech Engineering recommends examining the accuracy of input data and ensuring that it is in the reported units of $\mu g/m^3$. Since the model has over predicted phosphorus concentration in the reservoirs, one possible reason is the high concentration of phosphorus specified in the air. To determine the model sensitivity to the high phosphorus concentration, a simulation was run setting the air concentration of phosphorus to zero. An alternate file with the time series of rain and air concentrations was created. The phosphorus air concentration was set to zero and the alternate file was assigned to every catchment and reservoir segment in the watershed.

### *Simulation Results*

The changes described above do not represent a calibration. Rather, they are recommended improvements over the original model coefficients.

Simulations were run under four conditions:

- Simulation with the original coefficients
- Simulation with changes in the Lake Wateree diffusion coefficients only,
- Simulation with changes of Wateree diffusion and changes of algal settling rates for all reservoirs,
- Simulation with zero phosphorus in the air and all other changes.

This was done to demonstrate the incremental effect of each change.

Figure 10 through Figure 14 show the simulation results for Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, Lake Wateree Segment 2 (12 km upstream of the dam), and Lake Wateree Segment 3 (at the dam). There are four scenarios presented. Blue is the original model coefficients; green is with only the change in diffusion coefficients of Lake Wateree; red is with changes of diffusion coefficients for Lake Wateree and algal settling rates for all reservoirs; magenta is with diffusion coefficient changes, algal settling rate changes, and elimination of phosphorus in the air. The incremental effect of each change can be seen by the difference between each successive simulation as shown in the figures.

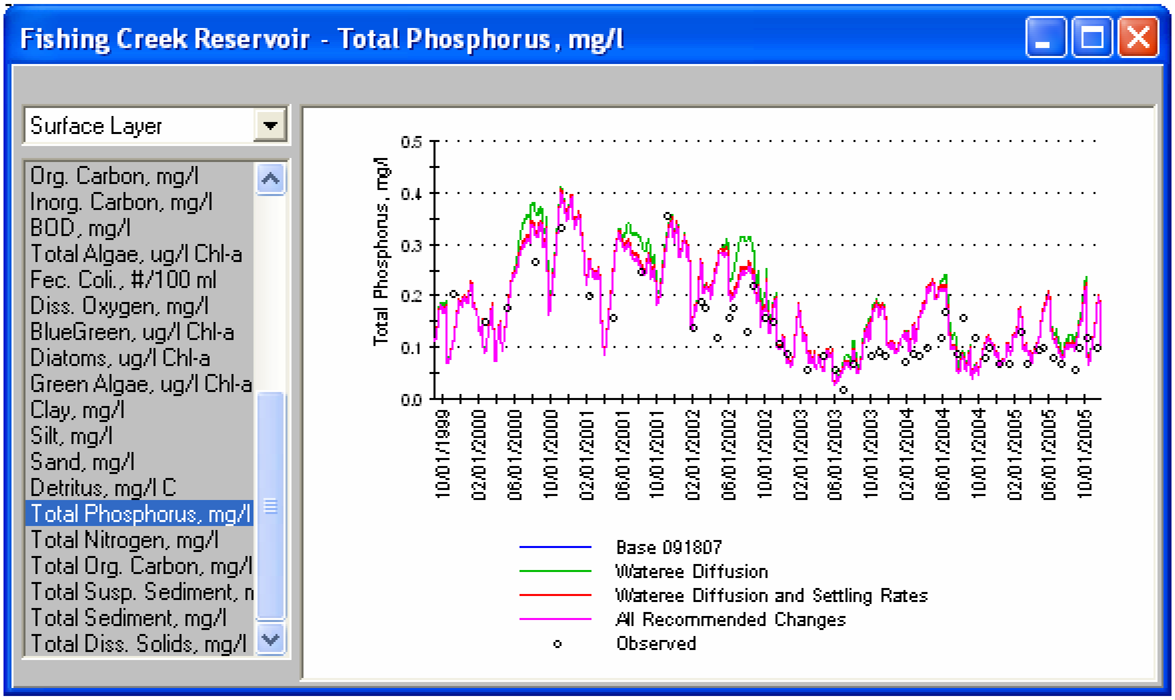


**Figure 10: Simulated and observed total phosphorus, Fishing Creek Reservoir**

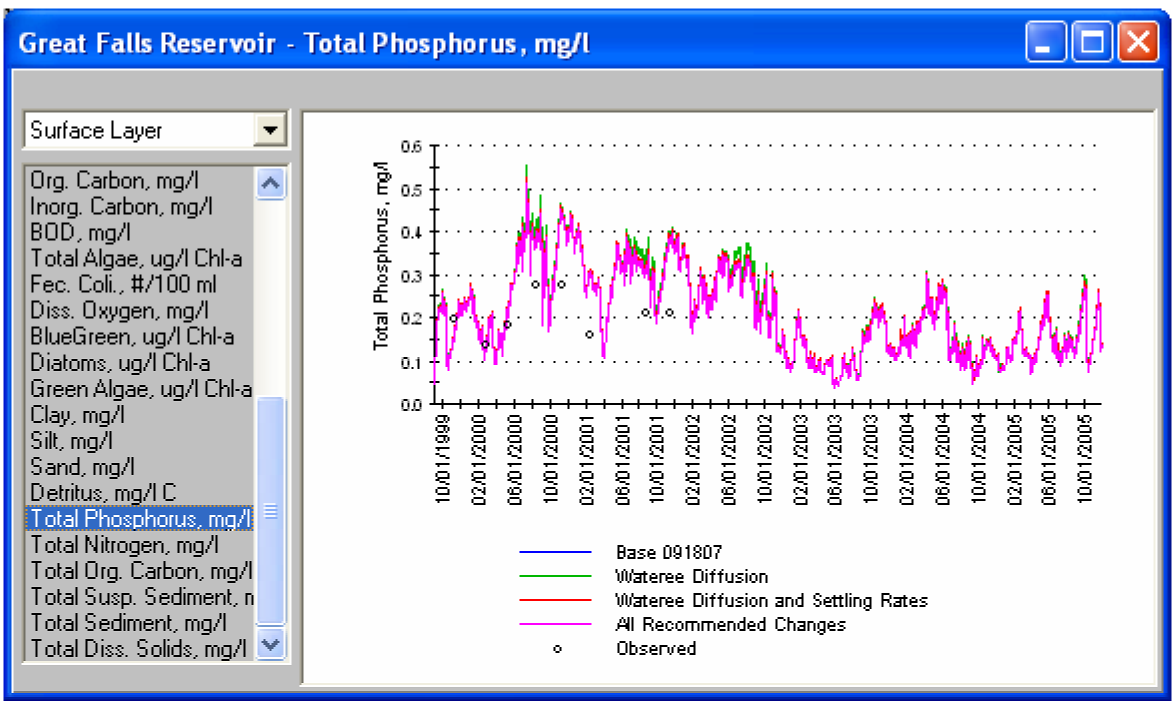


**Figure 11: Simulated and observed total phosphorus, Great Falls Reservoir**

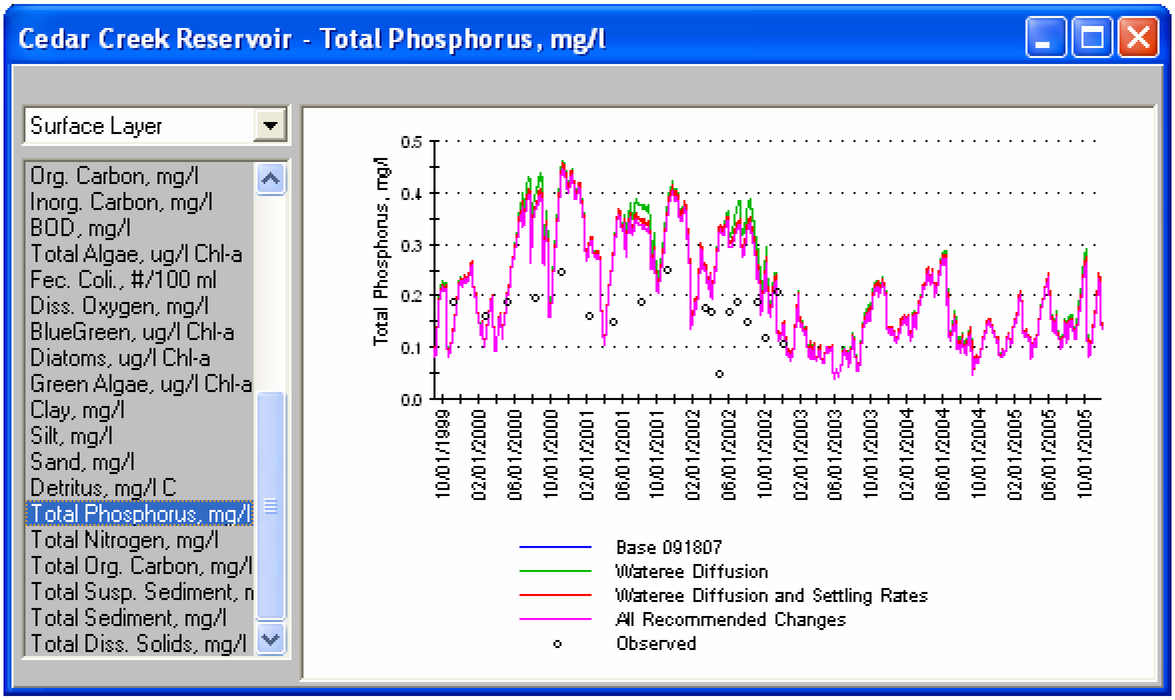


**Figure 12: Simulated and observed total phosphorus, Cedar Creek Reservoir**

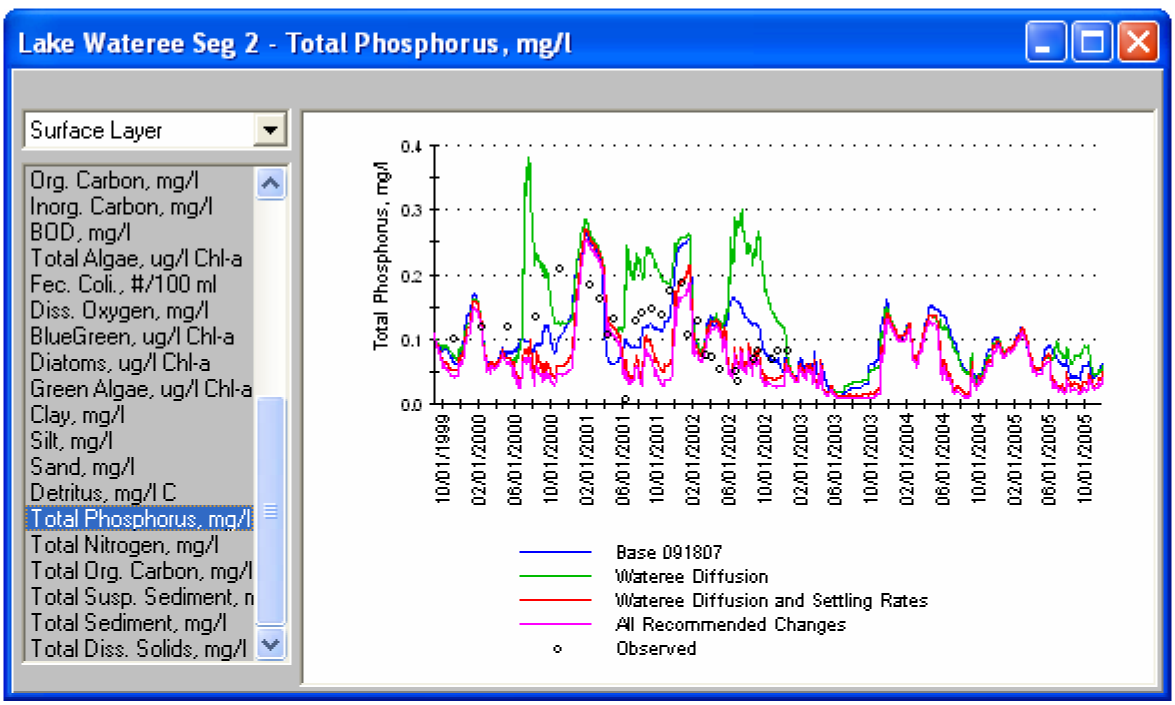


**Figure 13: Simulated and observed total phosphorus, Lake Wateree Segment 2**

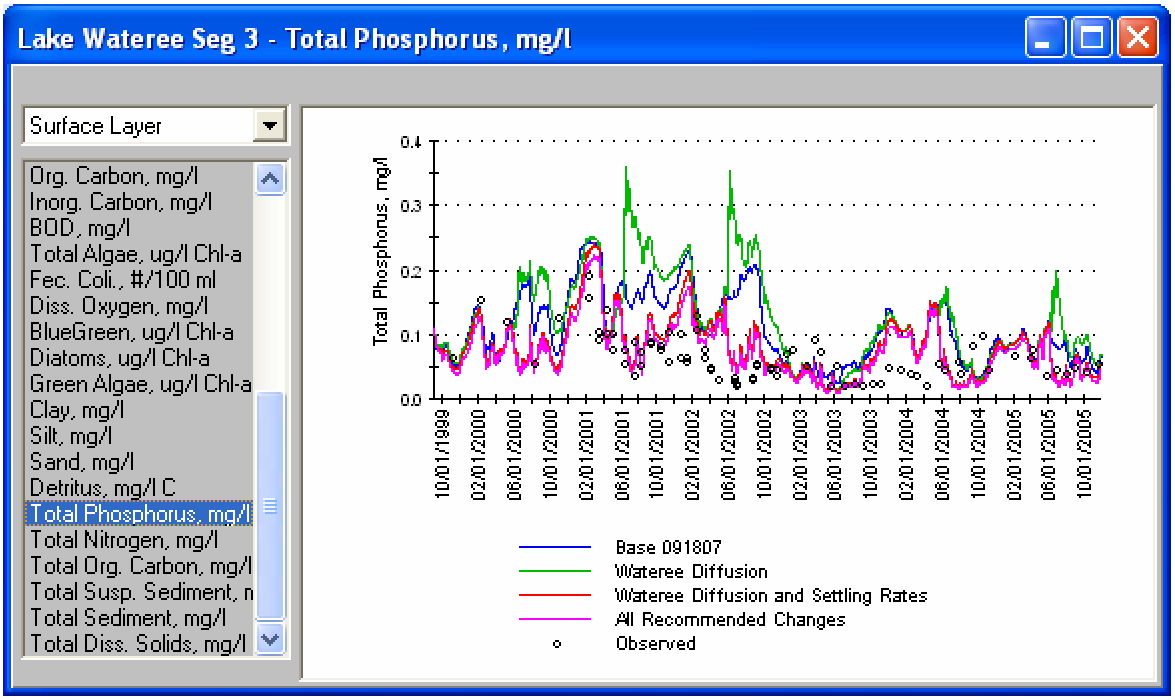


**Figure 14: Simulated and observed total phosphorus, Lake Wateree Segment 3**

The green line is for the change in the diffusion coefficients of Lake Wateree. Therefore, the green line shows no difference in results for reservoirs upstream of Lake Wateree.

Changes in the settling rate of algae made a small improvement in the total phosphorus of Fishing Creek Reservoir, Great Falls Reservoir, and Cedar Creek Reservoir. Changing the settling rate made a much bigger difference in Lake Wateree, as shown by the difference between the green and red lines in Figure 13 and Figure 14.

Eliminating the dry deposition of phosphorus caused a small but significant reduction in simulated total phosphorus at Lake Wateree, as shown by the difference between the red and magenta lines in Figure 13 and Figure 14. The effect was smaller for the other three reservoirs because they have less surface area to collect atmospheric deposition.

The model error can be quantified by the relative error:

$$E_R = \frac{\sum (C_{sim} - C_{obs})}{\sum C_{obs}}$$

Where $C_{sim}$ is the simulated concentration on each day there is observed data and $C_{obs}$ is the observed concentration. It is a measure of model bias.

Table 3 shows the relative error of total phosphorus simulation at each of the reservoirs under each of the four scenarios. The model bias appears to be over predictions of phosphorus concentration. This bias has been reduced by the recommended changes in model coefficients.

Further improvements may be made by examining the parameters for land application and soil erosion, which contribute phosphorus loads to the reservoirs.

**Table 3 Relative Error of Total Phosphorus Simulations**

| Reservoir | Original | Diffusion Changes Only | Diffusion and Settling Rate Changes | All Recommended Changes |
|---|---|---|---|---|
| Fishing Creek | +32% | +32% | +26% | +22% |
| Great Falls | +34% | +34% | +31% | +28% |
| Cedar Creek | +61% | +61% | +55% | +50% |
| Wateree, Segment 2 | +9% | +55% | -15% | -26% |
| Wateree, Segment 3 | +73% | +100% | +26% | +13% |

## Review Calibration Report

### ***SCDHEC Task Description***

Assist in the development and review of the technical WARMF calibration report that SCDHEC is developing.

### ***Systech Engineering Task Report***

Systech Engineering reviewed section 3 of the report "Lower Catawba River Basin WARMF Model Calibration Report". Section 3 includes phosphorus loading and adsorption, land application rates, phosphorus isotherms, and the maximum phosphorus adsorption.

#### *Review of Section 3.1: Land Application Rates*

Section 3.1 discusses the land application rates of phosphorus, ammonia, and nitrate to various land uses. The phosphorus application rate was developed in cooperation with the Natural Resources Conservation Service, which has information about local farming practices.

The 6 kg/ha/month of phosphorus applied to pasture land is higher than the typical value. Ammonia application rates of 12-15 kg/ha/month for the Recreational Grasses, Cultivated, and Pasture land uses are comparable to application rates of other watersheds. The phosphorus application rate of 2 hg/ha/month to Recreational Grasses and Cultivated land uses is also comparable with other watersheds.

In view of the fact that the model is currently over predicting phosphorus concentration, SCDHEC may want to discuss with NRCS about whether the land application rates may be lower. They may have the local knowledge to support such adjustments.

#### *Review of Section 3.2: Phosphorus Adsorption Isotherms*

Section 3.2 discusses the selection of phosphorus adsorption isotherms. The adsorption isotherm in lakes and in rivers is a key model coefficient when differentiating between dissolved and adsorbed phosphorus. Dissolved phosphate is shown in WARMF simulation output of phosphate. Dissolved, adsorbed, and organically bound phosphorus are shown combined in the WARMF simulation output of total phosphorus. If the model's relative simulation error of phosphate is markedly different from the relative error of simulated total phosphorus concentration, that would indicate either an error in simulated suspended sediment concentration or an incorrect phosphorus adsorption isotherm.

The phosphorus adsorption isotherm in lakes and rivers is a function of the sediment types which predominate in suspension in the water column. The adsorption isotherm can vary over at least an order of magnitude depending on the specific sediment conditions. The isotherms used, from 15,000-60,000 L/kg, are within the typical range for phosphate. Simulation results of dissolved phosphate indicate a higher relative error than those shown in Table 3 for all the reservoirs. This indicates that the model has partitioned too much of the phosphorus into the dissolved form, which can lead to over prediction of dissolved phosphate concentration.

A likely cause of this is the under prediction of suspended sediment concentration in the reservoirs. Lake Wateree Segment 3 has ample suspended sediment measurements averaging 5.8 mg/l, but simulation results average only 0.7 mg/l. Lake Wateree Segment 2 has a similar discrepancy between simulated and observed suspended sediment. The under prediction of suspended sediment not only lead to higher partitioning of total phosphorus to the dissolved form but also to lower removal of phosphorus by settling.

The other reservoirs lack sufficient data to determine the model accuracy in predicting suspended sediment concentration. Simulation results for suspended sediment entering Fishing Creek Reservoir from the Catawba River are reasonable when compared to observed data. The lack of sediment in the model in Lake Wateree would be due to either too much sediment settling out in the 3 reservoirs upstream or from too little suspended sediment predicted by the model entering the reservoir from its local tributaries. Adjustment of the model simulation of suspended sediment should improve the model prediction of phosphorus due to its dual roles both as a sink and as a source of phosphorus.

### *Review of Section 3.3: Maximum Phosphate Adsorption*

Section 3.3 discusses the limit of phosphorus adsorption in the soil. Since the soil readily adsorbs phosphate, it attenuates loading of phosphate to the land surface before it reaches surface waters. If the maximum phosphate adsorption is exceeded, however, phosphorus can flow unimpeded to surface waters through shallow ground water flow, increasing the concentration of phosphorus in surface waters. The maximum phosphate adsorption coefficient appears to be set high enough so it is not likely to be exceeded. The comparison between simulated and observed total phosphorus would indicate that the calibrated value for the maximum phosphate adsorption is reasonable.

# 5 CONCLUSIONS AND RECOMMENDATIONS

## Conclusion

SCDHEC identified several items for review and technical support by Systech Engineering. This document and the adjusted model coefficients provided to SCDHEC address these concerns. The WARMF model now uses the latest land use information favored by SCDHEC. The previously reported simulation errors of temperature and periphyton have been resolved with the updated set of WARMF model coefficients. This report describes three recommended changes which improve the simulation of total phosphorus in Fishing Creek Reservoir, Great Falls Reservoir, Cedar Creek Reservoir, and Lake Wateree. The current calibration provides a generally reasonable match between simulated and observed data.

## Recommendations

Following recommendations are made:

1. Implement the described changes to the Lake Wateree diffusion coefficients.

2. Implement the described changes to the algal and detrital settling rates to all four reservoirs. If possible, gather information from local research to determine algal settling rates in Catawba River reservoirs to ensure the calibrated values are reasonable.

3. Examine the source of phosphate air concentration data to verify its validity and the units in which it is reported. If the data is not verified, an assumption of zero air concentration is likely to accurately reflect the significance of dry deposition relative to total loading of phosphorus.

4. Since the model is over predicting phosphorus concentration, it is advisable for SCDHEC to consult with NRCS to find if there is justification for lowering land application rate of phosphours to various land uses, which may lower the nonpoint load of phosphorus to the reservoirs.

5. Conduct further calibration of total phosphorus for each of the four reservoirs.

# 6 REFERENCES

Chen, C.W., Herr, J., and Weintraub, L.H.Z. 2001. "Watershed Analysis Risk Management Framework: Update One: A Decision Support System for Watershed Analysis and Total Maximum Daily Load Calculation, Allocation, and Implementation," EPRI, Palo Alto, CA. Topical Report 1005181.

Herr, J., Weintraub, L.H.Z., and Chen, C.W. 2001. "User's Guide to WARMF: Documentation of Graphical User Interface," EPRI, Palo Alto, CA. Topical Report.