SYSTECH WATER RESOURCES, INC.
ENVIRONMENTAL ENGINEERING AND
WATER RESOURCES SYSTEMS ANALYSIS

Technical Memorandum

South Carolina Department of Health and Environmental Control, Bureau of Water Section 319 Grant Project #9

Catawba River WARMF Model Update

Prepared by

Systech Water Resources, Inc.
1200 Mount Diablo Blvd, Suite 102
Walnut Creek, CA 94596
(925) 355-1780

June 26, 2013

Introduction

Systech Water Resources, Inc. (Systech) has been tasked to assist the South Carolina Department of Health and Environmental Control (SC DHEC) in updating the Catawba River application of the Watershed Analysis Risk Management Framework (WARMF). The model updates are part of efforts to prepare for the development of nutrient TMDLs (which may include total phosphorus, total nitrogen, chlorophyll, pH, or DO) for the South Carolina Catawba River reservoirs. The tasks described below were performed by Systech as part of this project.

Task 1: Update WARMF Time Series Database

WARMF uses several sets of time series data as inputs to drive model simulations: meteorology, air & rain chemistry, point sources, reservoir surface elevation, reservoir releases, and diversions. Measured flow and water quality data are used to determine how well the simulations match historical in-stream conditions. The database was previously complete from 1992 through 2005. Systech collected data from online sources and directly from SC DHEC in order to update the database through 9/30/2012 and later. Table 1 below lists each input data type and the date up to which data files were updated.

Table 1 – WARMF input data types and last dates of update

Input Datatype	**WARMF file extension**	**Last date in data files**
Meteorology	MET	9/30/2012
Air & Rain Chemistry	AIR	10/23/2012
Point Sources	PTS	9/30/2012
Diversions	FLO	9/30/2012
Reservoir Operations	OLH	11/6/2012
Lake Wylie Boundary Inflow	PTS	11/6/2012

Meteorology

The Catawba River WARMF application includes the 27 meteorology stations listed below in Table 1. Meteorology data were collected for 1/1/2003 through 9/30/2012 from the National Climatic Data Center (NCDC) Climate Data Online (CDO) and Global Summary of the Day (GSOD) websites. The CDO website is the current source for downloading data from NCDC COOP stations. Twenty-four of the 27 Catawba meteorology stations are NCDC COOP stations, of which 6 are also part of the GSOD network. The remaining 3 stations (Catawba Nuclear Station, Long Creek, and McGuire Nuclear Station) are locations where data were previously obtained from Duke Energy Corporation. No updated meteorology data were collected from Duke Energy for this project.

Table 2 below indicates which stations and variables had data available for the 2003-2012 period. An “x” indicates that data were available for at least a portion of the period. For variables with only partial or no data available, surrounding stations were used to fill the data record using WARMF’s “Fill Missing Data” function within the Data Module. This function finds the nearest station with available data, calculates a multiplier to adjust values up or down based on coinciding historical data, and fills the missing variable with the adjusted value from the filler station.   In Table 2, variables of a given station labeled as “Filled” are those that were filled completely using surrounding stations. Cloud cover was estimated for stations that had data available for precipitation, minimum and maximum temperature, and dew point temperature using the following logic:

If Precipitation > 2cm, Cloud Cover = 1
If Precipitation > 1cm, Cloud Cover = 0.9
If Precipitation > 0cm, Cloud Cover = 0.8
If Precipitation = 0cm and (Average Temp – Dew Point Temp) >= 6, Cloud Cover = 0
If Precipitation = 0cm and (Average Temp – Dew Point Temp) >= 4, Cloud Cover = 0.3
If Precipitation = 0cm and (Average Temp – Dew Point Temp) < 4, Cloud Cover = 0.6

Table 2 – Data availability in the updated period for WARMF meteorology stations

WARMF Filename	COOP ID	GSOD ID	Precip	Min Temp	Max Temp	Wind	Dew Point	Cloud Cover	Air Press
Hickory.met	314020	723010, 723145	x	x	x	x	x	Estimated	x
Chardoug.met	311690	723140	x	x	x	x	x	Estimated	x
jamesduke.met	311081	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
Lookout.met	311579	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
Oxfordam.met	311990	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
Gastonia.met	313356	723147	x	x	x	x	x	Estimated	x
grndfthr.met	313565	NA	x	x	x	Filled	Filled	Filled	Filled
Lenoir.met	314938	NA	x	x	x	Filled	Filled	Filled	Filled
Lincoln.met	314996	722128	x	x	x	x	x	Estimated	x
Marion.met	315340	NA	x	x	x	Filled	Filled	Filled	Filled
Morgantn.met	315838	NA	x	x	x	Filled	Filled	Filled	Filled
mtholly.met	315913	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
mtmitch.met	315923	NA	x	x	x	Filled	Filled	Filled	Filled
pattersn.met	316602	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
Rhodhiss.met	317229	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
swannano.met	318448	NA	x	x	x	Filled	Filled	Filled	Filled
taylorsv.met	318519	NA	x	x	x	Filled	Filled	Filled	Filled
Catawba.met	381462	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
Chester.met	381633	720599	x	x	x	x	x	Estimated	x
Fortmill.met	383216	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
Grtfalls.met	383700	NA	x	Filled	Filled	Filled	Filled	Filled	Filled
Wateree.met	388979	998208	x	x	x	x	Filled	Filled	Filled
Winnsbor.met	389327	NA	x	x	x	Filled	Filled	Filled	Filled
Winthrop.met	389350	NA	x	x	x	Filled	Filled	Filled	Filled
catawbanuc.met	NA	NA	Filled	Filled	Filled	Filled	Filled	Filled	Filled
longcr.met	NA	NA	Filled	Filled	Filled	Filled	Filled	Filled	Filled
mcguire.met	NA	NA	Filled	Filled	Filled	Filled	Filled	Filled	Filled

Air and Rain Chemistry

The Catawba River WARMF application uses data from the CASTNET station "Cranberry" (Station ID PNF126) for air chemistry (dry deposition). It uses data from NADP station "Mt Mitchell" (Station ID NC45) for rain chemistry (wet deposition). Data from these two stations were collected from 7/2005 – 7/2012, from the CASTNET and NADP websites. The AIR file used in the most up to date version of the Catawba River WARMF model (Cranberry no dry P.AIR) was updated with the 2005-2012 data.

Point Sources

The Catawba River WARMF application includes 305 point sources, of which 293 were previously included in the model and 12 were added to the model as part of this project. The added point sources are listed in Table 3 below.

Table 3 – Point sources added to the model

Point Source Filename	**Description**	**WARMF Segment ID**
NC0004979_3.PTS	Duke Power Co., ALLEN S.E. , Outfall 003	Reservoir 261
NC0004979_4.PTS	Duke Power Co., ALLEN S.E. , Outfall 004	Reservoir 261
NC0004979_5.PTS	Duke Power Co., ALLEN S.E. , Outfall 005	Reservoir 261
NC0004987_4.PTS	Duke Power Co., MARSHALL S.E. , Outfall 004	Reservoir 1114
NC0005177_4.PTS	FMC Corporation-Lithium Division, Outfall 004	River 1119
NC0024392_4.PTS	Duke Power Co., MCGUIRE S.E. , Outfall 004	River 132
NC0074900.PTS	Hydraulics Ltd Hwy 150 WWTP	Reservoir 1128
NC0080691.PTS	Windmere WWTP	Reservoir 1161
NC0081370.PTS	McLin Creek WWTP	River 151
NC0084689.PTS	City of Mount Holly WTP	Reservoir 821
NC0088722.PTS	Killian Creek WWTP	River 132
SC0004278_6.PTS	Duke Power/Catawba Nuclear Station, Outfall 6	Reservoir 315

Effluent data for point sources (46) in the South Carolina part of the basin was obtained by SC DHEC from Discharge Monitoring Reports (DMR), which are reported monthly. For most major South Carolina point sources more detailed data (usually daily for flow and DO at least) was obtained directly from the dischargers (SC0001015, SC0001741, SC0020443, SC0026751, SC0036056, SC0046892, and SC0047864).

Effluent data for the large point sources (3) in Charlotte were obtained directly from Charlotte-Mecklenburg Utilities (CMU) (NC0024937, NC0024945, and NC0024970). CMU typically reports daily flow, temperature, DO, and BOD and nutrients weekly at least. Data for the remaining major and larger minor (> 0.05 mgd) point sources (74) in the North Carolina portion of the basin were obtained from NC DENR. Typically these dischargers report flow and some other parameters daily. The smaller minor North Carolina point sources were not updated. These sources collectively are a small percentage of the total point source flow and load. Since the focus of this model update is the portion of the basin downstream of Lake Wylie, the cost of including these very small point sources was not warranted.

A total of 123 of the total 305 point sources were updated. Of the updated discharges, 22 (15 in SC, 7 in NC) became inactive and were set to zero prior to the end of the update period (9/30/2012). The remaining 170 for which no data were provided were either inactive or minor dischargers with no data available and/or minimal impact on simulation results. Of these 170, 37 were located in SC (all inactive) and 133 were located in NC (130 minor/no data and 3 inactive). Tables A1-A2 in the Appendix list the updated and non-updated point source files.
Although input data is not required for every day in a point source input file (*.PTS file), each row (i.e. each date included) in the file must have actual values (i.e. no missing indicators) for every constituent included in the file. However, for a given discharge, data samples are often taken for different constituents on different days. Thus it was necessary to fill data for any constituent not available on a given date by some estimation method. For most constituents the filling procedure was as described below (in all cases filling was performed using concentrations values, prior to calculating loading).

- If data gap < 120 days, repeat the last value
- If data gap > 120 days, use the monthly average (of available data in the updated period)
- If no updated data is available for a constituent in the previous PTS file, the mean concentration from the previous data is used
- If updated data is available for a constituent that was *not* previously included in the PTS file, monthly average concentrations from the updated data were used to fill data for that constituent on dates prior to the update period.

The above rules applied to all constituents except nitrate and ammonia (in some cases) and temperature for South Carolina dischargers. For the latter, if no temperature data were available, the combined average monthly temperatures from the three CMUD dischargers were used (NC0024937, NC0024945, and NC0024970). The estimation method for nitrate and ammonia depended on which species of nitrogen were available and for what time interval they were available. The following rules were applied for estimating nitrate and ammonia concentrations:

- If NO3 data were available, the values were used directly as for other constituents
- If NH3 data were available, the values were used directly as for other constituents
- If only TN data were available (no NO3 or NH3), and the previous PTS file included only NO3, NO3 was assumed to equal TN and NH3 was continued to be assumed as zero.
- If only TN data were available (no NO3 or NH3), and the previous PTS file included only NH3, NH3 was assumed to equal TN and NO3 was continued to be assumed as zero.
- If both NH3 and TN data were available at the same time interval, NO3 was estimated as TN minus NH3
- If daily or weekly NH3 but monthly (or less) TN were available, the average NH3 value ($NH3_{ave}$) was calculated over N days (N= # of days between TN values) or 30 days (if N>30). Then NO3 was estimated as TN minus $NH3_{ave}$. If the resulting estimate was negative (i.e., $NH3_{ave}$ > TN), the previous value was repeated.
- If no TN or NO3 data were available, but NO3 was included in the previous PTS file, the average concentration was calculated from previous data and applied for the updated period. (Thus if prior data assumed a specific concentration, the same assumption was applied).

- If no TN or NO3 data were available and NO3 was NOT previously included in the PTS file, it was also not included in the updated period (continued to be assumed zero).
- If no TN or NH3 data were available, but NH3 was included in the previous PTS file, the average concentration was calculated from previous data and applied for the updated period. (Thus if prior data assumed a specific concentration, the same assumption was applied).
- If no TN or NH3 data were available and NH3 was NOT previously included in the PTS file, it was also not included in the updated period (continued to be assumed zero).
- For all constituents, values reported as "<" or "< X" (where X is the detection limit), were assumed equal to ½ the value of the detection limit. In cases where the detection limit was not specified (i.e., just a "<" symbol), a detection limit was assumed as the median value of all detection limit values for that constituent.

All point source files were updated through 9/30/2012 as indicated in Table 1. If data were not provided up to this date, values from the last available date were repeated for 9/30/2012 (unless the discharge became inactive) as a means of estimating data through 9/30/2012 (to allow for model runs up to this date). This line is labeled "`Last line repeated for model extrapolation`" in the source column. Once complete records of concentration values for all available constituents for a given point source were compiled, loading values were calculated and included in the corresponding *.PTS file.

Diversions

The Catawba River WARMF application includes 67 diversions, drawing water from river and lake segments. Nine of the diversions were previously not included in the model and were added as part of this project. In addition, 2 diversions were shifted from an existing data file (bowater.flo file) into a new data file (RMInd.flo) due to conflicting locations with another diversion contained in the file. The new and shifted diversions are listed in Table 4 below. Note that WARMF Reservoir 838 corresponds to the previous Reservoir 1654. All river, reservoir and catchment ID changes resulting from catchment subdivisions are outlined in the report section for Task 2.

Table 4 – Diversions added or moved to new WARMF *.FLO files

New WARMF Filename	Diversion Name/Description	WARMF Segment ID
RMInd.flo	Nations Ford Chemical (R M Industries)	River 87
RMInd.flo	Chester Intake (Inactive 2005)	River 87
FISHCR_6.flo	Lancaster, City of - Emergency Intake	Reservoir 1562
SpgGr_Complex.flo	Springs-Grace Complex	River 61
RiverHillsGC.flo	River Hills Golf Club	Reservoir 838 (old ID 1654)
TegaCayGC.flo	Tega Cay Golf Club	Reservoir 838 (old ID 1654)
WaterfordGC.flo	Waterford Golf Club	River 87
HooperGC.flo	Hooper Creek golf withdrawal	River 577
HooperIrrig.flo	Irrigation Pond	River 577
CatawbaOther.flo	Withdrawal ID 46OT100S01	River 87
lincolnton.flo	Lincolnton public water supply	River 486

Data for diversions were provided by SC DHEC. All diversions were updated at least through 9/30/2012. If actual data were not provided up to that date, average monthly values were used to fill the record through 9/30/2012, as well as fill missing periods. Reservoir releases (Turbine and Spill "diversions") were updated through 11/6/2012. Five of the diversions in the model are associated with power plant operations. For these facilities, the amount of water removed and returned to the reservoir is specified in the point source file. The diversion file for these facilities specified the net water loss or consumptive use. The associated diversion files and consumptive use estimate are listed in Table 5 below. These estimates were previously provided by Duke Energy and were continued in the updated files.

Table 5 – Power plant diversion files and consumptive use estimates

WARMF Filename	Power Plant	Consumptive Use Estimate
MTISLAND_6.FLO	Riverbend Steam Station	0.0651 cfs
WYLIE_6.FLO	Allen Steam Station	0.121 cfs
NORMAN_9.FLO	Marshall Steam Station	0.3341 cfs
NORMAN_8.FLO	McGuire Nuclear Station	1.1 cfs
WYLIE_5.FLO	Catawba Nuclear Station	1.75 cfs

Reservoir Operations

Reservoir elevation and spill information is input to WARMF via observed lake hydrology (*.OLH) files. WARMF uses the elevation data to adjust simulation lake elevation and adjust outflow if necessary in order to match the observed elevation. The Catawba River WARMF application includes 11 simulated reservoirs. Elevation and spill data for these reservoirs were provided to Systech by SC DHEC who in turn received the data from Duke Energy. All OLH files were updated through 11/6/2012.

Observed Hydrology

Observed hydrology data is used in WARMF to compare and calibrate simulations of flow and elevation. In order to assess WARMF simulations during the updated period, hydrology observations were collected and added to WARMF observed river hydrology files (*.ORH). Systech collected data directly from the USGS website for the 24 gaging stations previously defined in model that use USGS data. Table 6 lists the WARMF filename and river ID, USGS name and identifier, and the last date of data included.

Table 6 – Updated observed hydrology files

WARMF Filename	USGS ID	Name	WARMF River ID	Last Date
Cat1221.orh	2137727	Catawba R nr Pleasant Gardens	1063	3/19/2013
Linville.orh	2138500	Linville River Near Nebo	1006	3/19/2013
Johns.orh	2140991	Johns River at Arneys Store	79	3/19/2013
Lowlittl.orh	2142000	Lower Little River nr All Healing Spg	452	3/19/2013
Longpaw.orh	2142900	Long Creek near Paw Creek	165	3/19/2013
Hnryfk.orh	2143000	Henry Fork near Henry River	583	3/19/2013
Jacob.orh	2143040	Jacob Fork at Ramsey	556	3/19/2013
Indian.orh	2143500	Indian Creek near Laboratory	406	3/19/2013
Longbess.orh	2144000	Long Creek near Bessemer City	325	3/19/2013

Sfmcaden.orh	2145000	South Fork Catawba River at Lowell	121	3/19/2013
Catbelwy.orh	2146000	Catawba River near Rock Hill	87	3/19/2013
Irwin.orh	2146211	Irwin Cr at Statesville Ave	526	3/19/2013
Sugar1.orh	2146300	Irwin Creek near Charlotte	510	3/19/2013
Sugar3.orh	2146381	Sugar Creek at NC 51 near Pineville	498	3/19/2013
Litsugar.orh	2146507	Little Sugar Creek at Archdale Dr	455	3/19/2013
LitSugar-NC51.orh	2146530	Little Sugar Creek at Pineville	433	3/19/2013
Mcalp1.orh	2146600	McAlpine Cr at Sardis Road	425	3/19/2013
Mcmullen.orh	2146700	McMullen Cr at Sharon View Rd	366	3/19/2013
Mcalp2.orh	2146750	McAlpine Cr below McMullen Cr	863	3/19/2013
Twelve.orh	2146900	Twelvemile Creek near Waxhaw	437	2/29/2004
Catabvfc.orh	2147020	Catawba River below Catawba	61	3/19/2013
Rocky1.orh	2147500	Rocky Creek at Great Falls	551	3/19/2013
Abvrhod.orh	213903612	Catawba River at Calvin	203	9/30/2009
McDowell.ORH	214266000	McDowell Creek nr Charlotte	41	3/19/2013
mcalp5.orh	0214676115	McAlpine Creek at SR-29-64 near Camp Cox, SC	355	12/31/2012
sugar4.orh	02146800	Sugar Creek at SC-160 near Fort Mill, SC	246	12/31/2012
wildcat.orh	021473428	Wildcat Creek at Robertson Rd E below Rock Hill, SC	362	12/31/2012

Observed Water Quality

Observed water quality data is used in WARMF to compare and calibrate simulations of chemical and physical constituents in river and lake model segments. Ambient water quality data for nutrient-related constituents were provided by SC DHEC. Systech added the data to WARMF observed river chemistry (*.ORC) and observed lake chemistry (*.OLC) files. Table 7 lists the WARMF filename and segment (river or reservoir) ID, station name and identifier, and the last date of data provided for river locations, and Table 8 lists reservoir locations.

Table 7 – Updated observed river water quality files

WARMF Filename	SCDHEC Station ID	Other Station ID*	Station Description	WARMF ID	Last Date
Rockyup.orc	CW-002		Rocky Creek at S-12-335	605	1/5/2010
wildcat2.orc	CW-006		Wildcat Creek at S-46-650	365	8/22/2007
fishcr1.orc	CW-008		Fishing Creek at SC-223	239	1/5/2010
steele3.ORC	CW-009		Steele Creek at S-46-22	340	12/13/2007
steele.orc	CW-011		Steele Creek at S-46-270	301	12/13/2007
sugar4.orc	CW-013	C9790000 & SC-5	Sugar Creek at SC-160	246	5/28/2013
CATBELWY.orc	CW-014		Catawba River at US-21	87	12/5/2012
cane.orc	CW-017		Cane Creek at SR-50	24	12/4/2012
CROWDER.orc	CW-023	C8660000	Crowders Creek at Ridge Rd	1095	11/13/2012
FishBr.orc	CW-029		Fishing Creek Headwaters	397	12/15/2009

sugar2.orc	CW-036		Sugar Creek above confl	39	12/5/2012
littlewat.orc	CW-040		Little Wateree Creek	617	9/18/2007
CATABVFC.orc	CW-041		Catawba River at SC-5	69	11/8/2011
gills.orc	CW-047		Gills Creek	27	9/4/2007
mcalp5.orc	CW-064	C9680000	McAlpine Creek at S-29-64	355	11/15/2011
bigwat.ORC	CW-072		Wateree Creek	563	10/23/2012
twelve2.orc	CW-083		Twelvemile Creek at S-29-55	18	12/5/2012
grassy.orc	CW-088		Grassy Run Branch	606	12/22/2009
wildcat.orc	CW-096		Wildcat Creek at S 46-998	362	12/13/2007
bear2.orc	CW-131		Bear Creek	202	10/3/2007
calabash.orc	CW-134		Calabash Branch	1059	1/19/2010
waxhaw.orc	CW-145		Waxhaw Creek	746	12/4/2008
bear.orc	CW-151		Bear Creek	250	5/2/2007
crowder2.orc	CW-152		Crowders Creek at US-321	1100	12/1/2008
beaverdam.orc	CW-153		Beaverdam Creek	1082	1/19/2010
allison.orc	CW-171		Allison Creek	1067	1/19/2010
gfallstr.orc	CW-174		Great Falls Reservoir Tailrace	573	12/27/2007
rocky2.orc	CW-175		Rocky Creek above confl	551	1/5/2010
sixmile.orc	CW-176		Sixmile Creek	157	12/13/2007
cane2.orc	CW-185		Cane Creek at SC-200	528	10/3/2007
CROWDER3.ORC	CW-192		S F Crowders Creek	1106	12/5/2007
fishcr2.orc	CW-224		Fishing Creek	361	2/3/2009
fishcr3.orc	CW-225		Fishing Creek	375	12/4/2008
mcalp2.orc	CW-226		McAlpine Creek below WWTP	358	2/9/2006
neelys.orc	CW-227		Neelys Creek at S-46-997	222	8/7/2007
ABVWAT.orc	CW-231		Lake Wateree headwater	624	12/5/2012
rum.orc	CW-232		Rum Creek	21	10/3/2007
fishcr4.orc	CW-233		Fishing Creek	149	12/4/2012
tinkers.orc	CW-234		Tinkers Creek at S-12-599	207	8/19/2011
camp.orc	CW-235		Camp Creek at SC-97	174	12/18/2008
rocky1.orc	CW-236		Rocky Creek	160	12/4/2012
sugar1.orc	CW-247	C9050000	Sugar Creek at NC-51	498	4/18/2012
FishCr1172.orc	RS-11056		Fishing Creek at S-46-1172	389	12/5/2012
CatawbaLansford.orc	RS-12088		Catawba River at end of Landsford Rd	646	12/5/2012
cat1221.orc		C0250000	Catawba River near Pleasant Gardens	1063	4/12/2012
catbelmi.orc		C3900000	Catawba River at NC-27	614	4/12/2012
irwin3.orc		C8896500	Irwin Creek abv WWTP	510	4/11/2012
linville.orc		C1000000	Linville River at NC126 near Nebo, NC	1006	4/12/2012
litsugar.orc		C9210000	Little Sugar Creek at NC-51	453	4/18/2012
lowercr.orc		C1750000	Lower Creek at SR 1501	74	4/23/2012
SFMcAden.orc		C6500000	S F Catawba R upstream of McAdenville	121	4/1/2012

twelve.orc		C9819500	Twelvemile Creek at NC-16	437	4/23/2012

*Station IDs in the form of C####### were collected by NC DENR DWQ Stream Ambient System
Station IDs in the form of SC-# were collected by Charlotte-Mecklenburg Utilities

Table 8 – Updated observed reservoir water quality files

WARMF Filename	SCDHEC Station ID(s)	Other Station ID*	Name	WARMF ID	Last Date
CedarCr.olc	CW-033, RL-06443, RL-08046, RL-12125		Cedar Creek Reservoir	1567	12/5/2012
fishcr.olc	RS-11056, CW-057		Fishing Creek Reservoir	1562	1/8/2013
Fishcr1.olc	CW-016		Fishing Creek Reservoir	48	1/8/2013
GRFALL.OLC	RL-06429, RL-07019, RL-08062, RL-10106, RL-11117, RL-11119		Great Falls Reservoir	1563	12/12/2011
Rhodhiss7.olc		CTB040B	Lake Rhodhiss Seg 7	230	9/22/2011
WATEREE2.olc	CW-207			2310	11/15/2012
WATEREE3.olc	Cl-089		Lake Wateree Seg 2	2292	11/15/2012
WATEREE5.olc	CW-208, RL-08035, RL-12056		Lake Wateree Seg 3	15	12/5/2012
WatereeHead.olc	RL-11040		Lake Wateree Seg 5	579	12/7/2011
Wylie16.olc	CW-027		Lake Wateree Headwaters	290	11/30/2009
Wylie17.olc	CW-245		Lake Wylie, Crowders Creek	298	12/5/2007
Wylie18.olc	CW-200		Lake Wylie, Seg 17	302	8/16/2007
Wylie5.olc	CW-197	CTB198C5	Lake Wylie, Allison Creek Arm	273	1/9/2013
Wylie8.olc	CW-201, RL-06433		Lake Wylie abv Mill Creek Seg 5	786	1/9/2013
Wylie9.olc	CW-230	CTB198D	Lake Wylie, Seg 9	838	1/9/2013

*Station IDs in the form of CTB###** were collected by NC DENR DWQ Ambient Lake Monitoring Program.

Lake Wylie Boundary Inflow

Prior to this project, SC DHEC had been testing the Catawba River WARMF model both with and without treating Lake Wylie as a boundary inflow. In WARMF, any location can be treated as a boundary inflow by including a point source for that location and disconnecting all upstream area from the model. A boundary inflow point source file should be created using observed flow and water quality from that location or a near to it as possible. The Lake Wylie boundary inflow point source file (Lake Wylie PS.PTS) was updated through 11/6/2012. Flow data were calculated as the total release from Lake Wylie (turbine plus spill flows) and constituent concentrations were compiled from station CW-230 and CW-014, the latter on dates for which CW-230 had no data. During the updating process for the boundary inflow data, an outlier was found in the original source data for nitrate (station CW-014 on 5/29/2002). The outlier caused an unreasonable spike in the resulting boundary inflow file. This outlier was removed in the updated version of the file.

Task 2: Catchment Delineation for State, MS4 Boundaries

To allocate TMDL loading, SC DHEC needs to separate out those areas whose loading is regulated by other means. This includes the boundary between North and South Carolina and MS4 permitted urbanized areas. The previous catchment delineation in WARMF followed natural drainage boundaries and crossed these administrative boundaries (Figure 1).

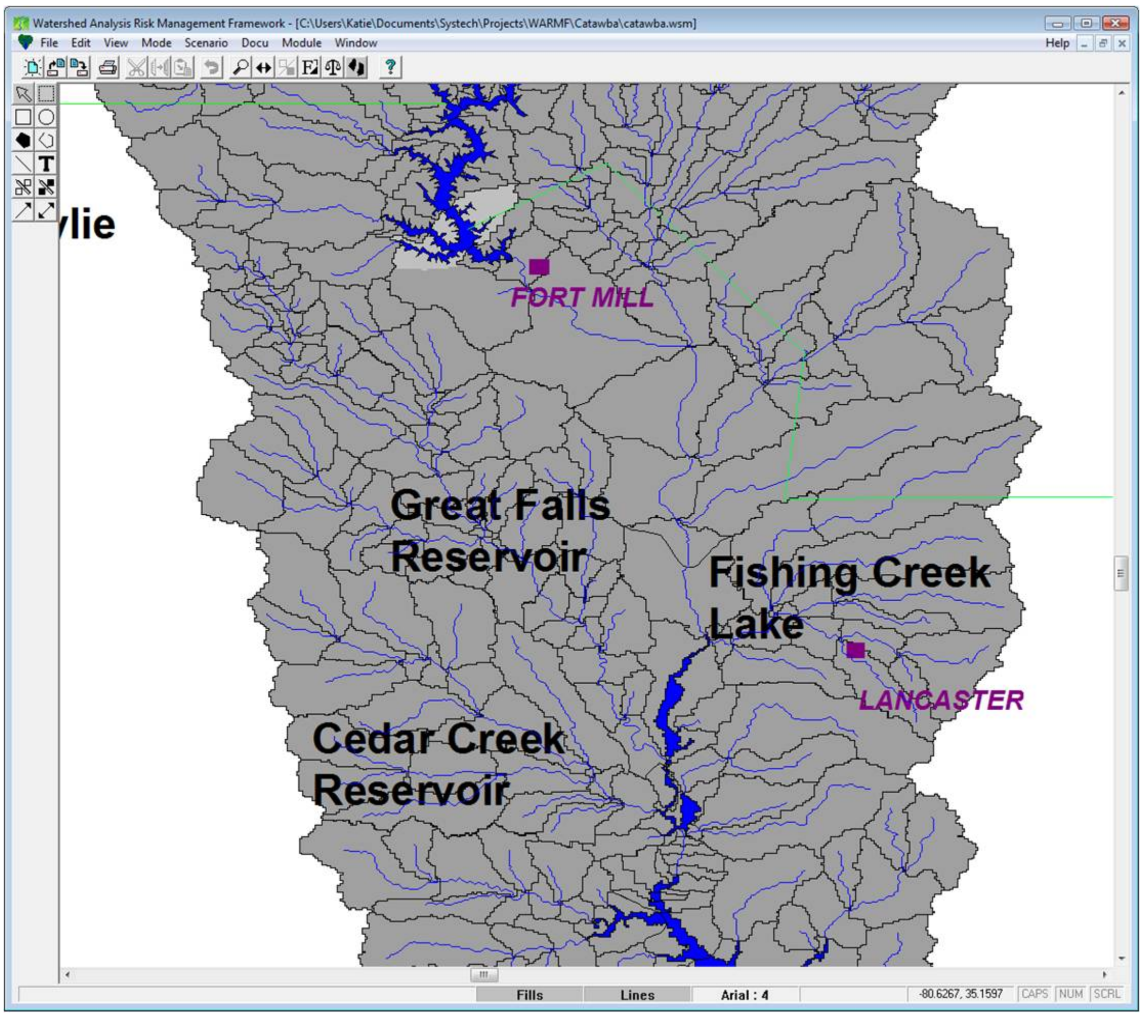

Figure 1 – Previous WARMF catchment delineations downstream of Lake Wylie

For this project the WARMF catchments east of the Catawba River were split along the state boundaries and MS4 boundaries. To identify the MS4 boundaries, a shapefile of urban areas (year 2010) was obtained from the US Census Bureau website (Figure 2). The designated urban areas east of the Catawba River and within South Carolina (right side of Figure 2) were isolated and used, along with the NC-SC border, for subdivision of WARMF catchments. Preexisting catchment boundaries were intersected with the state and urban boundaries to result in new catchment boundaries. Small fragments (i.e., any polygons with an area less than 85,000 m^2) were combined with larger polygons. In total, 51 preexisting catchments were subdivided and replaced by 126 new catchments (shown in light gray, dark gray and brown in Figure 3).

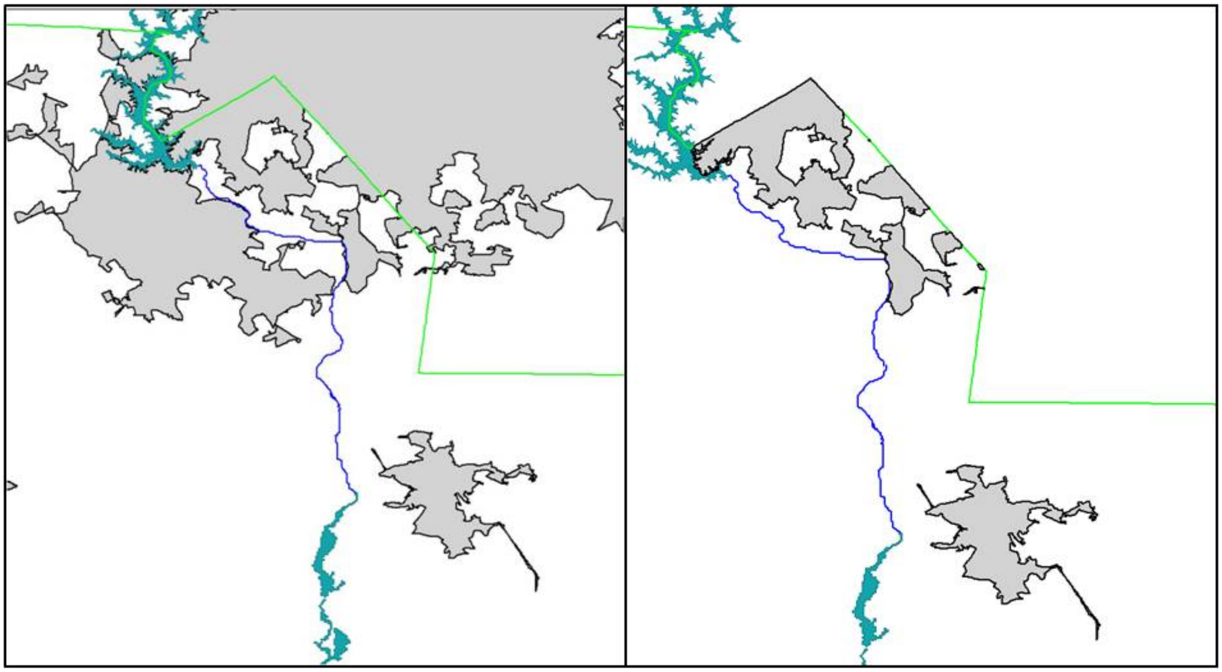

Figure 2 – US Census Bureau 2010 Urban Areas (gray) – left side is all areas, right side is areas within South Carolina and east of the Catawba River (used for subdivision).

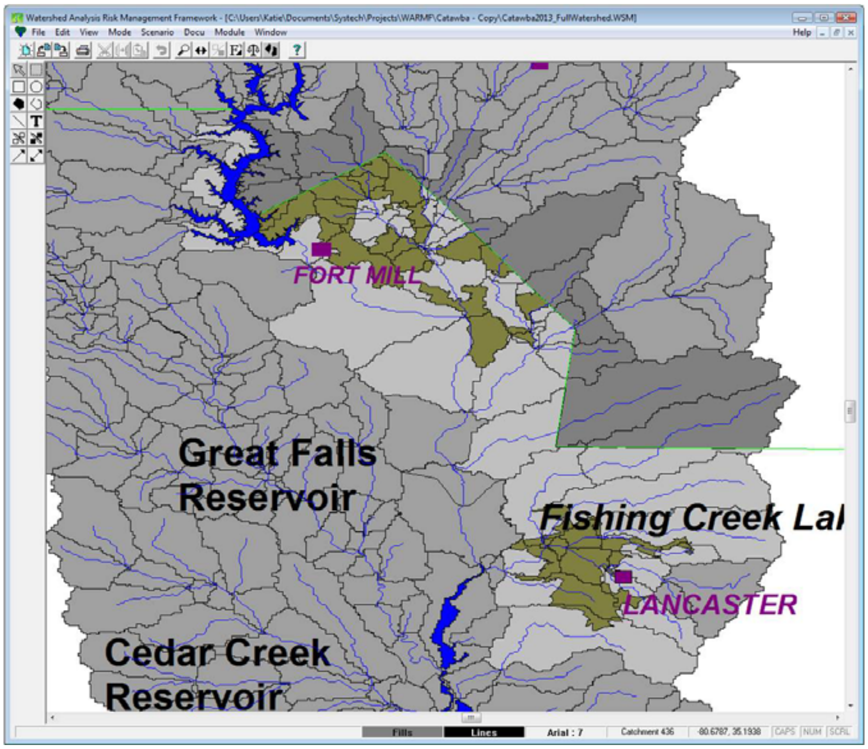

Figure 3 – WARMF catchments subdivided by state boundary (light gray in South Carolina, dark gray in North Carolina) and urban areas in South Carolina, east of the Catawba River (brown).

Due to the complexity and scale of the catchment subdivision, it was not feasible to do the subdivision efficiently using tools within the WARMF interface. Thus the subdivisions were performed externally in GIS and later imported back into WARMF. However as a result, catchment identifiers changed for all 126 newly subdivided catchments. Some reservoir and river identifiers also changed and will be described later. In Table 9, preexisting WARMF catchment identifiers are listed along with the identifiers of all corresponding new subdivided catchments (those which comprise the area of that preexisting catchment). Urban area catchments are indicated by bold type and catchments in North Carolina are indicated in parenthesis (all other are in South Carolina). The cases for which the original catchment was subdivided into more than two new catchments were due to multiple disconnected pieces (e.g. an urban area in the center was subdivided and left two or more non-urban pieces on opposite sides). Catchment input coefficients from previous catchments were entered for each corresponding subdivided catchment. With the exception of septic system population and catchment width, which were calculated proportionally based on area.

Table 9 – WARMF subdivided catchment IDs (bold = urban)

Previous WARMF ID	**New WARMF IDs**					
18	828					
21	**696**	722	755			
24	**725**	720				
26	**719**					
27	**759**	797				

28	**799**	**802**	726	760		
39	**728**	**731**	730	823		
62	**798**	704				
69	**829**	822	826			
87	**660**	736	820			
89	**505**	**744**	773			
95	**735**	771	830			
104	**670**	774	775	834	832 (NC)	
112	**831**	827				
157	**729**	727	668 (NC)			
201	**695**	691				
202	**756**	698				
210	**721**	**723**	800			
235	**700**	801				
246	**789**	671	791			
247	**790**	824	733 (NC)			
265	793					
301	**757**	**794**	778	792		
312	**788**	739	779			
323	**776**	**825**	750			
324	**787**	748				
326	**653**	**747**	**751**	743		
330	**753**	732 (NC)				
333	**758**					
340	**689**					
341	**737**	659 (NC)				
353	**763**	680 (NC)				
354	**781**	519				
355	782					
358	738	734 (NC)				
413	769	672 (NC)				
424	833	767 (NC)	770 (NC)			
426	**702**					
429	**715**	**772**	**796**	648	777	765 (NC)
437	676 (NC)					
450	**780**	**783**	546	749		
453	740	742 (NC)				
456	694 (NC)					
496	**803**	678	795	649 (NC)		
497	**682**	745 (NC)				
505	317	844 (NC)				
519	661	752 (NC)				

528	677	706 (NC)				
546	**761**	784				
746	768	766 (NC)				
1654	**287**	300	754	666 (NC)		

In addition to catchments, four reservoir segments were redelineated and reimported into WARMF to maintain consistent boundaries with neighboring subdivided catchments. The WARMF IDs of these four reservoir segments changed as well, as listed in Table 10.

Table 10 – New WARMF reservoir IDs

Segment Name	Previous WARMF ID	New WARMF ID
Lake Wylie Seg 9	1654	838
Lake Wylie Seg 8	317	786
Lake Wylie Seg 7	300	785
Lake Wylie Seg 6	287	764

River segments were subdivided in locations where a new catchment boundary crosses the river segment and the resulting upper and lower portions of the river could be reasonably assumed to receive water from different catchments. In cases where a new catchment boundary is parallel to a river, or is an isolated interior portion of a preexisting catchment (or another situation preventing validity of the above assumption), river segments were not subdivided. River subdivisions were performed using tools within the WARMF interface. Thus previous WARMF IDs were retained for one portion, while new IDs were assigned to the second portion. Table 11 lists the previous river segments subdivided, new IDs, new segment states, urban area contribution (if any, or "both" if both urban and non-urban contribute), and point sources.

Table 11 – Subdivided river segments and characteristics

Previous ID	Name	New IDs	State	Urban	Point Sources
21	Rum Creek	21	SC	no	
		839	SC	yes	
24	Cane Creek	24	SC	no	
		840	SC	yes	
210	Turkey Quarter Creek	210	SC	both	
		841	SC	yes	
429	Camp Creek	429	SC	no	
		842	SC	both	
496	Cane Creek	496	SC	no	SC0027383
		843	SC	yes	
528	Cane Creek	528	SC	no	
		845	NC	no	
746	Waxhaw Creek	746	SC	no	SC0041807
		846	NC	no	

413	Rone Branch	413	SC	no	
		847	NC	no	
437	Twelve Mile Creek	437	NC	no	NC0085359
		848	SC	no	
424	Twelve Mile Creek	424	SC	no	
		849	NC	no	
104	Tarkill Branch	104	SC	both	
		850	NC	no	
39	Sugar Cr near Road 36	39	SC	yes	SC0035055
		851	SC	no	
157	Six Mile Creek	157	SC	no	
		853	SC	yes	
		852	NC	no	NC0034541, NC0058882 NC0069094, NC0075884
247	Clems Branch	247	SC	both	
		854	NC	no	
301	Steele Creek	301	SC	both	
		855	SC	yes	
358	McAlpine Cr at S-29-64	358	SC	no	SC0030112
		863	NC	no	NC0024970
453	Little Sugar Cr at US 521	453	NC	no	
		864	SC	no	
492	Sugar Creek	492	SC	both	SC0031208, SC0022799 SC0022705
		865	NC	no	
330	UT Steele Creek	330	SC	yes	
		870	NC	no	
324	Jackson Branch	324	SC	no	
		871	SC	yes	SC0022985, SC0038113, SC0041483, SC0042510

Task 3: Update WARMF Land Use

To update landuse information in the Catawba River WARMF application, Systech downloaded gridded land cover data from the National Land Cover Database (NLCD) 2006 (Figure 4). The land cover data were overlaid with the updated catchment boundaries and percentages of each land cover classification contained within each catchment were calculated. The WARMF landuse classifications corresponding to the NLCD classifications in Figure 4 are listed in Table 12.

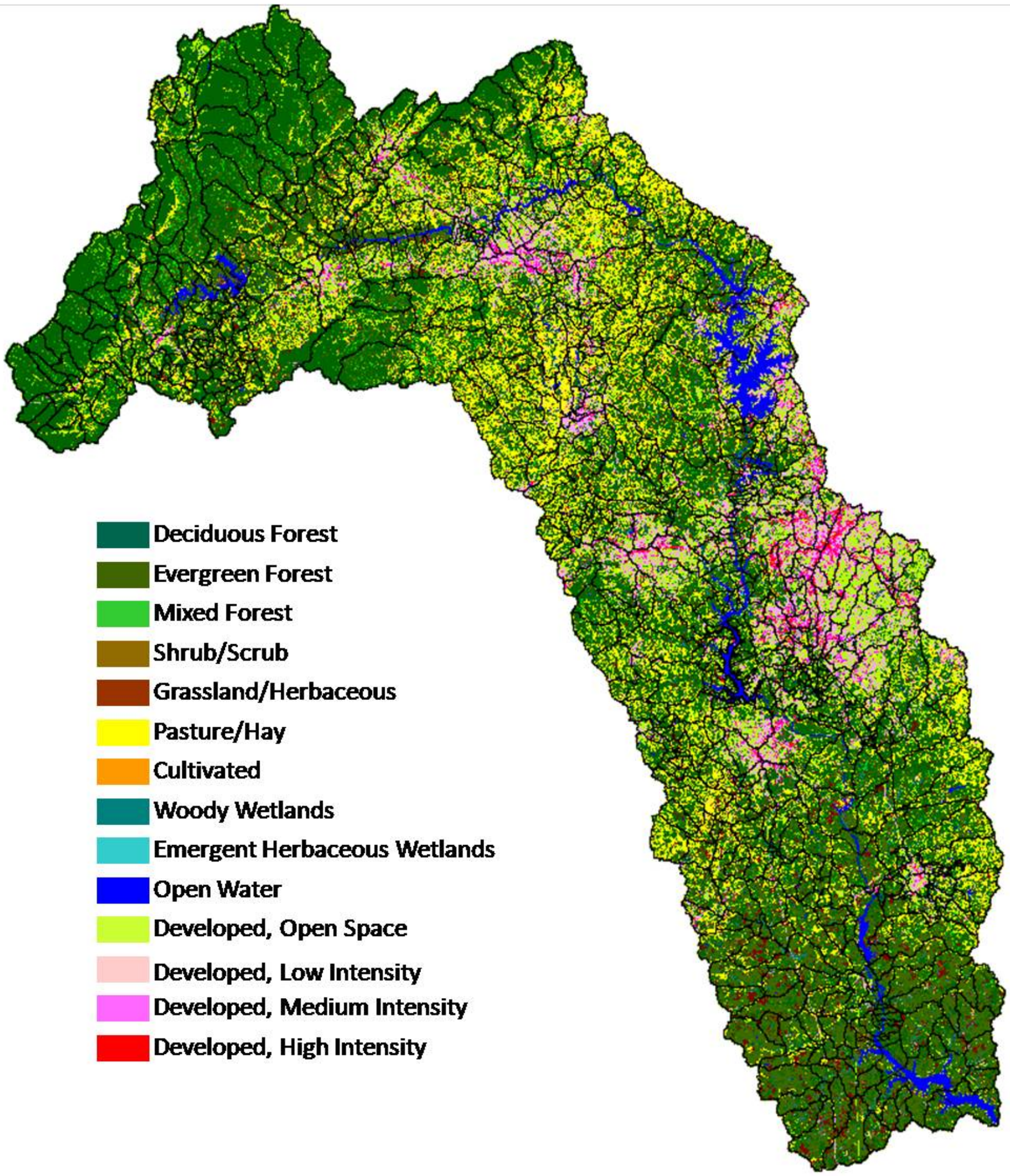

Figure 4 – Catawba River Watershed Landuse (NLCD 2006).

Table 12 – WARMF Landuse and Corresponding NLCD Landuse Classifications.

NLCD Classification	**WARMF Classification**	**% of Total Watershed Area**
Water	Water	2.6
Developed, Open Space	Recr.Grasses	10.7
Developed, Low Intensity	Low Int. Develop.	5.6
Developed, Medium Intensity	Medium Int. Develop.	1.7
Developed, High Intensity	High Int. Develop.	0.7

Barren Land	Barren	0.3
Deciduous Forest	Deciduous Forest	39.1
Evergreen Forest	Evergreen Forest	15.2
Mixed Forest	Mixed Forest	2.1
Shrub/Scrub	Shrub / Scrub	1.4
Grassland/Herbaceous	Grassland	4.3
Pasture/Hay	Pasture	15.6
Cultivated	Cultivated	0.2
Woody Wetlands	Wetlands	0.7
Emergent Herbaceous Wetlands	Herbaceous Wetland	0.01

Task 4: Model Validation

After the Task 1 through 3 model updates were completed, Systech performed test runs of the updated model to validate its function and performance. Two different versions of the model were set-up and test runs were performed separately for each. The first version, referred to here as the 'Full Watershed' version, includes the entire Catawba River Watershed in the simulation. The second version, referred to as 'Below Wylie', uses Lake Wylie as a boundary inflow point, thus any model elements (catchments, rivers and lakes) upstream of and including Lake Wylie are not included in the simulation. Instead, the outflow and water quality of Lake Wylie is added to the immediately downstream river segment as a point source. The 'Below Wylie' version corresponds to the set-up of the model being used prior to this model update (the 'All Recommended Changes' scenario). Thus, only model results from the 'Below Wylie' version can be directly compared to the previous calibration in order to validate the updated model.

Test runs of both versions included a simulation from 1999-2005 to compare the calibration to the previous version, and a simulation from 2005-2012 to verify continued functionality in the extended period. Simulations of flow were assessed by visual inspection for four gauge locations – 2 on the mainstem Catawba River, 1 on Rocky Creek and 1 on Sugar Creek. Simulations of total nitrogen, total phosphorus, and total phytoplankton were assessed by visual inspection and calculated statistics for the four South Carolina reservoirs downstream of Lake Wylie (Fishing Creek Lake, Great Falls Reservoir, Cedar Creek Reservoir, and Lake Wateree).

To validate the updated model, 1999-2005 simulations of the 'Below Wylie' version were compared to the previous ('All Recommended Changes') simulations for the same time period. If the calibration (i.e. agreement with observed) of the 'Below Wylie' simulations are roughly as good or better than the previous version, the updated model is considered validated for this period (i.e., model updates did not reduce the quality of performance of the model as compared to the pre-update state). Simulations from the 'Full Watershed' version are also compared for the same period to assess how well this version performs as compared to the 'Below Wylie' version. Simulation performance of both versions from the extended period (2005-2012) are then compared to the same version's earlier period to check the model's functionality and performance in the extended period and determined if database updates introduced any errors into the simulations.

Flow

Catawba River above Sugar Creek (River Segment 87)

Simulation results of flow in the Catawba River above Sugar Creek (segment 87) are shown in Figure 5. Results from the 'Below Wylie' version for the full period closely match the observed though peaks in 2003 and 2004 are slightly under simulated. The 'Full Watershed' version matches the overall trend of the observed, though contains oscillating error (i.e., above and below the observed) due to adjustments to reservoir outflow made by the model to correct for error in simulated reservoir elevation.

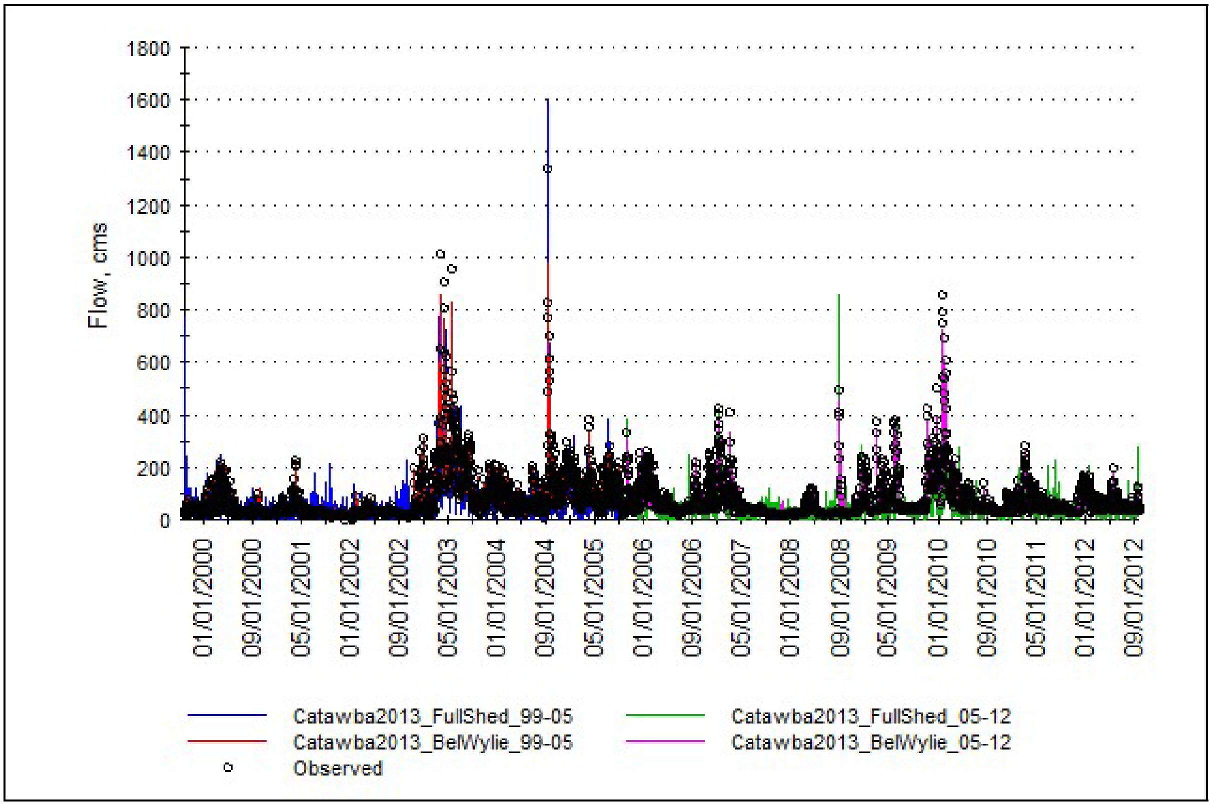

Figure 5 – Catawba River above Sugar Creek (segment 87) updated flow simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from hydrology file CATBELWY.ORH.

Catawba River (River Segment 61)

Simulation results of flow in the Catawba River (segment 61) are shown in Figure 6. Results for both versions are similar to those of segment 87, with larger under simulation of peaks. The under simulation worsens here due to under simulation of tributaries joining the Catawba above this point (e.g. Sugar Creek).

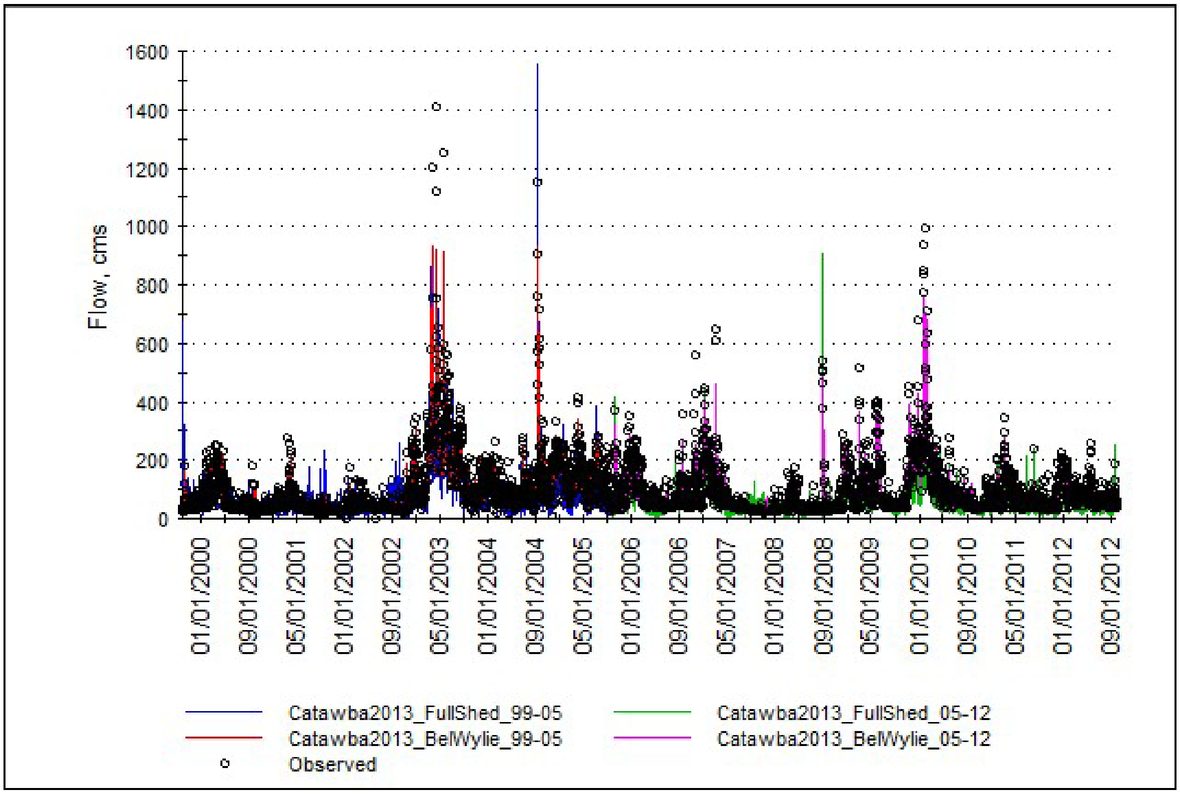

Figure 6 – Catawba River (segment 61) updated flow simulation results from 1999-2012 for ‘Full Watershed’ version (blue, green) and ‘Below Wylie’ version (red, pink). Observed data from hydrology file CATABVFC.ORH.

Sugar Creek near Fort Mill (River Segment 246)

Simulation results of flow in Sugar Creek near Fort Mill (segment 246) are shown in Figure 7. The results of the two versions are identical here since it is a tributary to the Catawba River and is not downstream of Lake Wylie. Significant under simulation is apparent in the period with observed data (2006-2012).

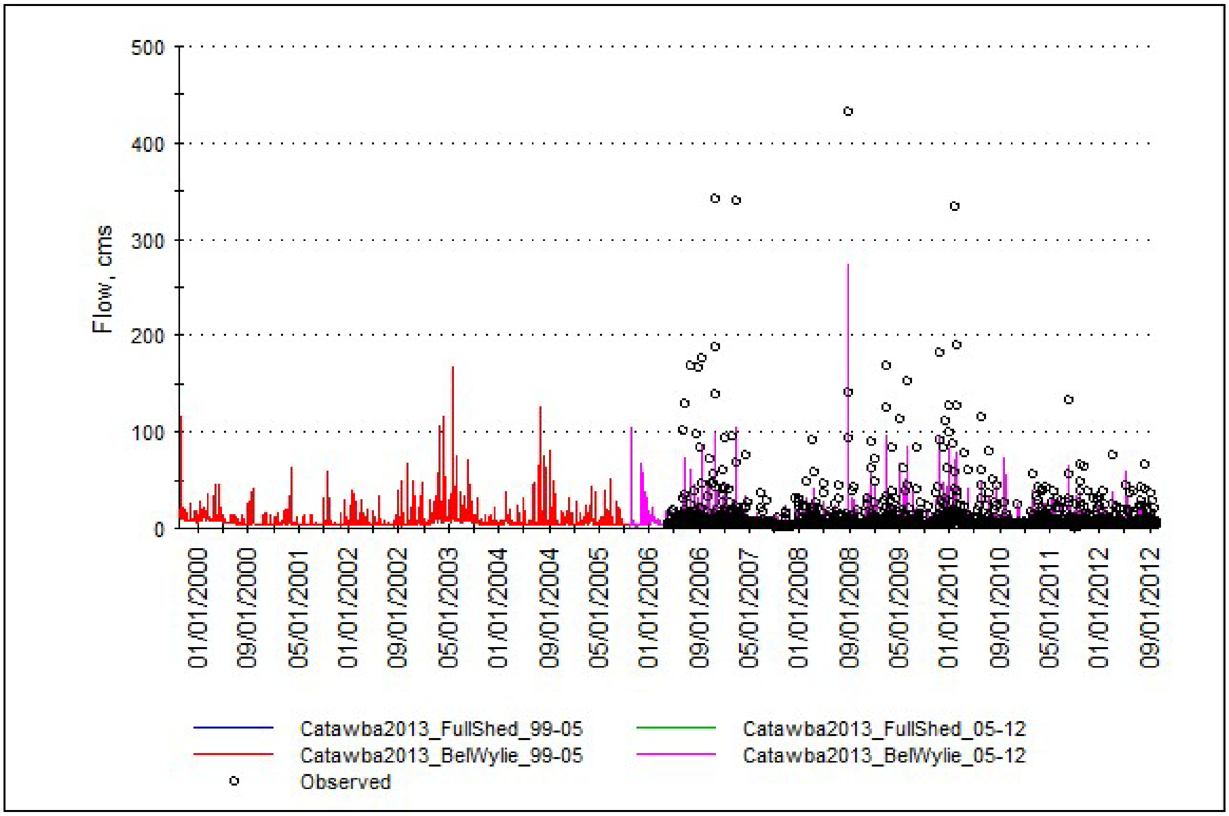

Figure 7 – Sugar Creek near Fort Mill (segment 246) updated flow simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from hydrology file sugar4.ORH.

Rocky Creek (River Segment 551)

Simulation results of flow in Rocky Creek (segment 551) are shown in Figure 8. As for Sugar Creek, results are identical between the 'Full Watershed' and 'Below Wylie' versions since it is a tributary to the Catawba River. Under simulation of flow is evident at this location as it was for Sugar Creek, suggesting that some systematic hydrology recalibration is needed.

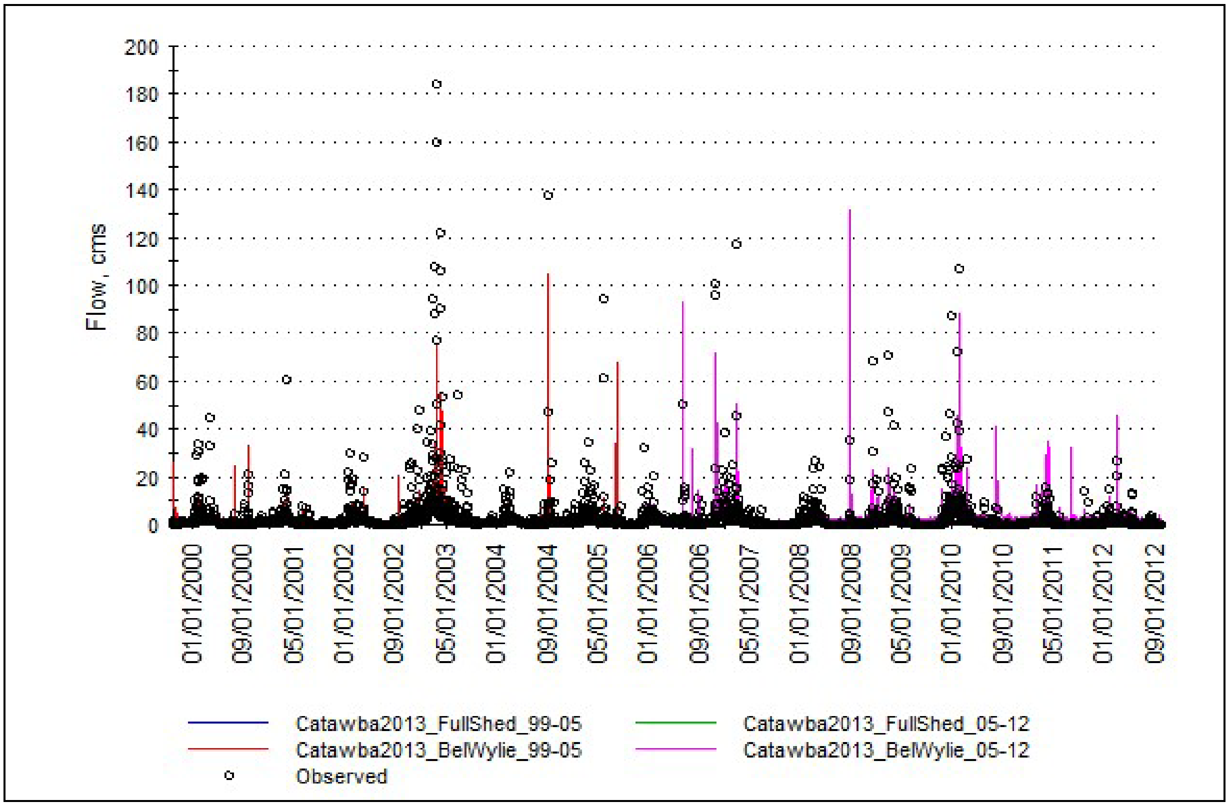

Figure 8 – Rocky Creek (segment 551) updated flow simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from hydrology file Rocky1.ORH.

Total Nitrogen

Fishing Creek Lake (Reservoir Segment 1562)

Simulation results of total nitrogen in Fishing Creek Lake are shown in Figures 9 and 10. Figure 9 compares the previous simulation (blue) to the updated 'Below Wylie' version (red) and the 'Full Watershed' version (green). The previous and 'Below Wylie' simulations are nearly identical (with the exception of the previously mentioned outlier in 2002 that was removed from the boundary inflow point source). Thus model updates did not adversely affect model performance. In comparing the 'Full Watershed' version results, higher concentrations in winter months are apparent in some years, stemming from differences between simulated concentrations in Lake Wylie (and above) and prescribed concentrations in the Lake Wylie point source. In Figure 10, the previous simulation is removed and updated simulation results are extended to 2012 (blue and green for 'Full Watershed', red and pink for 'Below Wylie'). The overall match between simulated and observed remains reasonable in both versions.

In addition to visual analysis, simulations were validated by comparing calibration statistics. Table 13 lists the total nitrogen calibration statistics for Fishing Creek Lake for all simulations. The number of compare points is number of observed data points available for comparison within the simulation period of the run. Relative error is the average of all errors at each comparison point and is a measure of overall model accuracy (i.e., accuracy of the mean value) since over- and under-predictions cancel each other out. Absolute error is the average of the absolute value of all errors at each comparison point and is a measure of model precision. R-squared is the square of the correlation coefficient between simulated and observed at comparison points. It is a measure of the model's ability to predict trends in the data, but is often not very useful (i.e. can be very low) when there is a large amount of scatter in observed data.

The statistics corroborate the visual assessment that 'Below Wylie' updated version from 1999-2005 closely matches the previous version of the model (prior to updates), while the 'Full Watershed' version has slightly lower error and higher correlation. For the 2005-2012 simulations, relative error in both versions is reduced and correlation is higher than the same version's 1999-2005 simulation. Thus the updated model version both validates and improves on the previous model calibration of total nitrogen in Fishing Creek Lake.

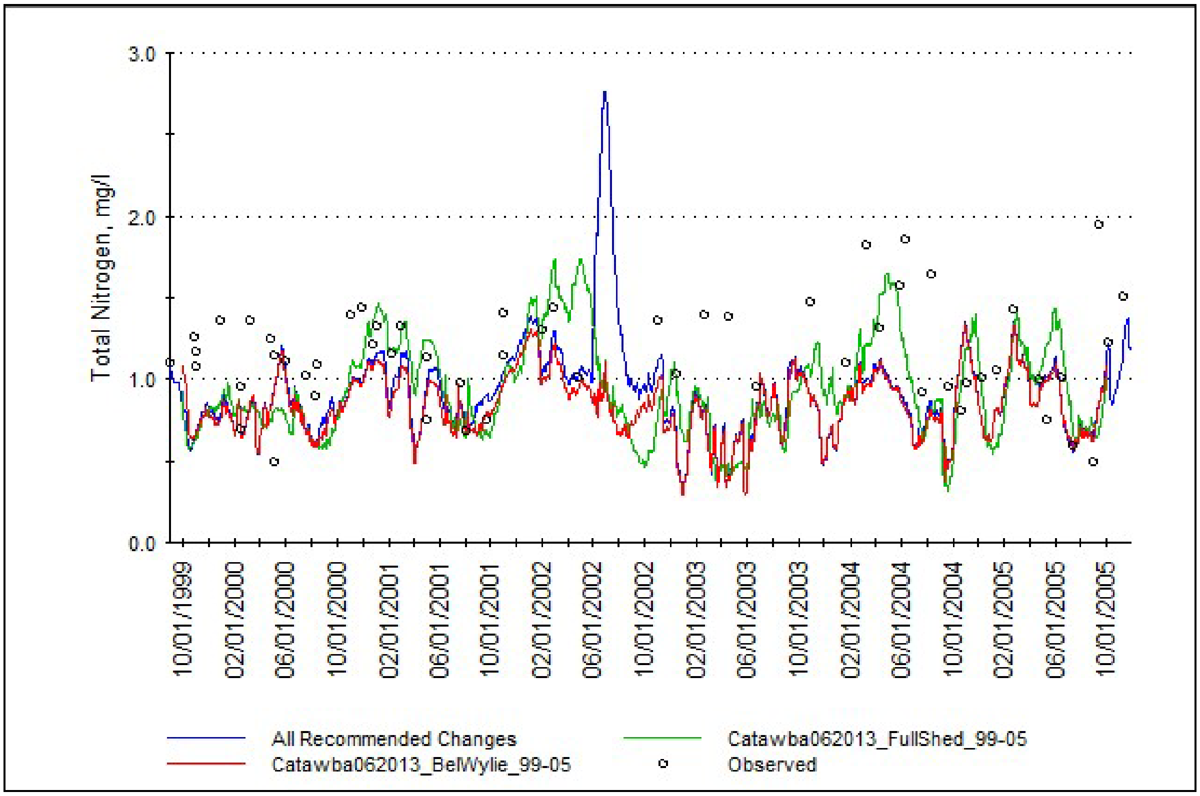

Figure 9 – Fishing Creek Lake TN calibration comparison – previous simulation (blue), updated 'Below Wylie' simulation (red), and updated 'Full Watershed' simulation (green). Observed data from water quality file fishcr.olc.

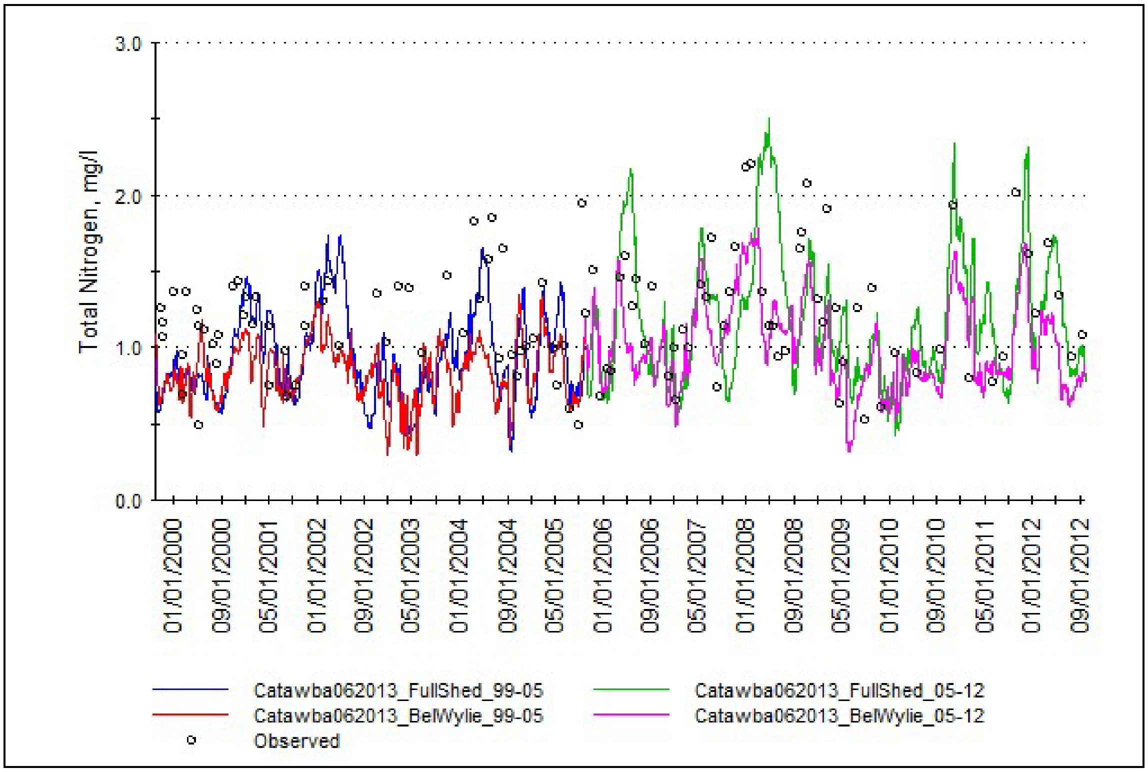

Figure 10 – Fishing Creek Lake TN updated simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from water quality file fishcr.olc.

Table 13 – Total nitrogen calibration statistics for Fishing Creek Lake

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	55	52	52	57	57
Relative Error	-0.287	-0.328	-0.222	-0.225	-0.0247
Absolute Error	0.342	0.369	0.343	0.295	0.4
R squared	0.0647	0.065	0.0684	0.567	0.134

Great Falls Reservoir (Reservoir Segment 1563)

Simulation results of total nitrogen in Great Falls Reservoir are shown in Figures 11 and 12. Like in Fishing Creek, the 1999-2005 'Below Wylie' simulation (red) in Figure 11 closely matches the previous simulation (blue). Calibration statistics (Table 14) support the validation of the updated model as compared to the previous version. The 'Full Watershed' simulation again has higher winter concentrations (most years), lower overall error and higher correlation. Also again evident both in plots and statistics is the fact that the model performed roughly as well or better in the extended period (2005-2012) than the previous period (1999-2005). The 'Below Wylie' version in particular has significantly higher correlation with observations in the extended period (0.0417 versus 0.644). Thus the updated model in Great Falls Reservoir both validates and improves upon the previous model calibration of total nitrogen.

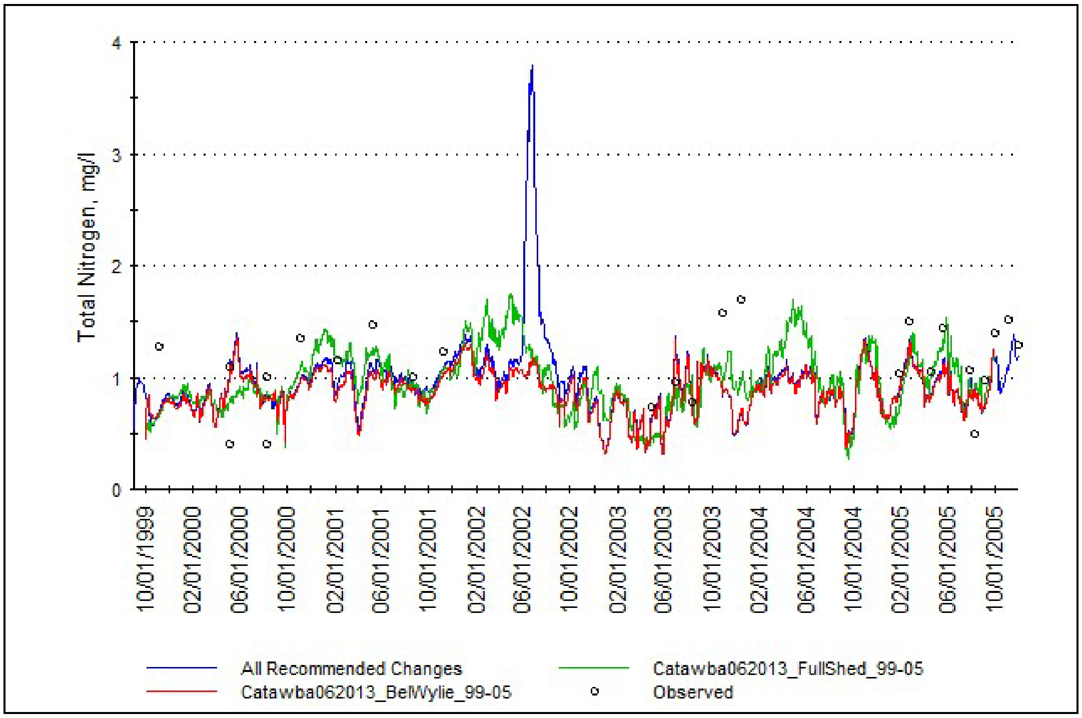

Figure 11 – Great Falls Reservoir TN calibration comparison – previous simulation (blue), updated 'Below Wylie' simulation (red), and updated 'Full Watershed' simulation (green). Observed data from water quality file GRFALL.OLC.

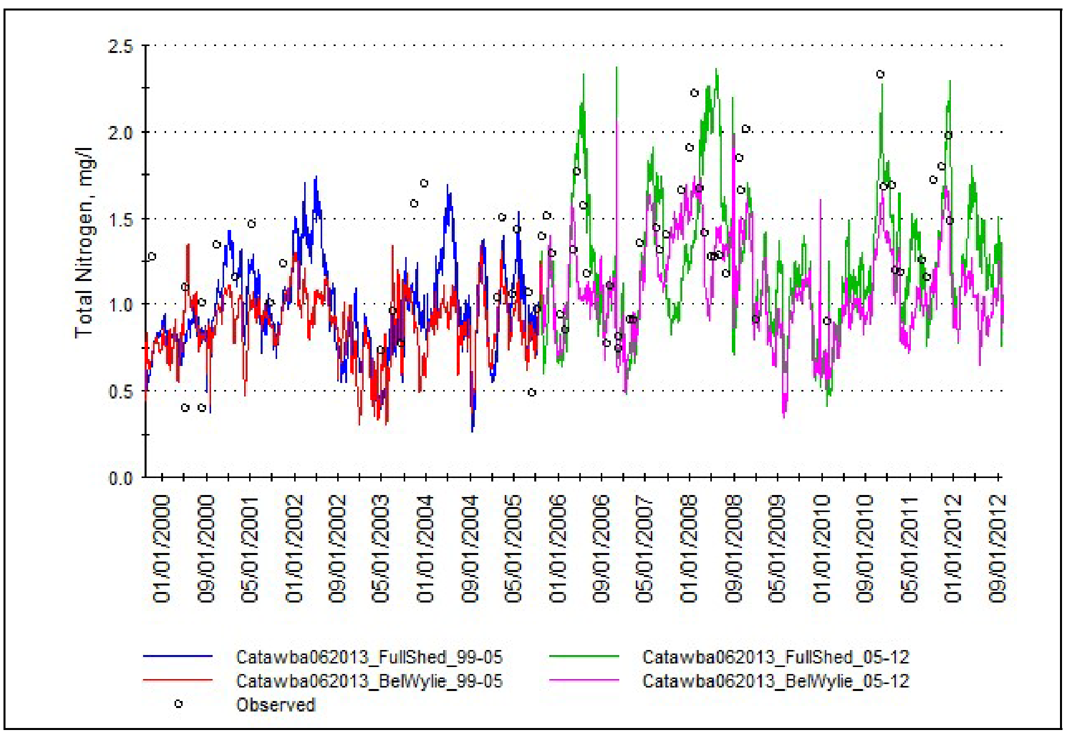

Figure 12 – Great Falls Reservoir TN updated simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from water quality file GRFALL.OLC.

Table 14 – Total nitrogen calibration statistics for Great Falls Reservoir

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	22	20	20	44	44
Relative Error	-0.184	-0.221	-0.166	-0.23	-0.0462
Absolute Error	0.346	0.356	0.267	0.263	0.356
R squared	0.0721	0.0436	0.271	0.632	0.258

Cedar Creek Reservoir (Reservoir Segment 1567)

Simulation results of total nitrogen in Cedar Creek Reservoir are shown in Figures 13-14 and calibration statistics are shown in Table 15. Results and comparisons are very similar to those in Great Falls Reservoir. The "Below Wylie' simulation from 1999-2005 is nearly identical to the previous simulation, thus validating the calibration of the updated model. In the extended period (2005-2012) relative error is slightly reduced in both versions and correlation increases significantly.

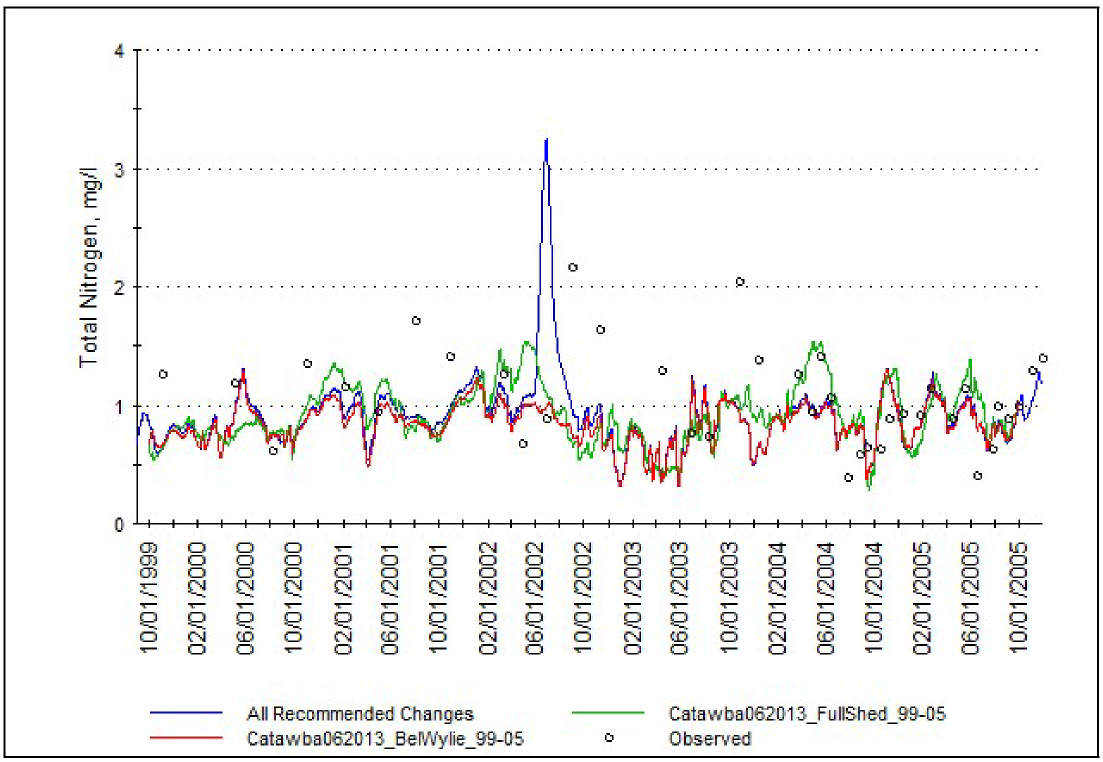

Figure 13 – Cedar Creek Reservoir TN calibration comparison – previous simulation (blue), updated 'Below Wylie' simulation (red), and updated 'Full Watershed' simulation (green). Observed data from water quality file CedarCr.OLC.

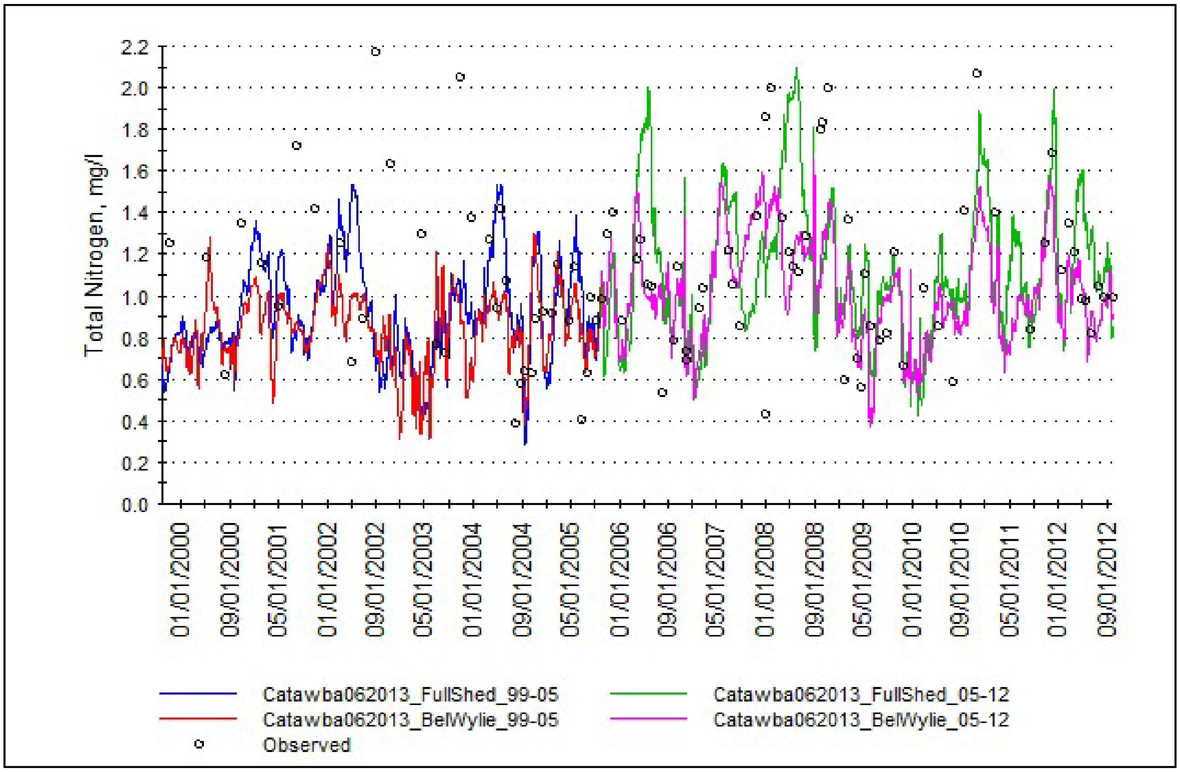

Figure 14 – Cedar Creek TN updated simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from water quality file CedarCr.OLC.

Table 15 – Total nitrogen calibration statistics for Cedar Creek Reservoir

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	38	36	36	58	58
Relative Error	-0.114	-0.201	-0.114	-0.0966	0.0471
Absolute Error	0.398	0.37	0.378	0.219	0.34
R squared	0.000262	0.00143	0.000217	0.44	0.131

Lake Wateree (Reservoir Segment 2292)

Simulation results of total nitrogen in Lake Wateree are shown in Figures 15-16 and calibration statistics are shown in Table 16. As in the other reservoirs, previous and updated simulations from 1999-2005 are very similar. As with the reservoirs upstream, simulations in the extended (2005-2012) period are somewhat better than simulations in the prior (1999-2005) period in the 'Below Wylie' version. In this case however, there is greater agreement between the 'Below Wylie' and 'Full Watershed' versions in the extended period at Lake Wateree than there was in the other reservoirs. This can likely be attributed to the fact that it is further downstream and the effects of Lake Wylie outflow characteristics are lessened. These plots and statistics validate the performance of the updated model for total nitrogen at Lake Wateree.

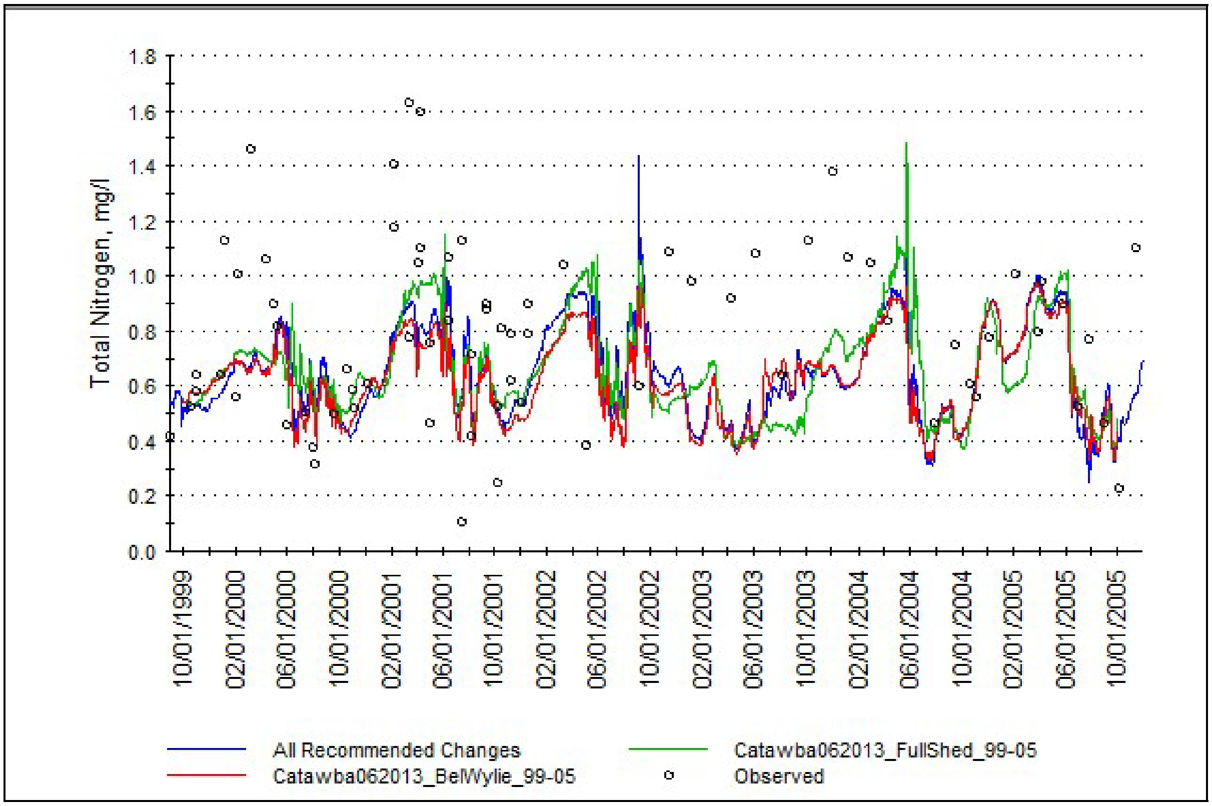

Figure 15 – Lake Wateree TN calibration comparison – previous simulation (blue), updated 'Below Wylie' simulation (red), and updated 'Full Watershed' simulation (green). Observed data from water quality file WATEREE3.OLC.

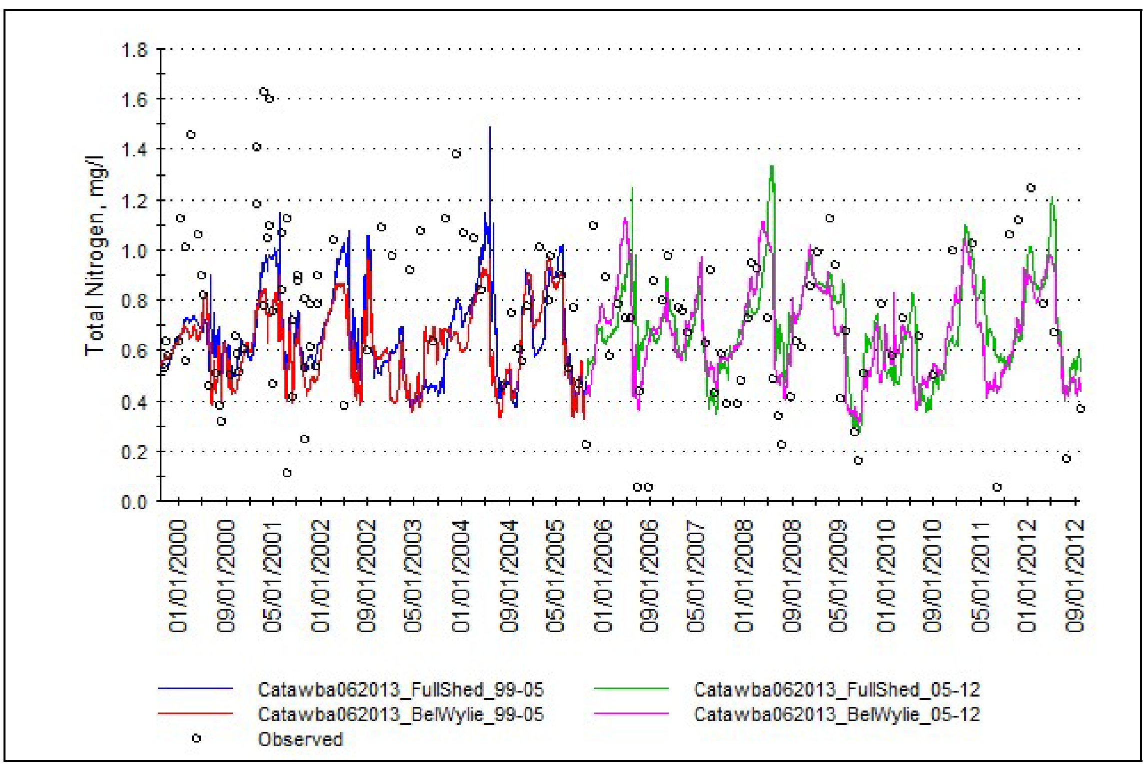

Figure 16 – Lake Wateree TN updated simulation results from 1999-2012 for ‘Full Watershed’ version (blue, green) and ‘Below Wylie’ version (red, pink). Observed data from water quality file WATEREE3.OLC.

Table 16 – Total nitrogen calibration statistics for Lake Wateree

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	62	59	59	57	57
Relative Error	-0.15	-0.169	-0.13	0.0107	0.0314
Absolute Error	0.266	0.252	0.244	0.199	0.223
R squared	0.0883	0.125	0.156	0.33	0.152

Total Phosphorus

Fishing Creek Lake (Reservoir Segment 1562)

Simulation results of total phosphorus in Fishing Creek Lake are shown in Figures 17 and 18. As for total nitrogen, the previous and updated ‘Below Wylie’ simulations of total phosphorus (blue and red lines) in Figure 17 are very similar, though there are a few more noticeable differences than were seen in total nitrogen simulations (e.g. 8/2000). The differences slightly improved (reduced) the overall error and slightly decreased correlation, though differences are minor. However there is significantly larger error in the ‘Full Watershed’ simulation for this case propagating from over simulation of total phosphorus at Lake Wylie (and/or upstream). In addition, the error is slightly higher and correlation is significantly lower in the extended period compared to 1999-2005 for both versions. Thus improvements in the total phosphorus calibration would be beneficial for both versions. Recommendations will be discussed later in the final section of this report.

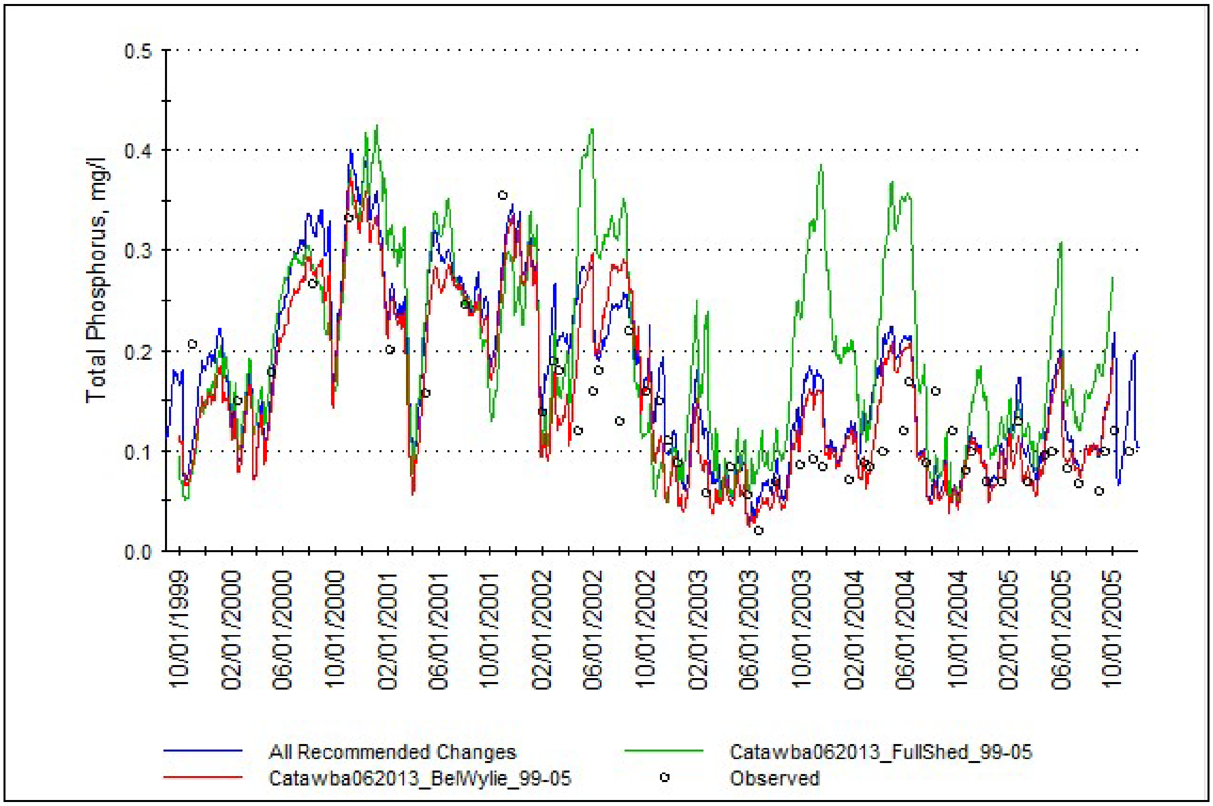

Figure 17 – Fishing Creek Lake TP calibration comparison – previous simulation (blue), updated 'Below Wylie' simulation (red), and updated 'Full Watershed' simulation (green). Observed data from water quality file fishcr.olc.

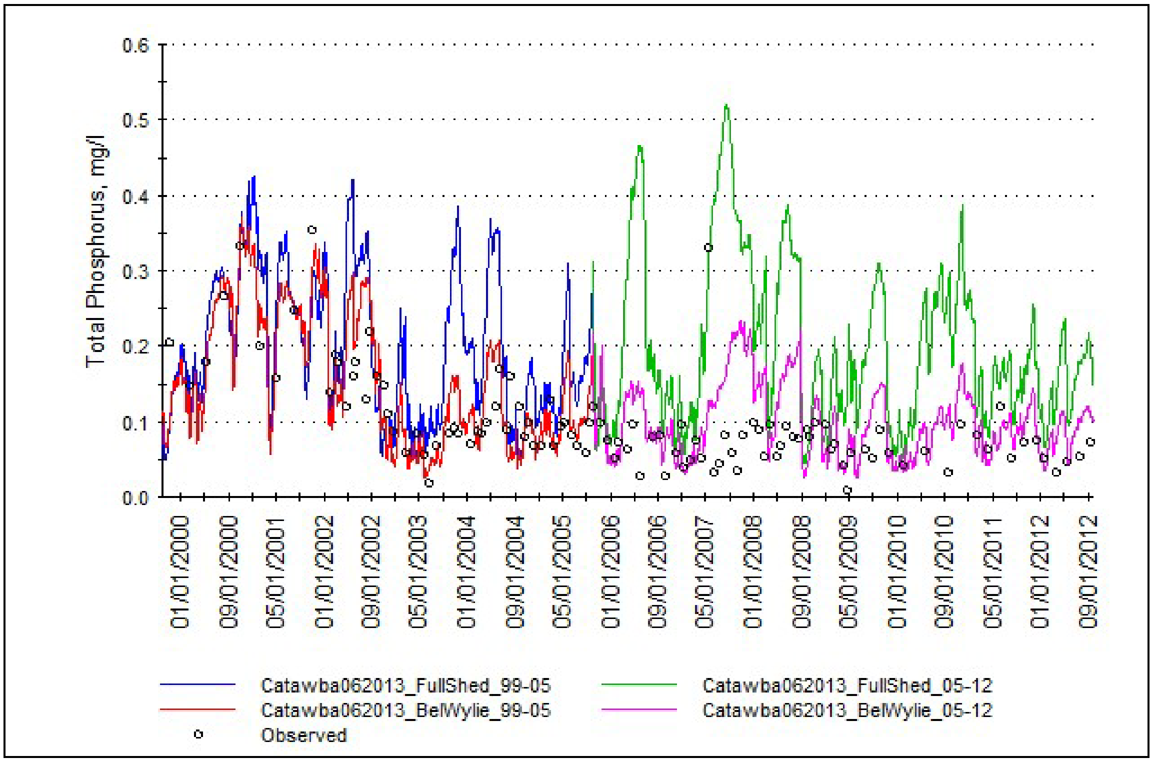

Figure 18 – Fishing Creek Lake TP updated simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from water quality file fishcr.olc.

Table 17 – Total phosphorus calibration statistics for Fishing Creek Lake

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	52	50	50	61	61
Relative Error	0.0285	0.0079	0.0597	0.0313	0.136
Absolute Error	0.0467	0.0399	0.0868	0.0515	0.139
R squared	0.607	0.576	0.158	0.0349	0.00938

Great Falls Reservoir (Reservoir Segment 1563)

Simulation results of total phosphorus in Great Falls Reservoir are shown in Figures 19 and 20 and calibration statistics are shown in Table 18. In this case the updated model ('Below Wylie' version) performs slightly better than the previous version (red compared to blue in Figure 19) for the 1999-2005 simulation period in terms of both error and correlation. However errors in the extended period for both versions are significant as compared to observed concentrations. In addition, overall calibration error from 1999-2005 is greater for all simulations than for the same period in Fishing Creek Lake. Thus, though the updated model is validated for total phosphorus in terms of maintaining performance of the pre-project model, simulation improvements of total phosphorus in Great Falls Reservoir for both updated model versions are recommended and will be discussed later.

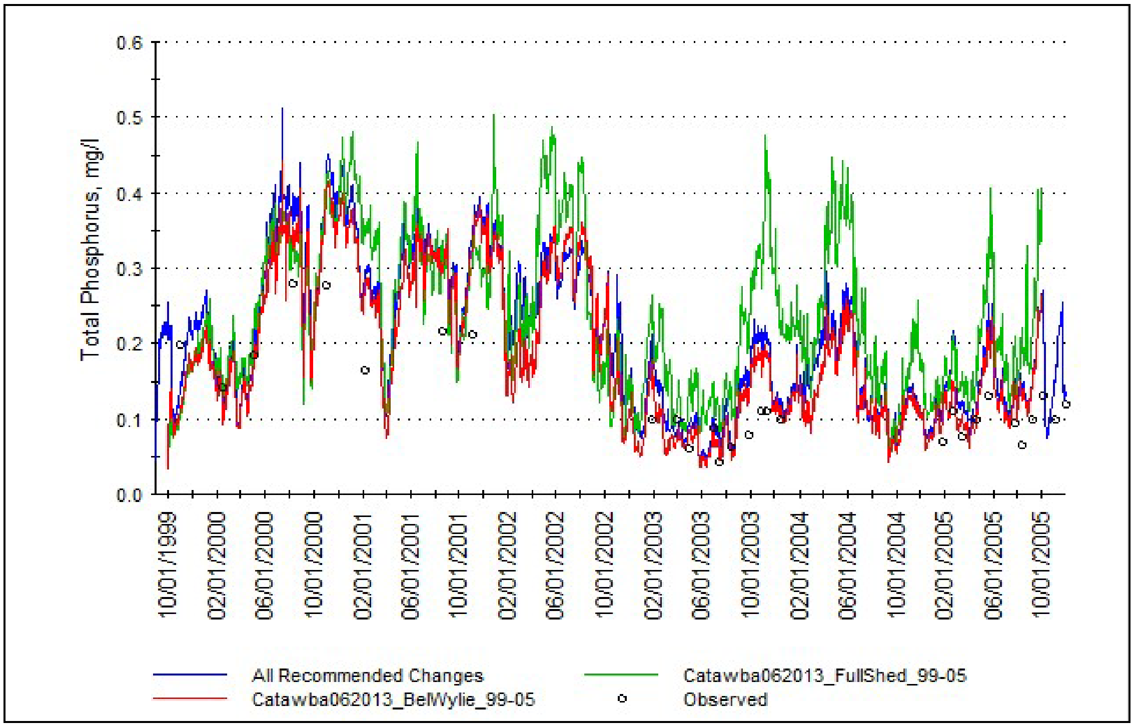

Figure 19 – Great Falls Reservoir TP calibration comparison – previous simulation (blue), updated ‘Below Wylie’ simulation (red), and updated ‘Full Watershed’ simulation (green). Observed data from water quality file GRFALL.OLC.

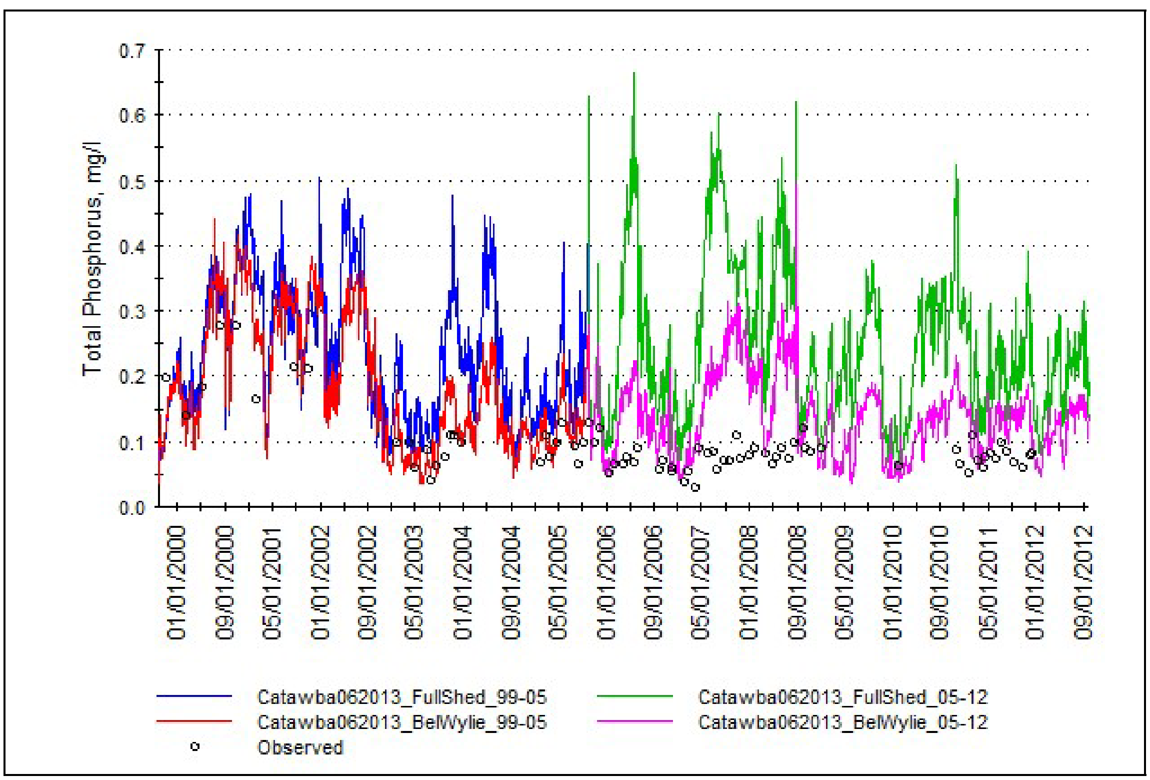

Figure 20 – Great Falls Reservoir TP updated simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from water quality file GRFALL.OLC.

Table 18 – Total phosphorus calibration statistics for Great Falls Reservoir

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	28	26	26	52	52
Relative Error	0.0548	0.0354	0.0968	0.0684	0.189
Absolute Error	0.0635	0.0501	0.104	0.0731	0.19
R squared	0.707	0.729	0.367	0.1	0.0367

Cedar Creek Reservoir (Reservoir Segment 1567)

Simulation results of total phosphorus in Cedar Creek Reservoir are shown in Figures 21 and 22 and calibration statistics are shown in Table 19. The situation is the same as that of Great Falls Reservoir. The updated model can be validated in terms of comparison with the previous simulation; however significant error is present in both versions, particularly from 2005-2012. Improvements to the model simulations of total phosphorus in Cedar Creek reservoir are recommended.

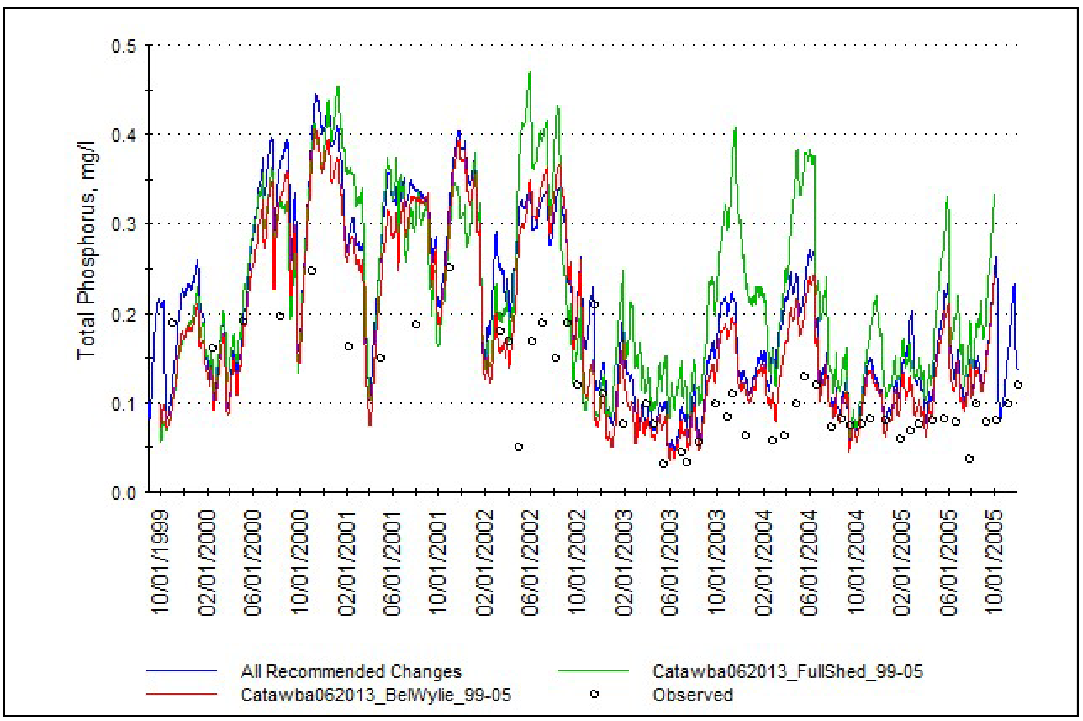

Figure 21 – Cedar Creek Reservoir TP calibration comparison – previous simulation (blue), updated 'Below Wylie' simulation (red), and updated 'Full Watershed' simulation (green). Observed data from water quality file CedarCr.OLC.

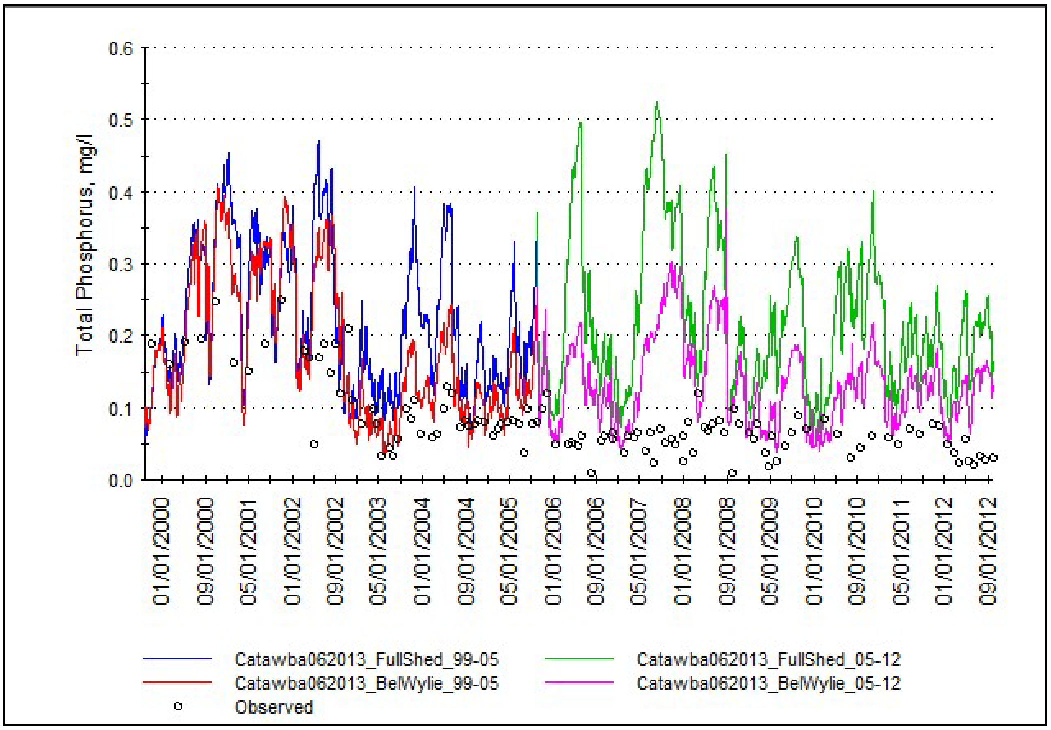

Figure 22 – Cedar Creek Reservoir TP updated simulation results from 1999-2012 for 'Full Watershed' version (blue, green) and 'Below Wylie' version (red, pink). Observed data from water quality file CedarCr.OLC.

Table 19 – Total phosphorus calibration statistics for Cedar Creek Reservoir

	Previous Version	**Below Wylie 1999-2005**	**Full Watershed 1999-2005**	**Below Wylie 2005-2012**	**Full Watershed 2005-2012**
# Compare Pts	52	50	50	68	68
Relative Error	0.073	0.0516	0.0998	0.0814	0.174
Absolute Error	0.0802	0.0668	0.108	0.0842	0.174
R squared	0.453	0.44	0.171	0.021	0.000253

Lake Wateree (Reservoir Segment 2292)

Simulation results of total phosphorus in Lake Wateree are shown in Figures 23 and 24 and calibration statistics are shown in Table 20. In Figure 23, differences between the previous (blue) and updated (red) 'Below Wylie' simulations appear larger than they were in other reservoirs. However this is somewhat due to the scale of the plot. Calibration statistics (Table 20), demonstrate that the updated version is very similar, thus validating the updated simulations at Lake Wateree. Overall the total phosphorus simulations for both model versions are better at Lake Wateree than at the other reservoirs. Calibration adjustments to improve simulation at upstream reservoirs should be done with care so as to not adversely impact the calibration at Lake Wateree.

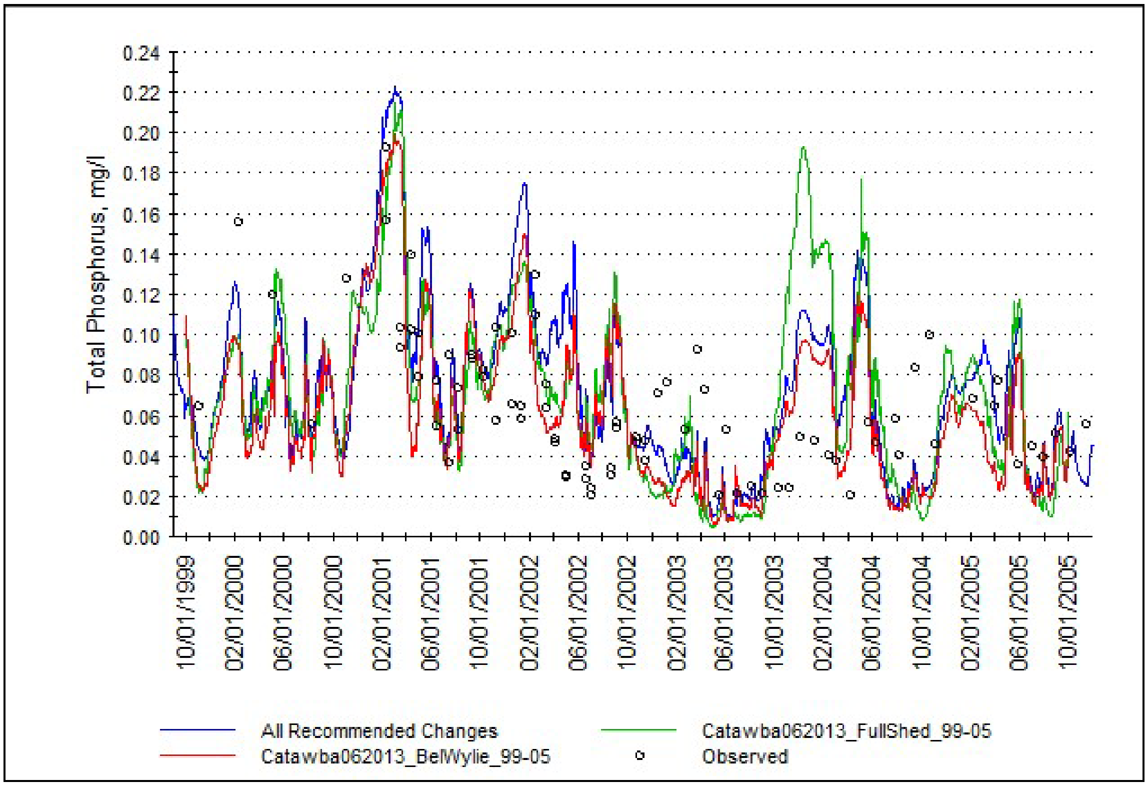

Figure 23 – Lake Wateree TP calibration comparison – previous simulation (blue), updated 'Below Wylie' simulation (red), and updated 'Full Watershed' simulation (green). Observed data from water quality file WATEREE3.OLC.

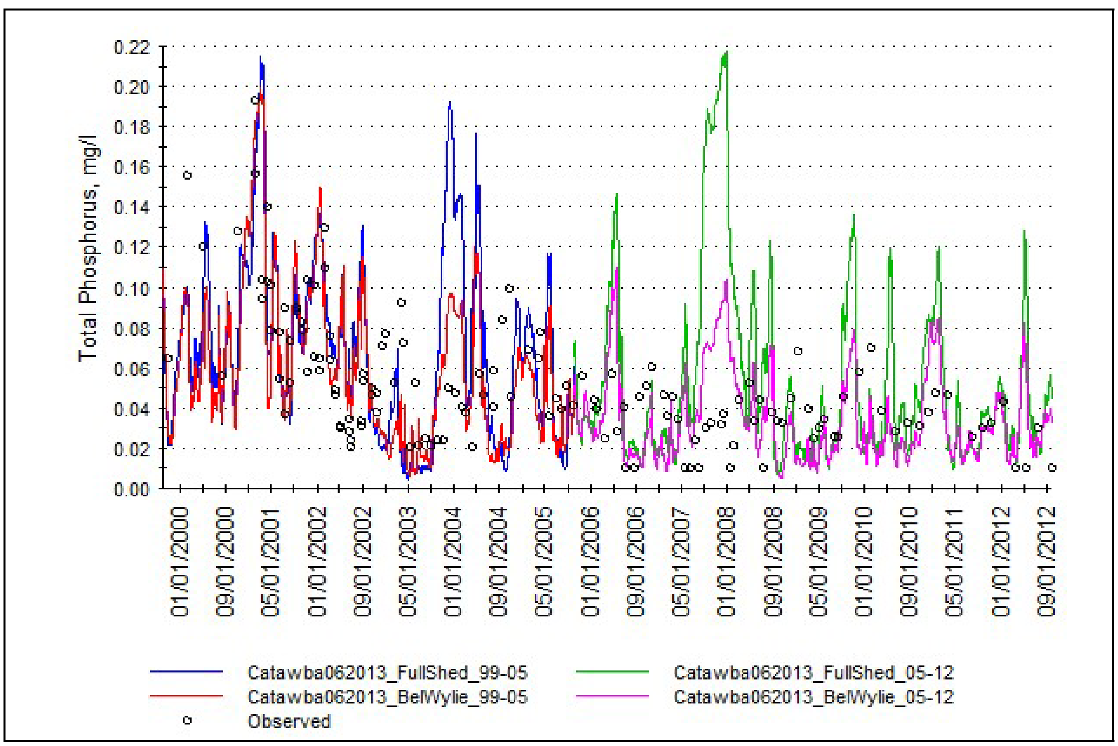

Figure 24 – Lake Wateree TP updated simulation results from 1999-2012 for ‘Full Watershed’ version (blue, green) and ‘Below Wylie’ version (red, pink). Observed data from water quality file WATEREE3.OLC.

Table 20 – Total phosphorus calibration statistics for Lake Wateree

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	60	58	58	61	61
Relative Error	0.00797	-0.00462	0.00424	0.000891	0.0218
Absolute Error	0.0338	0.0328	0.0405	0.0233	0.0379
R squared	0.162	0.156	0.0616	0.00219	0.0122

Total Phytoplankton

Fishing Creek Lake (Reservoir Segment 1562)

Simulation results of total phytoplankton (chlorophyll a) in Fishing Creek Lake are shown in Figures 25 and 26 and calibration statistics are shown in Table 21. Differences are relatively minor between the pre-project total phytoplankton simulation (blue) and updated ‘Below Wylie’ simulation (red). WARMF predicts phytoplankton peaks higher than measured data in early summers of 2006-2008, but statistics show that the model performance from 2005-2012 was roughly comparable to the 1999-2005 time period and the previous version simulation. (Note that a suspected outlier on 8/2/2001 was removed from these plots to avoid bias in the calculation of statistics). Additional calibration is not recommended.

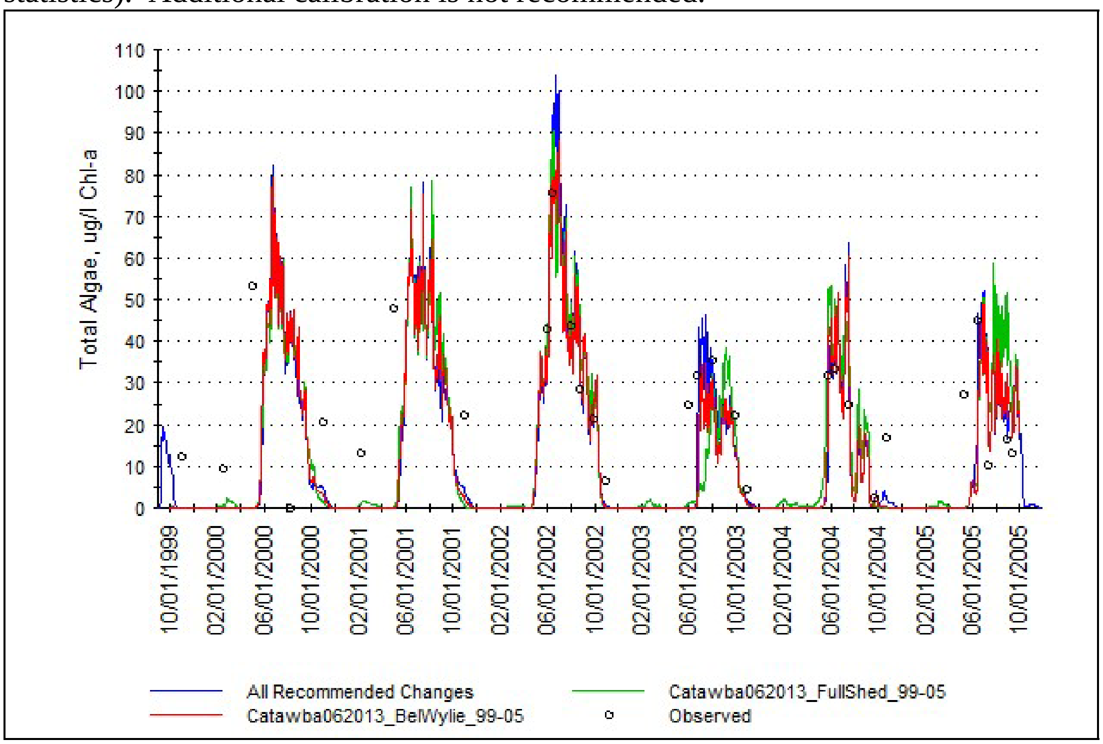

Figure 25 – Fishing Creek Lake total phytoplankton previous (blue) and updated (red) ‘Below Wylie’ calibration comparison. Observed data from water quality file fishcr.olc.

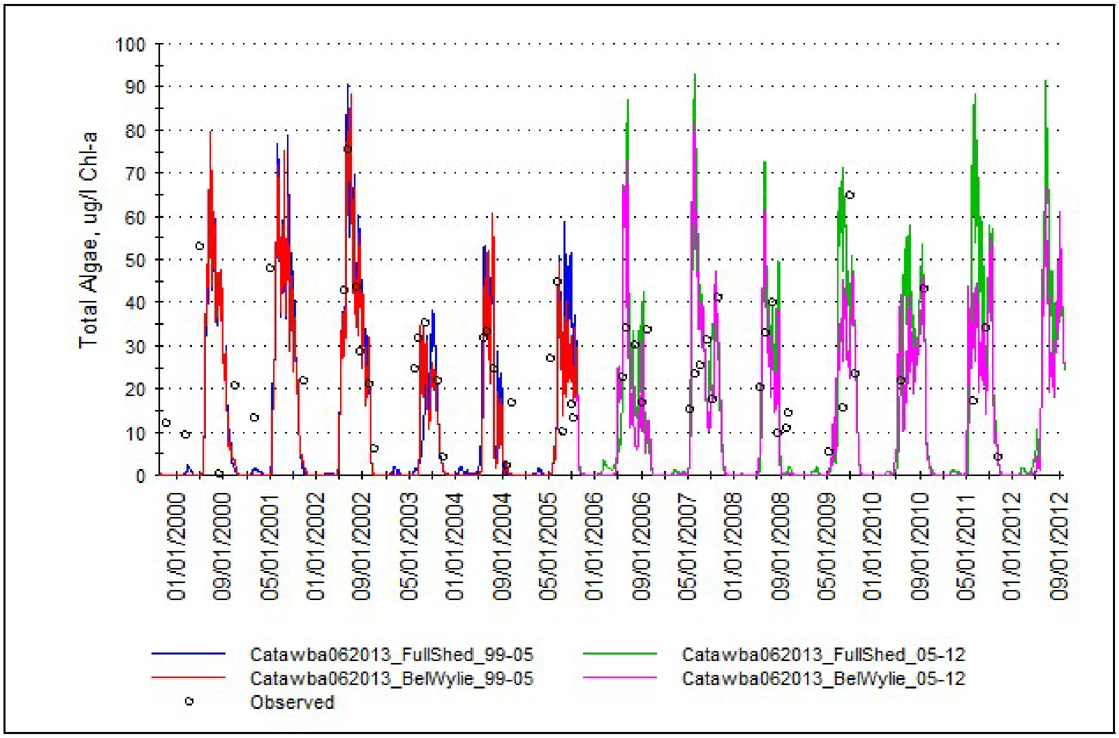

Figure 26 – Fishing Creek Lake total phytoplankton updated simulation results from 1999-2012. Observed data from water quality file fishcr.olc.

Table 21 – Total phytoplankton calibration statistics for Fishing Creek Lake

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	29	29	29	26	26
Relative Error	-6.988	-8.128	-5.971	1.433	6.066
Absolute Error	14.13	15.65	17.15	14.8	18.2
R squared	0.261	0.208	0.19	0.15	0.126

Great Falls Reservoir (Reservoir Segment 1563)

Simulation results of total phytoplankton in Great Falls Reservoir are shown in Figures 27 and 28 and calibration statistics are shown in Table 22. Visual inspection and calibration statistics reveal that errors are slightly lower and correlation is slightly higher in the ‘Below Wylie’ version as compared to the previous version, validating that the updated model does not introduce new errors as compared to the previous version. However simulated phytoplankton appears to be too high most summers, even more so than in Fishing Creek Reservoir. The statistical performance is likely adversely affected by the fact that fewer observed data points are available, and the majority of those that are available occur in the summer when the model over predicts.

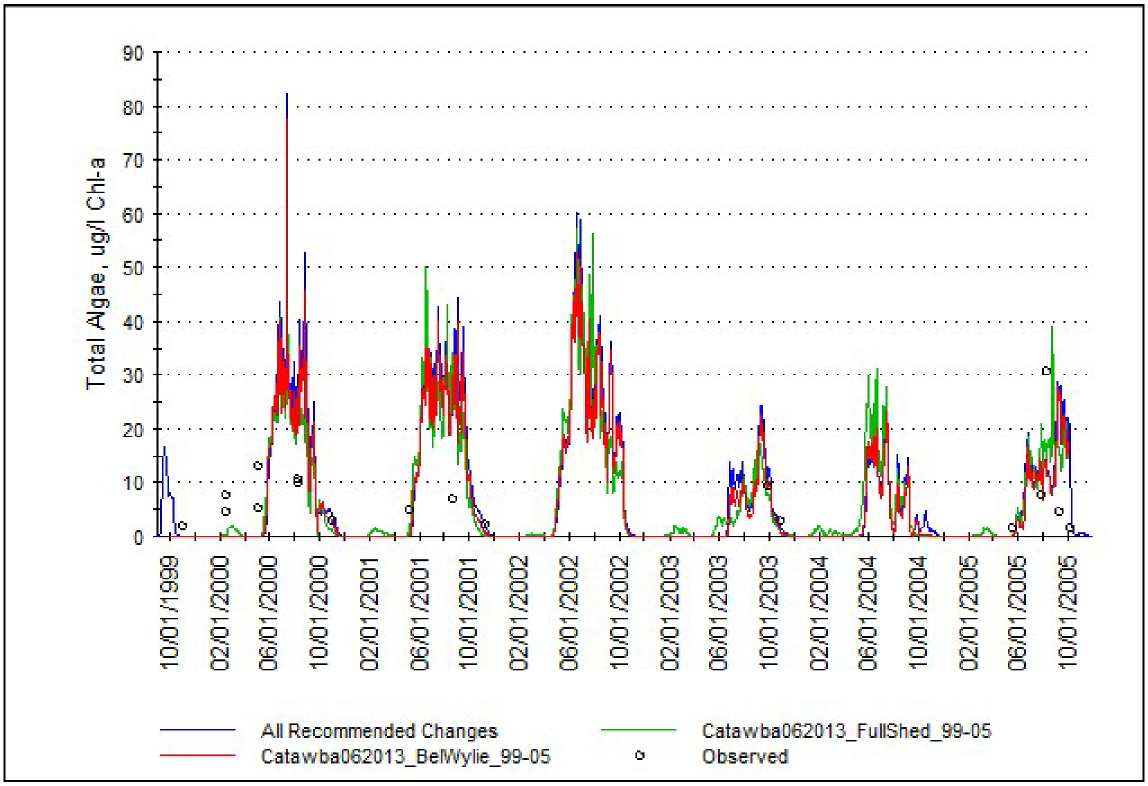

Figure 27 – Great Falls Reservoir total phytoplankton previous (blue) and updated (red) 'Below Wylie' calibration comparison. Observed data from water quality file GRFALL.OLC.

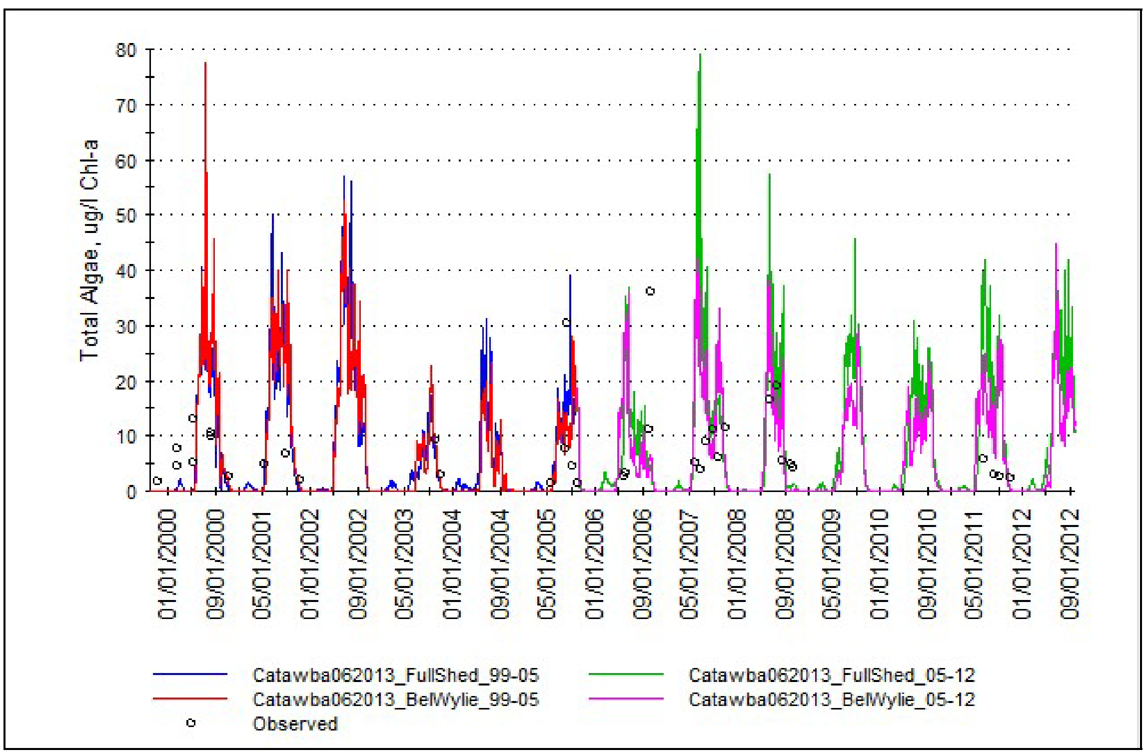

Figure 28 – Great Falls Reservoir total phytoplankton updated simulation results from 1999-2012. Observed data from water quality file GRFALL.OLC.

Table 22 – Total phytoplankton calibration statistics for Great Falls Reservoir

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	15	14	14	20	20
Relative Error	2.127	0.649	1.098	5.759	9.223
Absolute Error	8.616	7.675	7.825	12.4	15.05
R squared	0.0263	0.0595	0.123	0.0174	0.00151

Cedar Creek Reservoir (Reservoir Segment 1567)

Simulation results of total phytoplankton in Cedar Creek Reservoir are shown in Figures 29 and 30 and calibration statistics are shown in Table 23. Only a few small differences are visible in Figure 29 between the previous (blue) and 'Below Wylie' (red) simulations from 1999-2005. Calibration statistics corroborate the similarity of the two simulations. The model's performance for 2005-2012 is comparable to the 1999-2005 period, so the model can be considered validated.

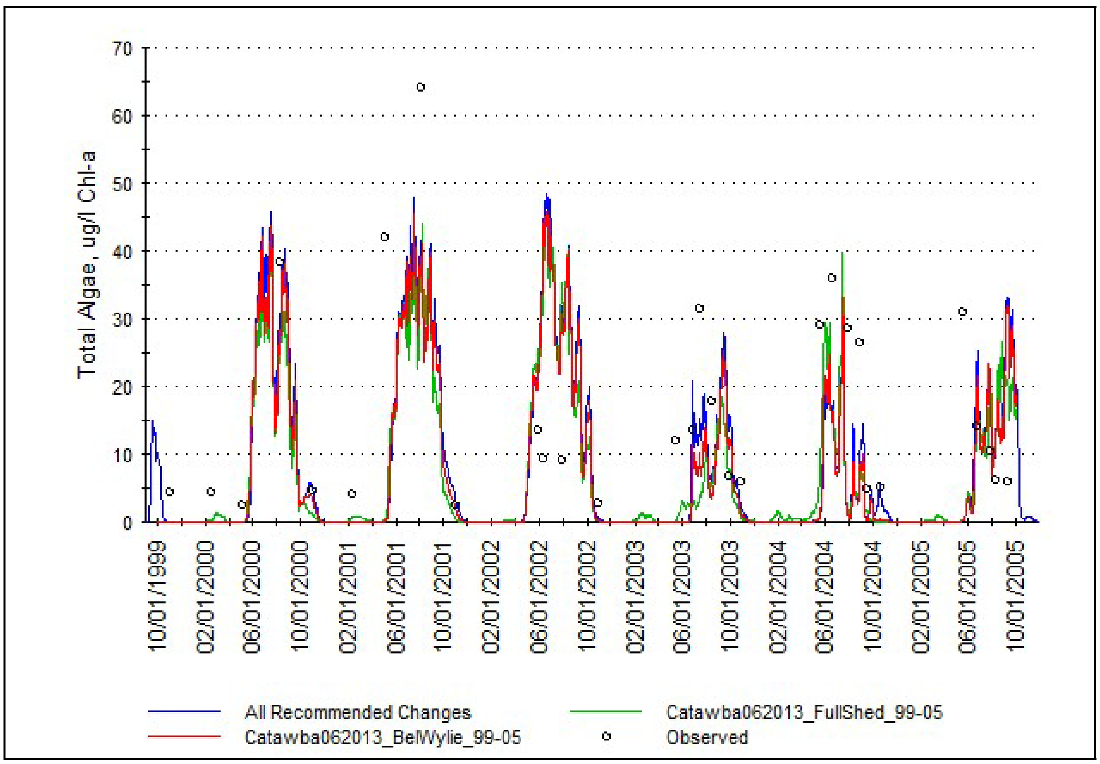

Figure 29 – Cedar Creek Reservoir total phytoplankton previous (blue) and updated (red) 'Below Wylie' calibration comparison. Observed data from water quality file CedarCr.OLC.

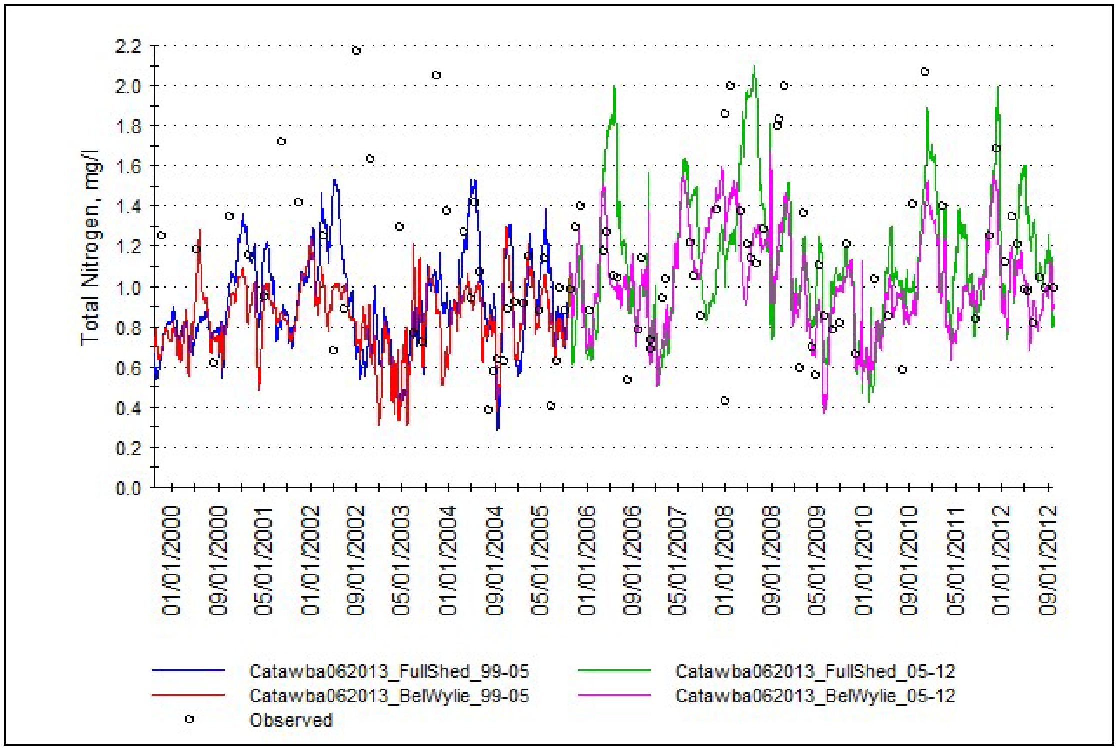

Figure 30 – Cedar Creek Reservoir total phytoplankton updated simulation results from 1999-2012. Observed data from water quality file CedarCr.OLC.

Table 23 – Total phytoplankton calibration statistics for Cedar Creek Reservoir

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	30	30	30	28	28
Relative Error	-6.6	-6.624	-7.333	-1.668	-0.453
Absolute Error	13.31	13.31	13.38	11.55	11.62
R squared	0.086	0.0857	0.096	0.0864	0.157

Lake Wateree (Reservoir Segment 2292)

Simulation results of total phytoplankton in Lake Wateree are shown in Figures 31 and 32 and calibration statistics are shown in Table 24. Based on visual inspection and calibration statistics, the updated 'Below Wylie' version of the model closely replicates the previous version. Model absolute error is lower for the 2005-2012 period than it is for 1999-2005 (as well as the previous simulation), so the model is considered validated with respect to total phytoplankton at Lake Wateree.

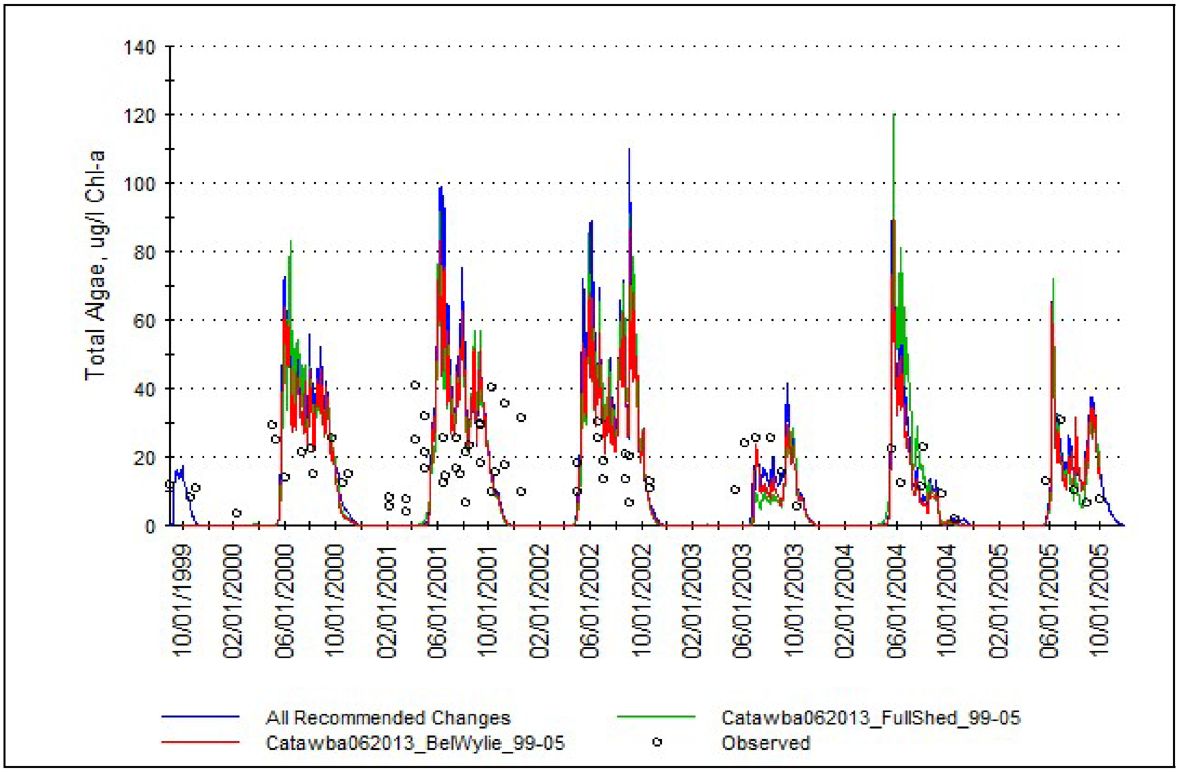

Figure 31 – Lake Wateree total phytoplankton previous (blue) and updated (red) 'Below Wylie' calibration comparison. Observed data from water quality file WATEREE3.OLC.

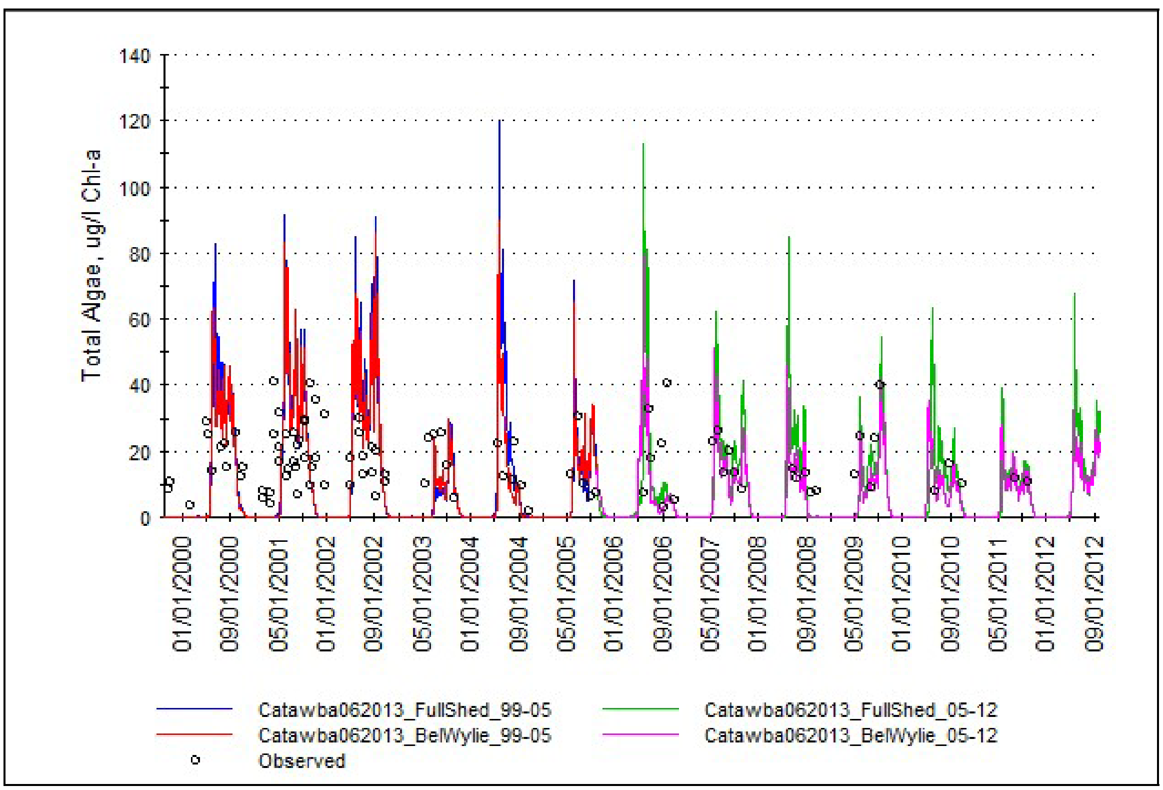

Figure 32 – Lake Wateree total phytoplankton updated simulation results from 1999-2012. Observed data from water quality file WATEREE3.OLC.

Table 24 – Total phytoplankton calibration statistics for Lake Wateree

	Previous Version	Below Wylie 1999-2005	Full Watershed 1999-2005	Below Wylie 2005-2012	Full Watershed 2005-2012
# Compare Pts	51	50	50	28	28
Relative Error	5.219	2.011	2.269	-4.527	-2.157
Absolute Error	17.5	15.1	15.45	9.872	8.64
R squared	0.0404	0.0488	0.0493	0.00349	0.144

Recommended Improvements

Simulations of flow along the mainstem Catawba River are generally good and do not require recalibration. However, improvements to the simulation of flow in Sugar Creek and Rocky Creek are recommended. For both tributaries, flow is significantly under simulated. Catchment soil hydrology coefficients should be adjusted regionally to improve the water balance and peak flows. In addition, meteorology station assignments and precipitation weighting factors should be reviewed and adjusted if necessary to ensure that the appropriate station is being used and the long term climatological characteristics of the catchment are maintained. Errors in meteorology station assignments and/or weighting factors could be contributing to error in simulations. Improvements in the tributary flow simulations would be expected to also improve the simulation of some peaks in the Catawba River (e.g. below the confluence with Sugar Creek).

Simulation of total nitrogen was validated at all four South Carolina reservoirs, so no improvements are recommended for the model's simulation of nitrogen. Improvements are recommended for the updated models' simulations of total phosphorus in Fishing Creek Reservoir, Great Falls Reservoir, and Cedar Creek Reservoir. Improvements to the simulation of total phytoplankton are recommended for Great Falls Reservoir. If the 'Full Watershed' version will be used in the future, improvements both upstream and downstream of Lake Wylie will be necessary, while if only the 'Below Wylie' version will be used further improvements can be focused on the outflow and downstream of Lake Wylie.

Some general observations and suggestions are possible regarding the source of phosphorus error, though a more in-depth investigation of sources is recommended to guide recalibration efforts. In the 'Below Wylie' version, total phosphorus simulations in Fishing Creek Lake are reasonable prior to 2005, then the calibration somewhat degrades. After 2005 observed values are lower (rarely greater than 0.1) than prior to 2005 (ranging up to 0.3). The model does not replicate this reduction as the simulated range of values after 2005 is about the same as the range from 2003-2005. This same issue (with larger error) is seen at Great Falls and Cedar Creek reservoirs. This initially suggests that a change in phosphorus load that occurred in reality around 2005 might not be well represented in the data that was used for model inputs. The match between simulated and observed total phosphorus in the 'Below Wylie' version is generally very good in Catawba River above Sugar Creek (segment ID 87), just downstream of Lake Wylie. Thus the boundary inflow point source file does not appear to be a significant source of error. At Catawba River downstream of shoals (just above Fishing Creek Reservoir), total phosphorus is under predicted after 2007, particularly in 2007-2008. This is the reverse direction of error as compared to simulations within Fishing Creek Reservoir, where over prediction occurs. Observed data for these two locations (stations CW-016 and CW-057 should be verified to determine if total phosphorus is truly under predicted upstream of Fishing Creek Reservoir (despite the reverse errors in the reservoir itself). Total phosphorus is over predicted in tributaries entering Fishing Creek Reservoir from the East (Cane Creek and Rum Creek), however it occurs during periods of very low flow so is not likely the main cause of error in the reservoir.

In Fishing Creek Reservoir the model error is largest after 2005, while in Great Falls and Cedar Creek Lakes, large errors are present prior to 2005 as well. Phosphorus is significantly over predicted in Fishing Creek (eg. segment ID 149) throughout both run periods. Loading plots indicate that non-point sources, particularly from pasture landuse but from other landuses as well, are the main sources of total phosphorus in Fishing Creek. Thus recalibration efforts in Fishing Creek should focus on model inputs that affect non-point sources of total phosphorus such as land application and livestock exclusion. Total phosphorus is also over predicted in Rocky Creek, however since it occurs primarily during periods of low flow periods this is not likely a large source of error in the reservoirs.

Despite large errors in the total phosphorus simulation upstream, simulations in Lake Wateree are more reasonable. A notable reduction in simulated total phosphorus occurs in the 2nd reservoir segment of Lake Wateree (Lake Wateree Seg 1B, WARMF ID 570), which contributes to the improved calibration (it reduces the extent of phosphorus over prediction). After improvements are made to the upstream simulations, it may be necessary to adjust coefficients in Lake Wateree to maintain (or improve) the quality of the simulation.

To improve the simulation of total phosphorus in the 'Full Watershed' version, sources of error will need to be identified upstream of Lake Wylie. The error in the last Lake Wylie model segment (Lake Wylie Seg 9) is very large and thus propagates downstream contributing to the large error observed in the four downstream reservoirs described previously. By reviewing simulations upstream of Lake Wylie, we found that total phosphorus simulations dramatically increase in Catawba River segments downstream of Dutchman's Creek. Point sources contributing to Dutchman's Creek and tributaries (river segments 128, 131 and 132), as well as to the Catawba River upstream of Lake Wylie (segment 106) are suspected as the main sources of phosphorus loads contributing to the over simulation of phosphorus in Lake Wylie and downstream. The raw data provided for these point sources and the associated units should be carefully reviewed and verified (e.g. if data is mislabeled as mg/l instead of kg/d). In addition, calibration data was only updated for the South Carolina portion of the model for this project. Thus to better identify the sources and extent of error in the total phosphorus simulation upstream of Lake Wylie, additional ambient water quality data should be collected and included in the model, particularly for the river segments just upstream of Lake Wylie.

Improvements to the total phosphorus simulations would be expected to subsequently improve the simulations of total phytoplankton. If the over simulation of phosphorus is corrected, the model's over prediction of peak phytoplankton concentrations should be improved in all reservoirs.

Appendix

Table A-1 Updated Point Source Input Files (PTS files)

NC Updated File	Becomes Inactive?	SC Updated File	Becomes Inactive?
nc0006564.pts	no	SC0001015.PTS	no
NC0020036.PTS	no	SC0001741.PTS	no
NC0020052.PTS	no	Sc0003255.pts	2012
NC0020966.PTS	no	sc0004278_1.pts	no
NC0021890.PTS	no	sc0004278_2.pts	no
NC0022497.PTS	no	SC0020371.PTS	no
NC0022756.PTS	no	SC0020443.PTS	no
NC0023124.PTS	no	SC0021211.PTS	no
NC0025542.PTS	no	Sc0026743.pts	no
NC0025861.PTS	no	Sc0026751.pts	no
NC0025917.PTS	no	SC0027111.PTS	no
NC0026271.PTS	no	SC0027146.PTS	no
NC0026654.PTS	no	SC0027189.PTS	no
Nc0029181.pts	no	SC0027341.PTS	no
NC0032662.PTS	no	SC0028321.PTS	no
NC0032760.PTS	no	sc0028321_2.pts	no
NC0036935.PTS	no	sc0028321_3.pts	no
NC0039446.PTS	no	SC0028622.PTS	no
NC0056154.PTS	no	SC0030112.PTS	no
Nc0057401.pts	no	SC0032417.PTS	no
NC0058742.PTS	no	SC0033651.PTS	no
Nc0062383.pts	no	SC0035360.PTS	no
NC0063355.PTS	no	SC0035980.PTS	no
Nc0063860.pts	no	SC0036056.PTS	no
NC0068888.PTS	no	SC0037605.PTS	no
Nc0071242.pts	no	SC0038113.PTS	no
NC0074012.PTS	no	SC0038156.PTS	no
NC0074772.PTS	no	SC0039217.PTS	no
nc0080098.pts	no	Sc0041670.pts	no
nc0004243.pts	no	sc0046892.pts	no
NC0004375.PTS	no	SC0047538.pts	no
NC0004812.PTS	no	SC0047864.pts	no
NC0004961_1.PTS	no	SC0004278_3.PTS	2005
NC0004961_2.PTS	no	SC0027383.PTS	2006
NC0004979_1.PTS	no	SC0029572.PTS	2006
NC0004979_2.PTS	no	sc0026751_2.pts	2007
NC0004987_1.pts	no	SC0031208.PTS	2007
NC0004987_2.PTS	no	SC0032662.PTS	2007
NC0005177.PTS	no	SC0035661.PTS	2007
NC0005185.PTS	no	SC0041807.PTS	2007

NC0006033.PTS	no	SC0001783.PTS	2008
NC0006190.PTS	no	sc0001783_2.pts	2008
NC0020184.PTS	no	SC0002801.PTS	2008
NC0020401.PTS	no	Sc0027391.pts	2009
NC0021156.PTS	no	SC0041904.PTS	2010
NC0021181.PTS	no	SC0044440.PTS	2010
NC0021229.PTS	no		
NC0023736.PTS	no		
NC0023981.PTS	no		
NC0024252.PTS	no		
NC0024392_1u.PTS	no		
NC0024392_2.PTS	no		
NC0024392_5.PTS	no		
NC0025135.PTS	no		
NC0025496.PTS	no		
NC0026573.PTS	no		
NC0031879.PTS	no		
NC0034860A.PTS	no		
NC0036196.PTS	no		
NC0036277.PTS	no		
NC0039594.PTS	no		
NC0040797.PTS	no		
NC0041696.PTS	no		
NC0044440.PTS	no		
NC0074268.PTS	no		
NC0085359.pts	no		
NC0024937.PTS	no		
NC0024945.PTS	no		
NC0024970.PTS	no		
NC0034860B.PTS	no		
NC0024279A.PTS	2005		
NC0024279B.PTS	2005		
NC0059579.PTS	2010		
NC0071200.PTS	2010		
NC0005274A.PTS	2010		
NC0005274B.PTS	2004		
NC0040070.PTS	2006		

Table A-2 Non-Updated Point Source Input Files (PTS files)

NC Non-Updated File	**Reason**	**SC Non-Updated File**	**Reason**
NC0020192.PTS	Inactive	SC0003263.PTS	Inactive
NC0020826.PTS	Inactive	SC0003280.PTS	Inactive
NC0024392_1l.PTS	Inactive	sc0003301.pts	Inactive
NC0024392_3.PTS	Minor, no data	SC0003352.PTS	Inactive
NC0004260.PTS	Minor, no data	sc0003352_2.pts	Inactive

NC0004723.PTS	Minor, no data	sc0003352_3.pts	Inactive
NC0004839.PTS	Minor, no data	SC0020303.PTS	Inactive
NC0005011A.PTS	Minor, no data	SC0022080.PTS	Inactive
NC0005011B.PTS	Minor, no data	SC0022705.PTS	Inactive
NC0005169.PTS	Minor, no data	SC0022799.PTS	Inactive
NC0005231A.PTS	Minor, no data	SC0022985.PTS	Inactive
NC0005231B.PTS	Minor, no data	SC0024759.PTS	Inactive
NC0005258.PTS	Minor, no data	Sc0026298.pts	Inactive
NC0005771.PTS	Minor, no data	SC0026301.PTS	Inactive
NC0021318.PTS	Minor, no data	sc0028134.pts	Inactive
NC0021962.PTS	Minor, no data	SC0029378.PTS	Inactive
NC0021971.PTS	Minor, no data	SC0031151.PTS	Inactive
NC0022071.PTS	Minor, no data	SC0032336.PTS	Inactive
NC0022187.PTS	Minor, no data	SC0032344.PTS	Inactive
NC0023540.PTS	Minor, no data	SC0035033.PTS	Inactive
NC0023761.PTS	Minor, no data	sc0035360_1b.pts	Inactive
NC0024155.PTS	Minor, no data	sc0035513.pts	Inactive
NC0024261.PTS	Minor, no data	SC0038563.PTS	Inactive
NC0024490.PTS	Minor, no data	SC0039004.PTS	Inactive
NC0026255A.PTS	Minor, no data	sc0039004_1a.pts	Inactive
NC0026255B.PTS	Minor, no data	SC0039250.PTS	Inactive
NC0026255C.PTS	Minor, no data	SC0040011.PTS	Inactive
NC0026255D.PTS	Minor, no data	SC0040941.PTS	Inactive
NC0026549.PTS	Minor, no data	SC0041483.PTS	Inactive
NC0026832.PTS	Minor, no data	sc0042048.pts	Inactive
NC0028274.PTS	Minor, no data	sc0042129.pts	Inactive
NC0028711.PTS	Minor, no data	SC0042510.PTS	Inactive
Nc0029220.pts	Minor, no data	sc0044598.pts	Inactive
NC0029297.PTS	Minor, no data	SC0046248.PTS	Inactive
NC0029831.PTS	Minor, no data	sc0001015_3.pts	Inactive
NC0030783.PTS	Minor, no data	sc0001015_5.pts	Inactive
NC0030996.PTS	Minor, no data	sc0001783_3.pts	Inactive
NC0031038.PTS	Minor, no data		
NC0031119.PTS	Minor, no data		
NC0032891A.PTS	Minor, no data		
NC0032891B.PTS	Minor, no data		
NC0032972.PTS	Minor, no data		
NC0033421.PTS	Minor, no data		
NC0034541.PTS	Minor, no data		
NC0034754A.PTS	Minor, no data		
NC0034754B.PTS	Minor, no data		
NC0034754C.PTS	Minor, no data		
NC0034967.PTS	Minor, no data		
NC0035157.PTS	Minor, no data		
NC0035211.PTS	Minor, no data		
NC0036871.PTS	Minor, no data		

NC0039853.PTS	Minor, no data		
NC0039934A.PTS	Minor, no data		
NC0039934B.PTS	Minor, no data		
NC0039934C.PTS	Minor, no data		
NC0040274.PTS	Minor, no data		
NC0040291.PTS	Minor, no data		
NC0040754.PTS	Minor, no data		
NC0041122.PTS	Minor, no data		
NC0041157.PTS	Minor, no data		
NC0041165.PTS	Minor, no data		
NC0041220.PTS	Minor, no data		
NC0041246.PTS	Minor, no data		
NC0041360.PTS	Minor, no data		
NC0041815.PTS	Minor, no data		
NC0043231.PTS	Minor, no data		
NC0044059.PTS	Minor, no data		
NC0044121.PTS	Minor, no data		
NC0044164.PTS	Minor, no data		
NC0044253.PTS	Minor, no data		
NC0045438.PTS	Minor, no data		
NC0045543.pts	Minor, no data		
NC0046213.PTS	Minor, no data		
NC0046531.PTS	Minor, no data		
NC0046892.PTS	Minor, no data		
NC0047147.PTS	Minor, no data		
NC0047627.PTS	Minor, no data		
NC0048453.PTS	Minor, no data		
NC0048755.PTS	Minor, no data		
NC0050075.PTS	Minor, no data		
NC0050920.PTS	Minor, no data		
NC0051608.PTS	Minor, no data		
NC0055221.PTS	Minor, no data		
NC0055948.PTS	Minor, no data		
NC0056669.PTS	Minor, no data		
NC0056855.PTS	Minor, no data		
NC0057819.PTS	Minor, no data		
NC0058882.PTS	Minor, no data		
NC0059226.PTS	Minor, no data		
NC0060194.PTS	Minor, no data		
NC0060208.PTS	Minor, no data		
NC0060224.PTS	Minor, no data		
NC0060593.PTS	Minor, no data		
NC0060755.PTS	Minor, no data		
NC0062278.PTS	Minor, no data		
NC0062413.PTS	Minor, no data		

NC0062430.PTS	Minor, no data		
NC0062448.PTS	Minor, no data		
NC0062481.PTS	Minor, no data		
NC0063789.PTS	Minor, no data		
NC0063835.PTS	Minor, no data		
NC0064599.PTS	Minor, no data		
NC0064602.PTS	Minor, no data		
NC0067121.PTS	Minor, no data		
NC0067130.PTS	Minor, no data		
NC0067148.PTS	Minor, no data		
NC0067784.PTS	Minor, no data		
Nc0068705.pts	Minor, no data		
NC0069094.PTS	Minor, no data		
NC0069175.PTS	Minor, no data		
NC0069965.PTS	Minor, no data		
NC0071447.PTS	Minor, no data		
NC0071528.PTS	Minor, no data		
NC0072621.PTS	Minor, no data		
NC0072940.PTS	Minor, no data		
NC0074233.PTS	Minor, no data		
NC0074535.PTS	Minor, no data		
NC0074705.PTS	Minor, no data		
NC0074799.PTS	Minor, no data		
NC0075205.PTS	Minor, no data		
NC0075353.PTS	Minor, no data		
NC0075884.PTS	Minor, no data		
NC0076163.PTS	Minor, no data		
NC0076180.PTS	Minor, no data		
nc0076180b.pts	Minor, no data		
NC0077551.PTS	Minor, no data		
NC0077623.PTS	Minor, no data		
NC0077763.PTS	Minor, no data		
NC0077801.PTS	Minor, no data		
nc0079481.pts	Minor, no data		
NC0080837.PTS	Minor, no data		
NC0082546.PTS	Minor, no data		
NC0086428.pts	Minor, no data		