# Catawba River Basin WARMF Model Update

*Technical Memorandum*

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# 1. Background

The Watershed Assessment and Risk Management Framework (WARMF) was developed by Systech Engineering, Inc. as a tool for Total Maximum Daily Load Development. Under a contract with Duke Energy, Systech Engineering applied the WARMF modeling framework to the Catawba River Basin in North and South Carolina. The Catawba River Basin application includes hydrography, hydrology, meteorology, and water quality information for the entire Catawba River Basin. Although WARMF itself is a proprietary model, the Catawba River Basin application has been widely distributed to state agencies, local governments, and Duke Power.

This current project involved updating the existing Catawba River Basin application of WARMF. The current Catawba River Basin application (V5.21) contains updated information through December 2000. The SC DHEC used WARMF for the Fishing Creek Reservoir and Lake Wateree nutrient TMDL. The DWQ used this version to develop a TMDL for fecal coliform in Clark Creek (Catawba and Lincoln Counties). DWQ staff intend to continue using the Catawba River Basin application for TMDL development, including the following TMDLs:

Clark Creek (Catawba and Lincoln Counties) Copper and Turbidity TMDLs
Crowders Creek (Gaston County) Fecal Coliform TMDL
Lower Creek (Caldwell County) Turbidity TMDL

In order to continue to utilize this framework, it is necessary for DWQ to have the model updated approximately every 2 years. This technical memorandum describes model updates that were performed to extend the data base through September 2003 and hydrology and water quality calibration that was performed for the Lower Creek watershed.

# 2. Database Upgrades

The following tasks were completed as part of the project:

## *2.1 Update of Meteorological Data*

Updated daily meteorological data was obtained from the National Climatic Data Center (NCDC) (http://cdo.ncdc.noaa.gov/CDO/cdo) and was imported into WARMF for 24 locations (Table 1). Data records in WARMF now extend through 9/30/2003. The airport stations supplied all parameters including maximum and minimum air temperatures, precipitation, dewpoint temperature, cloud cover, air pressure and wind speed. The Co-op stations only supplied air temperature and precipitation data. Therefore, these stations were supplemented with airport data for the remaining parameters. Data for three additional stations (Catawba Nuclear Station, McGuire Power

Plant and Long Creek) had originally come from other sources. For these stations, data from a nearby station was used for 2003.

**Table 1. Meterological Data Stations in the Catawba River Basin WARMF Application.**

| Station Name | Data Source | Notes |
|---|---|---|
| Chardoug.met | NCDC 311690 | Airport Station |
| Gastonia.met | NCDC 313356 | Co-op Station |
| Grndfthr.met | NCDC 313565 | Co-op Station |
| Hickory.met | NCDC 314020 | Airport Station |
| Jamesdam.met | NCDC 311081/ Duke Energy | Co-op Station |
| Lenoir.met | NCDC 314938 | Co-op Station |
| Lincoln.met | NCDC 314996 | Co-op Station |
| Lookout.met | NCDC 311579 | Co-op Station |
| Marion.met | NCDC 315340 | Co-op Station |
| Mtholly.met | NCDC 315913 | Co-op Station |
| Mtmitch.met | NCDC 315923 | Co-op Station |
| Oxfordam.met | NCDC 311990 | Co-op Station |
| Pattersn.met | NCDC 316602 | Co-op Station |
| Rhodhiss.met | NCDC 317229 | Co-op Station |
| Swannano.met | NCDC 318448 | Co-op Station |
| Taylorsv.met | NCDC 318519 | Co-op Station |
| Morgantn.met | NCDC 315838 | Co-op Station |
| Catawba.met | NCDC 381462 | Co-op Station |
| Chester.met | NCDC 381633 | Co-op Station |
| Fortmill.met | NCDC 383216 | Co-op Station |
| Grtfalls.met | NCDC 383700 | Co-op Station |
| Wateree.met | NCDC 388979 | Co-op Station |
| Winnsbor.met | NCDC 389327 | Co-op Station |
| Winthrop.met | NCDC 389350 | Co-op Station |
| Catawbanuc.met | Duke Energy | 2003 data from Fortmill Station |
| Longcr.met | Long Creek Project / Duke Energy | 2003 data from Gastonia Station |
| Mcguire.met | Duke Energy | 2003 data from Mt. Holly Station |

## *2.2 Update of Air Quality Data*

WARMF accepts both wet and dry air chemistry data. To extend the current database through December 2003, additional data was obtained from two sources. EPA Clean Air Status and Trends Network (CASNET) (http://www.epa.gov/castnet/) supplied dry deposition data for the Cranberry Station (PNF126) located in Avery County (Latitude: 36.1058, Longitude: -82.0454). This data was only available through 2000. Therefore, 2000 data was repeated for the years 2001 through 2003. Wet deposition rain chemistry data was obtained from the National Atmospheric Deposition Program (NADP) (http://nadp.sws.uiuc.edu/) for the Mt. Mitchell Station (NC45) located in Yancey County (35.7353,-82.2861). This data was available through June 2003. For the remaining months of 2003, data from 2002 was repeated.

## *2.3 Update of USGS Gaging Data*

Observed stream flow measured at USGS gaging stations is used for calibration in WARMF. Data for 21 stations in the Catawba watershed were obtained from the USGS (http://water.usgs.gov/) and imported into WARMF (Table 2). Data records now extend through water year (WY) 2003 for all but one station, which has since been discontinued. Because of a lag in data QAQC by the USGS, data records were marked "provisional" for water year 2003 for North Carolina stations and for water years 2002 and 2003 for South Carolina stations. When "final" data becomes available from USGS, these records will replace the "provisional" data in WARMF.

**Table 2. USGS Gaging Stations in the WARMF Catawba Database.**

| Station Name | USGS Station ID | Date File End Date | Notes |
|---|---|---|---|
| cat1221.orh | 2137728 | 9/30/2003 | WY 2003 provisional |
| linville.orh | 2138500 | 9/30/2003 | WY 2003 provisional |
| abvRhod.orh | 213903612 | 9/30/2003 | WY 2003 provisional |
| Johns.orh | 2140991 | 9/30/2003 | WY 2003 provisional |
| lowlittl.orh | 2142000 | 9/30/2003 | WY 2003 provisional |
| longpaw.orh | 2142900 | 9/30/2003 | WY 2003 provisional |
| henryfk.orh | 2143000 | 9/30/2003 | WY 2003 provisional |
| jacob.orh | 2143040 | 9/30/2003 | WY 2003 provisional |
| indian.orh | 2143500 | 9/30/2003 | WY 2003 provisional |
| longbess.orh | 2144000 | 9/30/2003 | WY 2003 provisional |
| Sfmcaden | 2145000 | 9/30/2003 | WY 2003 provisional |
| catbelwy.orh | 2146000 | 9/30/2003 | WY 2002, 2003 provisional |
| irwin.orh | 2146211 | 11/8/2001 | No Records after 2001 |
| Sugar1.orh | 2146300 | 9/30/2003 | WY 2003 provisional |
| litsugar.orh | 2146507 | 9/30/2003 | WY 2003 provisional |
| mcalp1.orh | 2146600 | 9/30/2003 | WY 2003 provisional |
| mcmullen.orh | 2146700 | 9/30/2003 | WY 2003 provisional |
| mcalp2.orh | 2146750 | 9/30/2003 | WY 2003 provisional |
| twelve.orh | 2146900 | 9/30/2003 | WY 2003 provisional |
| catabvfc.orh | 2147020 | 9/30/2003 | WY 2002, 2003 provisional |
| Rocky.orh | 2147500 | 9/30/2003 | WY 2002, 2003 provisional |

## *2.4 Update of Observed Water Quality Data*

Observed water quality data for streams and reservoirs are used for comparison during model calibration. The observed water quality database in WARMF-Catawba was updated through most current available using two different data sources. Data from EPA STORET (http://www.epa.gov/storet/) was obtained for 52 river and reservoir stations in South Carolina (Table 3). Data was collected on a monthly basis and was available through December 2002 for most stations. Parameters sampled included temperature, pH, nutrients, dissolved oxygen, and BOD.

**Table 3. WARMF Observed WQ Stations with SC STORET Data**

| WARMF Station Name | STORET ID # | WARMF Station Name | STORET ID # |
|---|---|---|---|
| AbvFishCr.orc | CW-016 | Littlewat.orc | CW-040 |
| Abvwat.orc | CW-231 | Mcalp2.orc | CW-226 |
| Allison.orc | CW-171 | Mcalp5.orc | CW-064 |
| Allison2.orc | CW-249 | Neelys.orc | CW-227 |
| Bear.orc | CW-151 | Rocky1.orc | CW-236 |
| Bear2.orc | CW-131 | RockyUp.orc | CW-002 |
| Beaverdam.orc | CW-153 | Rum.orc | CW-232 |
| Calabash.orc | CW-134 | Sixmile.orc | CW-176 |
| Camp.orc | CW-235 | Steele.orc | CW-011 |
| Cane.orc | CW-017 | Steele3.orc | CW-009 |
| Cane2.orc | CW-185 | Sugar1.orc | CW-247 |
| CatAbvFC.orc | CW-041 | Sugar2.orc | CW-036 |
| CatBelWy.orc | CW-014 | Sugar4.orc | CW-013 |
| Cedarcr.olc | CW-174 | Tinkers.orc | CW-234 |
| Crowder.orc | CW-023 | Twelve2.orc | CW-083 |
| Crowders2.orc | CW-152 | Unamd.orc | CW-221 |
| Crowders3.orc | CW-192 | Wateree2.olc | CW-207 |
| FishBr.orc | CW-029 | Wateree5.olc | CW-208 |
| FishCr.olc | CW-057 | Wildcat.orc | CW-096 |
| Fishcr2.orc | CW-224 | Wylie 5.orc | CW-197 |
| Fishcr3.orc | CW-225 | Wylie16.orc | CW-027 |
| Fishcr4.orc | CW-233 | Wylie17.olc | CW-245 |
| FishingCr1.orc | CW-008 | Wylie18.orc | CW-200 |
| Gills.orc | CW-049 | Wylie8.orc | CW-201 |
| Grassy.orc | CW-088 | Wylie9.orc | CW-230 |
| Litsugar.orc | CW-248 | | |

For North Carolina locations, sampling data was obtained directly from NCDENR-DWQ for 34 river and reservoir locations (Table 4). Data from this database included monthly samples of temperature, pH, nutrients, dissolved oxygen, copper and total suspended sediment, with records extending through December 2003.

**Table 4. WARMF Observed WQ Stations with NCDENR Data**

| WARMF Station Name | NCDNER ID # | WARMF Station Name | NCDNER ID # |
|---|---|---|---|
| Cat1147 | C1210000 | Lower Creek | C1750000 |
| Cat1221 | C0250000 | LowLittl | C2818000 |
| Cat1234 | C0145000 | McAlp2 | C9680000 |
| CatBelMi | C3900000 | McAlp3 | C9370000 |
| Clark | C4800000 | MtIsland9 | C3699000 |
| Crowder | C8660000 | Nfork | C0550000 |
| Dutch | C3860000 | Norman1 | C3420000 |
| Hickory6 | C2600000 | Rhodhiss3 | C2030000 |
| HnryFk | C4360000 | SFMcaden | C6500000 |
| HnryFk2 | C4300000 | SfStar | C4380000 |
| Indian | C5170000 | Sugar1 | C9050000 |
| Irwin3 | C8896500 | Sugar4 | C9790000 |
| Jacob | C4370000 | Twelve Mile Creek | C9891500 |
| Linville River | C1000000 | Wylie1 | C4220000 |
| LitSugar | C9210000 | Wylie13 | C7000000 |
| LongCrl | C5900000 | Wylie15 | C7400000 |
| LongPaw | C4040000 | Wylie6 | C7500000 |

## *2.5 Update of North Carolina Point Source Data*

Point source discharge data are an important input to WARMF. Discharge monitoring reports (DMRs) were obtained from DWQ. Previously, most point source data was only available on a monthly basis for larger dischargers and even less frequently for smaller dischargers. The recent data obtained (1999-2003) includes mostly daily records. Because of the large amount of data to process and the limited budget to do the work, the stations were prioritized. With highest priority were dischargers in the Lower Creek watershed. Then, the list of remaining dischargers was ranked based on permitted flow. The data was processed starting with the largest discharges and moving toward the smaller dischargers. To date, data for 33 dischargers has been processed. This includes all dischargers with permitted flows greater than 1 MGD. Table 5 lists the North Carolina NPDES discharges that have been updated with daily DMR data to date. Additional discharges with be processed as time and budget allows. Data provided in most DMRs included flow, temperature, BOD, dissolved oxygen, ammonia-N, total nitrogen, phosphorus, copper, and fecal coliform bacteria. For most facilities, nitrate-N was assumed to be equal the total nitrogen minus the ammonia-N. Due to budget constraints, updated NPDES data for South Carolina dischargers was not obtained or processed for input to WARMF. For point sources that were not updated with current data, WARMF will use the last available data point for all simulation dates beyond that point.

**Table 5. NPDES Dischargers with updated DMR data in WARMF-Catawba.**

| NPDES # | Facility Name | Permitted Flow (MGD) | Mean Flow (MGD) |
|---|---|---|---|
| NC0024970 | CMUD-MCALPINE | 48 | 30.65 |
| NC0024937 | CMUD-WWTP/SUGAR CREEK | 20 | 10.87 |
| NC0024945 | CMUD-IRWIN CREEK | 15 | 12.66 |
| NC0004979 | DUKE POWER CO., ALLEN S.E. | 10 | 11.64 |
| NC0020192 | GASTONIA,CITY/CATAWBA CRK WWTP | 9 | 6.23 |
| NC0026573 | MORGANTON WWTP, CITY OF | 8 | 6.46 |
| NC0020184 | GASTONIA, CITY/LONG CREEK WWTP | 8 | 5.21 |
| NC0041696 | VALDESE, TOWN-LAKE RHODISS WWT | 7.5 | 4.80 |
| NC0040797 | HICKORY WWTP, CITY OF | 6 | 3.62 |
| NC0074268 | GASTONIA, CITY/CROWDERS CRK | 6 | 3.42 |
| NC0020401 | HICKORY NORTHEAST WWTP | 6 | 3.33 |
| NC0025496 | LINCOLNTON WWTP, TOWN OF | 6 | 3.00 |
| NC0021181 | BELMONT, CITY OF - WWTP | 5 | 3.60 |
| NC0036196 | NEWTON (TOWN OF)-CLARK CREEK | 5 | 3.22 |
| NC0023981[a] | LENOIR, CITY-LOWER CREEK WWTP | 4.08 | 2.17 |
| NC0021156 | MOUNT HOLLY, CITY OF - WWTP | 4 | 2.65 |
| NC0006033 | TOWN OF CRAMERTON EAGLE ROAD WWTP | 4 | 2.037 |
| NC0004375 | CLARIANT CORP-MT HOLLY RD/SAND | 3.9 | 1.427 |
| NC0031879 | MARION, CITY-CORPENING CREEK | 3 | 2.371 |
| NC0036277 | CMUD-MCDOWELL CREEK WWTP | 3 | 2.10 |
| NC0044440 | CHERRYVILLE WWTP, TOWN OF | 2 | 1.48 |
| NC0004243 | COATS AMERICAN INC. | 2 | 1.03 |
| NC0020826 | BESSEMER CITY, CITY OF-WWTP | 1.5 | 0.811 |
| NC0024252 | CONOVER WWTP-NORTHEAST | 1.5 | 0.63 |
| NC0023736 | LENOIR, CITY-GUNPOWDER CRK WWT | 1.2 | 0.92 |
| NC0006564 | BAXTER HEALTHCARE CORP. | 1.2 | 0.67 |
| NC0040070 | GASTONIA, CITY OF - WTP | 1.2 | 0.47 |
| NC0006190 | DELTA MILLS, INC. | 1 | 0.77 |
| NC0039594 | MAIDEN, TOWN-WWTP/MAIDEN | 1 | 0.34 |
| NC0040274[a] | THE BULLEK CORPORATION OF N.C. | 0.05 | 0.0099 |
| NC0047627[a] | SEALED AIR CORPORATION | 0.0095 | 0.0073 |
| NC0043231[a] | CEDAR ROCK COUNTRY CLUB | 0.009 | 0.0022 |
| NC0047147[a] | QUALITY CARE ASSISTED LIVING | 0.0066 | 0.0010 |

[a]Located within Lower Creek Watershed.

## 2.6 Update of Duke Power Plant Point Sources

Duke Energy operates several power plants within the Catawba River Basin. Five of these power plants withdrawl cooling water and then return it to the basin with a raised temperature (Table 6). WARMF treats these power plants as *internal point sources*. This setting is located in the *point sources* tab of the river or reservoir input dialog where the point source is located. In the *.pts input file, a flow and delta temperature is specified and all other constituents are considered to be ambient concentrations. An effort was made to update these five files with current point source data. Data was obtained from Duke Energy (Robert Caccia, 704-382-3696) for the Allen, Riverbend, and Marshall fossil plants. A continued effort was being made to obtain data for Catawba and McGuire Nuclear plants as well, however the deadline to release this version came before the data was available. As with the point sources described in Section 2.5, stations not updated with current data will use the last available data point for all simulation dates beyond that point.

**Table 6. Duke Power Plant NPDES Dischargers**

| Plant | Type | NPDES # | Receiving Water | Date of Records |
|---|---|---|---|---|
| Allen | Fossil | NC0004979 | Lake Wylie | 1/1989 – 12/2004 |
| Catawba | Nuclear | SC0004278 | Lake Wylie | 1/1997 – 12/1999 |
| Marshall | Fossil | NC0004987 | Lake Norman | 1/1997 – 12/2004 |
| McGuire | Nuclear | NC0024392 | Lake Norman | 1/1997 – 12/1999 |
| Riverbend | Fossil | NC0004961 | Mt. Island Res. | 1/1997 – 12/2004 |

## 2.7 Import of Septic System Data

WARMF was recently enhanced to handle the import of septic system or onsite wastewater system (OWS) data (NDWRCDP 2003). Septic tank effluent flow and associated quality is discharged to the soil in catchments where septic systems are present. Then, soil reactions transform the effluent via nitrification, fecal coliform decay and BOD decay. WARMF calculates the amount of loading due to septic systems throughout the watershed. To make use of this feature, septic system data was imported to the Catawba River Basin application of WARMF. A GIS shape file showing the number of septic systems located in each Census Block within the watershed was created. First, a GIS cover of general Census Blocks was obtained from the Internet for each county (http://arcdata.esri.com/data/tiger2000/tiger_download.cfm). Then, 1990 Census Block data for septic systems was downloaded (http://www.census.gov/) and linked with the GIS cover. This shapefile was then imported into WARMF using the *File / Import / Septic Systems* feature. The Census Blocks were intersected with catchment boundaries and the *population served by septic systems* was imported as data for each catchment. It was assumed that each household was occupied by 2.5 people and that all systems are "standard" systems. The discharge quality of the septic tank effluent are 50th percentile values of what were determined during an extensive literature search (NDWRCDP 2003). The effluent flow and quality data are summarized in Table 7.

**Table 7. Septic Tank Effluent Flow and Quality Input Data**

| Parameter | Value |
|---|---|
| Flow | 165 L/cap/day |
| Ammonia-N | 58 mg/L |
| Phosphorus | 9.8 mg/L |
| BOD | 170 mg/L |
| Fecal Coliform | 1.0e6 cfu/100mL |

### 2.8 Update of Reservoir Release Data

In the previous database of WARMF-Catawba, reservoir release and surface elevation data from January 1991 through December 2002. Updated data was obtained from a sub-contractor of Duke Energy, Devine Tarbell & Associates (DTA) (Steve Gaffney, 704-342-7311). Due to previous water balance problems with the reservoir releases, DTA made an effort to improve the release records data for all historical years using updated power generation curves. WARMF now contains the revised release and elevation records for all eleven reservoirs. Data records extend through 12/2003. Due to budget constraints, there were no analyses performed to check the impact of the revised release data on simulation results.

## 3. Phosphorus Loading and Adsorption

One of the current uses of WARMF-Catawba is the development of a phosphorus TMDL in the Lower Catawba Watershed (Tufford et. al 2003). In this effort, Systech Engineering supported University of South Carolina (USC) researchers by making WARMF model enhancements to accommodate the project, compiling relevant input data, and performing a preliminary calibration. Then USC researchers performed a final model calibration.

### 3.1 Incorporation of USC Calibration Coefficients

After calibration, USC delivered the final WARMF input coefficient file back to Systech. These coefficients were then blended with the current version of WARMF-Catawba housed at Systech Engineering. The most significant changes to model coefficients were the cultivated fertilizer rates and the phosphorus adsorption isotherm in rivers and reservoirs.

For all land catchments downstream of Lake Wylie (including catchments in the Charlotte area), the land application rate for the cultivated land use was modified. The land application rate of phosphorus was increased from 45.5 kg/ha/month to 90 kg/ha/month. Likewise, the land application rate of ammonia was increase from 15 kg/ha/month to 115 kg/ha/month. The constituents were also now applied every month instead of just from May through August as was done previously. In land catchments upstream of Lake Wylie, land application rates for the cultivated land use were not changed.

For all rivers and reservoirs downstream of Lake Wylie, the phosphorus adsorption isotherm was set to 3000 L/kg. In all rivers and reservoirs upstream of Lake Wylie (and including Lake Wylie), the phosphorus adsorption isotherm remained at 30,000 L/kg.

### 3.2 Adjustment of Maximum Phosphorus Adsorption

Phosporus adsorption takes place in the soil media, and WARMF uses a linear isotherm represented by the equation:

$$S = K_D C \tag{3.1}$$

where $S$ is the mass solute sorbed per unit dry weight of solid (mg kg$^{-1}$), $C$ is the concentration of the solute in solution equilibrium with the mass of solute sorbed onto the solid (mg L$^{-1}$), and $K_D$ is the linear distribution coefficient (L kg$^{-1}$). One limitation of a linear isotherm is that it does not limit the amount of solute that can be sorbed onto the soil. With no upper limit, the soil would have an infinite capacity for phosphorus loading. To remedy this, in January 2004 a parameter setting the upper limit on phosphorus adsorbtion sites was introduced into WARMF.

As part of a WARMF project studying the impact of onsite wastewater systems (Siegrist et. al 2004), a literature review was conducted to provide estimates for a linear phosphorus isotherm and maximum phosphorus adsorbtion capacity. Literature reports maximum phosphorus adsorption capacitites ranging from 15 to 1368 mg/kg for clean sand. A default value of 400 mg/kg was used for simulation runs.

The phosphorus simulation in the northern half of the watershed (Lake Wylie and above) did not seem to be affected by the introduction of the maximum adsorption coefficient. Therefore, the coefficient for the catchments in this region was set to the default value of 400 mg/kg. However, when the blended version of WARMF-Catawba was run with the maximum phosphate adsorption set to a default value of 400 mg/kg, WARMF drastically overpredicted phosphorus in the Lower Catawba watershed. This was likely due to the higher phosphate cultivated land application and lower adsorption rate. The overprediction of phosphorus indicated that the maximum adsorption had been reach and phosphorus breakthrough was occurring in water flowing from catchments to rivers. Therefore, in subcatchments downstream of Lake Wylie, the maximum phosphate adsorption coefficient was increased to 3000 mg/kg. Simulation output at several locations was spot checked for consistency with earlier runs. An extensive recalibration was not performed. If desired, the phosphorus loading and adsorption coefficients could be further adjusted to obtain improved simulation results.

# 4. Calibration of Lower Creek Watershed

## *4.1 Introduction*

As part of this WARMF-Catawba upgrade, a full recalibration of the watershed was not performed. However, at the request of NCDENR, a recalibration of various constituents including flow, total suspended sediment, and nutrients was performed for the Lower Creek watershed. Lower Creek watershed drains approximately 98 square miles in Caldwell and Burke Counties. Lower Creek is a main tributary to Lake Rhodhiss, which is a water supply reservoir for several municipalities. Lower Creek has a support use rating of partially supporting and has been listed as a high priority stream for EPA Section 319 nonpoint source funding. Elevated coliform bacteria and sediment levels are a particular concern within this stream (WPCOG 1998).

## 4.2 Parameter Adjustment

Simulations were run for the Lower Creek watershed within WARMF. Hydrology and water quality results were compared to observed data. Model parameters were adjusted to improve the model results and reduce the error between simulated and observed data.

During hydrology calibration, parameters for soil thickness, initial soil moisture, field capacity, saturated moisture and hydraulic conductivity were adjusted. In addition precipitation weighting factors were adjusted to improve the water balance. Table 8 lists typical ranges of values set for the Lower Creek watershed. WARMF's autocalibrator tool was used to improve the hydrology calibration. Using this tool, multiple simulations are performed while small parameter adjustments are made until model results are improved.

**Table 8. Hydrology Parameter Ranges for Lower Creek Watershed.**

| Parameter | Lower Range | Upper Range |
|---|---|---|
| Soil thickness | 20 cm | 400 cm |
| Initial Mositure | 0.3 | 0.4 |
| Field Capacity | 0.2 | 0.25 |
| Saturated Moisture | 0.35 | 0.5 |
| Horizontal Conductivity | 500 cm/d | 10000 cm/d |
| Vertical Conductivity | 10 cm/d | 300 cm/d |
| Precipitation weighting | 0.8 | 1.3 |

Some of the input parameters which affect suspended sediment concentrations include buffer zone coefficients, livestock exclusion, and bank vegetation and stability factors. For each land catchment draining to a stream, a percent buffered parameter is specified. This is representative of the percent of runoff that will pass through a buffer before entering the stream. Other buffer inputs include buffer width, slope and roughness. Buffer parameters for the entire Catawba River Basin (including Lower Creek) were set based on a GIS study performed by a Duke Energy intern in 2001 (Job 2001). In the Lower Creek watershed, percent buffered ranged from 47% to 87% buffered, buffer width was assumed to be 20 m and slope and roughness were set at 0.01 and 0.3 respectively.

In the Lower Creek Watershed Report published by Western Piedmont Council of Governments (WPCOG 1998), it was stated that Lower Creek and many tributaries have steep incised banks which lack vegetation. The stream data collection performed by WPCOG indicated that bank erosion ranged from moderate to severe. It was also stated that at many locations, animals have direct access to the streams. Coefficients for bank erosion and vegetation as well as livestock exclusion BMPs were set based on this qualitative information. To account for livestock having direct access to streams, it was specified that in the *Pasture* land use, 5 percent of the loading from livestock was directly deposited to the stream instead of being applied to the land surface. Empirical factors for bank vegetation and bank stability factors were set to equal 0.003. A typical range for these parameters is from 0.0 to 0.01, with a higher value representing less vegetation and less bank stability. Based on stream substrate data collected by WPCOG (1998), which indicated a composition of mostly sand and some gravel and silt, the stream substrate for Lower Creek was set to be 60% sand, 20% silt and 40% clay in WARMF.

Other parameters that were adjusted during calibration include soil and steam reaction rates. Table 9 summarizes several reaction rates specified for the Lower Creek watershed.

**Table 9. Reaction rates for Lower Creek Watershed**

| Reaction | Soil | Stream |
|---|---|---|
| BOD Decay | 0.1 $day^{-1}$ | 0.5 $day^{-1}$ |
| Nitrification | 0.01 $day^{-1}$ | 0.1 $day^{-1}$ |
| Fecal Coliform Decay | 0.1 $day^{-1}$ | 1 $day^{-1}$ |

## *4.3 Model Results*

Simulated results were compared to all available data from 1992 through 2003 for a monitoring station (LOWER CK @ SR1501 NR MORGANTON NC MARION, Latitude: 35.8253, Longitude: -81.6361). Measured stream flow data was only available from 1/1/1993 through 9/30/1994. Therefore the hydrology calibration was performed for this time period. Water quality calibration was performed for the 1992 through 1997. Then, model verification was performed by holding all model coefficients constant and running simulations from 1997 through 2003. The following plots show both calibration and verification results for hydrology and various water quality parameters.

Figure 1 shows the simulated stream flow in Lower Creek compared to observed data for 1993 and 1994. The model captured the general hydrograph and recession though some peaks flows were under predicted and others were over predicted. Figure 2 presents the summary statistics and a scatter plot. This data shows a good comparison of mean, minimum and maximum flow values between simulated and observed. The correlation coefficient ($R^2$) is 0.718 and relative and absolute errors are 0.126 (3.96%) and 1.016 (31.9%) respectively. Figure 3 shows the frequency distribution of flow for both simulated and observed and Figure 4 shows a cumulative flow comparison. Both plots indicate good agreement with the overall water balance.

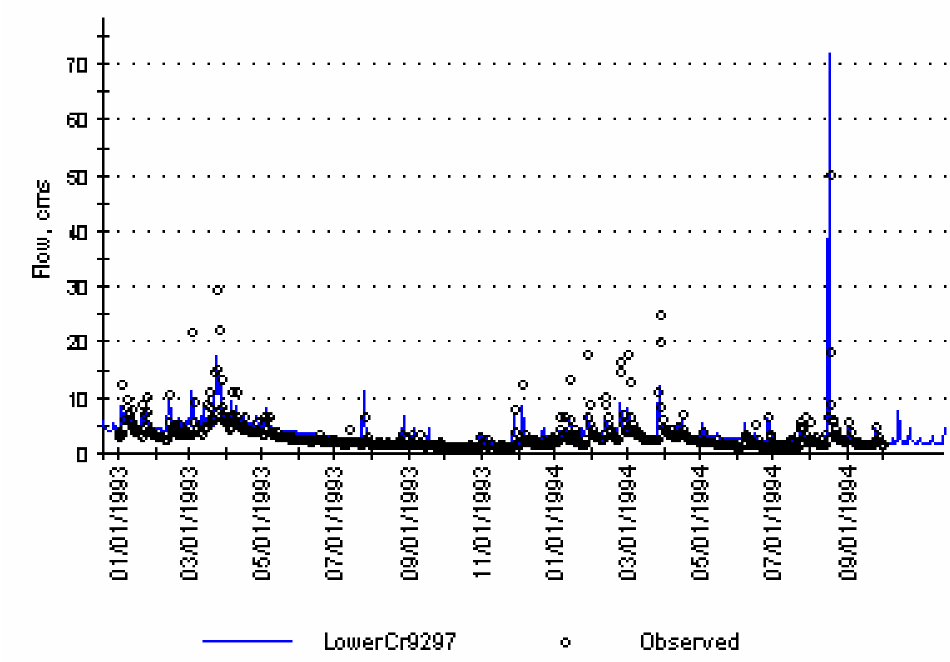
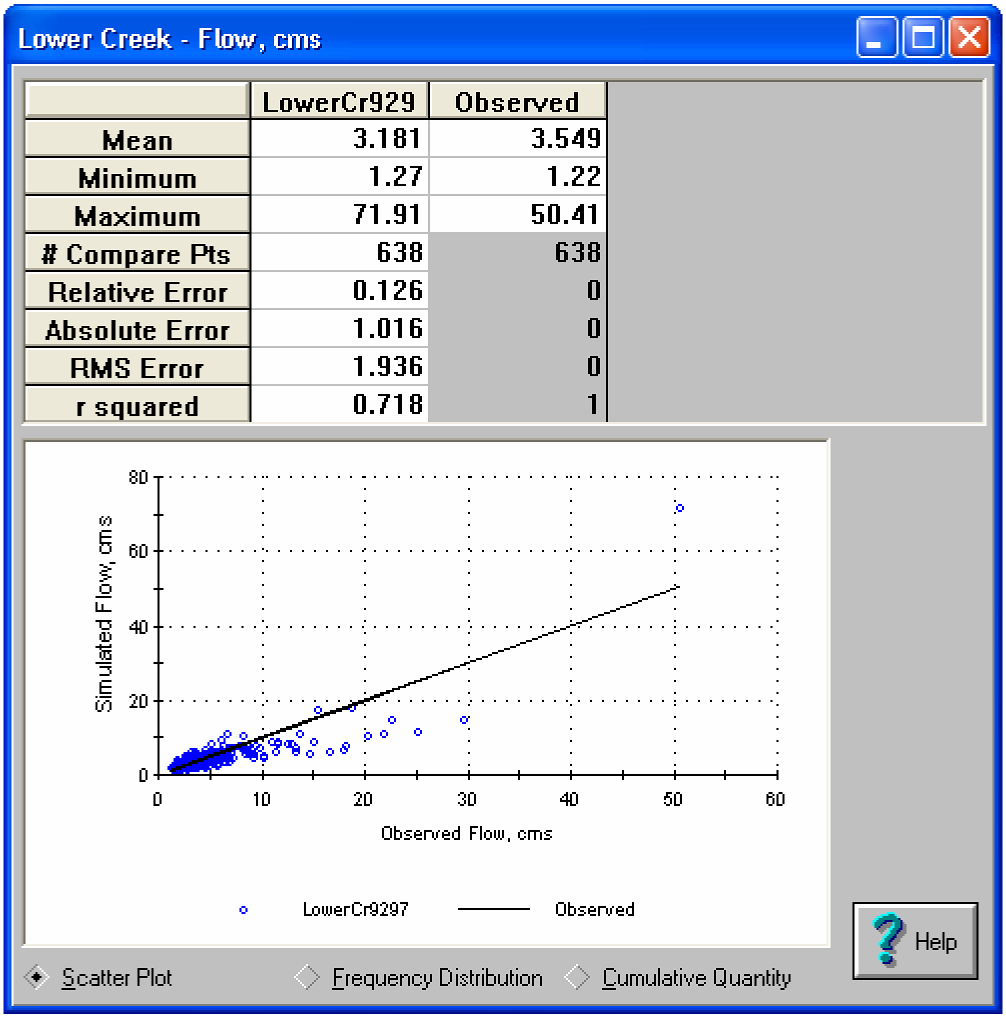



**Figure 1. Simulated and observed flow at Lower Creek.**



| | LowerCr929 | Observed |
|---|---|---|
| Mean | 3.181 | 3.549 |
| Minimum | 1.27 | 1.22 |
| Maximum | 71.91 | 50.41 |
| # Compare Pts | 638 | 638 |
| Relative Error | 0.126 | 0 |
| Absolute Error | 1.016 | 0 |
| RMS Error | 1.936 | 0 |
| r squared | 0.718 | 1 |



**Figure 2. Summary statistics and scatter plot for Lower Creek hydrology calibration.**

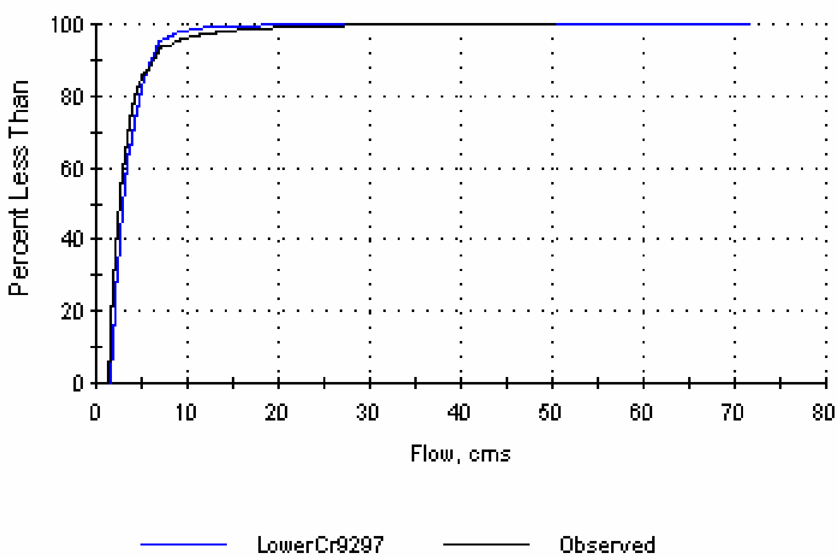



**Figure 3. Frequency distribution of flow for Lower Creek.**

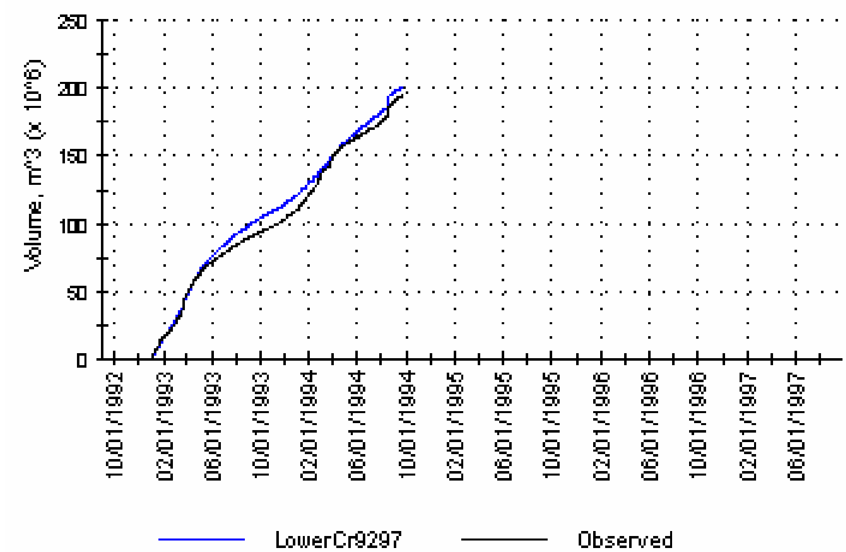



**Figure 4. Cumulative flow plot for Lower Creek.**

Figure 5 shows the simulated and observed temperature in Lower Creek for 1992-1997. The simulation shows good agreement with the seasonal pattern of temperature. Figure 6 and 7 show the summary statistics, scatter plot, and frequency distribution plot. The results indicate a good match of simulated with observed including an $R^2$ of 0.815. Figures 8-10 shows similar results for 1997-2003. The seasonal pattern of temperature is matched well and the resulting $R^2$ is 0.82.

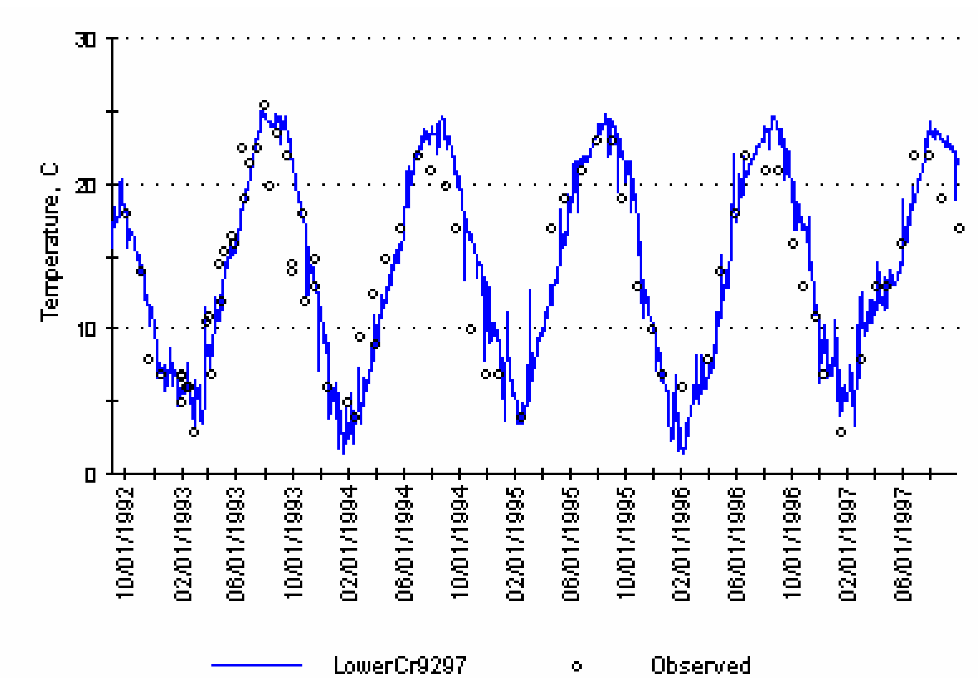
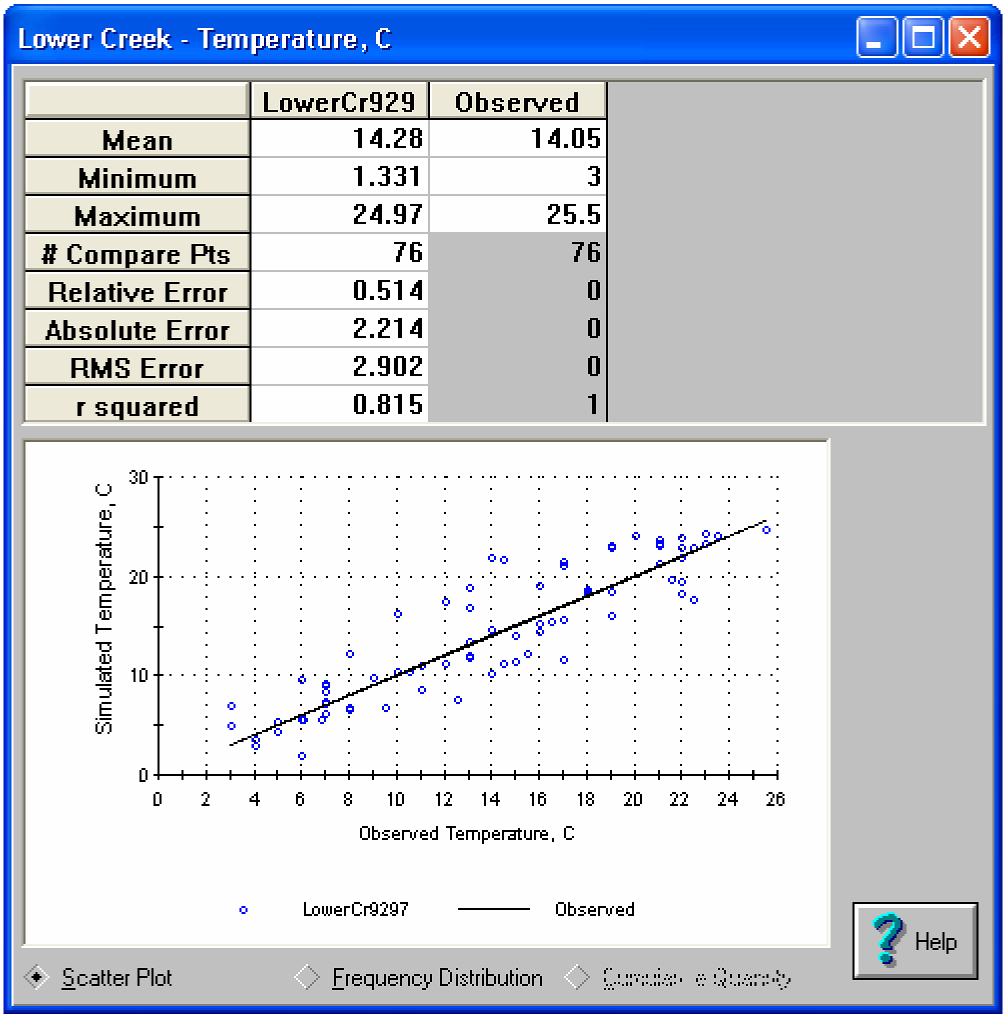



**Figure 5. Simulated and observed temperature in Lower Creek, 1992-1997.**



| | LowerCr929 | Observed |
|---|---|---|
| Mean | 14.28 | 14.05 |
| Minimum | 1.331 | 3 |
| Maximum | 24.97 | 25.5 |
| # Compare Pts | 76 | 76 |
| Relative Error | 0.514 | 0 |
| Absolute Error | 2.214 | 0 |
| RMS Error | 2.902 | 0 |
| r squared | 0.815 | 1 |



Figure 6. Summary statistics and scatter plot for Lower Creek temperature, 1992-1997.

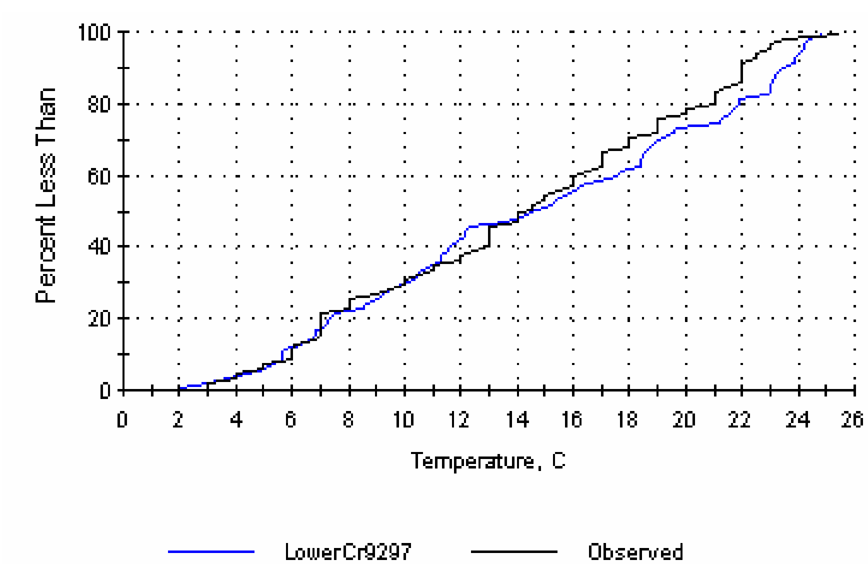



Figure 7. Frequency distribution plot for Lower Creek temperature 1992-1997.

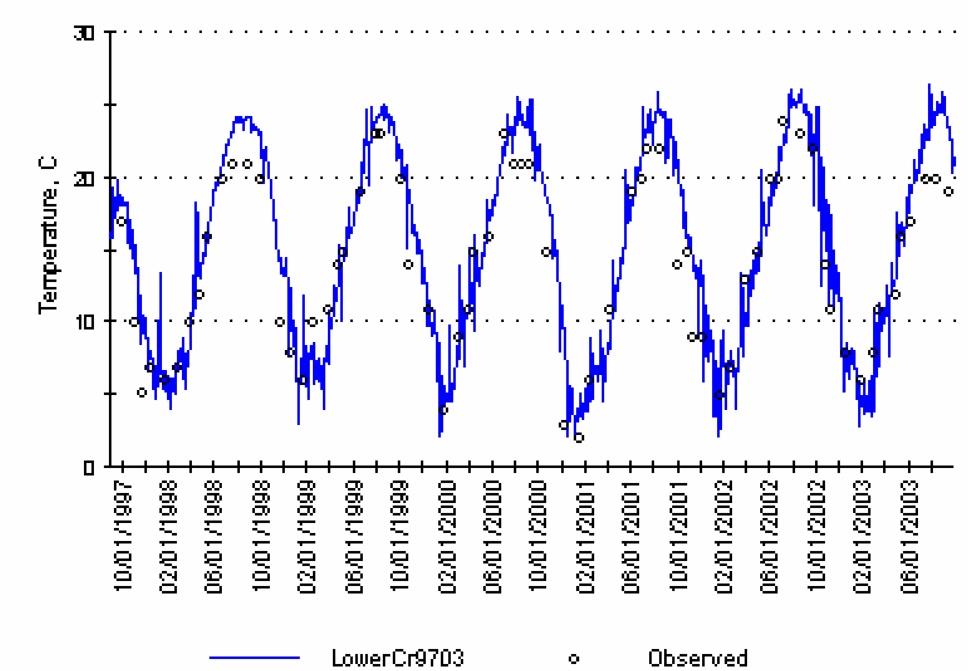



**Figure 8. Simulated and observed temperature in Lower Creek 1997-2003.**

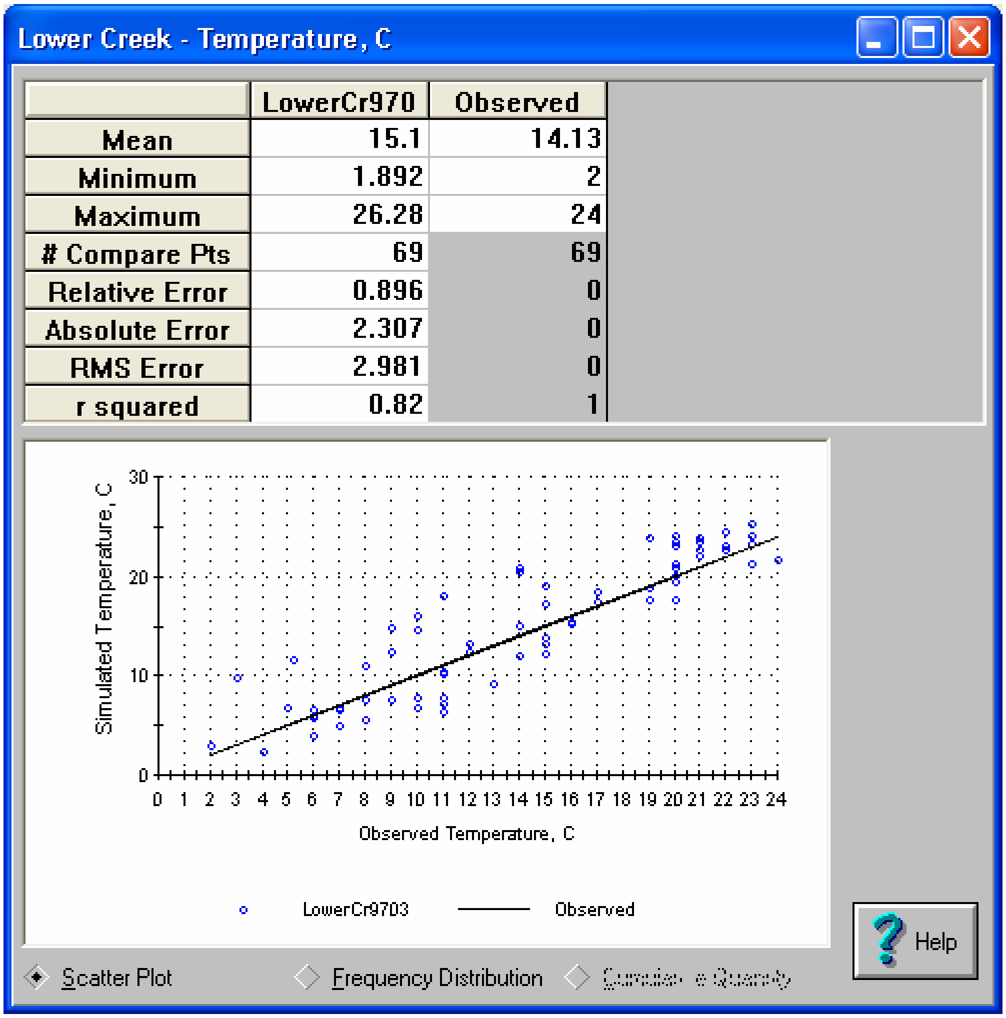



**Figure 9. Summary statistics and scatter plot for Lower Creek temperature, 1997-2003.**

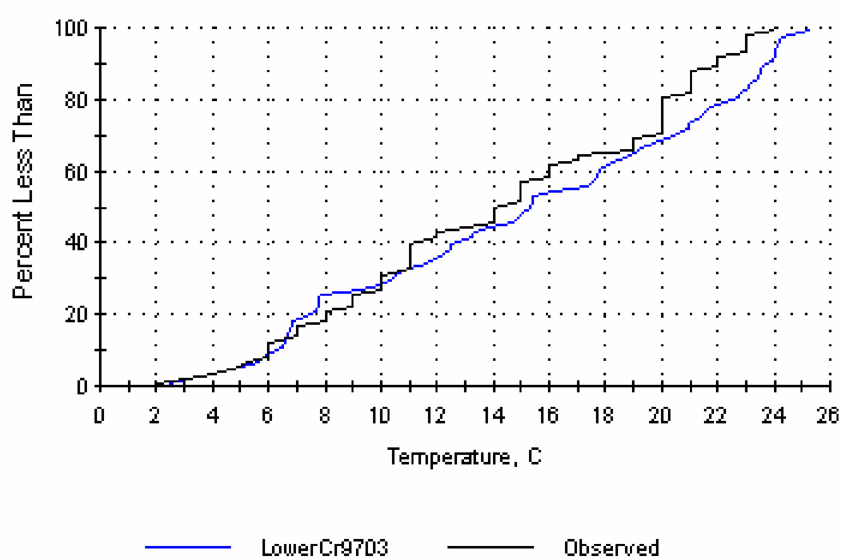



**Figure 10. Frequency distribution plot for Lower Creek temperature, 1997-2003.**

Figure 11 shows a comparison of simulated and observed pH for Lower Creek, 1992-1997. The observed range of pH from 6.2 to 7.6 was captured well by the model. Summary statistics, a scatter plot, and a frequency distribution plot are presented in Figures 12 and 13. Similar results were obtained when pH was simulated from 1997 through 2003 (Figure 14). Figures 15 and 16 show the summary statistics, scatter plot and frequency distribution plot for this time period.

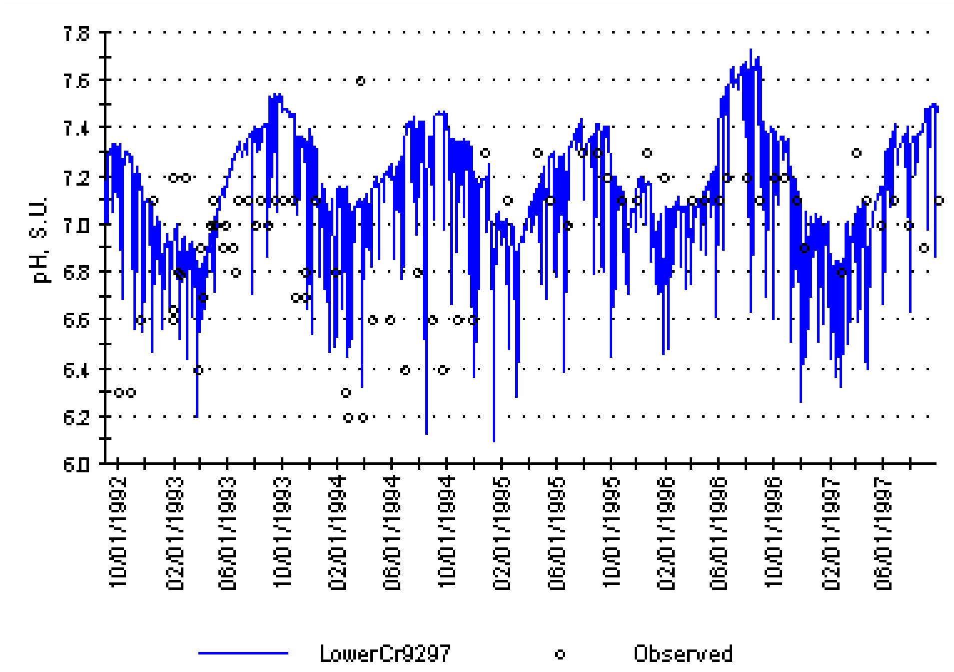
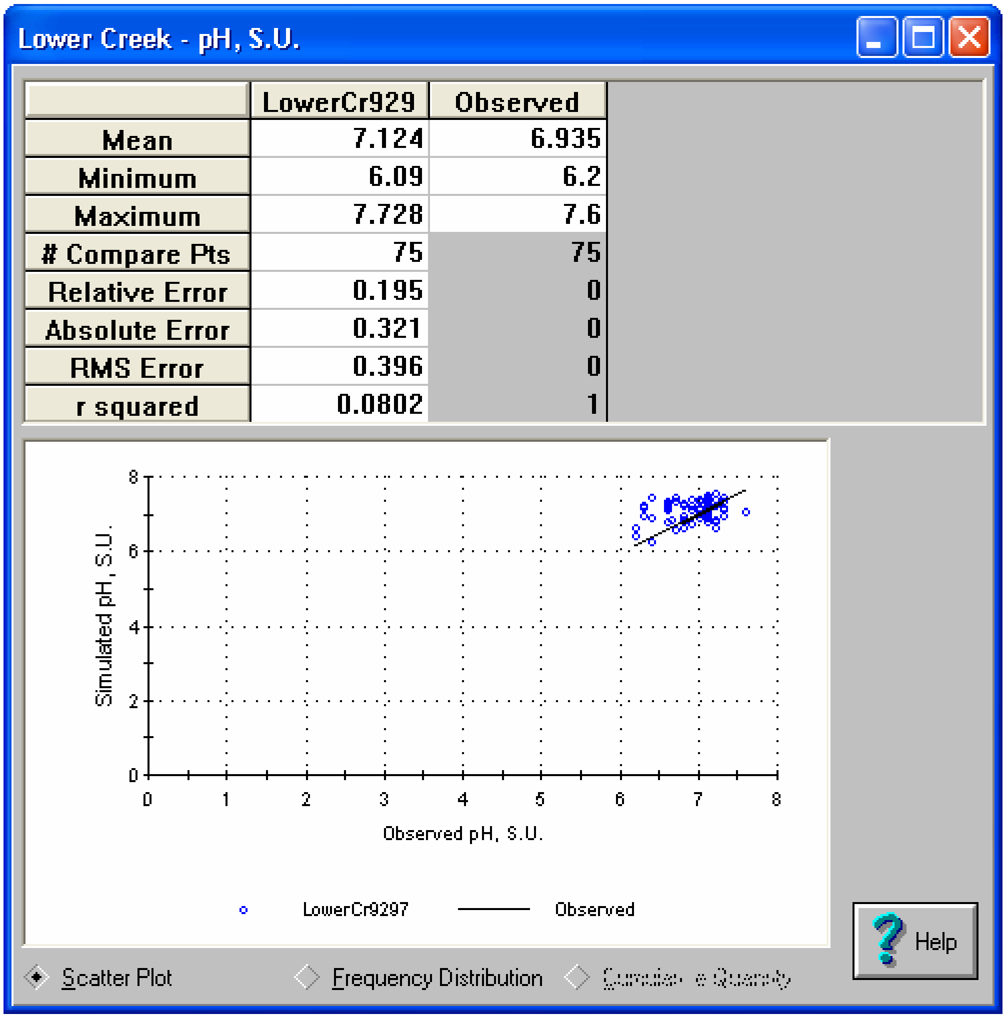



**Figure 11. Simulated and observed pH for Lower Creek, 1992-1997.**



| | LowerCr929 | Observed |
|---|---|---|
| Mean | 7.124 | 6.935 |
| Minimum | 6.09 | 6.2 |
| Maximum | 7.728 | 7.6 |
| # Compare Pts | 75 | 75 |
| Relative Error | 0.195 | 0 |
| Absolute Error | 0.321 | 0 |
| RMS Error | 0.396 | 0 |
| r squared | 0.0802 | 1 |



**Figure 12. Summary statistics and scatter plot for Lower Creek pH, 1992-1997.**

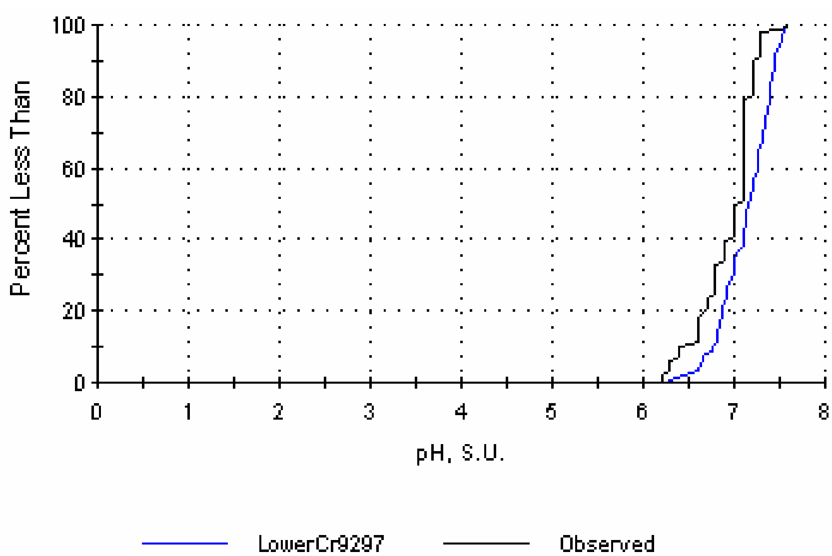



**Figure 13. Frequency distribution plot for Lower Creek pH, 1992-1997.**

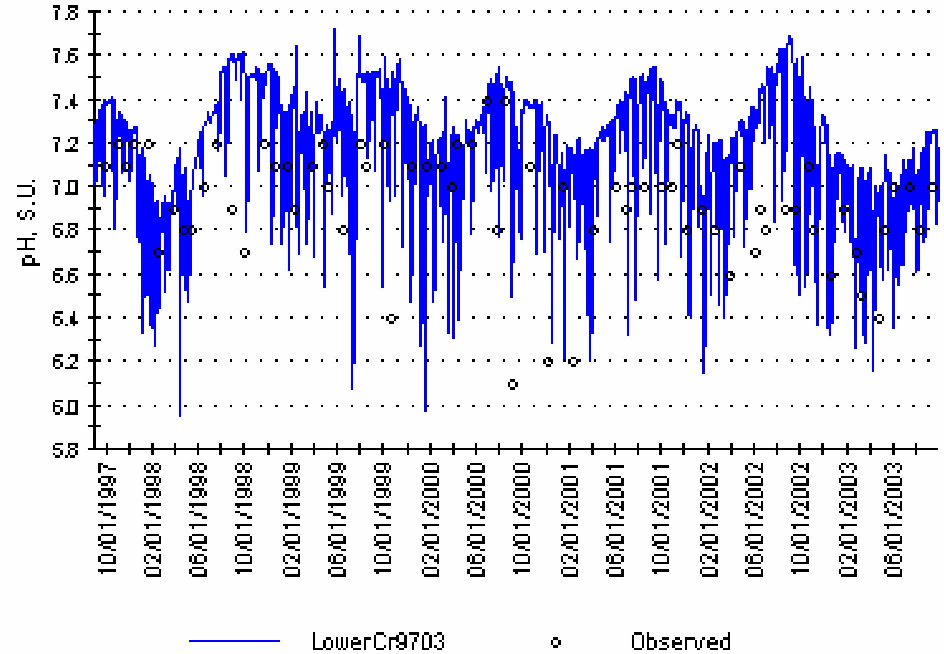
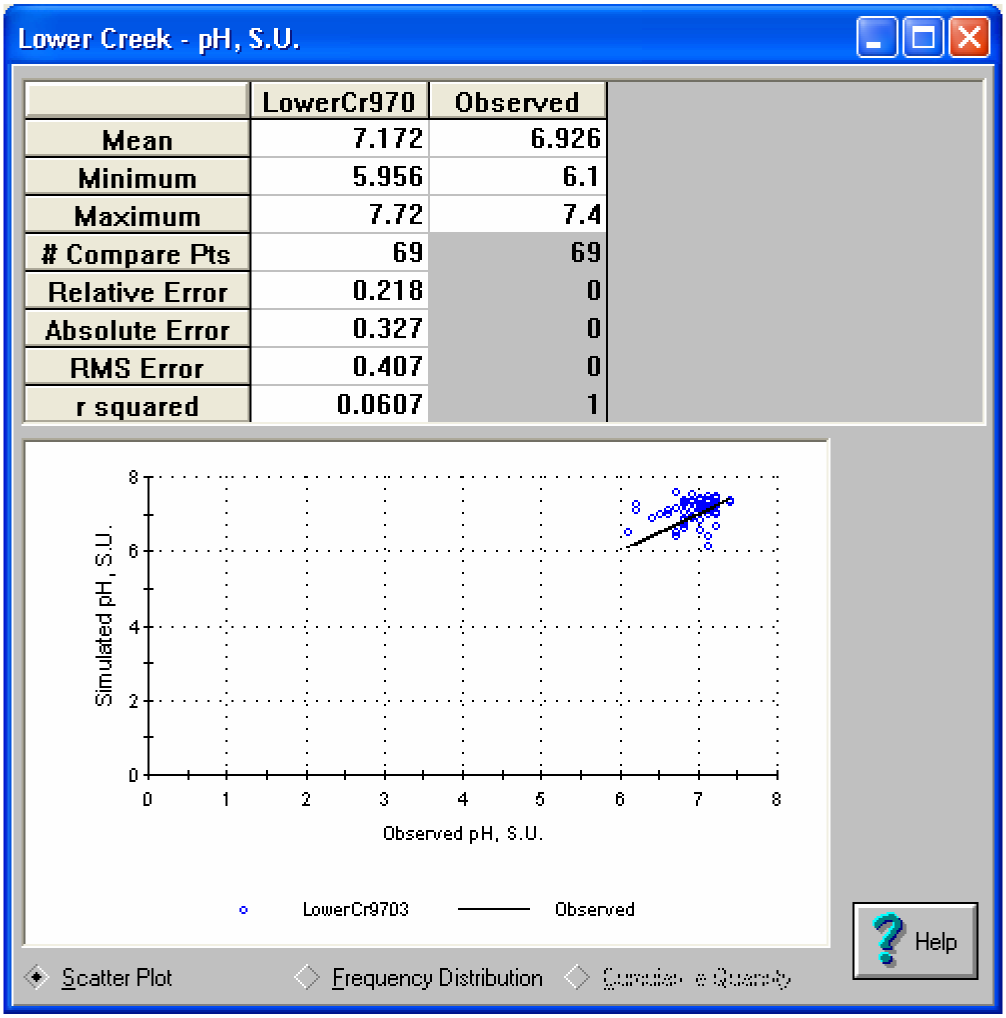



**Figure 14. Simulated and observed pH for Lower Creek, 1997-2003.**



| | LowerCr970 | Observed |
|---|---|---|
| Mean | 7.172 | 6.926 |
| Minimum | 5.956 | 6.1 |
| Maximum | 7.72 | 7.4 |
| # Compare Pts | 69 | 69 |
| Relative Error | 0.218 | 0 |
| Absolute Error | 0.327 | 0 |
| RMS Error | 0.407 | 0 |
| r squared | 0.0607 | 1 |



**Figure 15. Summary statistics and scatter plot for Lower Creek pH, 1997-2003.**

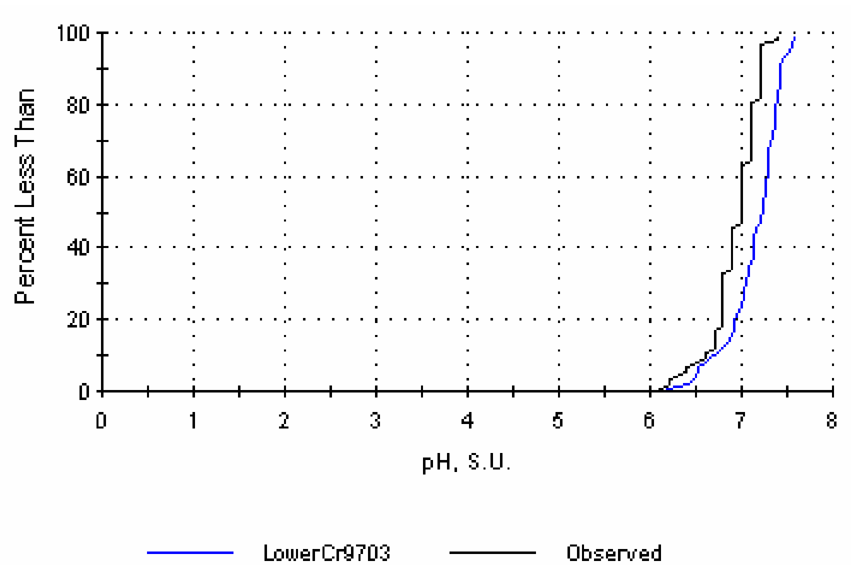



**Figure 16. Frequency distribution plot for Lower Creek pH, 1997-2003.**

Figure 17 shows simulated and observed ammonia in Lower Creek for 1992-1997. The range and general pattern of ammonia was captured well by the model. Figures 18 and 19 show summary statistics, a scatter plot and a cumulative frequency plot for this time period. Figure 20 shows a similar comparison of simulated and observed ammonia for 1997-2003. Again, the range and general pattern was matched well. The increased ammonia concentrations predicted during 1998 and 1999 correspond to increased loading from the City of Lenoir WWTP. Summary statistics, a scatter plot and cumulative frequency plot are presented in Figures 21 and 22.

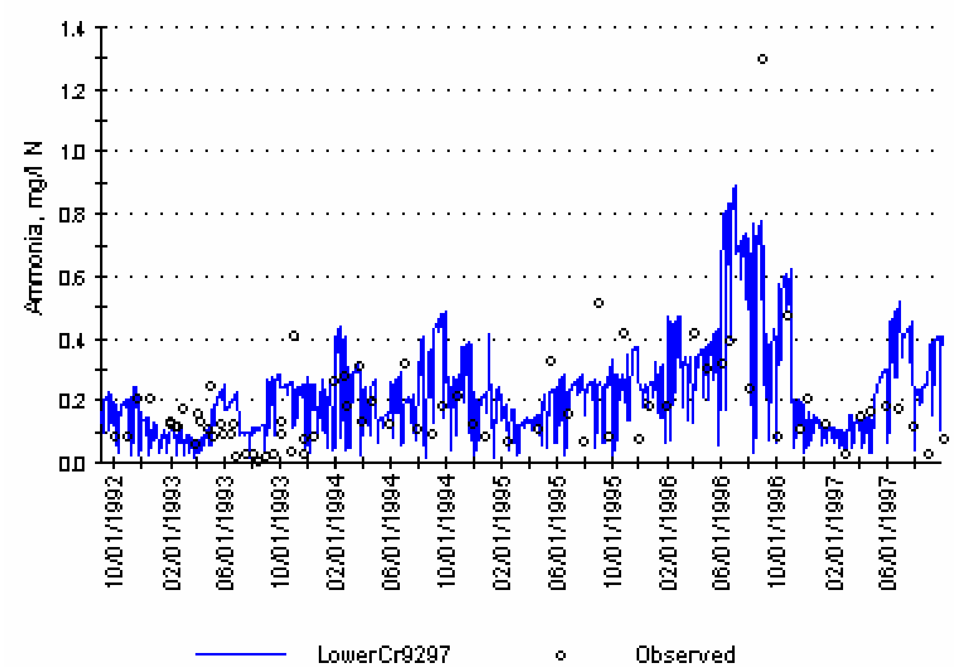



**Figure 17. Simulated and observed ammonia in Lower Creek 1992-1997.**

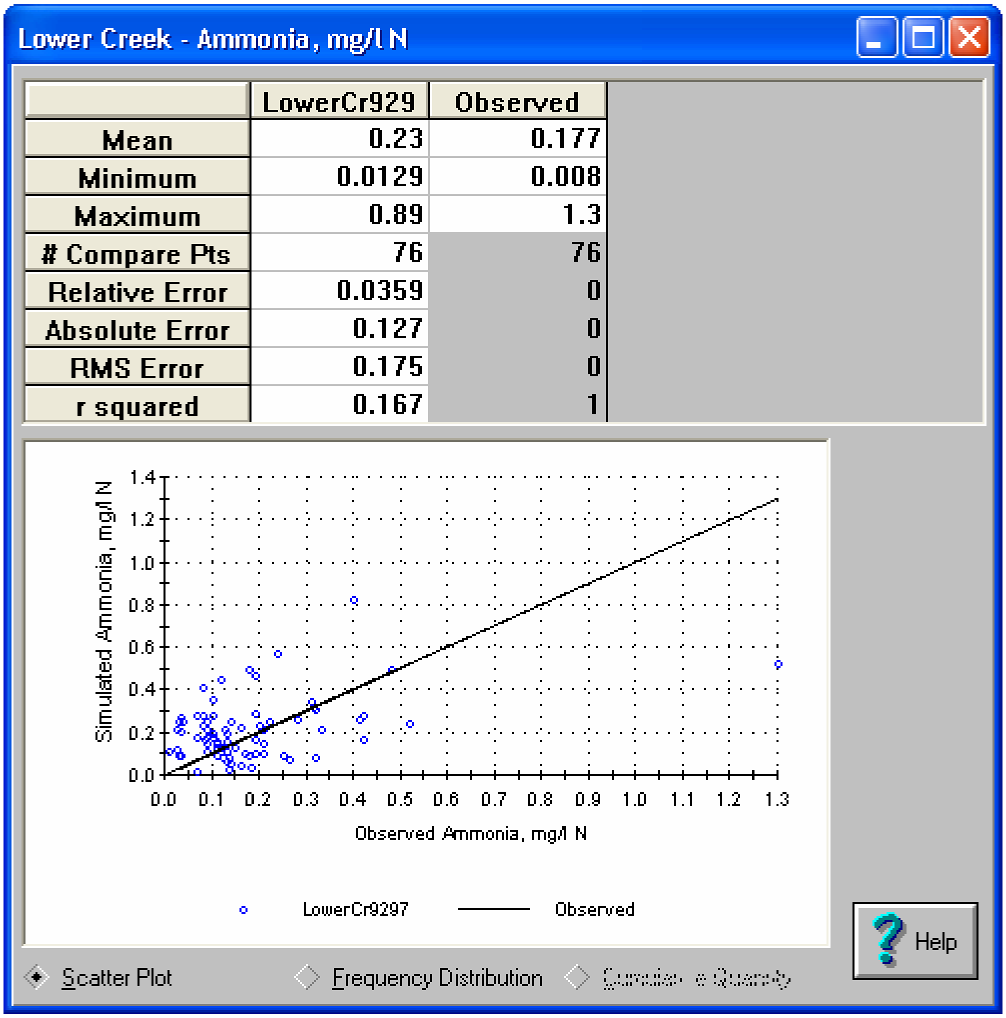


**Figure 18. Summary statistics and scatter plot for Lower Creek ammonia, 1992-1997.**

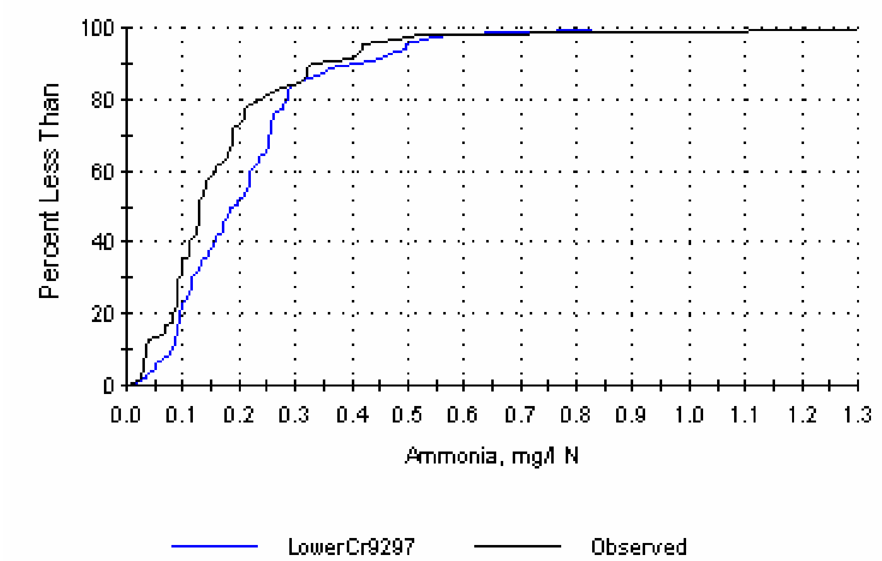



**Figure 19. Frequency distribution plot for Lower Creek ammonia, 1992-1997.**

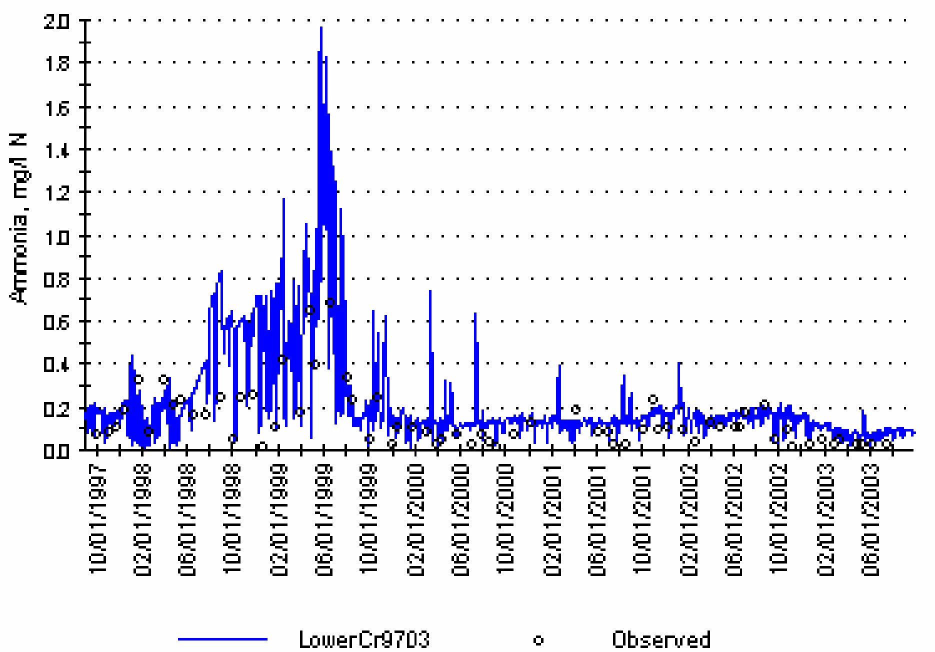
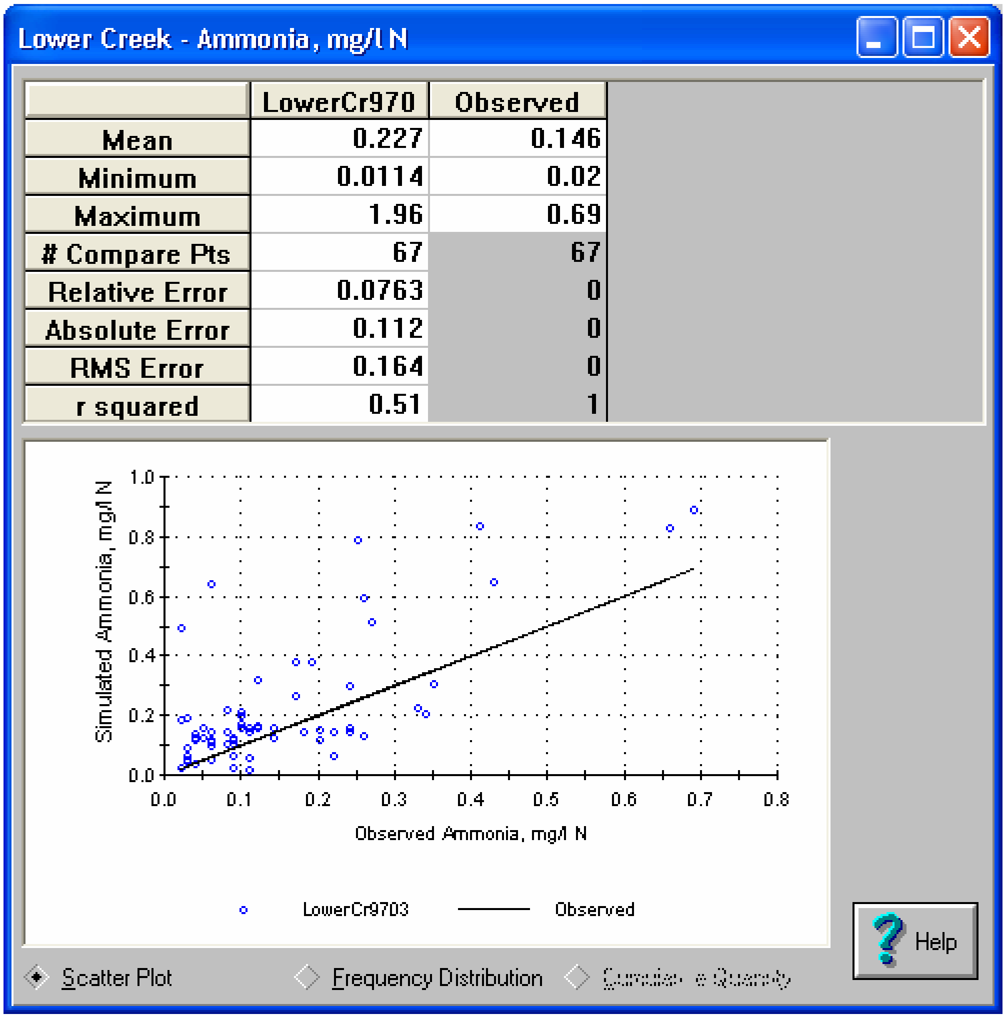



**Figure 20. Simulated and observed ammonia in Lower Creek, 1997-2003.**



| | LowerCr970 | Observed |
|---|---|---|
| Mean | 0.227 | 0.146 |
| Minimum | 0.0114 | 0.02 |
| Maximum | 1.96 | 0.69 |
| # Compare Pts | 67 | 67 |
| Relative Error | 0.0763 | 0 |
| Absolute Error | 0.112 | 0 |
| RMS Error | 0.164 | 0 |
| r squared | 0.51 | 1 |



**Figure 21. Summary statistics and scatter plot for Lower Creek ammonia, 1997-2003.**

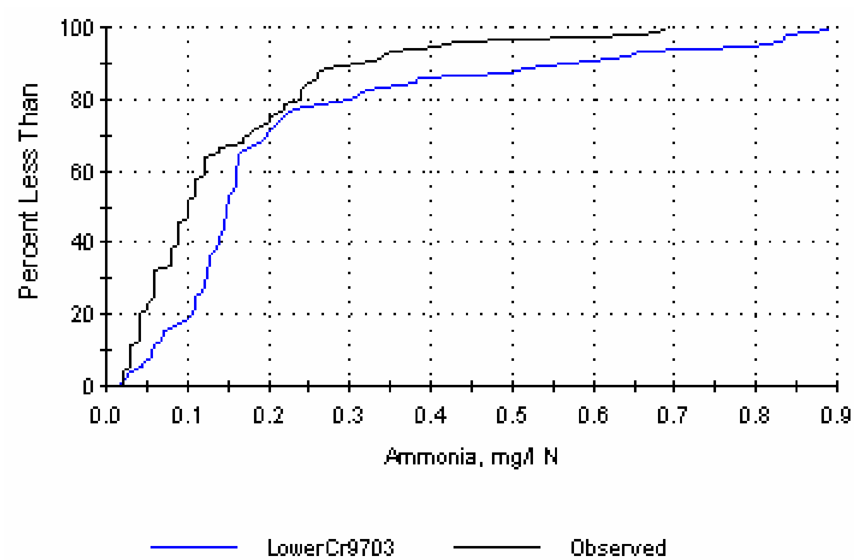



**Figure 22. Frequency distribution plot for Lower Creek ammonia, 1997-2003.**

Figure 23 shows simulated and observed nitrate in Lower Creek 1992-1997. WARMF simulated the observed range between 0.2 and 1.0 mg/L though some simulated peaks went as high as 1.5 mg/L. Summary statistics, a scatter plot and a frequency distribution plot are provided in Figures 24 and 25. Similar results were seen for nitrate simulations during 1997-2003 (Figures 26-28). As with ammonia, the spike in nitrate during 1999 corresponds with an increased nitrogen loading from the City of Lenoir WWTP during that time.

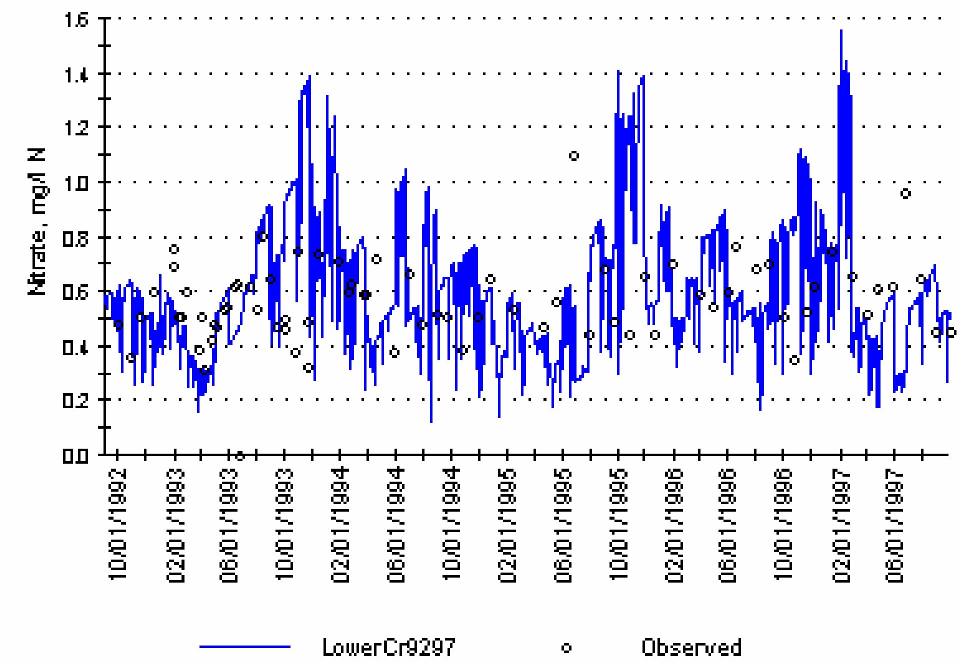
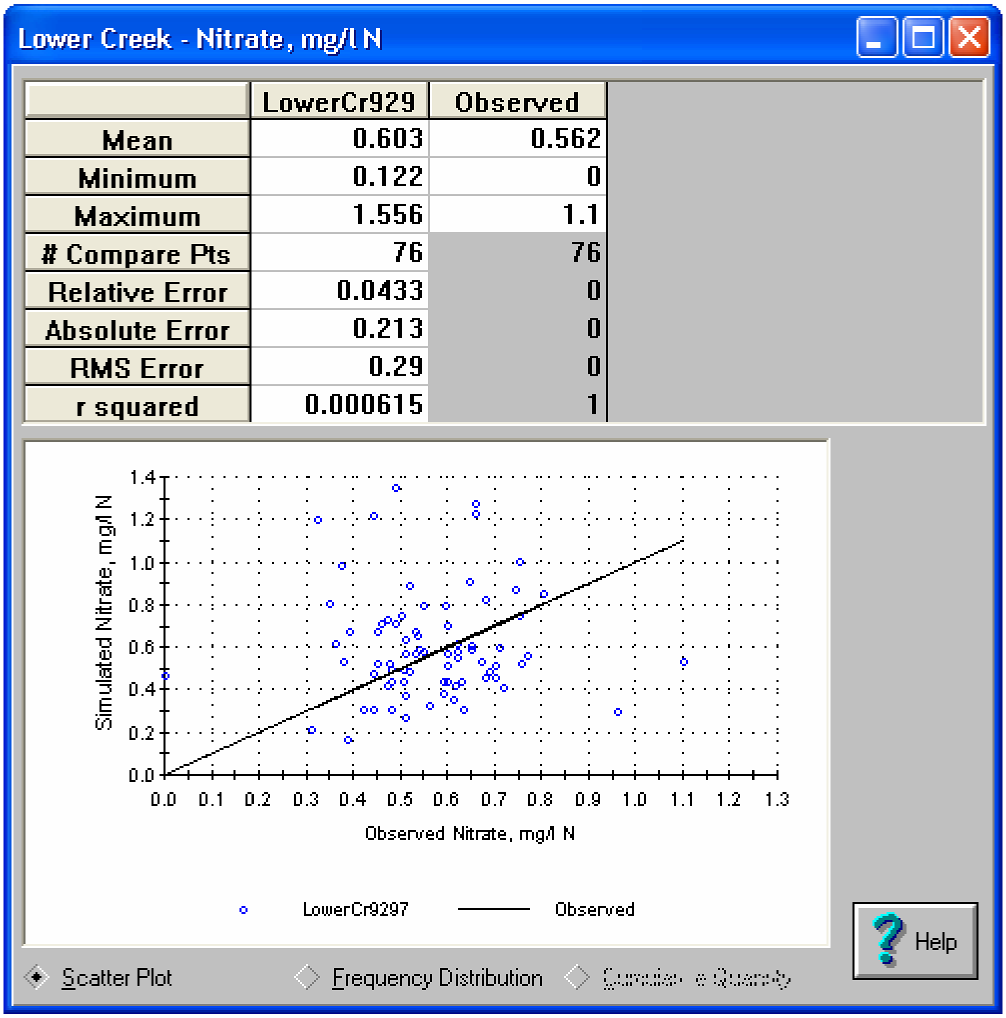



**Figure 23. Simulated and observed nitrate in Lower Creek, 1992-1997.**



| | LowerCr929 | Observed |
| --- | --- | --- |
| Mean | 0.603 | 0.562 |
| Minimum | 0.122 | 0 |
| Maximum | 1.556 | 1.1 |
| # Compare Pts | 76 | 76 |
| Relative Error | 0.0433 | 0 |
| Absolute Error | 0.213 | 0 |
| RMS Error | 0.29 | 0 |
| r squared | 0.000615 | 1 |



**Figure 24. Summary statistics and scatter plot for Lower Creek nitrate, 1992-1997.**

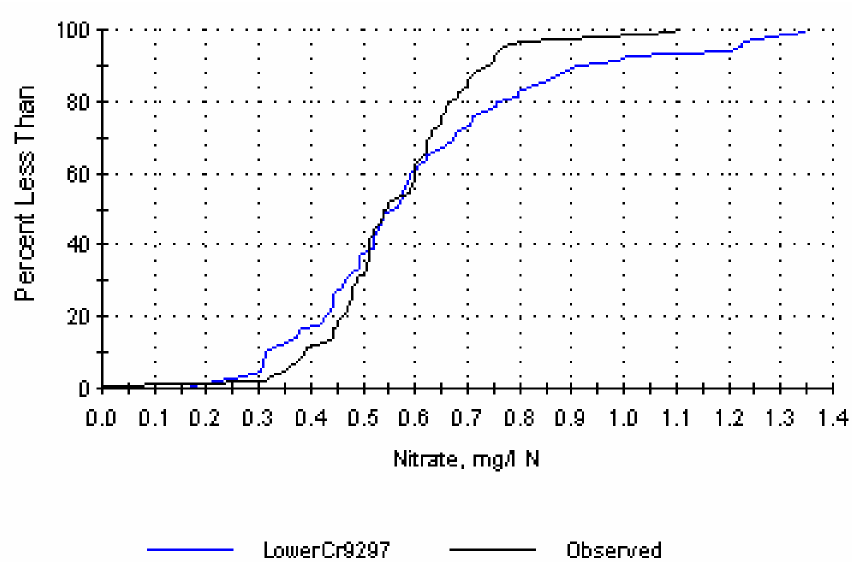



**Figure 25. Frequency distribution plot for Lower Creek nitrate, 1992-1997.**

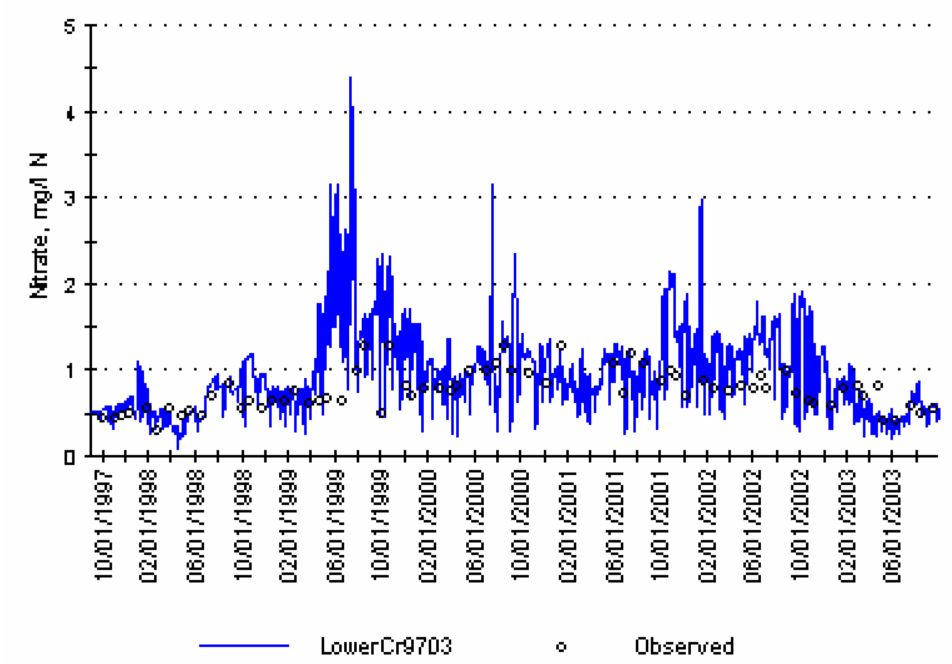
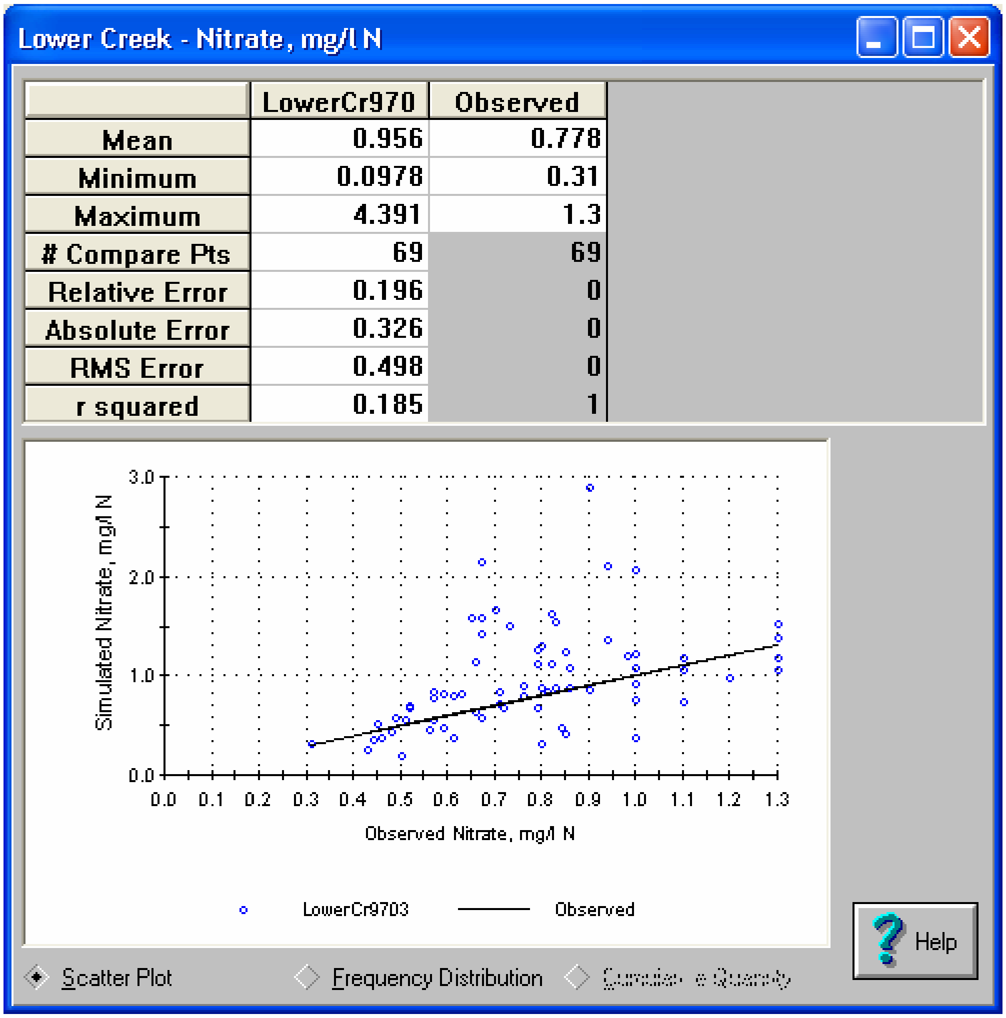



**Figure 26. Simulated and observed nitrate in Lower Creek, 1997-2003.**



| | LowerCr970 | Observed |
|---|---|---|
| Mean | 0.956 | 0.778 |
| Minimum | 0.0978 | 0.31 |
| Maximum | 4.391 | 1.3 |
| # Compare Pts | 69 | 69 |
| Relative Error | 0.196 | 0 |
| Absolute Error | 0.326 | 0 |
| RMS Error | 0.498 | 0 |
| r squared | 0.185 | 1 |



Figure 27. Summary statistics and scatter plot for Lower Creek nitrate, 1997-2003.

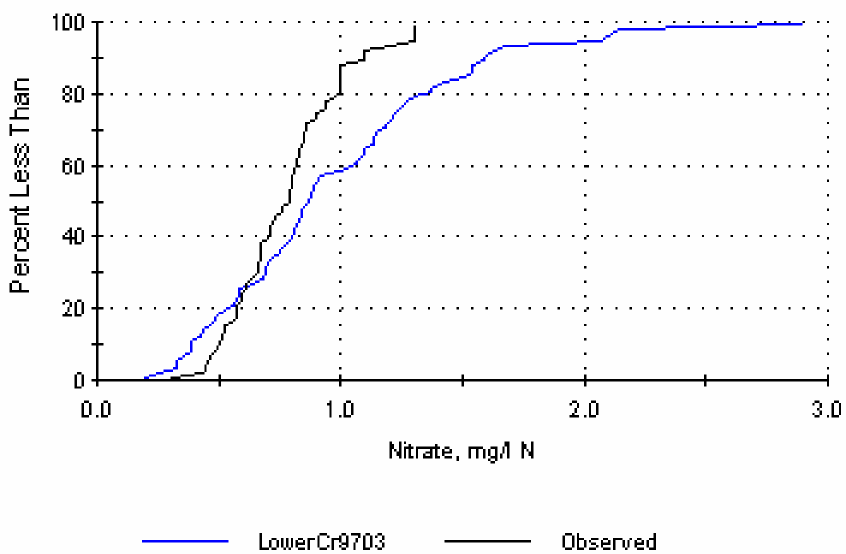



Figure 28. Frequency distribution plot for Lower Creek nitrate 1997-2003.

Figure 29 shows simulated and observed fecal coliform results in Lower Creek for 1992-1997. Note that the plot is in a log scale due to the high range of possible values. Simulated fecal coliform counts fall within the range of observed though some of the highest and lowest counts are outside of the simulated range. Figures 30 and 31 provide summary statistics, a scatter plot and a frequency distribution plot for this time period. Similar results are presented for 1997-2003 in Figures 32-34. For both time periods, a comparison of simulated and observed mean values, and the frequency plots indicate a good correlation between simulated and observed fecal coliform.

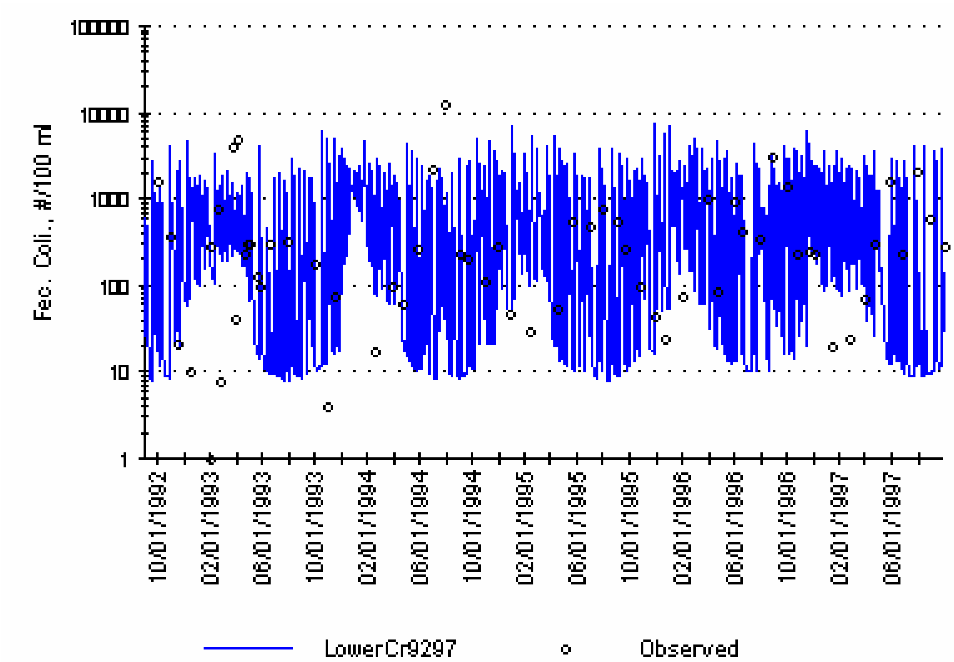
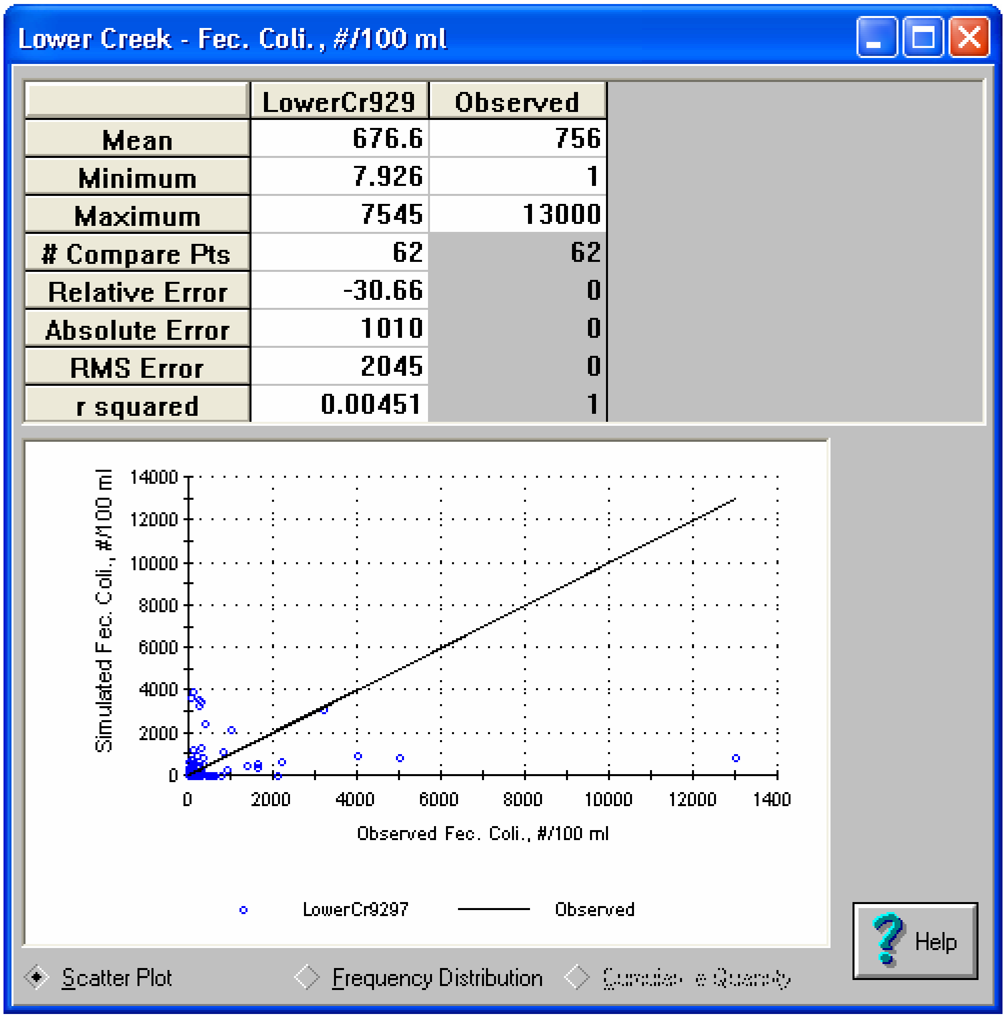


**Figure 29. Simulated and observed fecal coliform in Lower Creek 1992-1997.**




| | LowerCr929 | Observed |
|---|---|---|
| Mean | 676.6 | 756 |
| Minimum | 7.926 | 1 |
| Maximum | 7545 | 13000 |
| # Compare Pts | 62 | 62 |
| Relative Error | -30.66 | 0 |
| Absolute Error | 1010 | 0 |
| RMS Error | 2045 | 0 |
| r squared | 0.00451 | 1 |

**Figure 30. Summary statistics and scatter plot for Lower Creek fecal coliform, 1992-1997.**

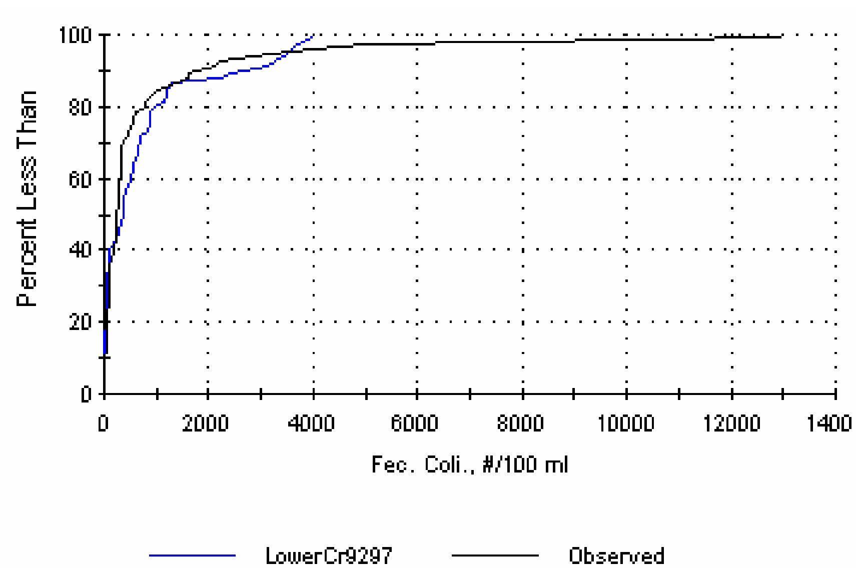



**Figure 31. Frequency distribution plot for Lower Creek fecal coliform, 1992-1997.**

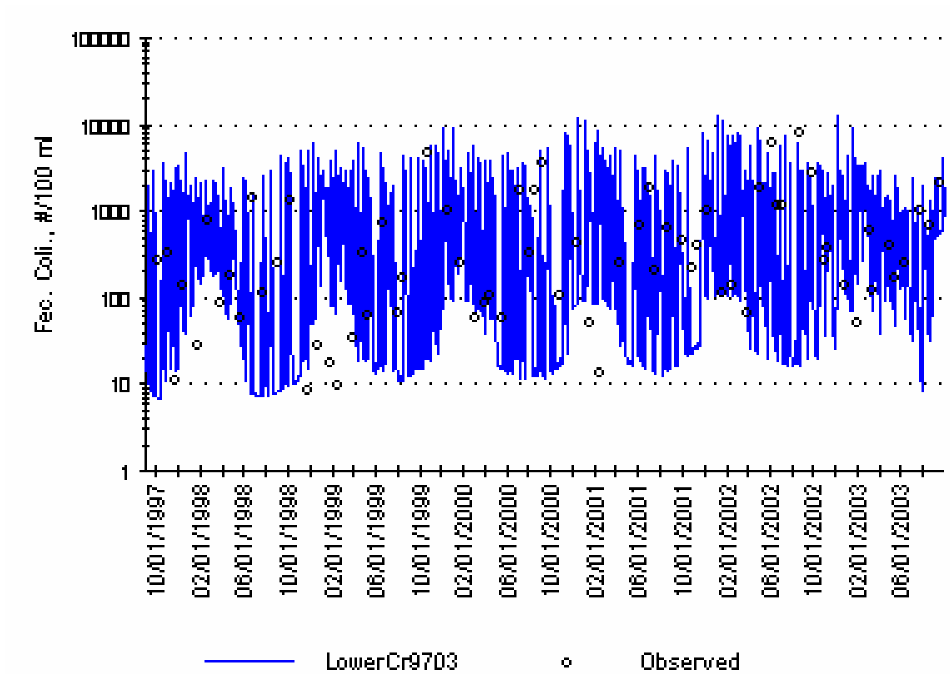
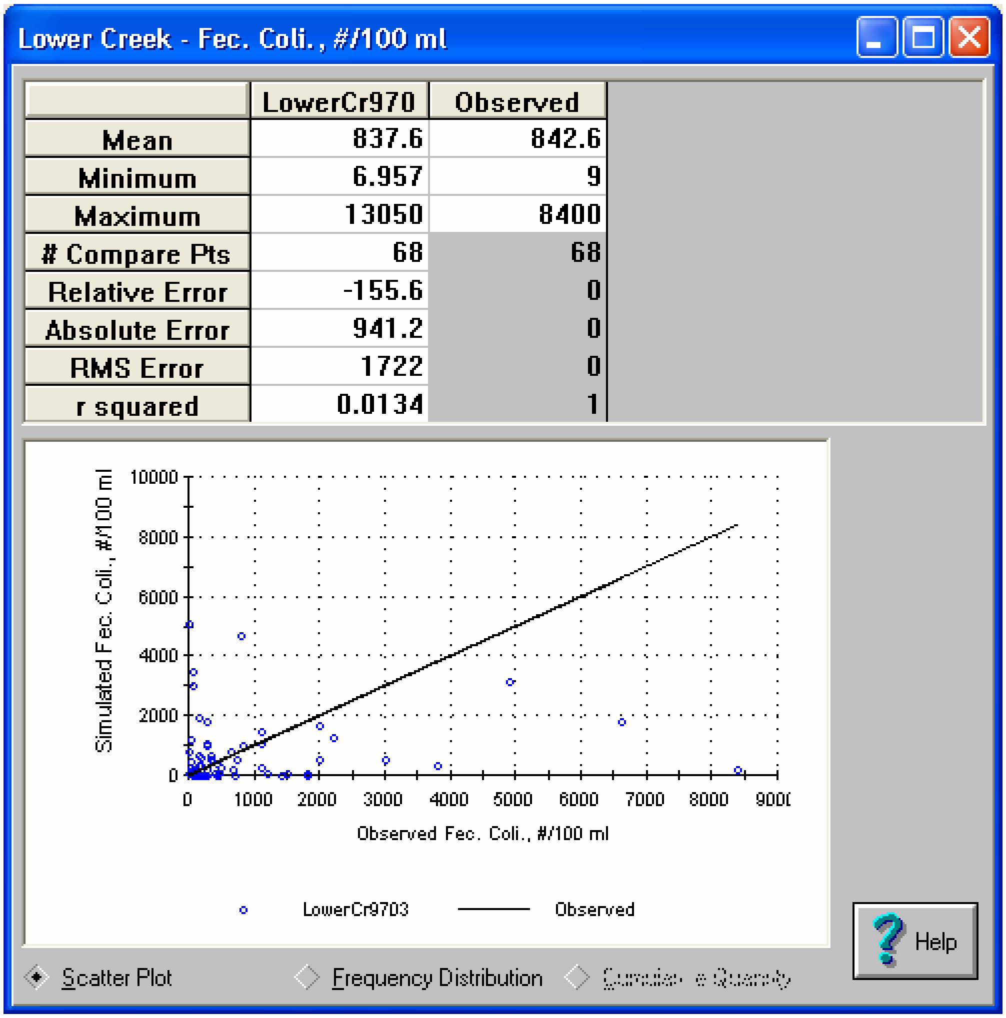



**Figure 32. Simulated and observed fecal coliform in Lower Creek, 1997-2003.**



| | LowerCr970 | Observed |
|---|---|---|
| Mean | 837.6 | 842.6 |
| Minimum | 6.957 | 9 |
| Maximum | 13050 | 8400 |
| # Compare Pts | 68 | 68 |
| Relative Error | -155.6 | 0 |
| Absolute Error | 941.2 | 0 |
| RMS Error | 1722 | 0 |
| r squared | 0.0134 | 1 |



Figure 33. Summary statistics and scatter plot for Lower Creek fecal coliform, 1997-2003.

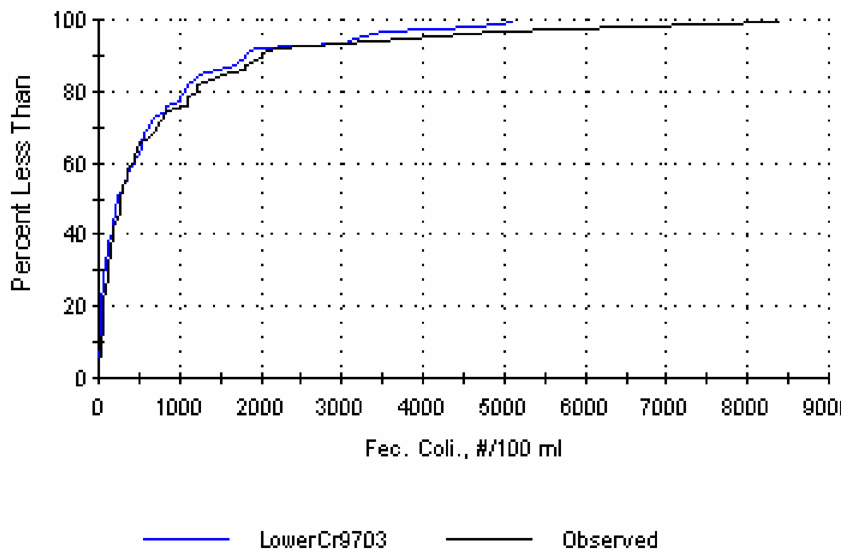



Figure 34. Frequency distribution plot for Lower Creek fecal coliform, 1997-2003.

Figure 35 shows simulated and observed dissolved oxygen in Lower Creek for 1992-1997. The seasonal pattern and range is predicted well by WARMF, however some of the high peaks and low dips were not predicted. This variation may be partly due to the models inability to capture diurnal variations because simulations were performed on a daily timestep. The summary statistics, scatter plot and frequency distribution plot shown in figures 36 and 37 indicate a good match when considering mean, minimum and maximum values and an $R^2$ of 0.632. Figures 38-40 show very comparable results for dissolved oxygen simulations for 1997-2003. An $R^2$ of 0.67 was reported for this simulation.

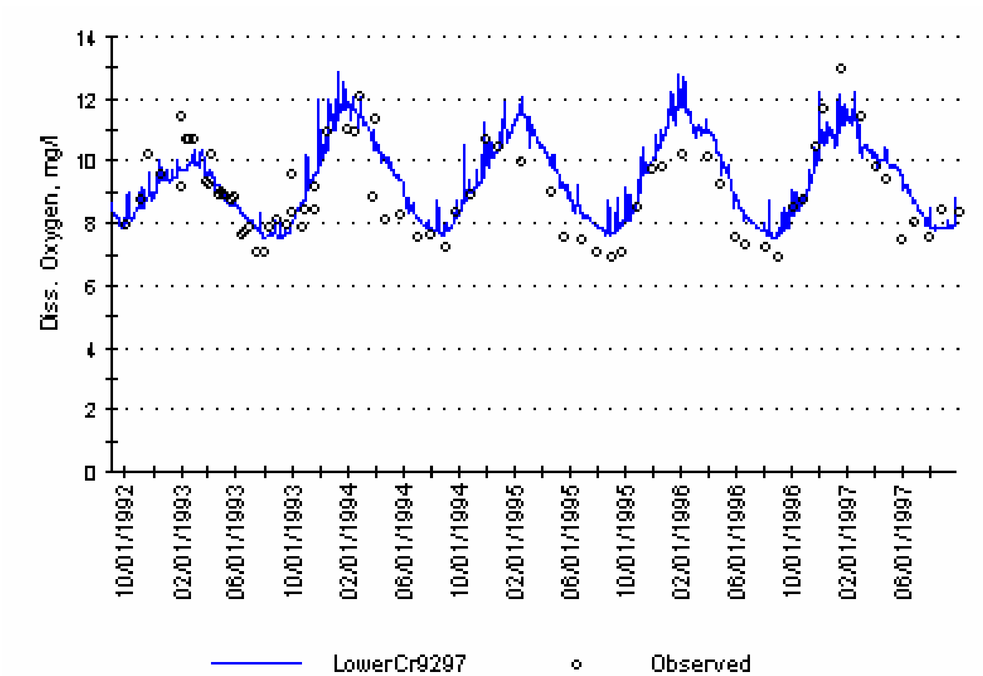
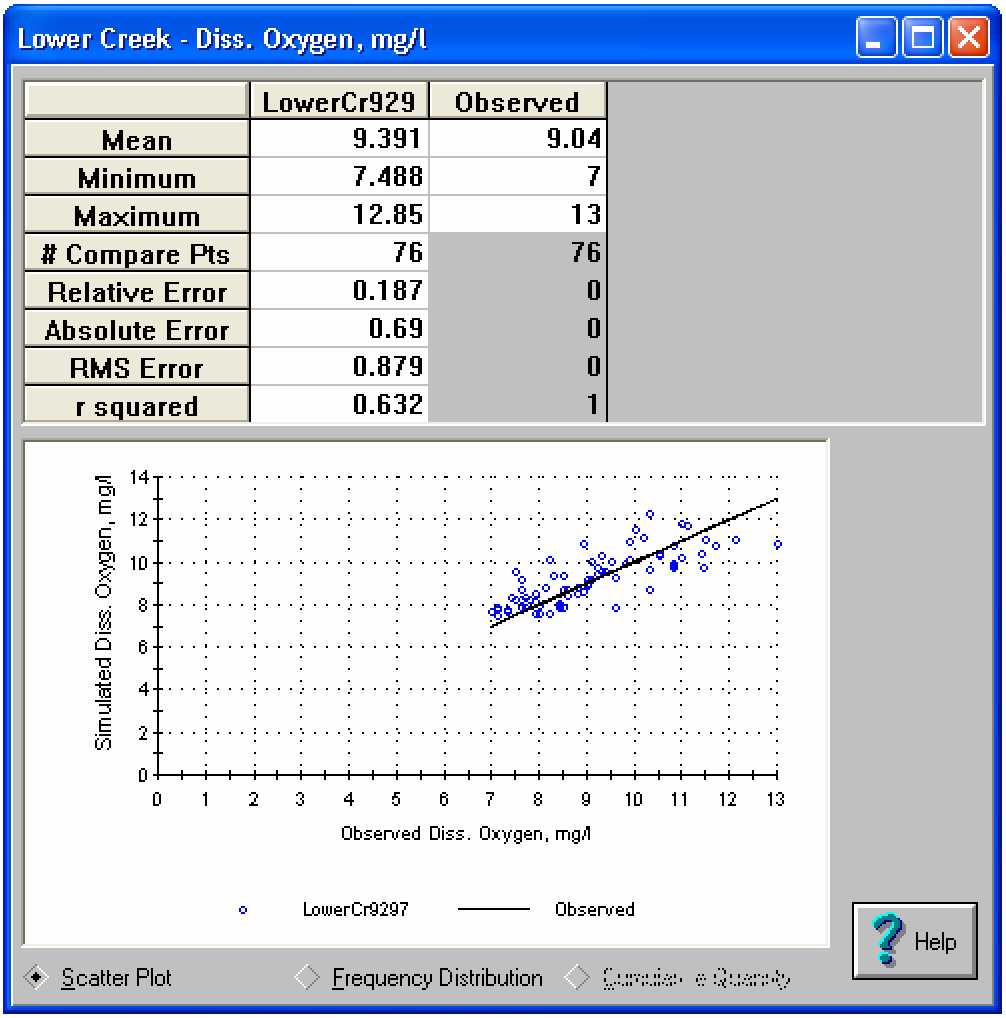



**Figure 35. Simulated and observed dissolved oxygen in Lower Creek, 1992-1997.**



| | LowerCr929 | Observed |
|---|---|---|
| Mean | 9.391 | 9.04 |
| Minimum | 7.488 | 7 |
| Maximum | 12.85 | 13 |
| # Compare Pts | 76 | 76 |
| Relative Error | 0.187 | 0 |
| Absolute Error | 0.69 | 0 |
| RMS Error | 0.879 | 0 |
| r squared | 0.632 | 1 |



**Figure 36. Summary statistics and scatter plot for Lower Creek dissolved oxygen, 1992-1997.**

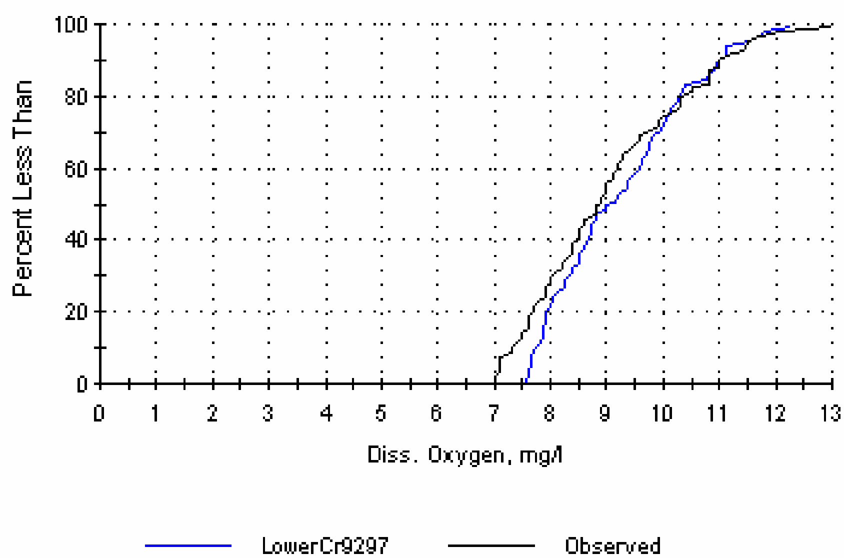



**Figure 37. Frequency distribution plot for Lower Creek dissolved oxygen, 1992-1997.**

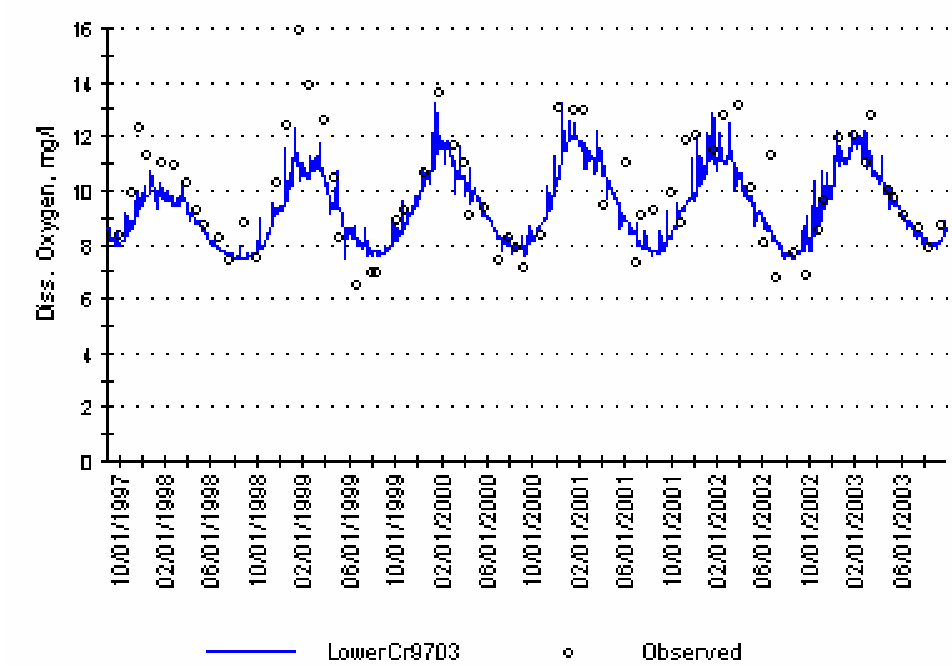
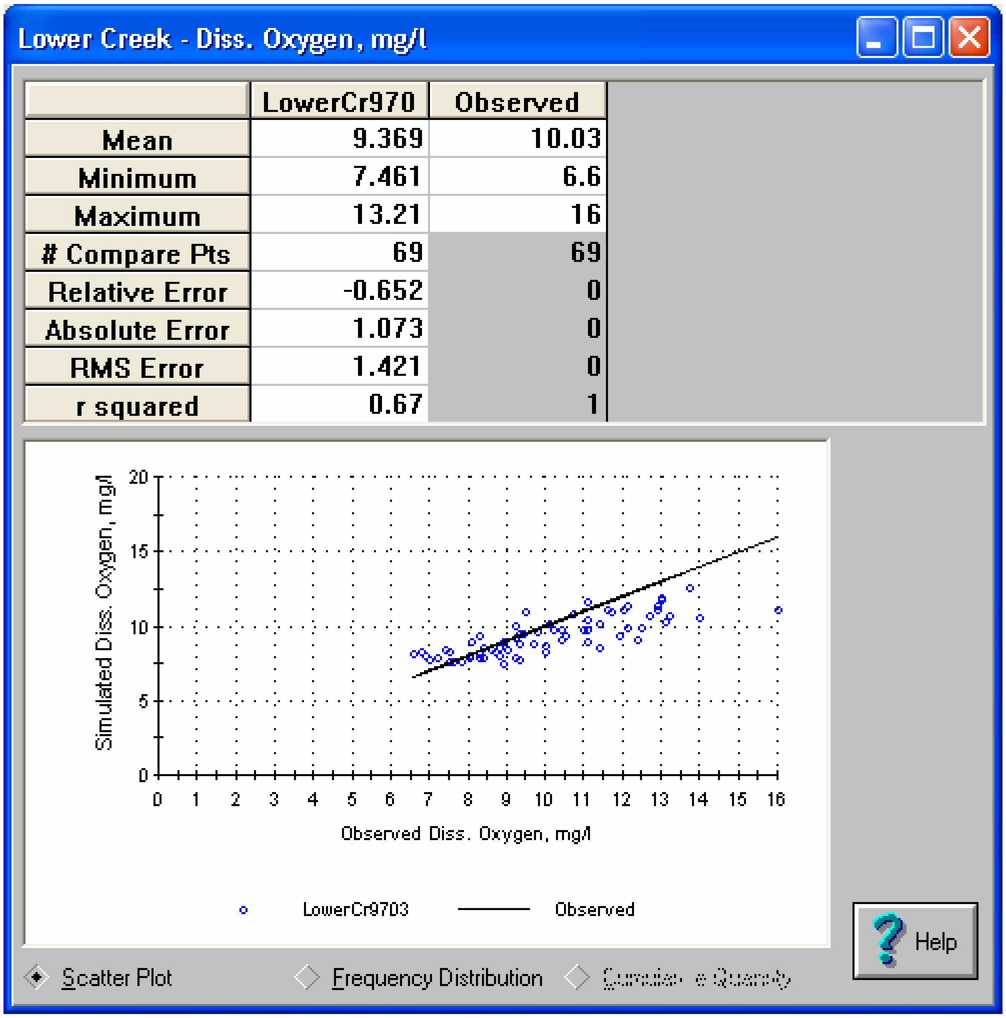



**Figure 38. Simulated and observed dissolved oxygen in Lower Creek, 1997-2003.**



| | LowerCr970 | Observed |
|---|---|---|
| Mean | 9.369 | 10.03 |
| Minimum | 7.461 | 6.6 |
| Maximum | 13.21 | 16 |
| # Compare Pts | 69 | 69 |
| Relative Error | -0.652 | 0 |
| Absolute Error | 1.073 | 0 |
| RMS Error | 1.421 | 0 |
| r squared | 0.67 | 1 |



**Figure 39. Summary statistics and scatter plot for Lower Creek dissolved oxygen, 1997-2003.**

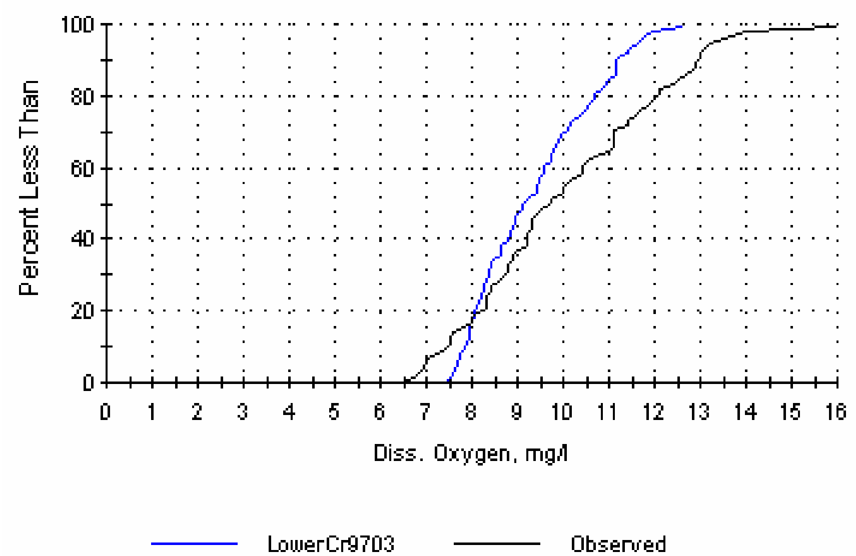



**Figure 40. Frequency distribution plot for Lower Creek dissolved oxygen, 1997-2003.**

Figure 41 compares simulated and observed total phosphorus for Lower Creek, 1992-1997. The model predicted a reasonable pattern within the range of observed data. The high spike predicted in 1994 corresponds to a very high flow event (50 cms observed) during which there was significant sediment transport and thus adsorbed phosphorus in the stream. Figures 42 and 43 provide a statistical comparison, scatter plot and frequency distribution plot. Figure 44 compares simulated and observed total phosphorus in Lower Creek, 1997-2003. Figures 45 and 46 provide a statistical summary, scatter plot and frequency distribution plot. The simulation for the later time period (1997-2003) was a much better match to observed data than the simulation for 1992-1997. This is most likely due to the quality of point source data for the different time periods. For, 1992 to 1998, average monthly point source loading were specified in WARMF. For 1999 to 2003, daily loading data was available. The higher resolution of input data yielded better predictions by the model.

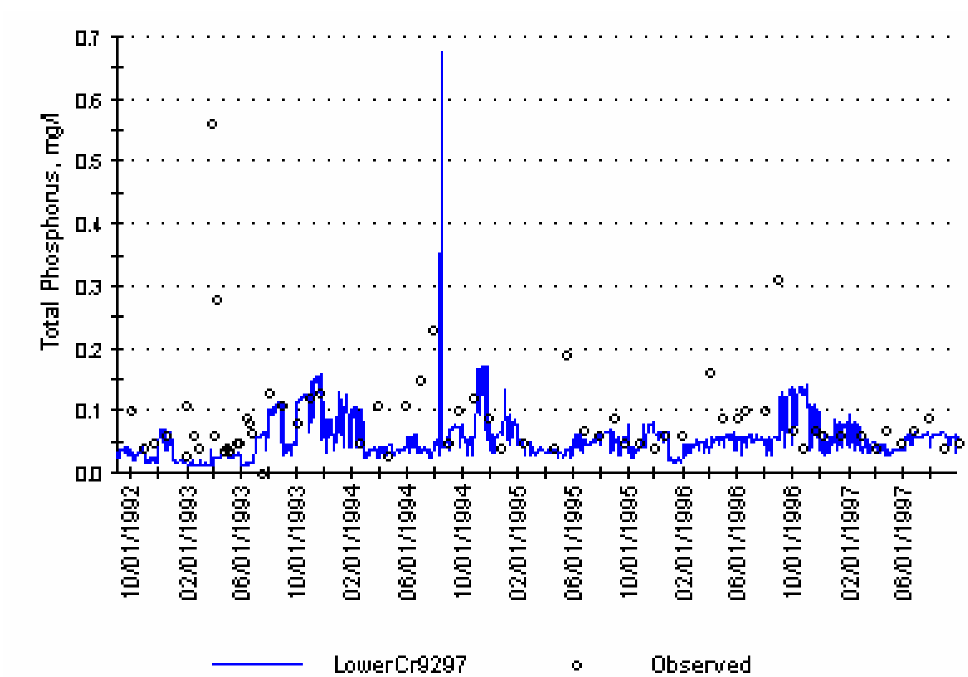
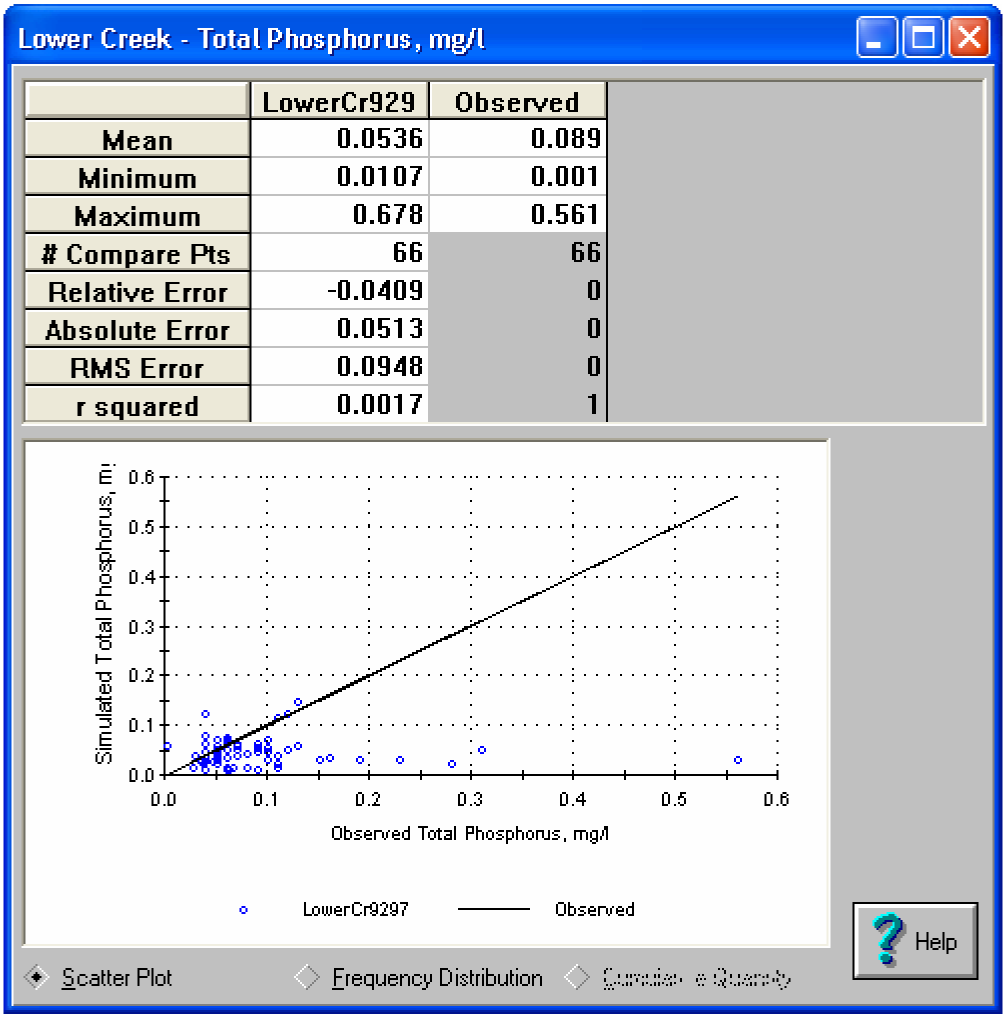



**Figure 41. Simulated and observed total phosphorus in Lower Creek, 1992-1997.**



| | LowerCr929 | Observed |
|---|---|---|
| Mean | 0.0536 | 0.089 |
| Minimum | 0.0107 | 0.001 |
| Maximum | 0.678 | 0.561 |
| # Compare Pts | 66 | 66 |
| Relative Error | -0.0409 | 0 |
| Absolute Error | 0.0513 | 0 |
| RMS Error | 0.0948 | 0 |
| r squared | 0.0017 | 1 |



**Figure 42. Summary statistics and scatter plot for Lower Creek total phosphorus, 1992-1997.**

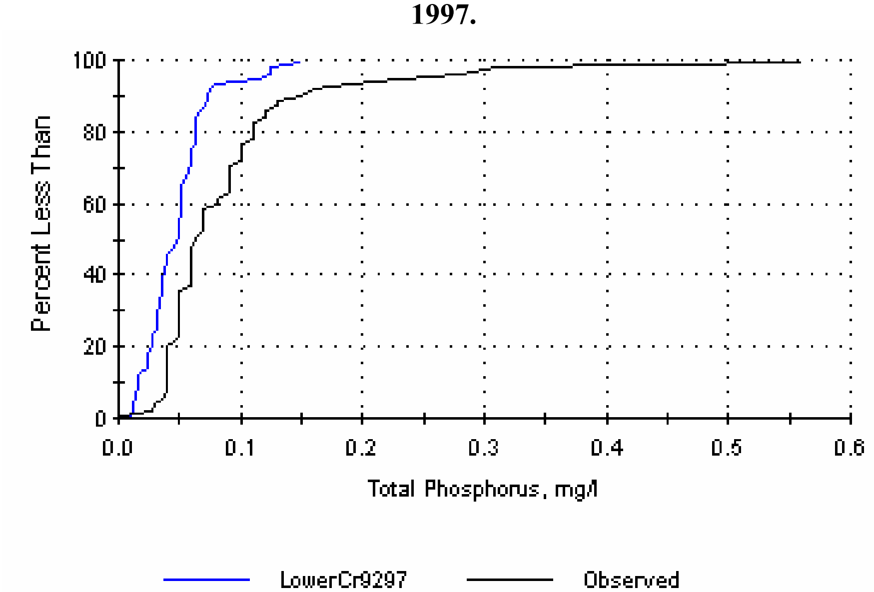



**Figure 43. Frequency distribution plot for Lower Creek total phosphorus, 1992-1997.**

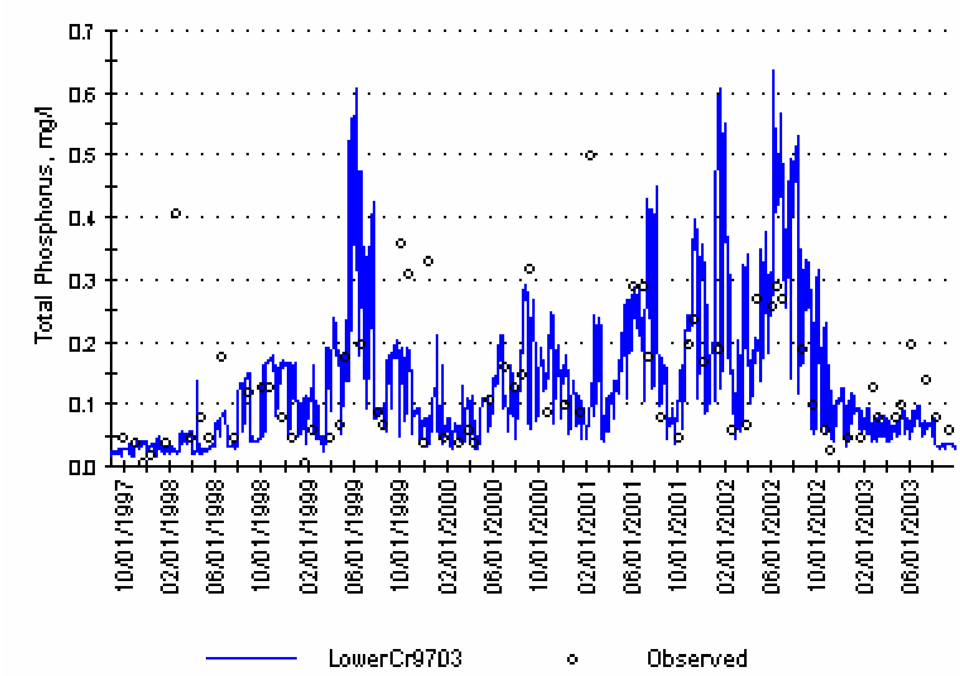
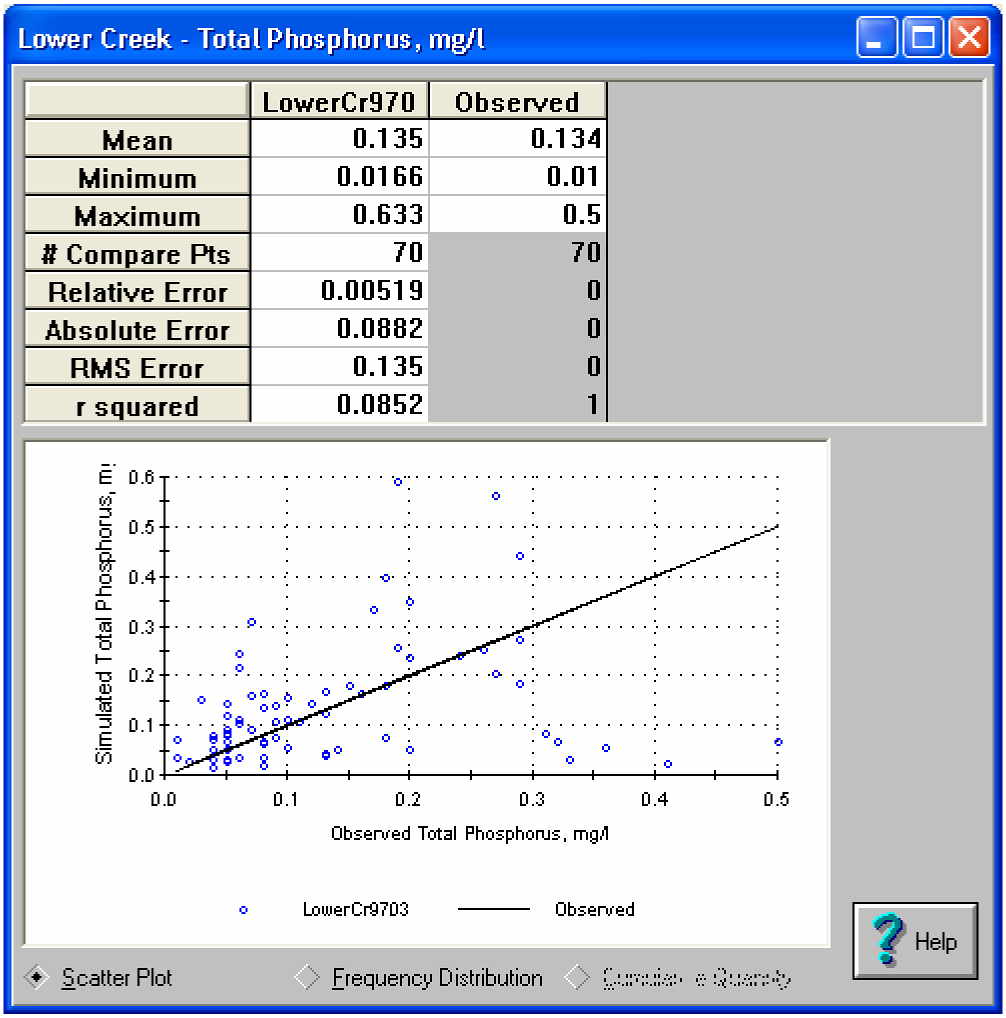



**Figure 44. Simulated and observed total phosphorus in Lower Creek, 1997-2003.**



| | LowerCr970 | Observed |
|---|---|---|
| Mean | 0.135 | 0.134 |
| Minimum | 0.0166 | 0.01 |
| Maximum | 0.633 | 0.5 |
| # Compare Pts | 70 | 70 |
| Relative Error | 0.00519 | 0 |
| Absolute Error | 0.0882 | 0 |
| RMS Error | 0.135 | 0 |
| r squared | 0.0852 | 1 |



**Figure 45. Summary statistics and scatter plot for Lower Creek total phosphorus, 1997-2003.**

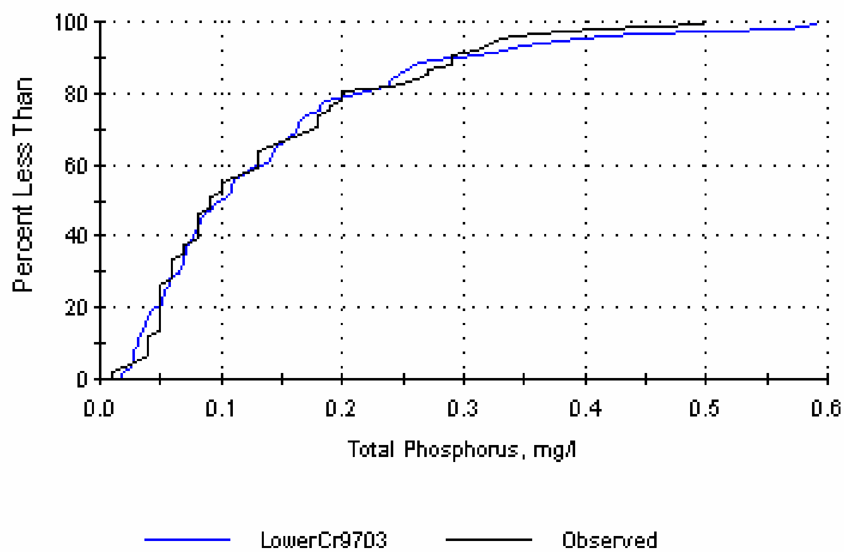



**Figure 46. Frequency distribution plot for Lower Creek total Phosphorus, 1997-2003.**

Figure 47 compares simulated and observed total nitrogen in Lower Creek, 1992-1997. Simulated values fall within the range of observed data. The spike of total nitrogen in 1994 corresponds to a high flow event, and is due to adsorbed ammonia being transported with sediment. A statistical summary, scatter plot and frequency distribution plot are shown in Figures 48 and 49. Similar results are presented for the 1998-2003 time period in Figures 50-52. The high concentrations of total nitrogen simulated in 1999 correspond with high nitrogen loadings from the City of Lenoir WWTP.

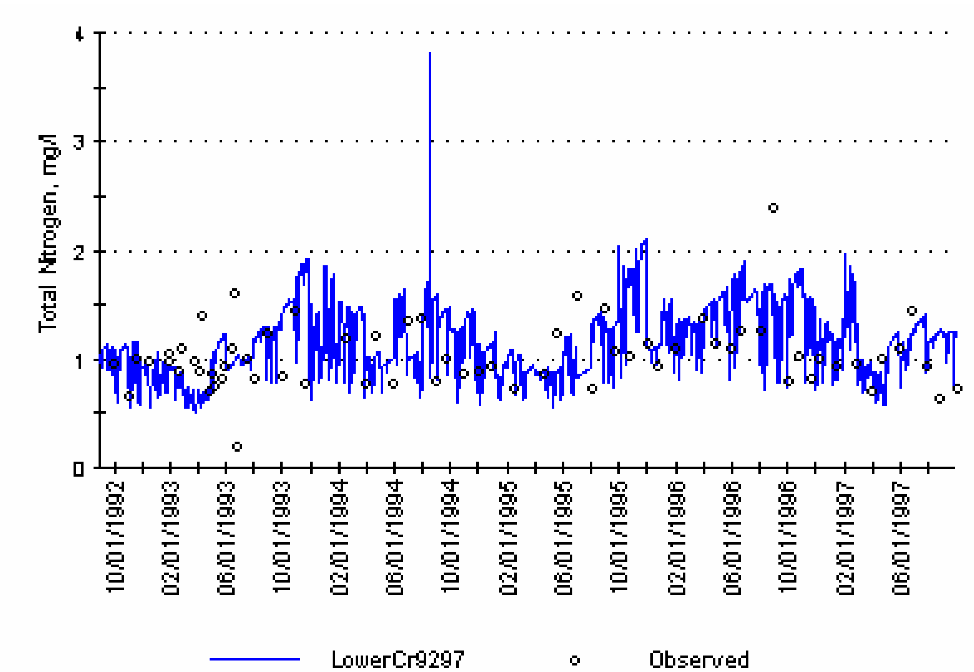
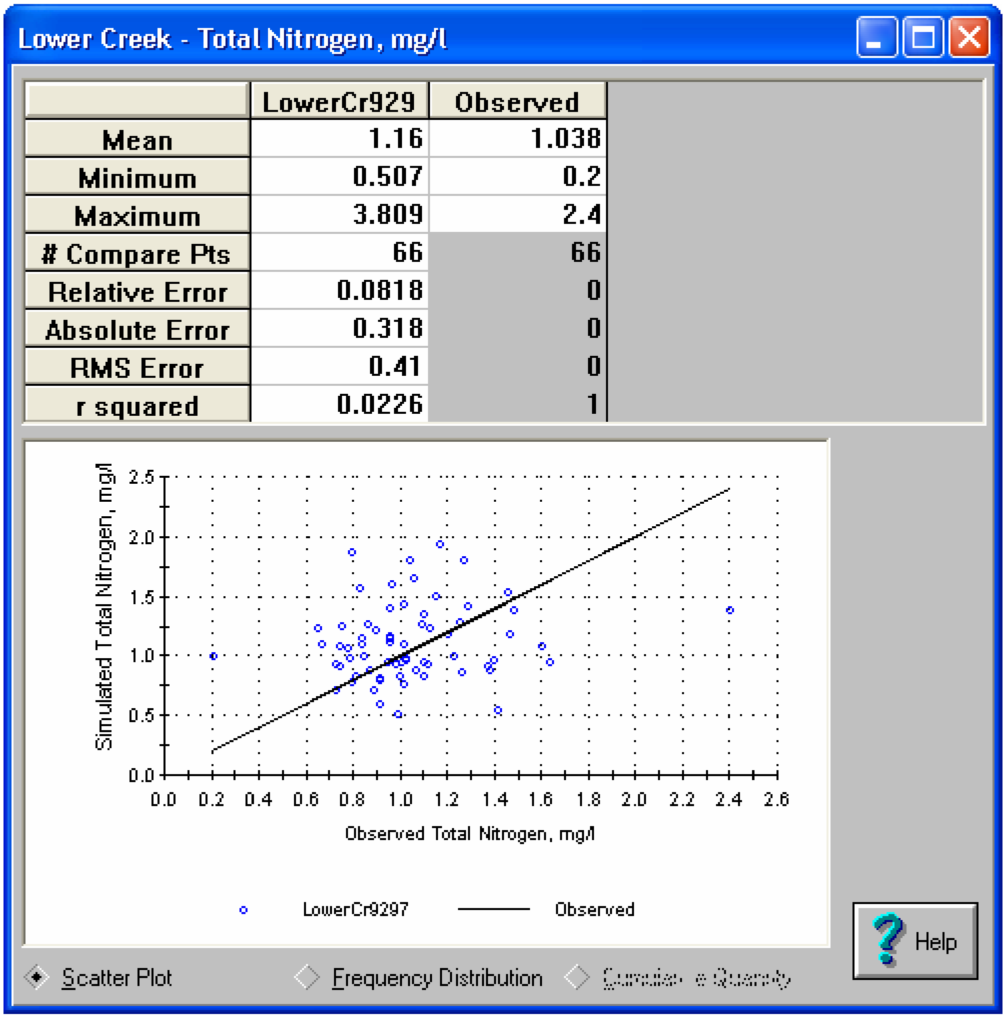



**Figure 47. Simulated and observed total nitrogen in Lower Creek, 1992-1997.**



Lower Creek - Total Nitrogen, mg/l

| | LowerCr929 | Observed |
|---|---|---|
| Mean | 1.16 | 1.038 |
| Minimum | 0.507 | 0.2 |
| Maximum | 3.809 | 2.4 |
| # Compare Pts | 66 | 66 |
| Relative Error | 0.0818 | 0 |
| Absolute Error | 0.318 | 0 |
| RMS Error | 0.41 | 0 |
| r squared | 0.0226 | 1 |



**Figure 48. Summary statistics and scatter plot for Lower Creek total nitrogen, 1992-1997.**

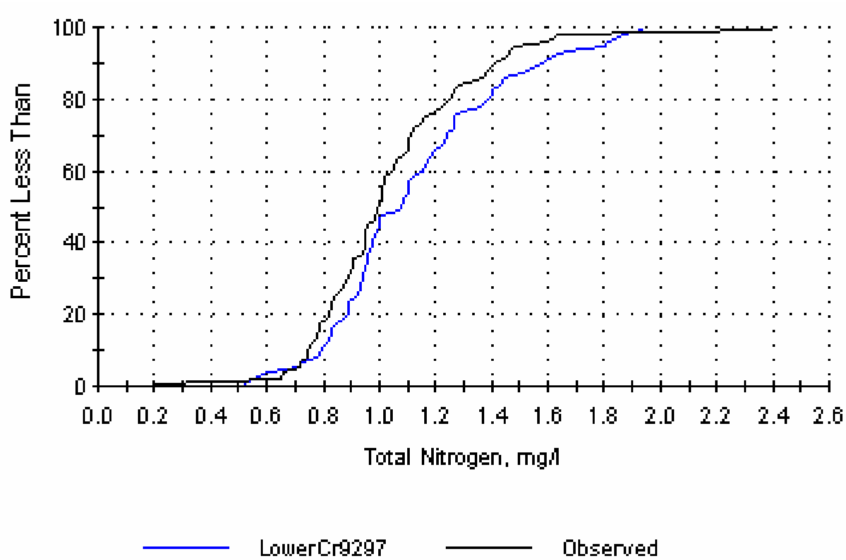



**Figure 49. Frequency distribution plot for Lower Creek total nitrogen, 1992-1997.**

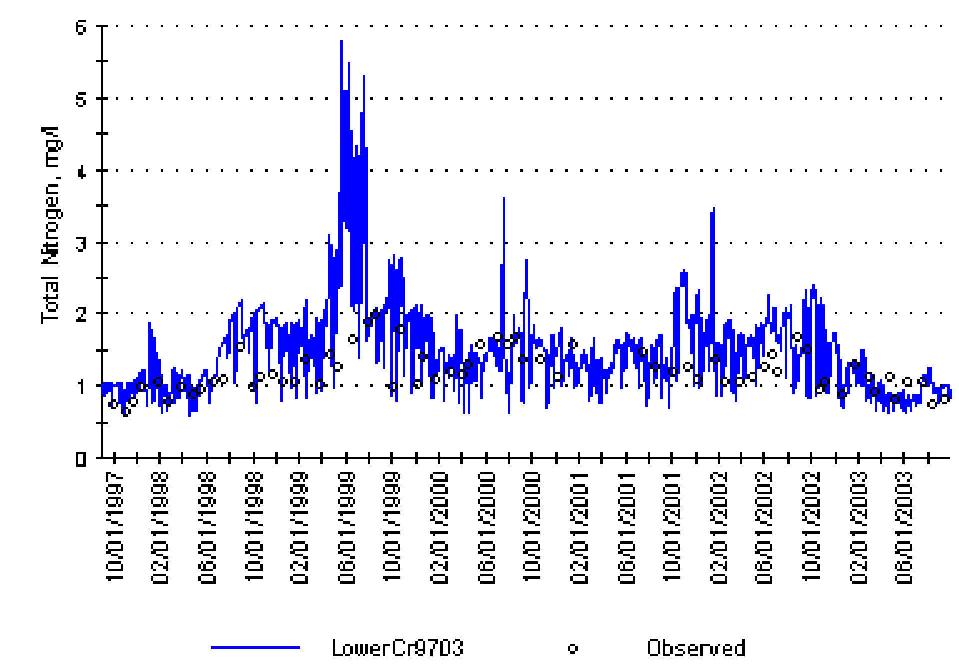
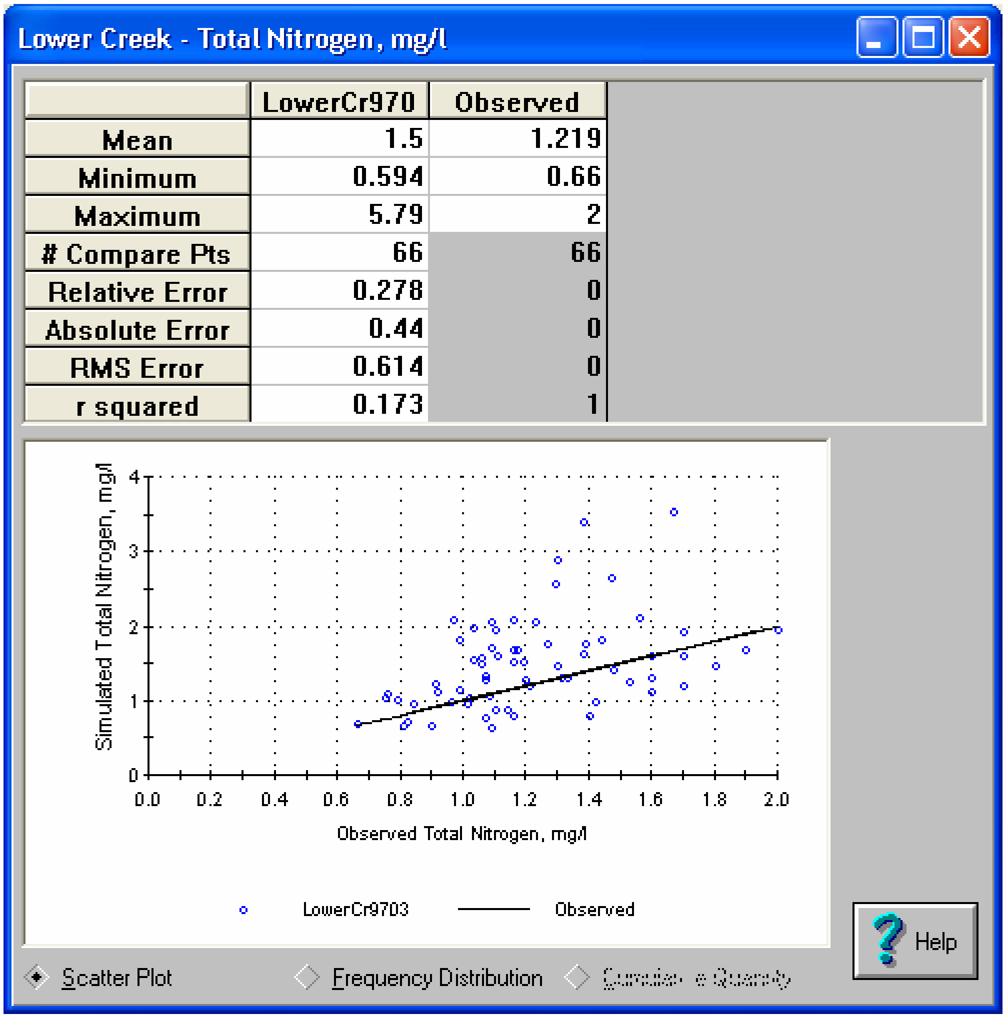



**Figure 50. Simulated and observed total nitrogen in Lower Creek, 1997-2003.**



| | LowerCr970 | Observed |
|---|---|---|
| Mean | 1.5 | 1.219 |
| Minimum | 0.594 | 0.66 |
| Maximum | 5.79 | 2 |
| # Compare Pts | 66 | 66 |
| Relative Error | 0.278 | 0 |
| Absolute Error | 0.44 | 0 |
| RMS Error | 0.614 | 0 |
| r squared | 0.173 | 1 |



**Figure 51. Summary statistics and scatter plot for Lower Creek total nitrogen, 1997-2003.**

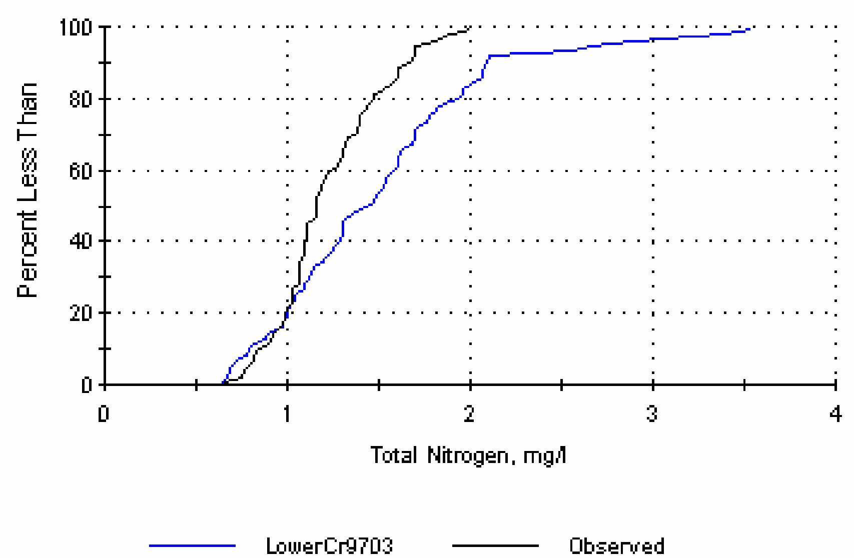



**Figure 52. Frequency distribution plot for Lower Creek total nitrogen, 1997-2003.**

A comparison of simulated and observed total suspended sediment (TSS) in Lower Creek (1992-1997) is presented in Figure 53. A close up view of this plot is provided in Figure 54. Though most TSS sampling data was collected during ambient and not storm conditions, the comparison between the simulation and the data that was available is good. Figures 55 and 56 show the statistical summary, scatter plot and frequency distribution plot. Similar results are provided for the 1997-2003 simulation in Figures 57-60.

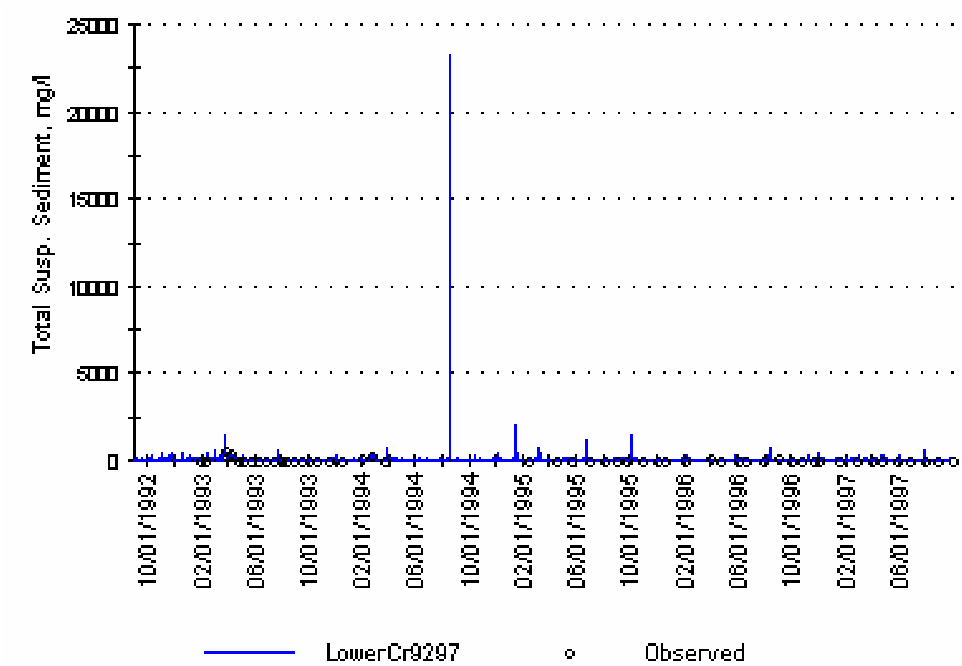



**Figure 53. Simulated and observed TSS in Lower Creek, 1992-1997.**

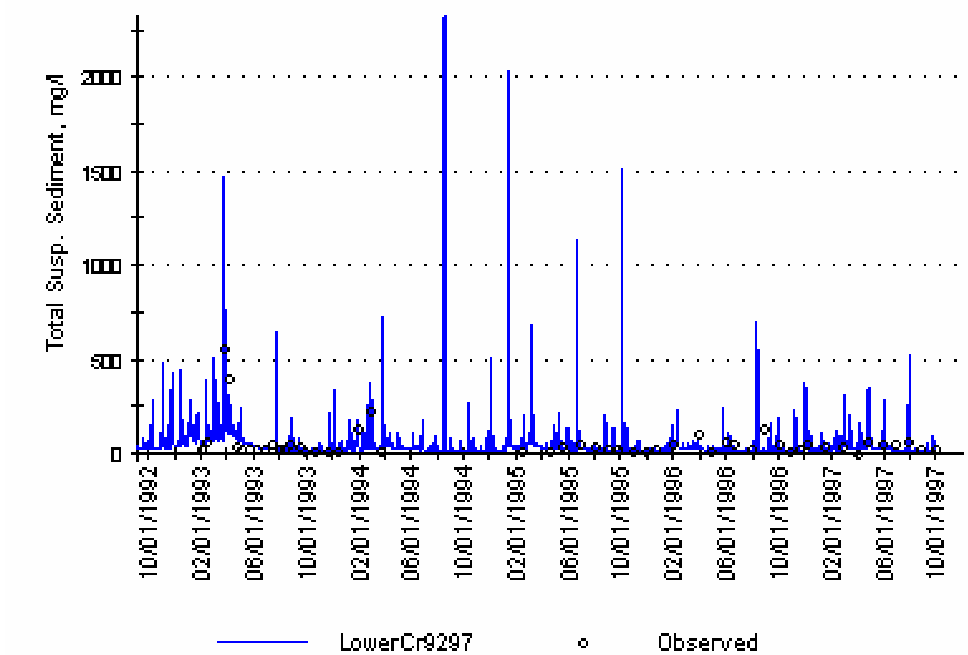
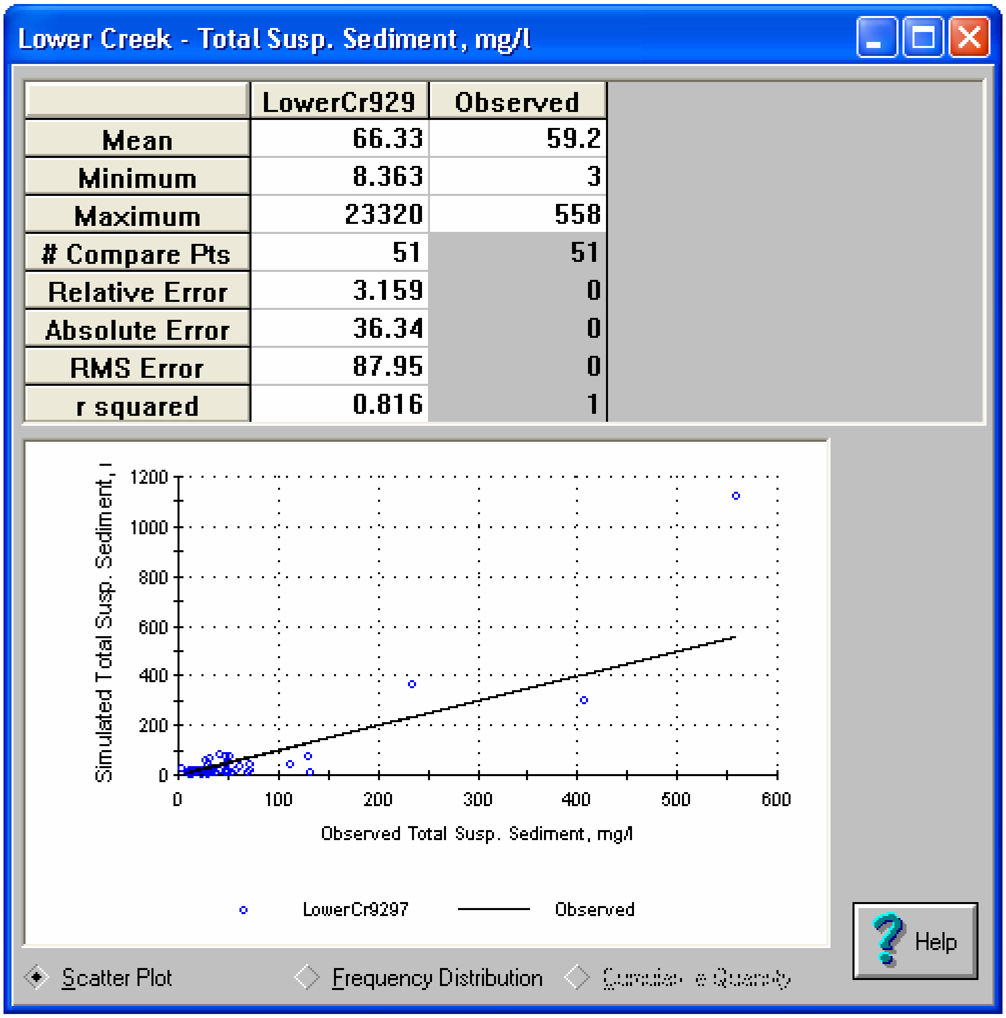


**Figure 54. Close up of simulated and observed TSS in Lower Creek, 1992-1997.**



| | LowerCr929 | Observed |
|---|---|---|
| Mean | 66.33 | 59.2 |
| Minimum | 8.363 | 3 |
| Maximum | 23320 | 558 |
| # Compare Pts | 51 | 51 |
| Relative Error | 3.159 | 0 |
| Absolute Error | 36.34 | 0 |
| RMS Error | 87.95 | 0 |
| r squared | 0.816 | 1 |



**Figure 55. Summary statistics and scatter plot for Lower Creek TSS, 1992-1997.**

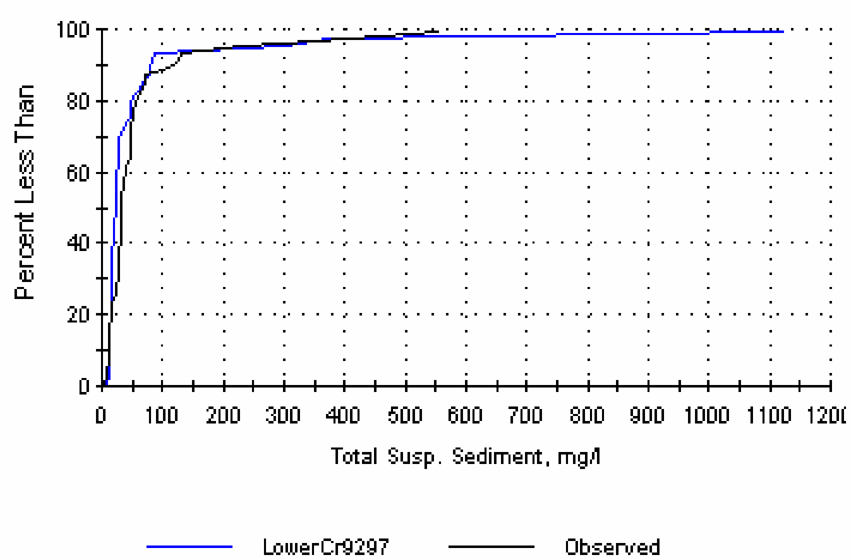



**Figure 56. Frequency distribution plot for Lower Creek TSS, 1992-1997.**

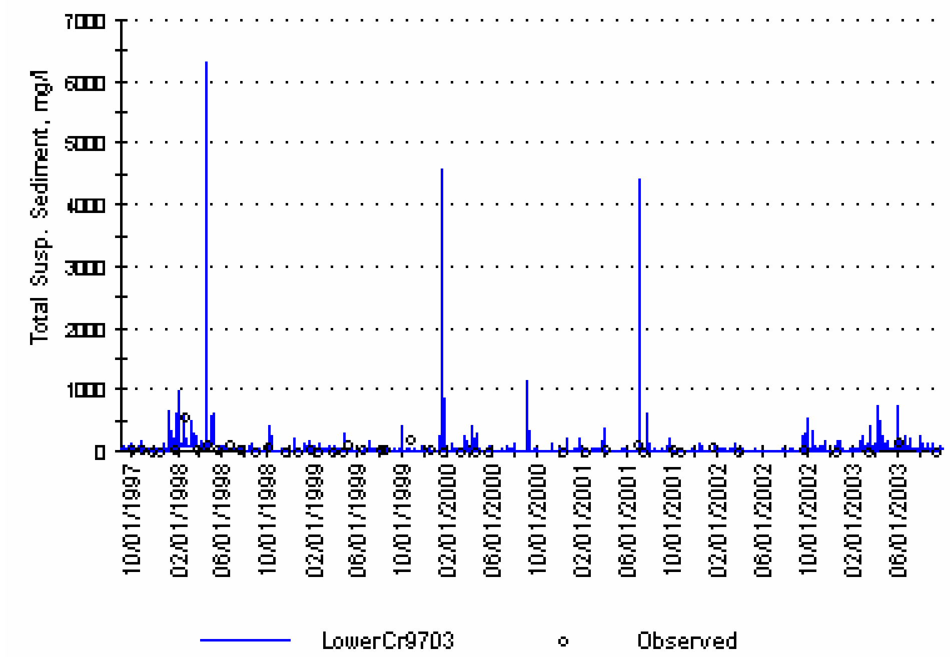



**Figure 57. Simulated and observed TSS in Lower Creek, 1997-2003.**

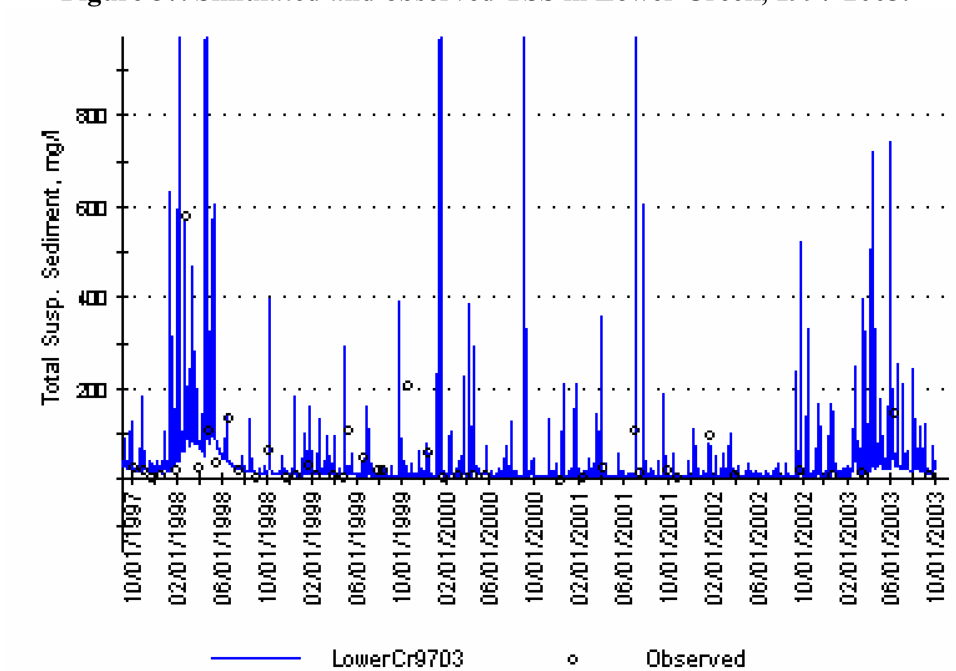



**Figure 58. Close up of simulated and observed TSS in Lower Creek, 1997-2003.**

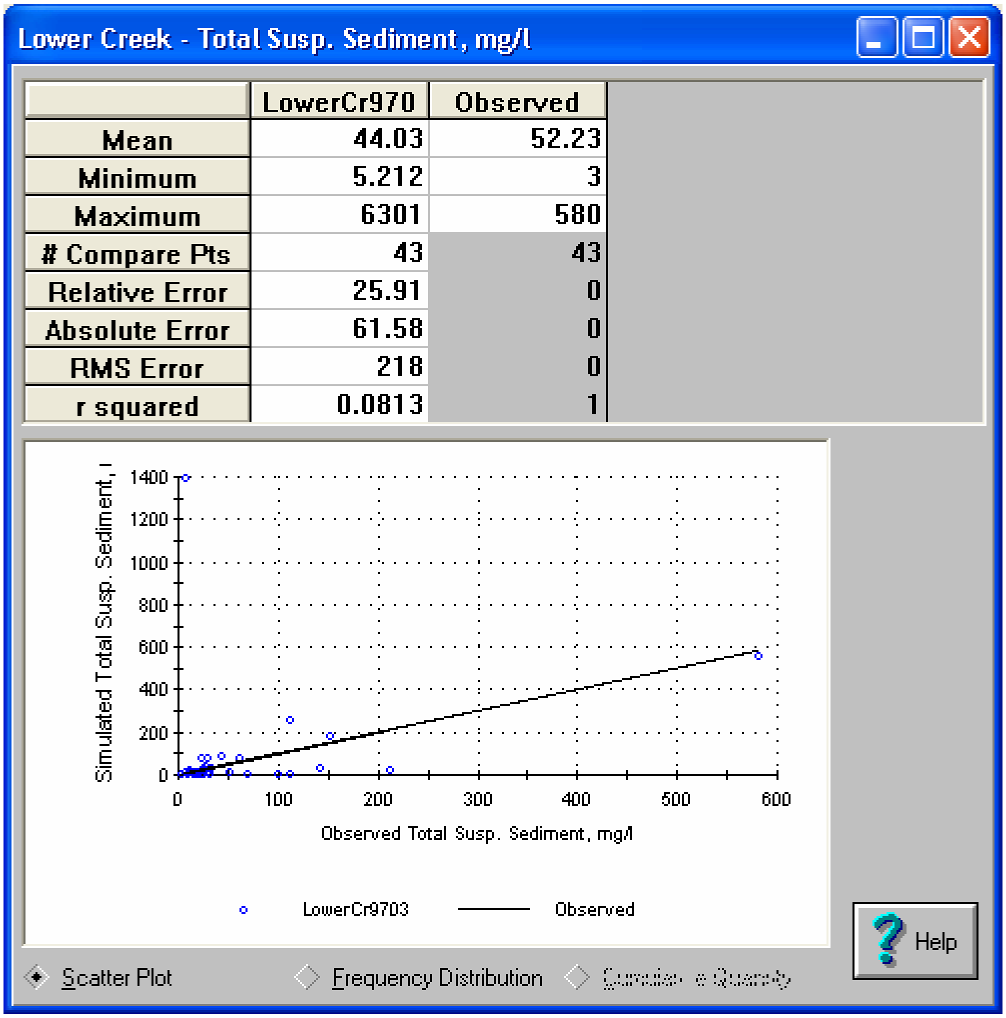


Figure 59. Summary statistics and scatter plot for Lower Creek TSS, 1997-2003.

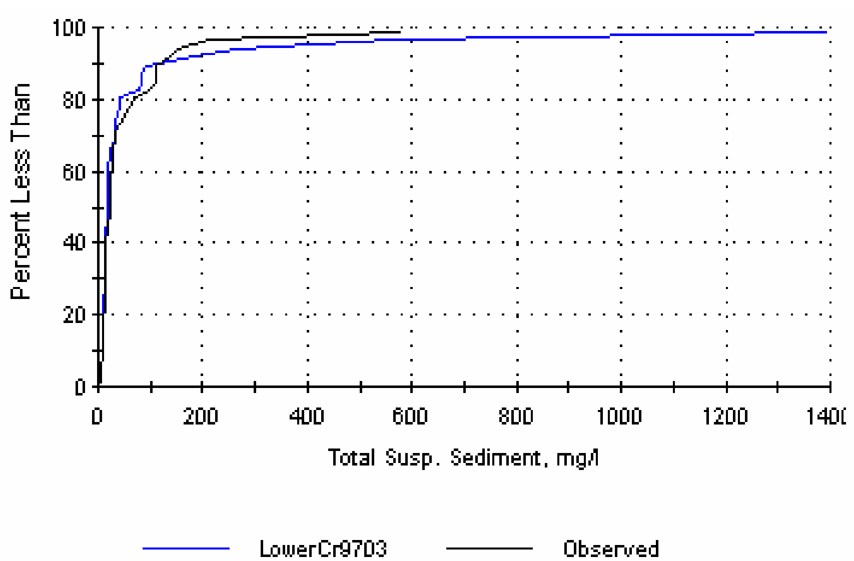


Figure 60. Frequency distribution plot of Lower Creek TSS, 1997-2003.

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