# TECHNICAL MEMORANDUM
# CEDAR CREEK WATERSHED: SWAT MODEL DEVELOPMENT, CALIBRATION AND VALIDATION

Balaji Narasimhan[1], Steven T. Bednarz[2], and Raghavan Srinivasan[1]
[1]*Spatial Sciences Laboratory, Texas A&M University, College Station, TX 77840.*
[2]*Natural Resources Conservation Service, Temple, TX 76501.*

## EXECUTIVE SUMMARY

A SWAT model was developed for Cedar Creek Watershed having a drainage area of about 1008 sq. miles located in the Trinity River basin. EPA BASINS3.0 interface was used for watershed delineation and developing input data for the SWAT model. GIS data layers of soil, landuse, weather, flow, sediment and nutrients were assembled from various data sources. Version 2000 of the SWAT model was modified to include chlorophyll 'a', BOD, and dissolved oxygen for point source input files, in addition to few other minor modifications. Management practices such as planting date, fertilizer application, and tillage information for cropland and pastureland were obtained from county extension agents. Using the information collected from various different sources, a SWAT model was developed Cedar Creek Watershed consisting of 106 subbasins which were further subdivided into 1,516 Hydrologic Response Units (HRU's).

The SWAT model was calibrated (1967-1987) for monthly flow using two USGS streamflow gauge data (Kings Creek $R^2$: 0.83; Cedar Creek $R^2$:0.81) and validated using flow balance data to compute inflows to Cedar Creek reservoir (1980-2002) ($R^2$:80). The sediment was calibrated based on reservoir volumetric surveys and lake sediment coring. SWAT model parameters related to channel erosion were adjusted based on field observations from watershed survey conducted by Baylor University. King Creek intensive field study in 2002 was used to adjust SWAT travel time calculation and instream water quality parameters especially during low flow period (no runoff – municipal waste water discharge only). Further, the grab samples collected from 1989 to 2002 along various tributaries were also used to calibrate instream water quality parameters. A comparison of median, 25$^{th}$ and 75$^{th}$ percentiles of observed and predicted water quality data showed that the SWAT model reasonably captured the variability in the observed data.

A program was developed to automatically convert SWAT output from basins.bsb and basins.rch to a non-point source load file (.nps) for input in the WASP model for reservoir water quality simulation.

The calibrated model show that most of the sediment and nutrient loading arise from cropland, pasture and urban landuses. In terms of spatial distribution, most of the sediment and nutrient load arise from Kings Creek segment followed by Cedar creek. Future efforts will involve simulating best management practice (BMP) scenarios and identifying BMPs that improve the water quality with least expense using hybrid economic models.

## BACKGROUND AND MODEL DEVELOPMENT

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) is the continuation of a long-term effort of nonpoint source pollution modeling by the USDA-Agricultural Research Service (ARS), including development of CREAMS (Knisel, 1980), SWRRB (Williams et al., 1985; Arnold et al., 1990), and ROTO (Arnold et al., 1995b).

SWAT was developed to predict the impact of management (e.g. climate and vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water, sediment, and agricultural chemical yields in large un-gauged basins. To satisfy the objective, the model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. SWAT allows a basin to be divided into hundreds or thousands of grid cells or sub-watersheds. It can be used to look at long-term impacts (e.g., reservoir sedimentation over 50-100 years) of land management, the effects of timing of agricultural practices within a year (e.g., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing), and land use or vegetative cover changes.

In recent years, there has been considerable effort devoted to utilizing GIS to extract inputs (e.g., soils, land use, and topography) for comprehensive simulation models, and spatially display model outputs. Much of the initial research was devoted to linking single-event, grid models with raster-based GIS (Srinivasan and Engel, 1991; Rewerts and Engel, 1991). An interface was developed for SWAT (Srinivasan and Arnold, 1994) using the Graphical Resources Analysis Support System (GRASS) ( U.S. Army, 1988). The input interface extracts model input data from map layers and associated relational databases for each subbasin. Soils, land use, weather, management, and topographic data are collected and written to appropriate model input files.

More recently, an interface using Arcview3.1 was developed (Di Luzio et al., 1998). In addition, SWAT2000 and the Arcview interface have been incorporated into a set of hydrological tools developed by EPA called BASINS3.0 (Di Luzio et al., accepted for publication).

SWAT2000 operating within Arcview and BASINS3.0 hydrologic toolset was used for modeling of Cedar Creek watershed along with few modifications described in the following section.

## SWAT MODEL MODIFICATIONS

1. Inputs for chlorophyll ‘a’, BOD, and dissolved oxygen were added to the point source input files. Values input for these parameters were based on TRWD measurements and self-reporting data from the municipal wastewater treatment plants.

2. SWAT functions for estimating the amount of chlorophyll 'a' in runoff were based on research conducted in Canada. These calculations were not appropriate for north central Texas. A regional adjustment factor (CHLA_SUBCO) for chlorophyll 'a' was added to the general water quality input file (basins.wwq).
3. A "switch" was added to main channel inputs to allow disabling of the QUAL2E function built into SWAT for individual subbasins. The purpose of this modification was to turn off QUAL2E in subbasins in which the main channel was partially or fully submerged by Cedar Creek Reservoir. This provided a more accurate estimate of loadings for the first WASP segment at each tributary outlet.
4. SWAT was modified to provide daily average channel flow velocity for each subbasin/reach. This output was used to estimate predicted travel time for comparison with measured travel time in Kings Creek.
5. SWAT water routing routine using variable Storage method was modified to an iterative approach for determining the flow depth, flow velocity and the flow rate. This modification simulated the flow velocity more realistically than the previous routine which used a "bucket" type approach that overestimated the velocity in smaller reach downstream of two big reaches (Narasimhan et al. 2007).
6. SWAT sediment routing routine was modified to account for the mass balance more explicitly and write a new output (CH_DEG) in the basins.rch file that quantifies channel erosion exclusively. Sediment deposition was also allowed to occur more gradually than instantaneously assuming a settling velocity of clay type particles.
7. The river water quality routine of SWAT was modified to simulate the nutrient loading due to channel erosion. Based on the concentration of nutrients such as Nitrate, Organic Nitrogen, Mineral Phosphorus and Organic Phosphorus in the stream bank and the amount of channel erosion during a time step, the total amount of nutrient load contribution from channel is calculated.

## MODEL INPUTS and DATA SOURCES

### GIS Data

Soils. The soils database describes the surface and upper subsurface of a watershed and is used to determine a water budget for the soil profile, daily runoff, and erosion. The SWAT model uses information about each soil horizon (e.g., thickness, depth, texture, water holding capacity, etc.).

The soils database used for this project was developed from two sources from the Natural Resources Conservation Service (NRCS):

1. The database known as the Computer Based Mapping System (CBMS) or Map Information Assembly Display System (MIADS) (Nichols, 1975) is a grid cell digital map created from 1:24,000 scale soil sheets with a cell resolution of 250 meters. The CBMS database differs from some grid GIS databases in that the attribute of each cell was determined by the soil that occurs under the center point of the cell instead of the soil that makes up the largest percentage of the cell.

2. The Soil Survey Geographic (SSURGO) is the most detailed soil database available. This 1:24,000-scale soils database is available as printed county soil surveys for over 90% of Texas counties. However, not all mapped counties are available in GIS format (vector or high resolution cell data). In the SSURGO database, each soil delineation (mapping unit) is described as a single soil series.

The SSURGO soils data for Hunt, Rockwall, Kaufman, and Van Zandt counties have been completed, but digitizing of Henderson County has not been completed. Therefore, a combination of SSURGO and CBMS soils data was used for simulations of Cedar Creek watershed.

Landuse. United States Geological Survey (USGS) National Land Cover Dataset (NLCD) data was developed by the Multi-Resolution Land Characteristics (MRLC) consortium from 1992 Landsat 5 Thematic Mapper (TM) satellite data (USGS, 2002). NLCD data has a resolution of 30 meters and represents the first new land cover information since the 1970's. Also, the Texas A&M Spatial Sciences Lab (SSL) developed a landuse/cover map (30-meter) from 2001 Landsat 7 data using ground control points collected by Tarrant Regional Water District (TRWD).

Because of rapid urban development in the watershed, urban landuse categories from the SSL 2001 landuse were superimposed onto the 1992 NLCD landuse to provide a more current representation of urban areas for this study (Figure 1a). Percentage of each landuse within the watershed is shown in Table 1.

Table 1. Percentage of each landuse in Cedar Creek Watershed.

| Landuse | Percent Cover |
|---|---|
| Urban | 7.08 |
| Forest | 15.79 |
| Rangeland (Grassland/Herbaceous) | 1.29 |
| Pasture/Hay | 60.86 |
| Cropland | 6.03 |
| Water | 5.99 |
| Wetland | 2.88 |
| Other | 0.08 |

Topography. The United States Geological Survey (USGS) database known as Digital Elevation Model (DEM) (USGS, 1987) described the surface of a watershed as a topographical database. The DEM available for the project area was the 1:24,000 scale map. The resolution of the DEM was 30 meters, allowing detailed delineation of subbasins within the watershed.

Climate. Daily precipitation totals were obtained for National Weather Service (NWS) stations within and adjacent to the watershed from 1950 to 2002. Daily maximum and minimum temperatures were obtained for the same period for the same NWS stations.

Precipitation data from nearby stations were substituted for missing data in each station record. Missing temperature data was generated by SWAT.

During calibration of flow, it was noted that predicted flow was much higher than measured in 1999 through 2002, but the remainder of the simulation (1980 – 1998) matched well. Five climate stations had no data for this period, and data from nearby stations were used to represent the missing data. This was suspected to be the cause of the over-prediction.

To correct the problem, NEXRAD data was used to "enhance" the climate stations with missing data from 1999 to 2002. This was done by averaging NEXRAD grid data for all subbasins near an individual climate station, and using those values for 1999 - 2002. This enhancement resulted in a much better match of simulated to measured flow.

**Subbasin Delineation**

Watershed Delineation. The BASINS 3.0/AVSWAT was used to delineate subbasins (automatic delineation) within the watershed using a stream definition threshold of 500 hectares. A stream layer was used (stream burn-in) to improve the accuracy of the subbasin delineation. Additional subbasin outlets were inserted at USGS stream gage stations, TRWD tributary sampling points, municipal waste water discharge points, WASP model input locations (Cedar Creek Reservoir boundaries), and at four of the larger lakes within the watershed (Terrell City Lake, Lake Kaufman, Forest Grove Dam, and Valley View Lake). The resulting subbasin map contained 106 subbasins (Figure 1b).

In the SWAT simulations, Cedar Creek Reservoir was not input as a reservoir because several subbasins were partially submerged by the lake (Figure 2). The effects of submergence were accounted for in main channel inputs (channel erodibility and channel cover were set to "0.0"), and QUAL2E in SWAT was turned off in affected subbasins. The land cover for these submerged areas was simulated as "WATER".

Hydrologic Response Units (HRU). The input interface divided each subbasin into HRU's with unique soil and landuse combinations. The number of HRU's within a subbasin was determined by: (1) creating an HRU for each land use that equaled or exceeded 2 percent of the area of a subbasin; and (2) creating an HRU for each soil type that equaled or exceeded 10 percent of any of the land uses selected in (1). Using these inputs, the interface created 1,516 HRUs for the watershed.

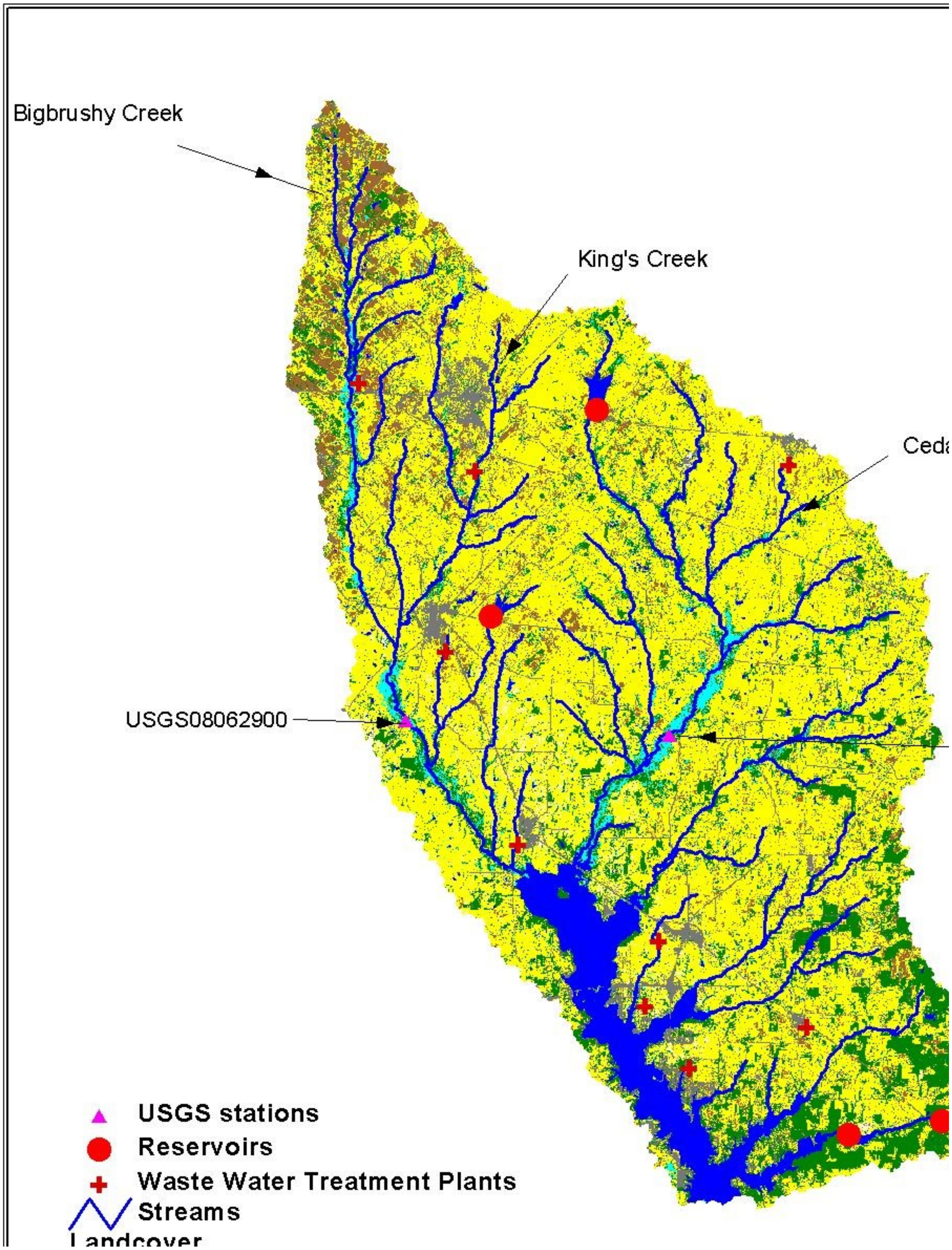

Figure 1a. Landcover of Cedar Creek Watershed (1992 NLCD + 2001 Urban).

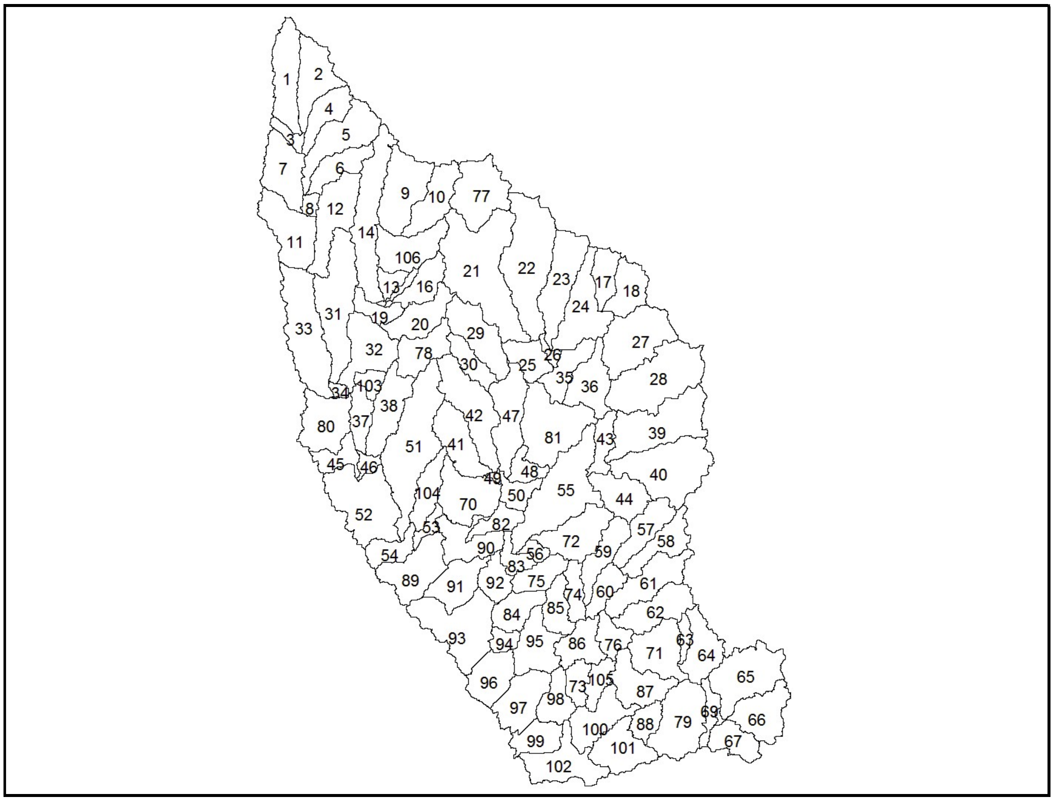

Figure 1b. Subbasins in Cedar Creek Watershed.

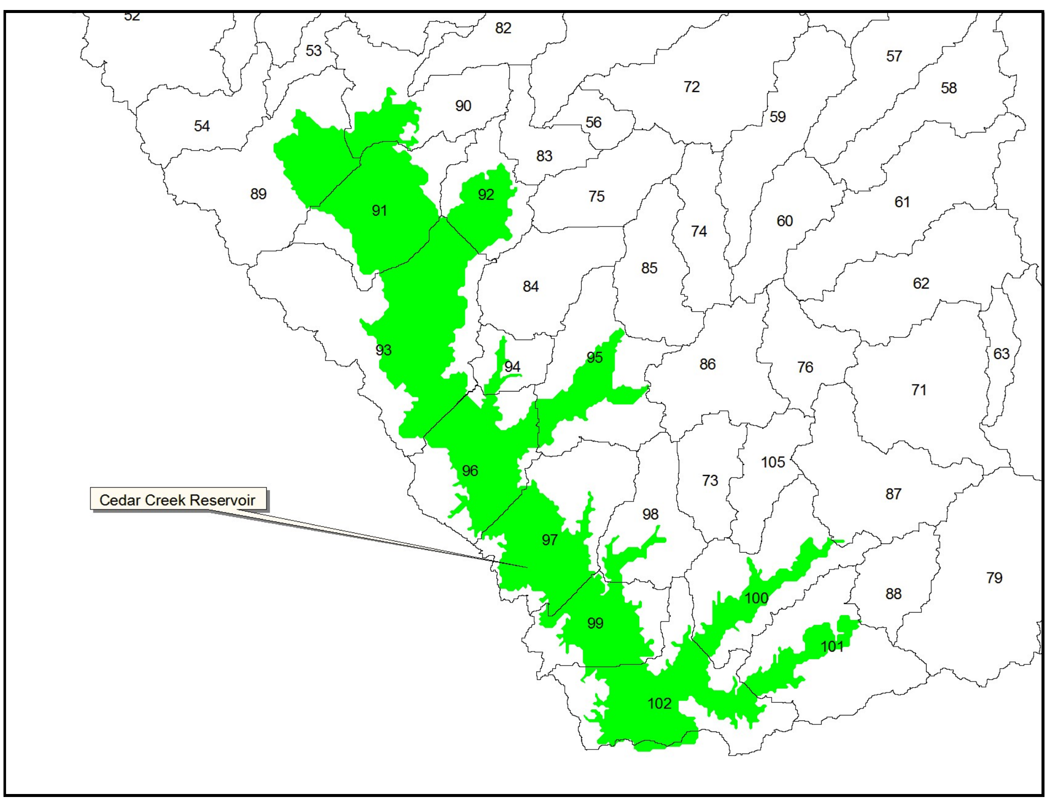

Figure 2. Subbasins submerged by Cedar Creek Reservoir.

**Management Practices**
Data on typical crops and management practices were obtained from NRCS field office personnel in the watershed. It was assumed that grain sorghum was grown on all cropland and that no conservation practices were applied (Universal Soil Loss Equation (USLE) "P" = 1.0). Fertilizer was applied to cropland (67 kg N and 34 kg P per hectare) and conventional tillage was assumed.

The pastureland in the watershed was assumed to be in fair hydrologic condition (personal communication – Homer Sanchez, NRCS State Range Conservationist). Based on conversation with county extension agents, 50% of the pastureland was assumed to be fertilized every year and two hay cuttings per year were conducted on the pastureland that was fertilized. Due to lack of spatial location of pasturelands that were actually fertilized, all pastureland were assumed to receive fertilizer. However, at any given year only 50% of the pastureland will receive fertilizer with the other half receiving fertilizer the subsequent year. Fertilizer was applied to pastureland at a rate of 67 kg N per hectare.

The pervious areas of urban land categories were assumed planted with bermudagrass and fertilizer was applied by SWAT automatically. Application rates and amounts were based on a nitrogen stress level of 0.9.

**Channel Dimensions, Properties, and Travel Time**
TRWD measured channel profiles at eight locations in the watershed to obtain channel depth and top width needed by the SWAT model. However, it was not possible to develop a statistically significant power function relationship between the measured parameter and cumulative watershed area for extrapolating the data to all 106 subbasins. Hence, the SWAT default channel dimensions calculated based on equations developed by Leopold and Maddock (1953) were used for simulation. The velocity output from SWAT was used to calculate travel time from the Terrell WWTP to the backwaters of Cedar Creek Reservoir (Subbasins 54) for comparison with estimated travel times from TRWD and Espey Consultants.

Based on a QUALTX flow rate of 0.07 cms ($m^3$/sec) and hydraulic data from dye studies, TRWD estimated travel time of about 16 days (this model included stream transmission loss). Espey Consultants used QUAL2E and a flow rate of 0.11 cms (no transmission loss) to arrive at a travel time of about 10 days. In the SWAT simulations, the flow rate varied from 0.11 cms just below the Terrell WWTP to about 0.064 cms at subbasin 54 (backwaters of Cedar Creek Reservoir). The original SWAT simulations were run with the default Mannings "n" of 0.014, which resulted in a travel time of about five days. In an effort to lengthen the travel time in SWAT, Mannings "n" was raised to 0.075. This value appeared to be more appropriate than default after reviewing photographs of the stream channel. With a Mannings "n" of 0.075, travel time predicted by SWAT was about 9.5 days. Further increases in "n" value did not seem appropriate, given the limited visual data for the stream.

## Other Inputs and Coefficients

Ponds and Reservoirs. The Cedar Creek watershed contains about 120 inventory-sized dams (as defined by the Texas Commission on Environmental Quality), which includes NRCS flood prevention dams, farm ponds, and other privately owned dams. The physical data (e.g. surface area, storage, drainage area, discharge rates) for these dams were input to the SWAT model to allow routing of runoff through the structures. Four structures were big enough to be simulated as reservoirs and rest of them simulated as small ponds (Figure 1a).

Surface Runoff. Surface runoff was predicted using the SCS curve number (CN2) equation (USDA-Soil Conservation Service, 1972). Higher curve numbers represent greater runoff potential. Curve numbers were selected assuming pastureland were in fair hydrologic condition, and cropland was farmed straight row with no contouring. USLE_C is the minimum value for water erosion applicable to the land cover/plant.

Soil Properties. The soil evaporation compensation factor (ESCO) and plant uptake compensation factor (EPCO) adjust the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, cracks, and plant transpiration. A factor of 0.85 is normally used for ESCO, but lower values are used in dry climates to account for moisture loss from deeper soil layers. A value of 1.0 is normally used for EPCO.

Plant Properties. Initial residue cover (RSDIN) may be input to account for plant residue on the soil surface at the beginning of the simulation. The USLE "C" plant cover factor is dependent on the characteristics of crops or other vegetation and affects sheet and rill erosion on the land surface.

Shallow Aquifer Properties. Shallow aquifer storage is water stored below the root zone. Flow from the shallow aquifer is not allowed until the depth of water in the aquifer is equal to or greater than the input value (GWQMN). Shallow aquifer re-evaporation coefficient (GW_REVAP) controls the amount of water that will move from the shallow aquifer to the root zone as a result of soil moisture depletion, and the amount of direct water uptake by deep-rooted trees and shrubs. Higher values represent higher potential water loss. Setting the minimum depth of water in the shallow aquifer before re-evaporation is allowed (REVAPMN) also controls the amount of re-evaporation. The lag between the time the water exits the soil profile and enters the shallow aquifer (GWDELAY) depends on the depth to the water table and the hydraulic properties of the geologic formations. Shallow aquifer storage, re-evaporation, and soil to shallow aquifer lag inputs affect base flow.

Main Channel Properties. Channel transmission loss (CHK2) is the effective hydraulic conductivity of channel alluvium, or water loss in the stream channel. The fraction of transmission loss that returns to the stream channel as base flow (BANKCO) is based on the amount of quick return flow that occurs after a storm. Mannings "n" for channel flow (CH_N2) is the roughness coefficient. SPCON is the linear parameter for calculating maximum amount of sediment that can be re-entrained during channel sediment routing.

CH_EROD is the channel erodibility factor and is similar to the soil erodibility factor used in the USLE equation. CH_COV is the channel cover factor and is defined as the ratio of degradation from a channel with a specified vegetative cover to the corresponding degradation from a channel with no vegetative cover.

## Soil Nutrient Initialization

In SWAT nutrients are initialized based on organic carbon content from the soils database and assuming a C:N ratio of 14:1 and N:P ratio of 8:1. Based on the 1992 NLCD landcover data superimposed with 2001 urban cover, about 60% of the land in the watershed is used as pasture for livestock grazing or the production of seed or hay crops. However, historically until the 1980's most of this pastureland was used for row crop productions such as cotton, corn or sorghum with intensive fertilizer and soil management. Long term row crop cultivation with fertilizer application would lead to build up of nutrients in the soil especially Phosphorus. Hence, the soil nutrient values have to be initialized appropriately for estimating current nutrient loads from the pastureland. Test runs with SWAT on a small area with cropland with the fertilizer application at the current rate on a cropland (67 kg N and 34 kg P per hectare) showed that phosphorus build-up (Mineral and Organic Phosphorus) takes place due to prolonged application of fertilizer. Figures 3 and 4 respectively show the nutrient value at the top soil layer with fertilizer application for cropland and no fertilizer application on a pastureland. Hence, in order to initialize the soil nutrient values, all pasturelands were assumed to be managed in the same way as a typical cropland (see management practices) and the model was run for 37 years. The soil nutrient values at the end of the 37 years were used as the initial soil nutrient value for all pastureland instead of the SWAT default nutrient initialization value. The same procedure was adopted to initialize the soil nutrient value in the croplands as well. For the rest of the land covers, the default SWAT nutrient initialization was used.

# SWAT CALIBRATION

## Flow Calibration/Validation

The calibration period was based on the available period of record for stream gauge flow. Measured stream flow was obtained from USGS for two stream gages in the watershed for 1963 through 1987, and this period was used for initial calibration. A base flow filter (Arnold et al., 1995a) was used to determine the fraction of base flow and surface runoff at selected gauging stations.

Appropriate plant growth parameters for brush, native grass, and other land covers were input for each model simulation. Initial inputs were based on known or estimated watershed characteristics. SWAT was calibrated for flow by adjusting appropriate inputs that affect surface runoff and base flow. Adjustments were made to runoff curve number, soil evaporation compensation factor, shallow aquifer storage, shallow aquifer re-evaporation, and channel transmission loss until the simulated total flow and fraction of base flow were approximately equal to the measured total flow and base flow, respectively.

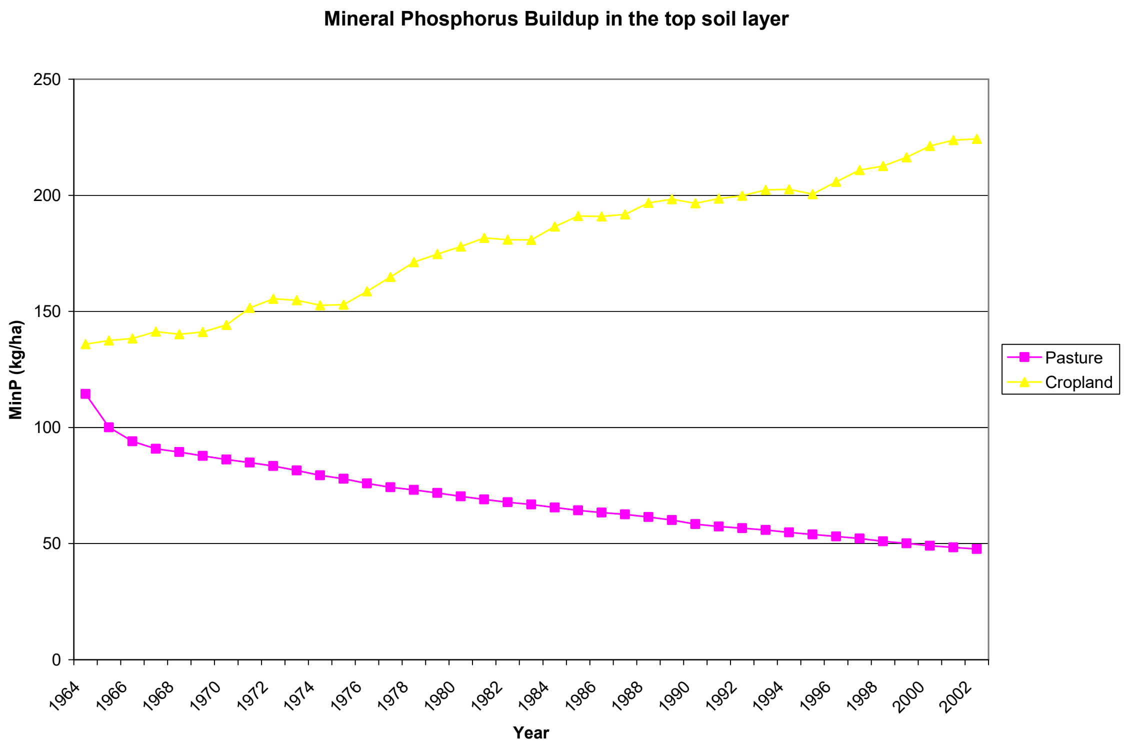


Figure 3. Mineral Phosphorus build-up due to fertilizer application.

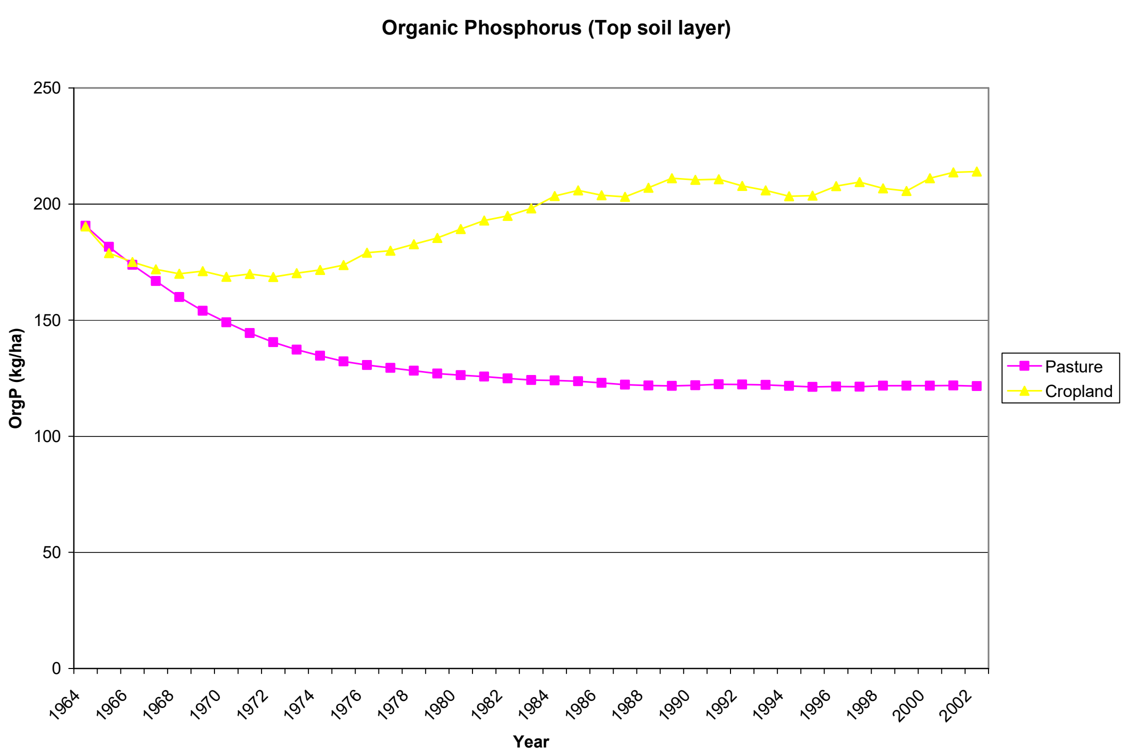


Figure 4. Organic Phosphorus build-up due to fertilizer application.

Validation was performed by comparing simulated flow to calculated inflow to Cedar Creek Reservoir. This calculated inflow was obtained from TRWD's mass balance of Cedar Creek Reservoir from 1980 through 2002. The analysis was performed using measured daily reservoir volume, water surface evaporation, withdrawals, discharges, and rainfall. NEXRAD data was used to "enhance" the climate stations with missing data for the 1999 – 2002 period.

**Sediment Calibration**

The Texas Water Development Board performed hydrographic surveys of Cedar Creek Reservoir in February 1995 (TWDB, 1995) and May 2005 (TWDB, 2006). The measurements performed during these two surveys were compared to the original design information for the reservoir (construction of the Cedar Creek Reservoir dam was completed in February 1966) to determine the volume of sediment deposited from 1966 to 1994 and 2005. A lake sediment survey was undertaken by Baylor University in early 2006 for collecting sediment cores to estimate average density and thickness of sediment at the lake bottom (Allen et al. 2006). In addition to that a watershed survey was also conducted by Allen et al. 2006 to identify stream segments with channel erosion problems and quantify channel erosion using NRCS field assessment techniques such as RAP-M. The sedimentation rate based on just the 1995 and 2005 is about 32.5 ac.ft/year. However, based on the original design volume to that 2005 survey indicated a sedimentation rate of 1032 ac.ft/year. The sedimentation rate of 1032 ac.ft/year was also consistent with the sediment thickness of 1.2 to 1.5ft observed from sediment cores than the sedimentation rate of 32.5 ac.ft/year based on 1995 and 2005 survey. Hence, the 1995 lake survey volume was ignored for the model calibration.

The average dry-weight density of the post-impoundment sediment was about 21.5 lbs/ft3. Based on the lake sediment survey and the watershed survey the erosion rate at the Cedar Creek watershed is estimated at about 446,558 Metric Tons/yr. Out of this Channel erosion contribution is about 152,572 Metric Tons/yr (34%) and the rest of the sediment (293,986 Metric Tons/yr) comes from overland erosion (Allen et al. 2006).

Simulated sediment from SWAT for the 1966 to 2002 period (37 years) was compared to the measured sediment, and appropriate input parameters were adjusted until the predicted annual sediment load from overland and channel erosion was approximately equal to the measured. Final values for SWAT input coefficients used in flow and sediment calibration are given in Table 2.

Table 2. SWAT input coefficients adjusted for calibration of flow and sediment.

| Variable | Description | Input Value | Units | File |
|---|---|---|---|---|
| **Coefficients related to flow** | | | | |
| CN2 | SCS Runoff curve number (adjustment range) | +3 to -3 | - | *.mgt |
| ESCO | Soil evaporation factor | 0.85 | - | *.hru |
| GW_REVAP | groundwater re-evaporation coefficient | 0.1 | - | *.gw |
| GW_DELAY | Groundwater delay time | 135 | Days | *.gw |
| GWQMN | Groundwater storage required for return flow | 1.00 | mm | *.gw |
| REVAPMN | Groundwater storage required for re-evaporation | 1.6000 | mm | *.gw |
| ALPHA_BF | Baseflow alpha factor | 0.0437 to 0.4606 | $Days^{-1}$ | *.gw |
| CH_N2 | Mannings "n" roughness for channel flow | 0.075 | - | *.rte |
| CH_K2 | Hydraulic conductivity of channel alluvium | 0.1 to 40 | mm/hr | *.rte |
| **Coefficients related to sediment** | | | | |
| RSDIN | Initial soil residue cover | 1000 | kg/ha | *.hru |
| USLE_C | Minimum "C" value for pastureland in fair condition | 0.007 | - | crop.dat |
| SPCON | Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing | 0.01 | - | basins.bsn |
| SPEXP | Exponent parameter for calculating sediment reentrained in channel sediment routing | 1.4 | - | basins.bsn |
| CH_COV | Channel cover factor | 0.1 to 1.0 | - | *.rte |
| CH_EROD | Channel erodibility factor | 0.3 to 0.8 | - | *.rte |

## Nutrient Calibration

The first step in the nutrient calibration of SWAT was to calibrate selected subbasins in the Kings Creek watershed that correlate to the Qual2E reaches set up by Espey Consultants, Inc. Final coefficients from the Espey model were used as a starting point for SWAT calibration. WWTP data measured during the TRWD King's Creek study was used for point source loads.

SWAT was calibrated for King's Creek by comparing daily output on September 16, 2002 with measured data from the King's Creek study performed by TRWD on September 17 and 18, 2002 in selected subbasins of the King's Creek tributary. The 16$^{th}$ was chosen for comparison of SWAT output because SWAT predicted rainfall and runoff on the 17$^{th}$, 18$^{th}$, and 19$^{th}$, but no rainfall actually occurred in the Kings Creek tributary. This was due to rainfall variability that was not reflected in measured rainfall data used in SWAT. The main goal was to compare measured and predicted values for a low flow period (no runoff – municipal waste water discharge only), and this was accomplished by using SWAT output from the $16^{th}$.

In the next step of the calibration, the SWAT defaults were used as a starting point for the remainder of the subbasins. The simulation period was 1989 through 2002. WWTP loads were generated from one year's worth of weekly self reporting data collected by TRWD in 2001 and 2002. The following rules were used to generate the data:

Data Issues

1. 12 months of data were used for analysis. If more than 12 months of data were reported, a subset of 12 months was used for the analysis.
2. If a value was reported as less than the detection limit, it was estimated to be the reported detection limit.
3. If a value was reported as non-detectable with no reported detection limit, the value was estimated to be approximately 0.01 mg/L less than the minimum value in the dataset.
4. If an $NH_3$ value was not reported, it was estimated as the value of the permit limit for the individual plant if applicable.
5. If a single flow was not reported, it was estimated as the average of the preceding and following week's flows.
6. If multiple flows were missing for any 1-month period, the average flow reported in the DMR was used for that month.
7. There is no weekly data available for Athens WWTP. The DMR average flows for Athens WWTP and the weekly concentration data from Kaufman WWTP were used to estimate monthly loads for Athens WWTP.
8. In the Terrell dataset, there was a 20-week period (11/14/01 – 3/27/02) that the lab data reported is not reliable data according to the Terrell WWTP operator. This data was not used for analysis. Rather, an average value for each parameter was calculated using the remaining data. This average value was used each week during the 20-week period of bad data. All reported flows were used.
9. If a calculated organic nitrogen or organic phosphorus value resulted in a negative value, this value was estimated to be zero.

Analysis Methodology

1. Calculate load (kg/day) for each measured parameter for each record of data.
2. Calculate OP and ON loads for each record. Zero any negative loads.
3. Calculate average load by month for NH3, NOx, ON, OPO4, and OP. These loads are the values to be input into SWAT and WASP.
4. For SWAT, monthly average flows were calculated for input. These flows are included in the table of monthly loads.
5. The current effluent speciation was calculated for each month by dividing the monthly average for each constituent by the respective monthly TN or TP value.
6. The concentrations for potential future treatment levels were determined by multiplying the fraction of each nutrient species by the projected TN or TP value.

The ratios are based on current wastewater effluent. No adjustments were made to account for future modifications to the plant that may alter the effluent speciation ratios.

7. The average annual concentrations were calculated by averaging the same individual records that were used to calculate the monthly averages.

The output from this simulation was compared to water quality data collected by TRWD from 1989 through 2000 in each major tributary (Kings, Cedar, Lacy, North Twin, South Twin, Lynn, Clear, Caney, and Prairie, Figure 5). In order to account for daily variability of SWAT, simulated output was averaged for the three days surrounding the day of the measured grab sample. The medians, 25th percentile, and 75th percentile of the 3-day averages from SWAT were compared to the medians, 25th and 75th percentiles of the measured grab samples. The coefficients for all subbasins, except those in the Kings Creek watershed that correlate to the TRWD study, were adjusted for each watershed to match the observed data. The only change that was made to the subbasins in the Kings Creek study was the point source loads were generated from a year's worth of weekly WWTP data rather than the one day of data that TRWD collected during the 2002 study.

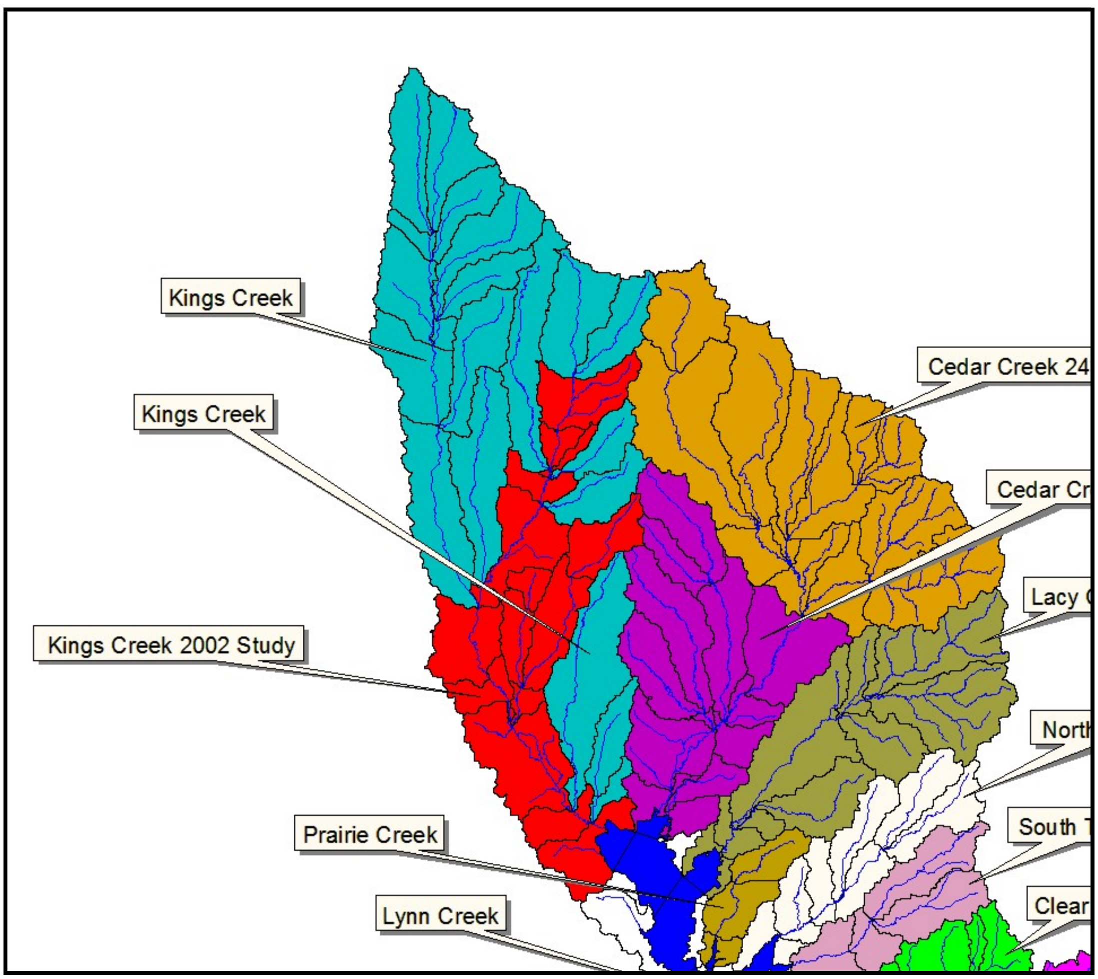


Figure 5. Tributaries of Cedar Creek Watershed.

Water quality input coefficients were adjusted until predicted values were approximately equal to measured values for both the 2002 Kings Creek Study and the 1989 through 2002 Tributary Study. Values determined by the Espey calibration were used in the general water quality input file (.wwq) (Table 3) and slightly adjusted for all simulations. For the stream water quality inputs (.swq) (Table 4), values from the Espey calibration were used in most subbasins of the Kings Creek 2002 study (Figure 6) with slight adjustments on some of the coefficients. Coefficients used in all other subbasins were determined by trial and error based on 1989 to 2002 grab sample data.

Tables 3 through 6 list water quality coefficients used for final calibration of SWAT. Enrichment ratios for nitrogen and phosphorus were also adjusted (Table 6).

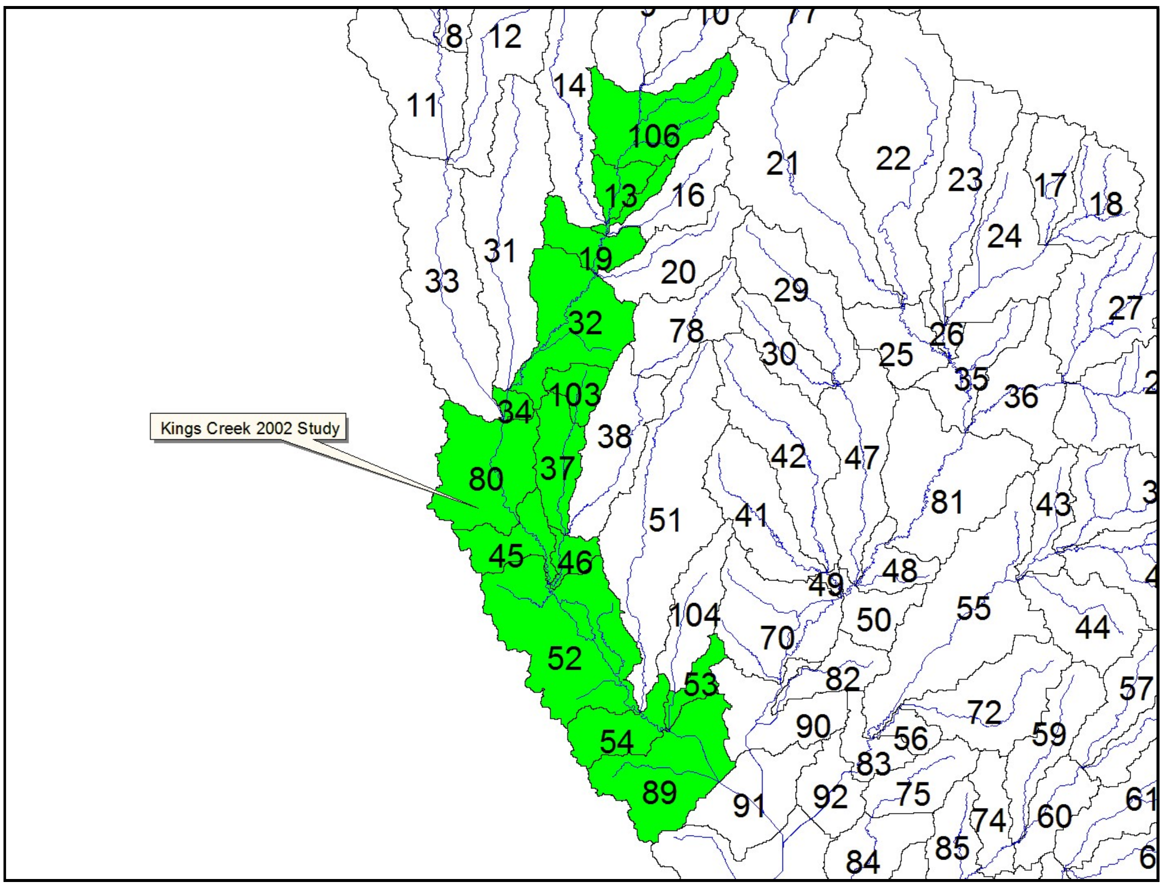

Figure 6. Kings Creek 2002 Study subbasins.

Table 3. General water quality input coefficients (.wwq) for calibration of QUAL2E and SWAT for 2002 King's Creek Study subbasins and 1989 to 2002 Tributary Study.

| **Variable Name** | **Definition** | **QUAL2E-Espey Cal. Coef** | **SWAT-SSL Cal. Coef.** | **SWAT Default** | **SWAT Range** |
|---|---|---|---|---|---|
| LAO | Light averaging option | 2 | 2 | 2 | 2 |
| IGROPT | Algal specific growth rate option | 2 | 2 | 2 | 3 options |
| AI0 | Ratio of chlorophyll-a to algal biomass [µg-chla/mg algae] | 10 | 10 | 50 | 10 - 100 |
| AI1 | Fraction of algal biomass that is nitrogen [mg N/mg alg] | 0.090 | 0.090 | 0.080 | 0.07 - 0.09 |
| AI2 | Fraction of algal biomass that is phosphorus [mg P/mg alg] | 0.020 | 0.020 | 0.015 | 0.01 - 0.02 |
| AI3 | The rate of oxygen production per unit of algal photosynthesis [mg O2/mg alg)] | 1.600 | 1.400 | 1.600 | 1.4 - 1.8 |
| AI4 | The rate of oxygen uptake per unit of algal respiration [mg O2/mg alg)] | 2.300 | 2.000 | 2.000 | 1.6 - 2.3 |
| AI5 | The rate of oxygen uptake per unit of NH3-N oxidation [mg O2/mg NH3-N] | 3.500 | 3.000 | 3.500 | 3.0 - 4.0 |
| AI6 | The rate of oxygen uptake per unit of NO2-N oxidation [mg O2/mg NO2-N] | 1.000 | 1.000 | 1.070 | 1.0 - 1.14 |
| MUMAX | Maximum specific algal growth rate at 20º C [day-1] | 1.800 | 1.000 | 2.000 | 1.0 - 3.0 |
| RHOQ | Algal respiration rate at 20º C [day-1] | 0.100 | 0.300 | 0.300 | 0.05 - 0.50 |
| TFACT | Fraction of solar radiation computed in the temperature heat balance that is photosynthetically active | 0.300 | 0.300 | 0.300 | 0.01 - 1.0 |
| K_L | Half-saturation coefficient for light [kJ/(m2·min)] | 0.418 | 0.418 | 0.750 | 0.2227-1.135 |
| K_N | Michaelis-Menton half-saturation constant for nitrogen [mg N/lL] | 0.400 | 0.400 | 0.020 | 0.01 - 0.30 |
| K_P | Michaelis-Menton half-saturation constant for phosphorus [mg P/l] | 0.040 | 0.040 | 0.025 | 0.001 - 0.05 |
| LAMBDA0 | Non-algal portion of the light extinction coefficient [m-1] | 1.500 | 1.500 | 1.000 | - |
| LAMBDA1 | Linear algal self-shading coefficient [m-1·(µg chla/l)-1)] | 0.002 | 0.002 | 0.030 | 0.0065-0.065 |
| LAMBDA2 | Nonlinear algal self-shading coefficient [m-1·(µg chla/l)-2] | 0.054 | 0.054 | 0.054 | 0.054 |
| P_N | Algal preference factor for ammonia | 0.100 | 0.100 | 0.500 | 0.01 - 1.0 |

Table 4. Stream water quality input coefficients (.swq) for calibration of QUAL2E and SWAT for 2002 Kings Creek Study subbasins.

| | | RS1 | | RS2 | | RS3 | | RS4 | | RS5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| QUAL2E Reach | SWAT Subbasin | Local Algal Settling (0.15 to 1.82) (Default=1.0) | | Benthos Source Rate for Dissolved P (Default=0.05) | | Benthos Source Rate for NH4-N (Default=0.5) | | Org N Settling Rate (0.001 to 0.10) (Default=0.05) | | Org P Settling Rate (0.001 to 0.10) (Default=0.05) | |
| | | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT |
| 1 | 106 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 2 | 13 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 3 | 15 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 4 | 19 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 5 | 32 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 6 | 32 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 7 | 80 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 8 | 45 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 9 | 103 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 10 | 37 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 11 | 37 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 12 | 37 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 13 | 46 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 14 | 52 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |
| 15 | 54 | 0.10 | 0.010 | 0.00 | 0.001 | 0.00 | 0.001 | 0.100 | 0.010 | 0.100 | 0.010 |

Table 4. Continued

| | | RK1 | | RK2 | | RK3 | | RK4 | |
|---|---|---|---|---|---|---|---|---|---|
| QUAL2E Reach | SWAT Subbasin | CBOD deoxygenation rate (0.02 to 3.4) (Default=1.71) | | Reaeration Rate (0.01 to 100) (Default=50.0) | | CBOD Settling loss Rate (-0.36 to 0.36) (Default=0.36) | | Benthic Oxygen Demand (Default=2.0) | |
| | | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT |
| 1 | 106 | 0.055 | 0.050 | 15.89 | 1.500 | 0.010 | 0.250 | 0.8 | 0.800 |
| 2 | 13 | 0.055 | 0.050 | 1.82 | 1.500 | 0.010 | 0.250 | 0.8 | 0.800 |
| 3 | 15 | 0.055 | 0.050 | 1.52 | 1.500 | 0.030 | 0.250 | 0.8 | 0.800 |
| 4 | 19 | 0.055 | 0.050 | 1.52 | 1.500 | 0.030 | 0.250 | 0.8 | 0.800 |
| 5 | 32 | 0.055 | 0.050 | 1.42 | 1.500 | 0.030 | 0.250 | 0.8 | 0.800 |
| 6 | 32 | 0.055 | 0.050 | 2.15 | 1.500 | 0.020 | 0.250 | 0.8 | 0.800 |
| 7 | 80 | 0.055 | 0.050 | 5.36 | 1.500 | 0.010 | 0.250 | 0.8 | 0.800 |
| 8 | 45 | 0.055 | 0.050 | 1.86 | 1.500 | 0.010 | 0.250 | 0.8 | 0.800 |
| 9 | 103 | 0.055 | 0.050 | 15.89 | 1.500 | 0.010 | 0.250 | 0.8 | 0.800 |
| 10 | 37 | 0.055 | 0.050 | 1.17 | 1.500 | 0.050 | 0.250 | 0.8 | 0.800 |
| 11 | 37 | 0.055 | 0.050 | 4.53 | 1.500 | 0.100 | 0.250 | 0.8 | 0.800 |
| 12 | 37 | 0.055 | 0.050 | 4.68 | 1.500 | 0.100 | 0.250 | 0.8 | 0.800 |
| 13 | 46 | 0.055 | 0.050 | 9.38 | 1.500 | 0.100 | 0.250 | 0.8 | 0.800 |
| 14 | 52 | 0.055 | 0.010 | 8.62 | 0.500 | 0.050 | 0.025 | 0.8 | 0.800 |
| 15 | 54 | 0.055 | 0.010 | 8.57 | 0.500 | 0.050 | 0.025 | 0.8 | 0.800 |

Table 4. Continued

| | | BC1 | | BC2 | | BC3 | | BC4 | |
|---|---|---|---|---|---|---|---|---|---|
| QUAL2E Reach | SWAT Subbasin | Decay Rate for NH4 to NO2 (0.1 to 1.0) (Default=0.55) | | Decay Rate for NO2 to NO3 (0.2 to 2.0) (Default=1.1) | | Decay Rate for Org N to NH4 (0.2 to 0.4) (Default=0.21) | | Decay Rate for Org p to Dissolved P (0.01 to 0.70) (Default=0.35) | |
| | | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT | Espey-QUAL2E | SSL-SWAT |
| 1 | 106 | 0.20 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 2 | 13 | 0.20 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 3 | 15 | 0.20 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 4 | 19 | 0.20 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 5 | 32 | 0.40 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 6 | 32 | 0.40 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 7 | 80 | 0.40 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 8 | 45 | 0.40 | 0.300 | 0.08 | 1.200 | 0.001 | 0.030 | 0.05 | 0.010 |
| 9 | 103 | 0.60 | 0.300 | 0.15 | 1.200 | 0.050 | 0.030 | 0.05 | 0.010 |
| 10 | 37 | 0.60 | 0.300 | 0.15 | 1.200 | 0.050 | 0.030 | 0.05 | 0.010 |
| 11 | 37 | 0.60 | 0.300 | 0.15 | 1.200 | 0.050 | 0.030 | 0.05 | 0.010 |
| 12 | 37 | 0.60 | 0.300 | 0.15 | 1.200 | 0.050 | 0.030 | 0.05 | 0.010 |
| 13 | 46 | 0.60 | 0.300 | 0.15 | 1.200 | 0.050 | 0.030 | 0.05 | 0.010 |
| 14 | 52 | 0.30 | 0.300 | 0.08 | 1.200 | 0.100 | 0.030 | 0.05 | 0.010 |
| 15 | 54 | 0.30 | 0.300 | 0.08 | 1.200 | 0.100 | 0.030 | 0.05 | 0.010 |

Table 5. Stream water quality coefficients (.swq) for calibration of SWAT for 1989 to 2002 Tributary Study.

| | RS1 | RS2 | RS3 | RS4 | RS5 | RK1 | RK2 |
|---|---|---|---|---|---|---|---|
| TRIBUTARY | Local Algal Settling (0.15 to 1.82) (Default=1.0) | Benthos Source Rate for Dissolved P (Default=0.05) | Benthos Source Rate for NH4-N (Default=0.5) | Org N Settling Rate (0.001 to 0.10) (Default=0.05) | Org P Settling Rate (0.001 to 0.10) (Default=0.05) | CBOD deoxygenation rate (0.02 to 3.4) (Default=1.71) | Reaeration Rate (0.01 to 100) (Default=50.0) |
| KINGS ** | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| CEDAR 1391 | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| CEDAR 243 | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| LACY | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| N.TWIN | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| S.TWIN | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| LYNN | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.010 | 0.500 |
| CLEAR | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| CANEY | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.050 | 1.500 |
| PRAIRIE | 0.010 | 0.001 | 0.001 | 0.010 | 0.010 | 0.010 | 0.500 |

Table 5. Continued

| | RK3 | RK4 | BC1 | BC2 | BC3 | BC4 |
|---|---|---|---|---|---|---|
| TRIBUTARY | CBOD Settling loss Rate (-0.36 to 0.36) (Default=0.36) | Benthic Oxygen Demand (Default=2.0) | Decay Rate for NH4 to NO2 (0.1 to 1.0) (Default=0.55) | Decay Rate for NO2 to NO3 (0.2 to 2.0) (Default=1.1) | Decay Rate for Org N to NH4 (0.2 to 0.4) (Default=0.21) | Decay Rate for Org p to Dissolved P (0.01 to 0.70) (Default=0.35) |
| KINGS ** | 0.250 | 0.800 | 0.300 | 1.200 | 0.030 | 0.01 |
| CEDAR 1391 | 0.250 | 0.800 | 0.300 | 1.200 | 0.030 | 0.01 |
| CEDAR 243 | 0.250 | 0.800 | 0.300 | 1.200 | 0.040 | 0.01 |
| LACY | 0.250 | 0.800 | 0.300 | 1.200 | 0.200 | 0.01 |
| N.TWIN | 0.250 | 0.800 | 0.300 | 1.200 | 0.050 | 0.01 |
| S.TWIN | 0.250 | 0.800 | 0.300 | 1.200 | 0.060 | 0.01 |
| LYNN | 0.025 | 0.800 | 0.300 | 1.200 | 0.200 | 0.01 |
| CLEAR | 0.250 | 0.800 | 0.300 | 1.200 | 0.060 | 0.01 |
| CANEY | 0.250 | 0.800 | 0.300 | 1.200 | 0.060 | 0.01 |
| PRAIRIE | 0.025 | 0.800 | 0.300 | 1.200 | 0.060 | 0.01 |

** Kings Creek subbasins not included in 2002 Kings Study (Brushy Creek tributary, etc.).

Table 6. Nitrogen and phosphorus enrichment ratios used for 1989 to 2002 Tributary calibration.

| TRIBUTARY | EORGN - Nitrogen Enrichment Ratio (Default - SWAT calculates) | EORGP - Phosphorus Enrichment Ratio (Default - SWAT calculates) |
|---|---|---|
| KINGS | 10 | 0.313 |
| CEDAR 1391 | 20 | 0.625 |
| CEDAR 243 | 50 | 1.563 |
| LACY | 20 | 1.250 |
| N.TWIN | 20 | 0.625 |
| S.TWIN | 15 | 0.469 |
| LYNN | 10 | 0.313 |
| CLEAR | 15 | 0.469 |
| CANEY | 50 | 1.563 |
| PRAIRIE | 40 | 1.250 |

# RESULTS

## Flow Calibration and Validation

Flow calibration was performed from 1966 through 1987. For this period predicted flow matched measured very well at USGS stream gages 08062800 (Cedar Creek) and 08062900 (Kings Creek) (Figures 7 and 8). Measured and predicted means were nearly equal, and $r^2$ values were 0.82 (Cedar Creek) and 0.89 (Kings Creek). The Nash-Sutcliffe Coefficients of Efficiency (COE) were 0.81 (Cedar - Figure 10) and 0.83 (Kings – Figure 11), which also indicated a good match.

With the same calibration inputs, flow was validated from 1980 through 2002 using the measured mass balance of Cedar Creek Reservoir for comparison to predicted inflow values (Figure 9). Again, predicted inflow match measured very well, with $r^2 = 0.76$ and Nash-Sutcliffe COE of 0.80 (Figure 12).

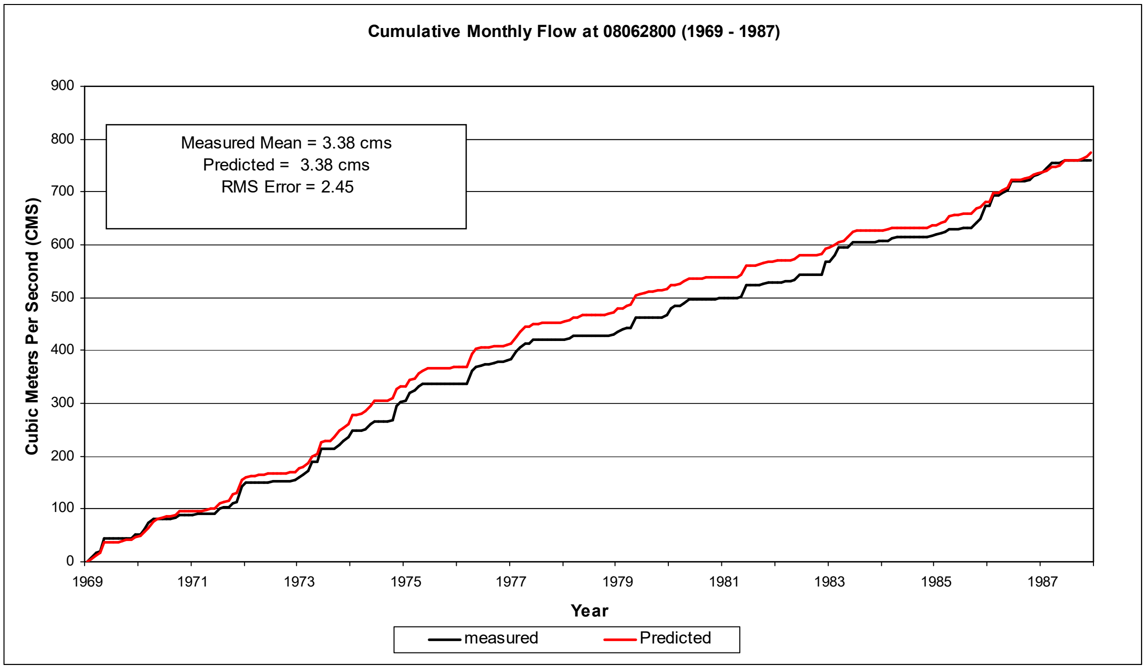


Figure 7. Cumulative monthly measured and predicted flow at stream gage 08062800 (subbasin 81), January 1969 through September 1987.

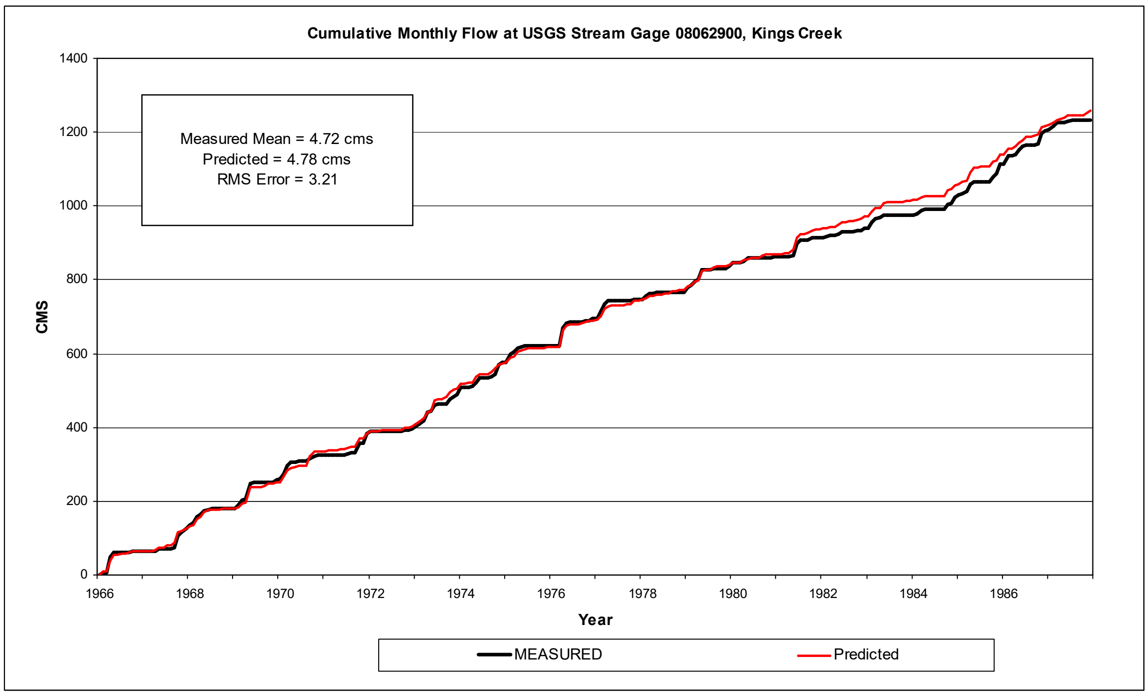


Figure 8. Cumulative monthly measured and predicted flow at stream gage 08062900 (subbasin 80), January 1963 through September 1987.

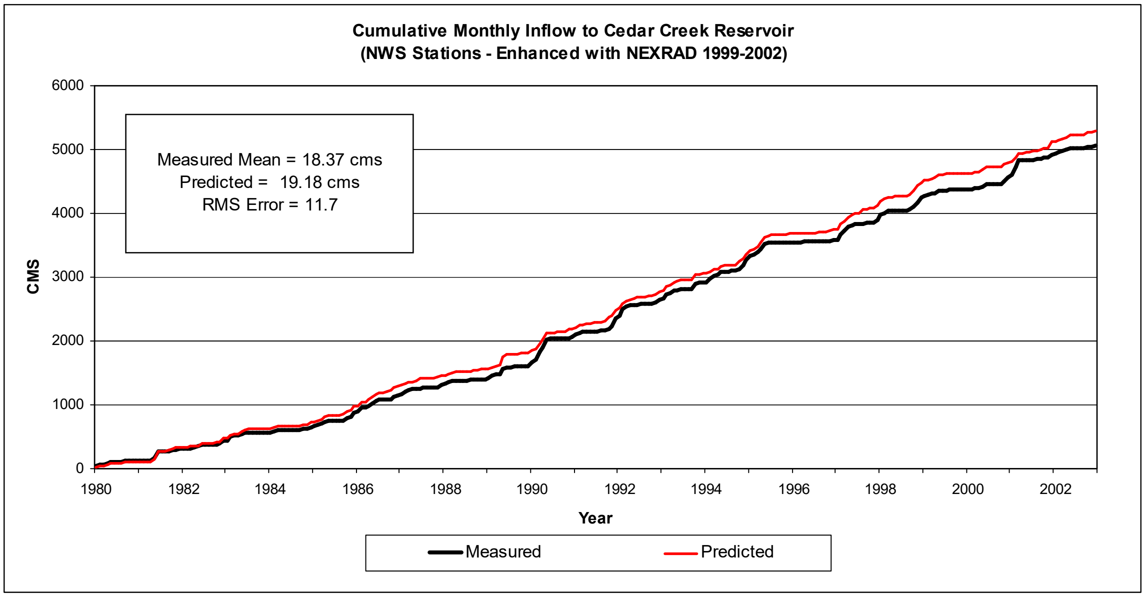


Figure 9. Cumulative monthly measured and predicted inflow to Cedar Creek Reservoir, January 1980 through December 2002.

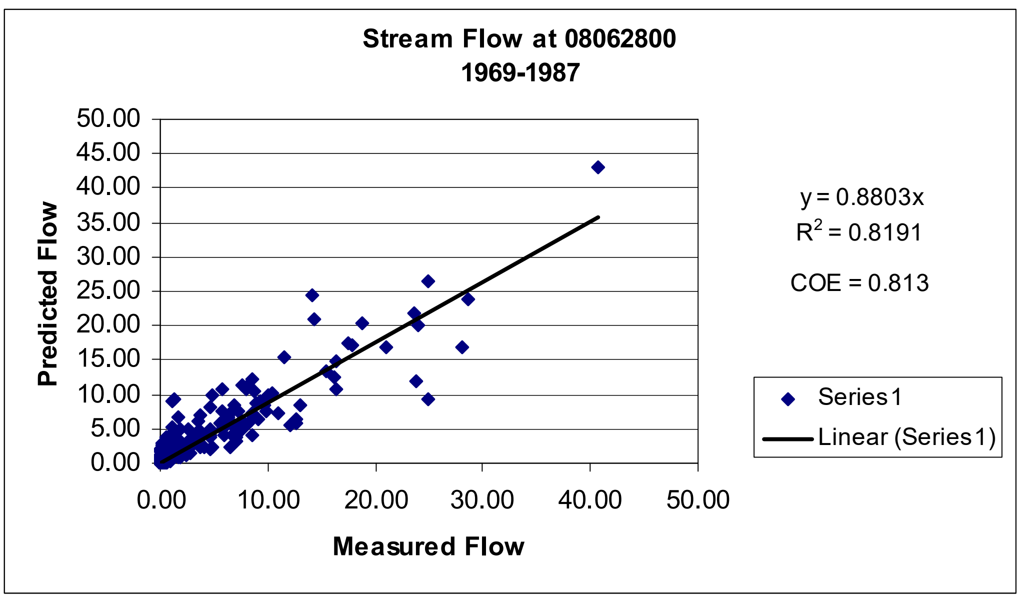


Figure 10. Measured versus predicted flow at stream gage 08062800.

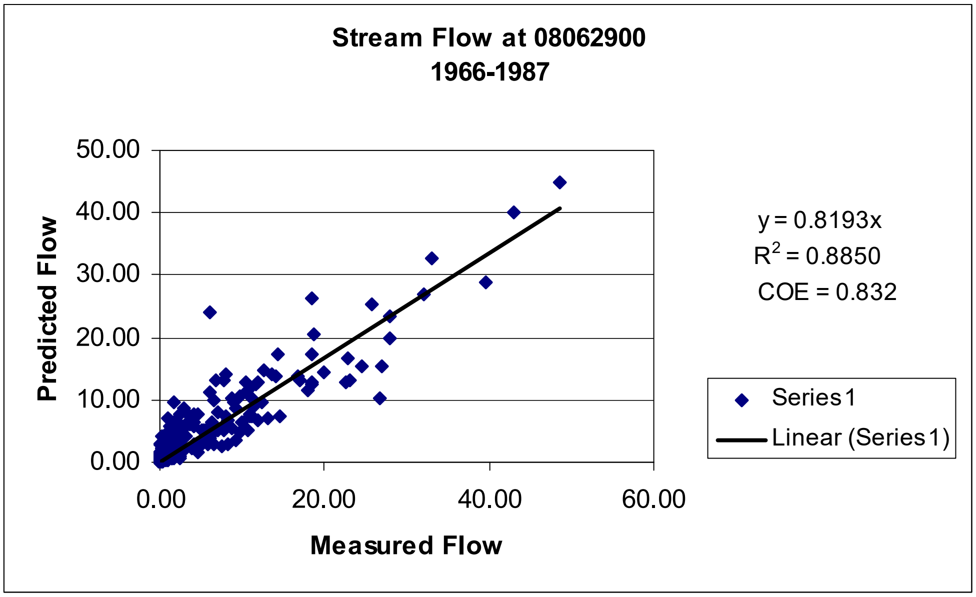


Figure 11. Measured versus predicted flow at stream gage 08062900.

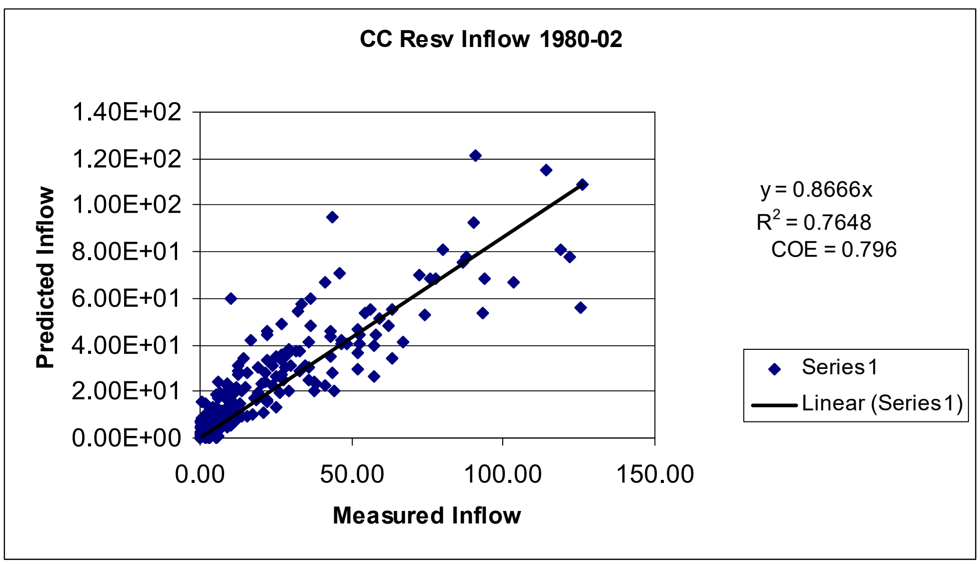


Figure 12. Measured versus predicted inflow to Cedar Creek Reservoir, 1980 through 2002.

## **Sediment Calibration**

After adjustment of appropriate inputs based on the TWDB volumetric survey and Baylor University lake and watershed survey, predicted sediment from 1966 to 2002 was nearly equal to measured sediment (Figure 13).

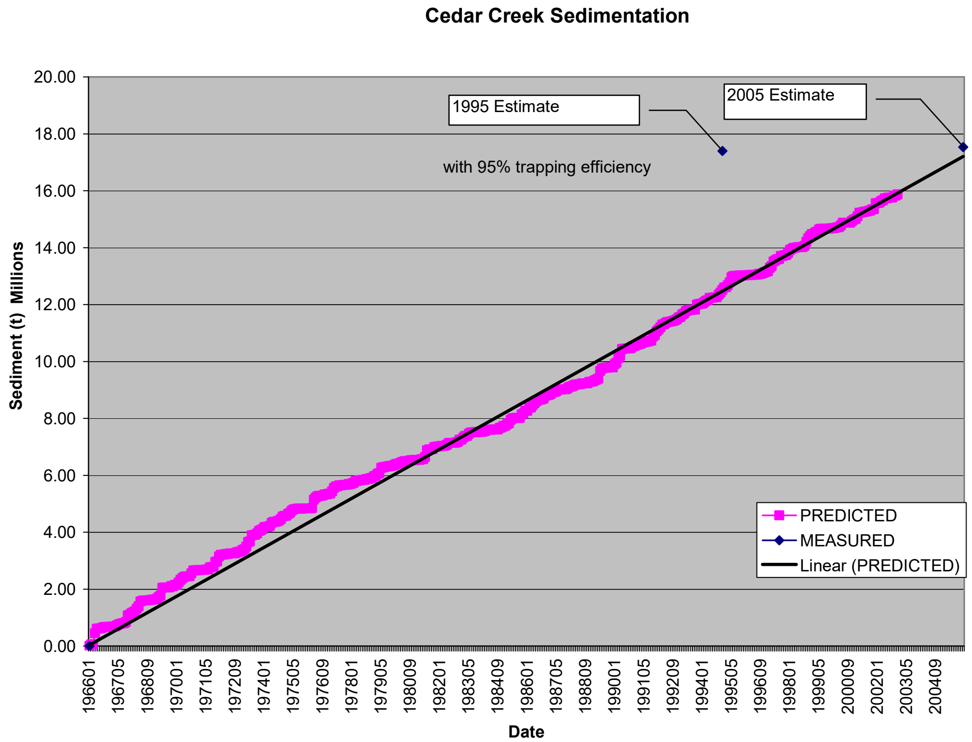


Figure 13. Measured and predicted sediment accumulation in Cedar Creek Reservoir from 1966 through 1994.

## Nutrient Calibration Kings Creek 2002 Study

The results of the Kings Creek 2002 Study calibration are shown in Figures 14 through 25. The figures show the values measured by TRWD, the predicted values from the Espey Consultants independent calibration of QUAL2E, and the predicted values from SWAT. Data points are shown left to right in downstream order, beginning with subbasin 13 located at the Highway 279 crossing of Kings Creek, which is downstream from the Terrell wastewater treatment plant. The last data point from SWAT is at the Highway 274 crossing of Kings Creek (subbasin 89).

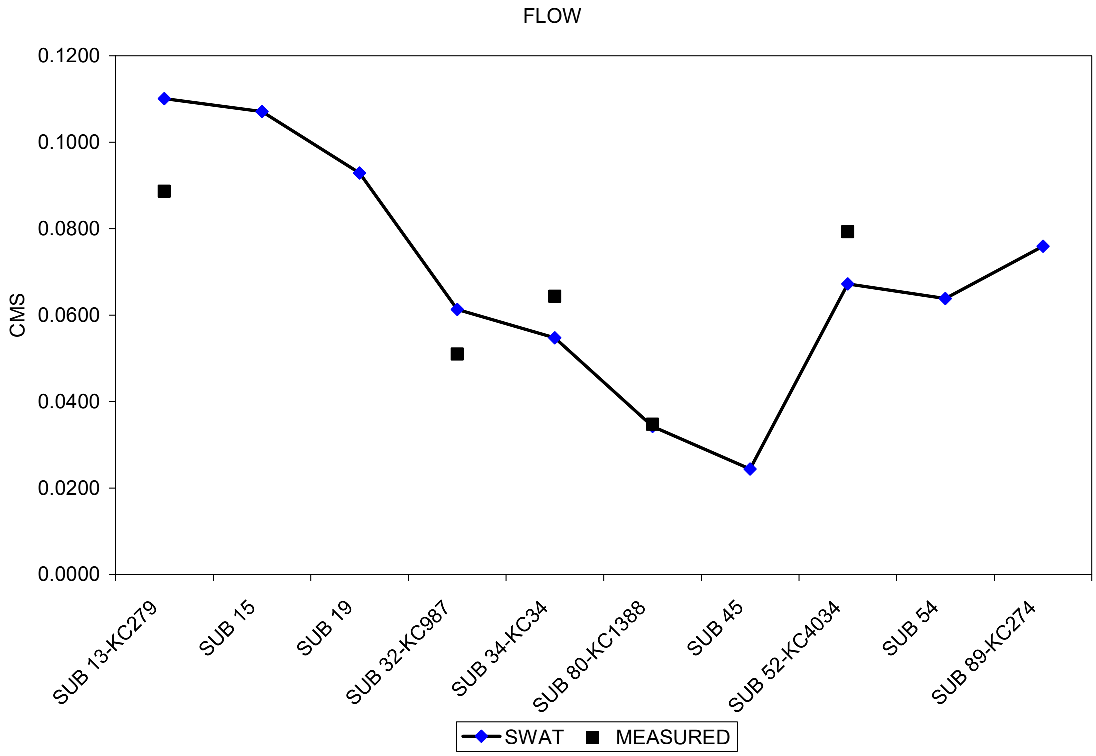


Figure 14. Measured and predicted flow, Kings Creek 2002 Study.

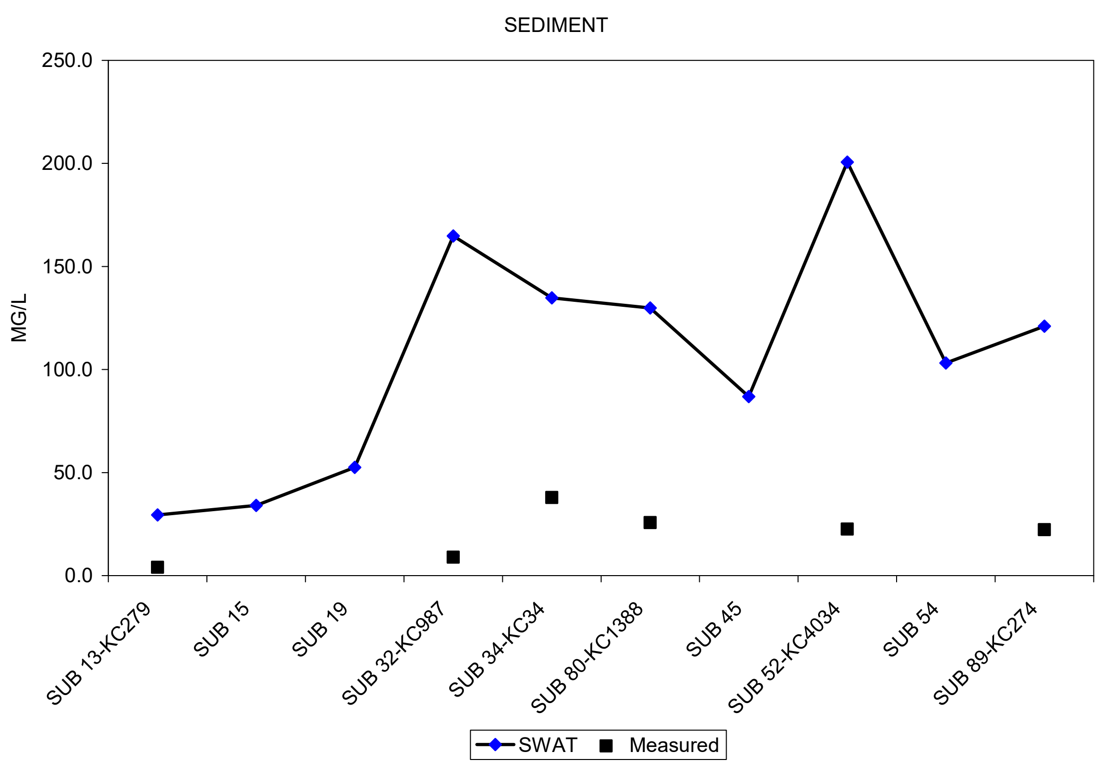


Figure 15. Measured and predicted sediment, Kings Creek 2002 Study.

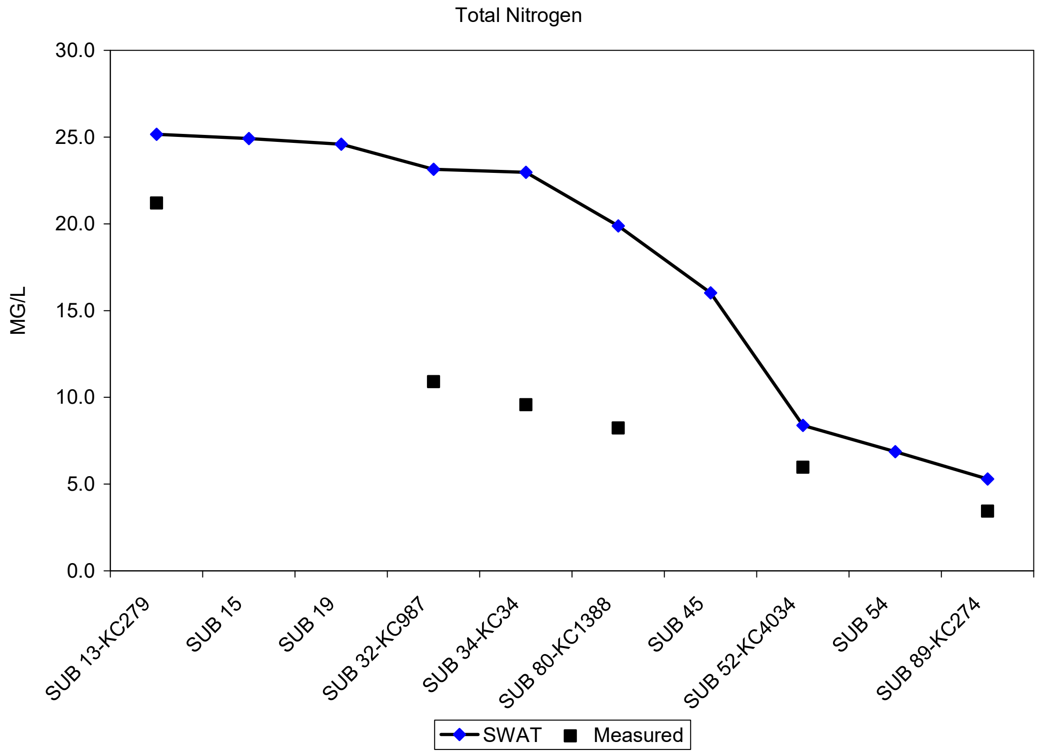


Figure 16. Measured and predicted total nitrogen, Kings Creek 2002 Study.

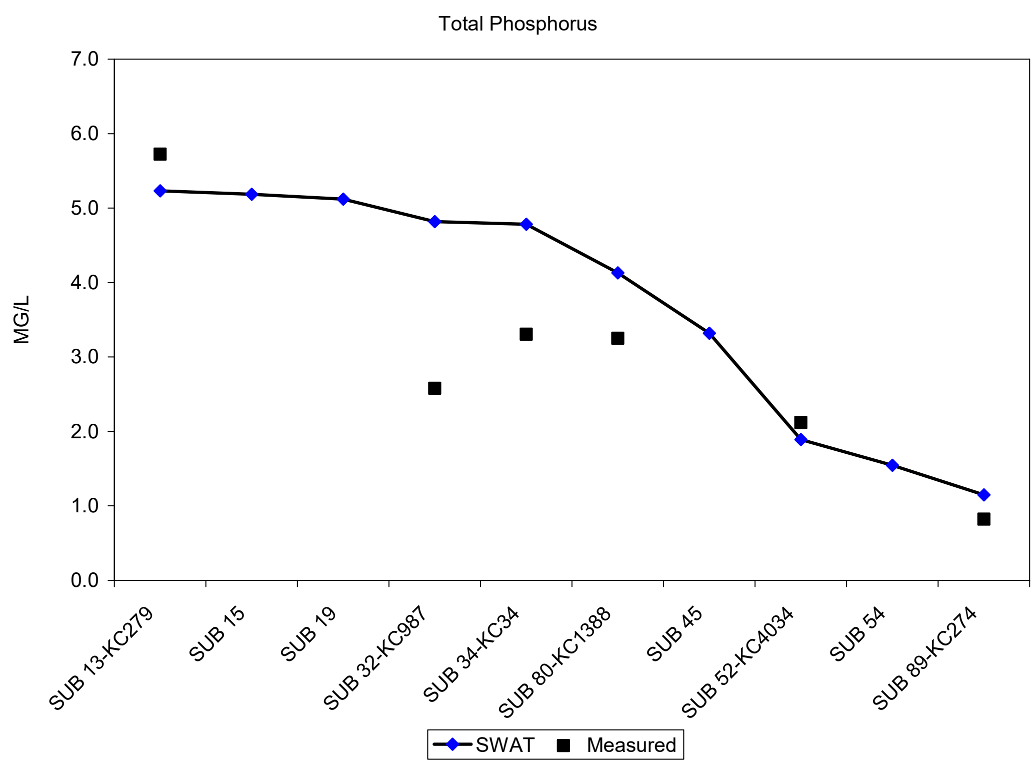


Figure 17. Measured and predicted total phosphorus, Kings Creek 2002 Study.

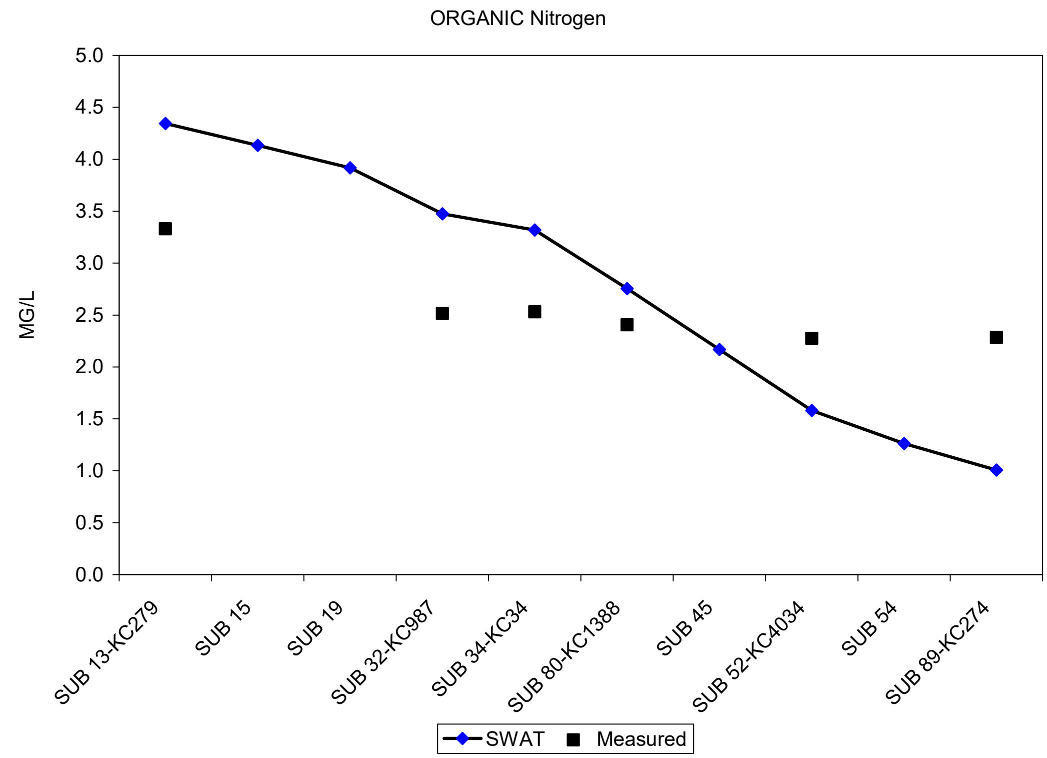


Figure 18. Measured and predicted organic nitrogen, Kings Creek 2002 Study.

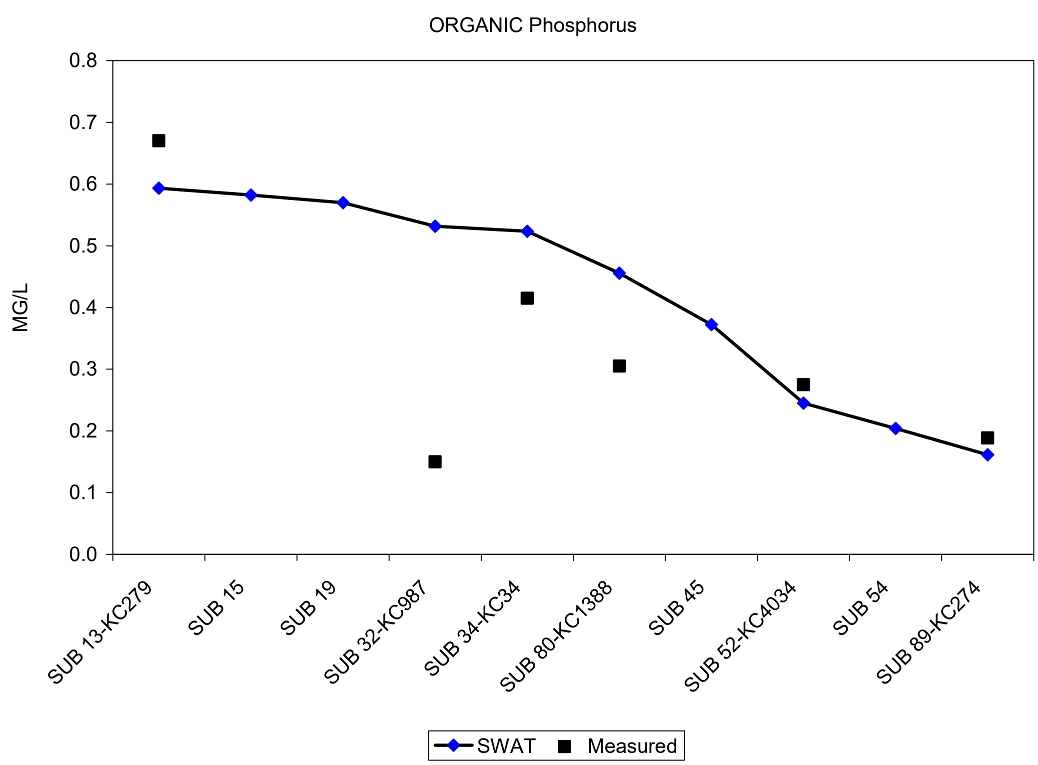


Figure 19. Measured and predicted organic phosphorus, Kings Creek 2002 Study.

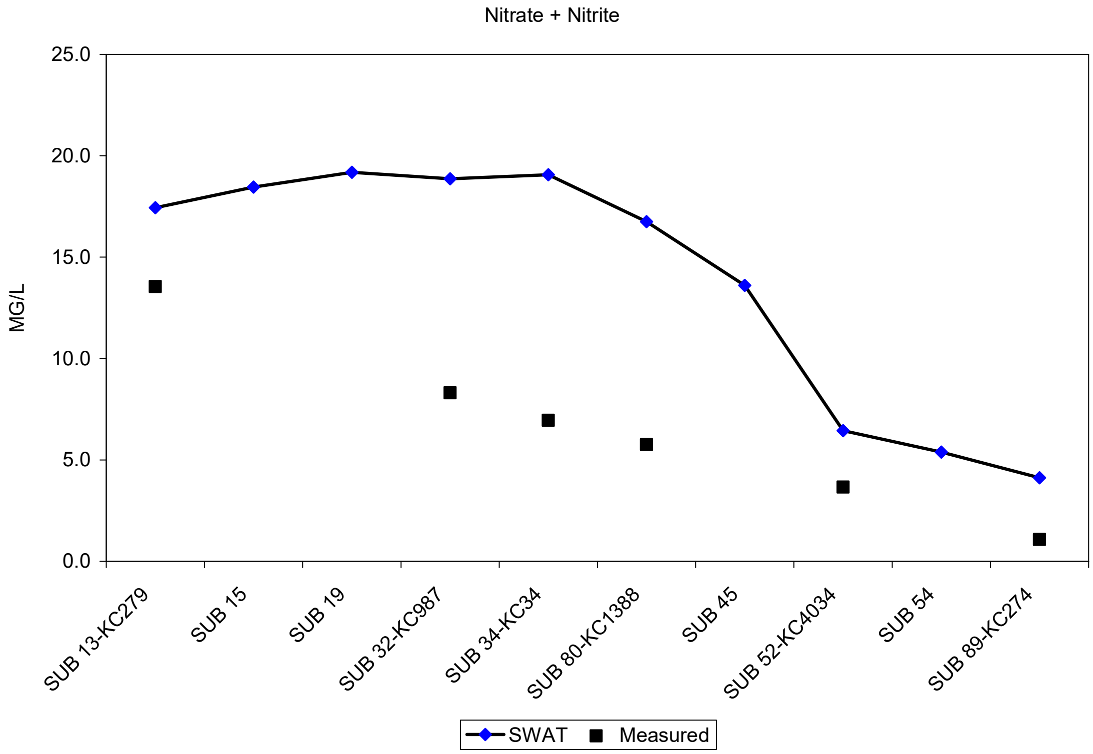


Figure 20. Measured and predicted nitrate + nitrite nitrogen, Kings Creek 2002 Study.

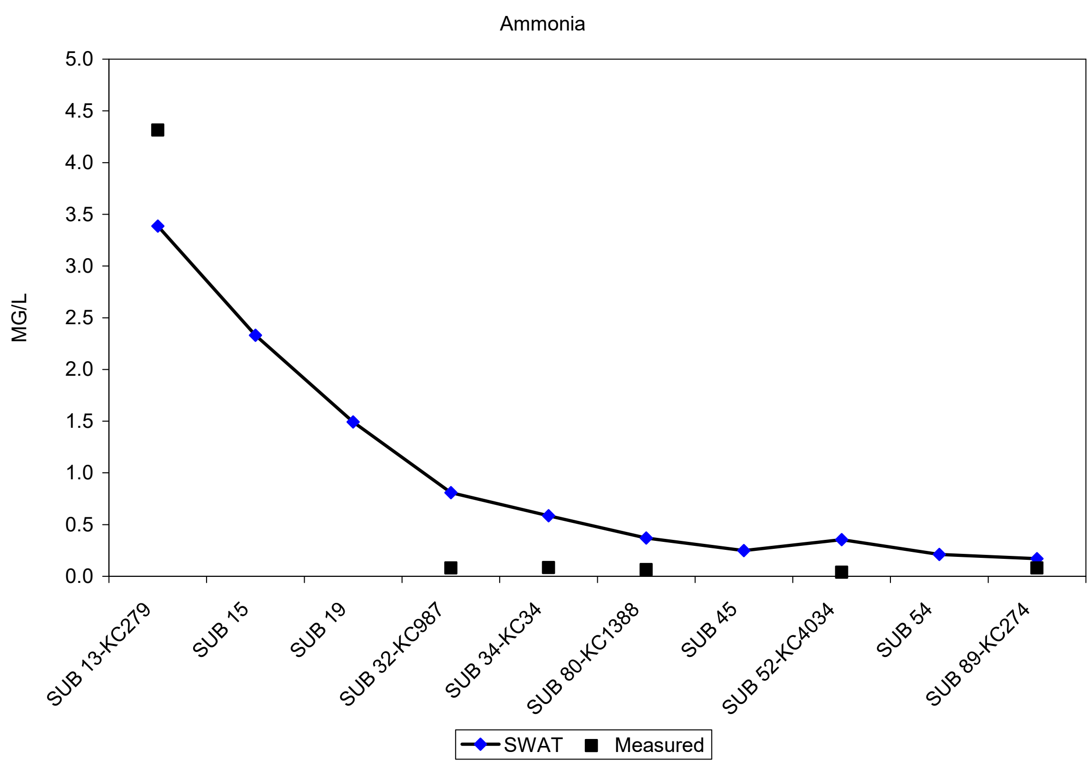


Figure 21. Measured and predicted ammonia nitrogen, Kings Creek 2002 Study.

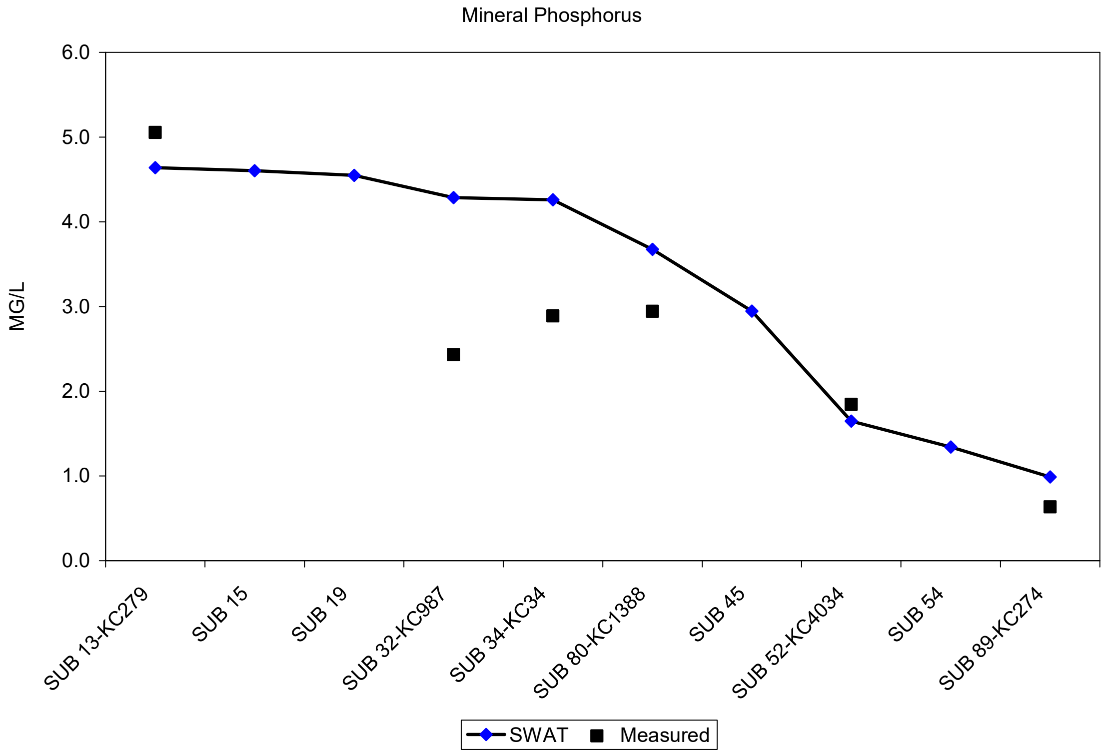


Figure 22. Measured and predicted mineral phosphorus, Kings Creek 2002 Study.

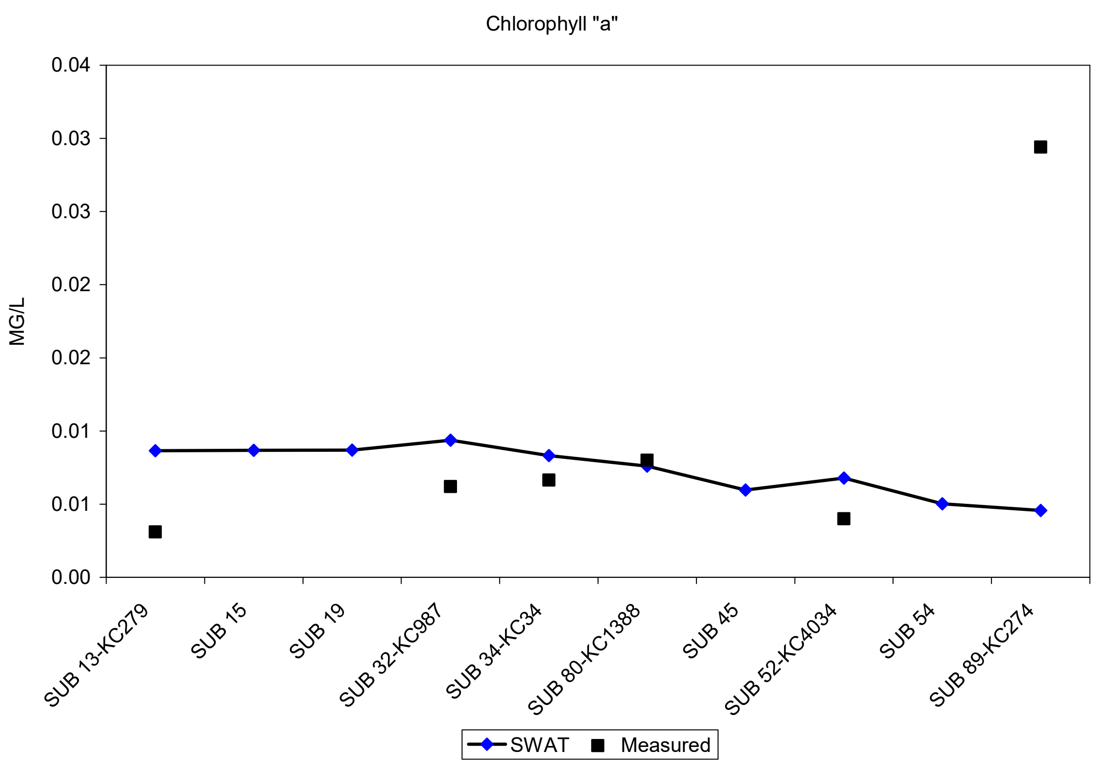


Figure 23. Measured and predicted chlorophyll ‘a’, Kings Creek 2002 Study.

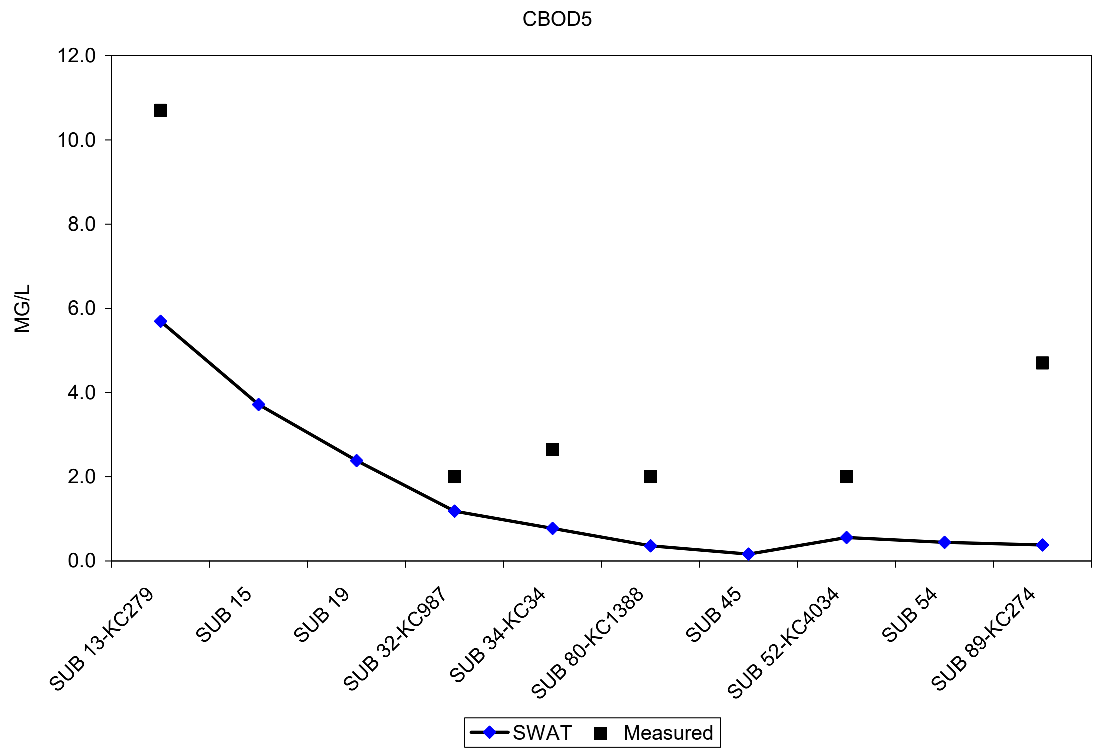


Figure 24. Measured and predicted CBOD5, Kings Creek 2002 Study.

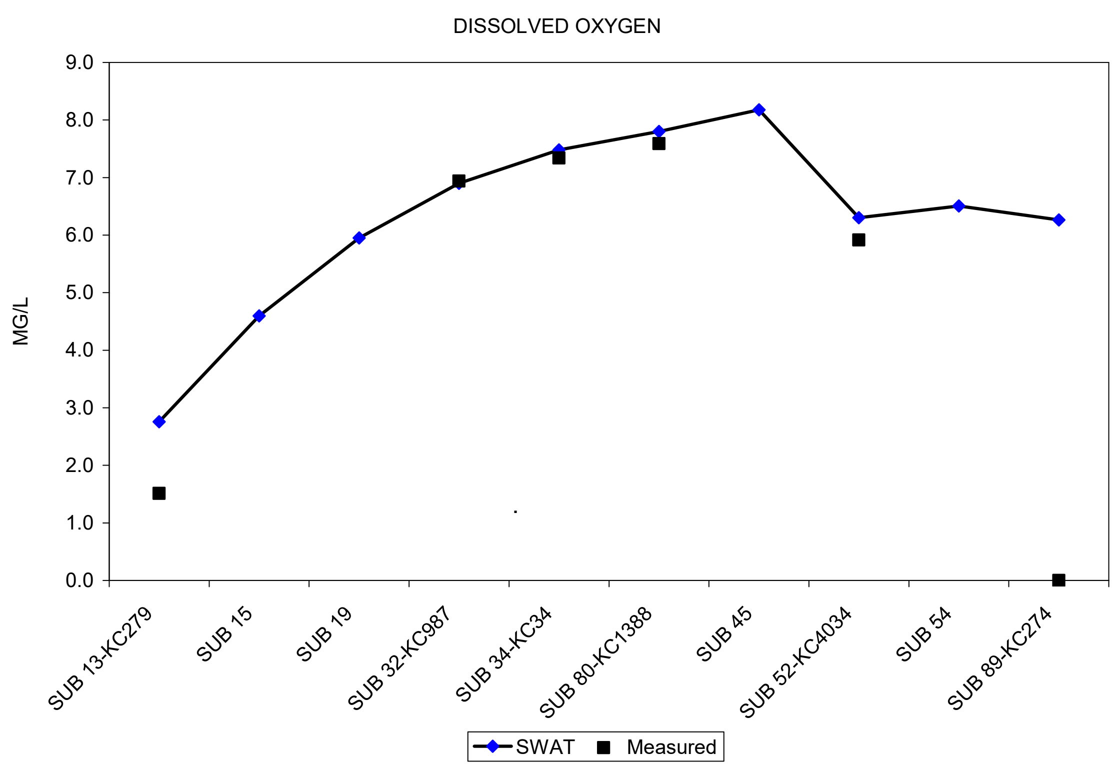


Figure 25. Measured and predicted dissolved oxygen, Kings Creek 2002 Study.

**Nutrient Calibration – 1989 to 2002 Tributary Study**

Figures 26 through 36 show comparisons of medians, 25th percentile, and 75th percentile of the 3-day averages from SWAT, and the medians, 25th, and 75th percentiles of the measured grab samples for each tributary of the Cedar Creek watershed. In each graph the measured data is labeled with the name of the tributary in which it was collected, and the predicted values for the corresponding tributary are labeled "SWAT". Summary statistics are shown in Table 7.

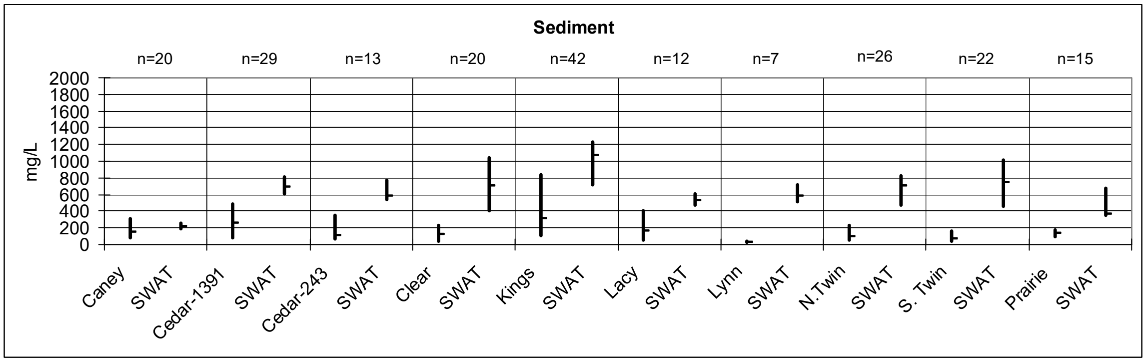


Figure 26. Measured and predicted sediment (TSS) (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

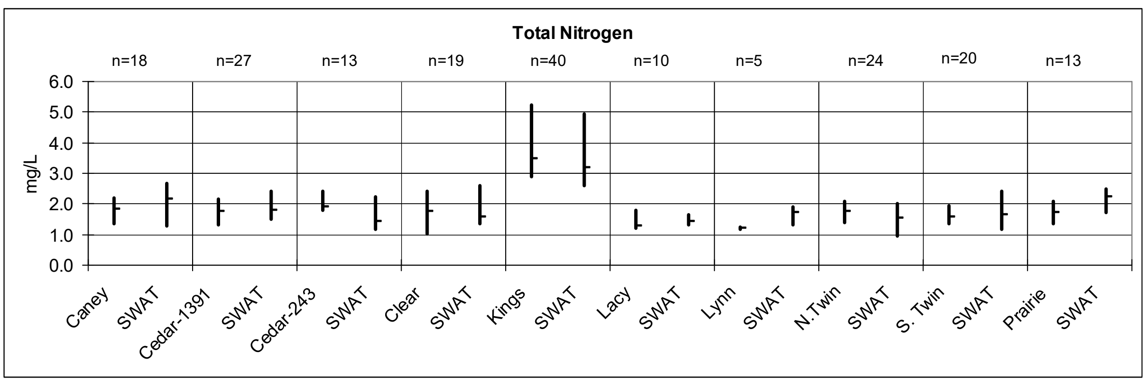


Figure 27. Measured and predicted total nitrogen (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

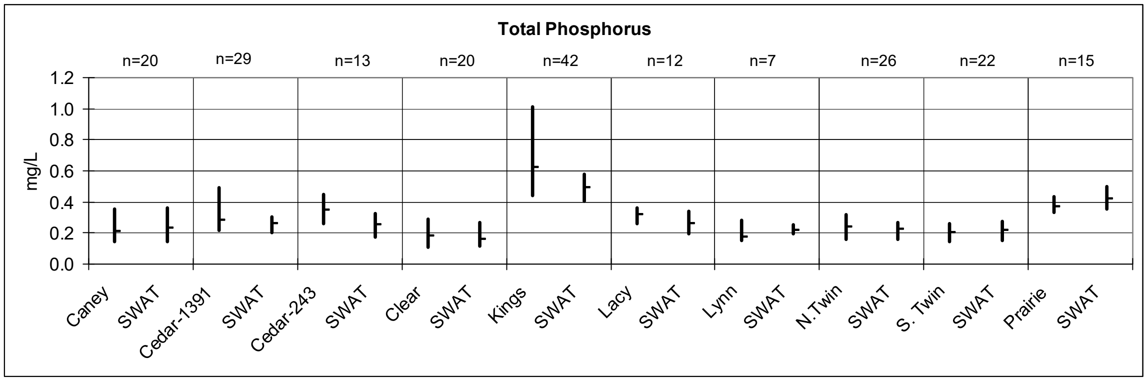


Figure 28. Measured and predicted total phosphorus (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

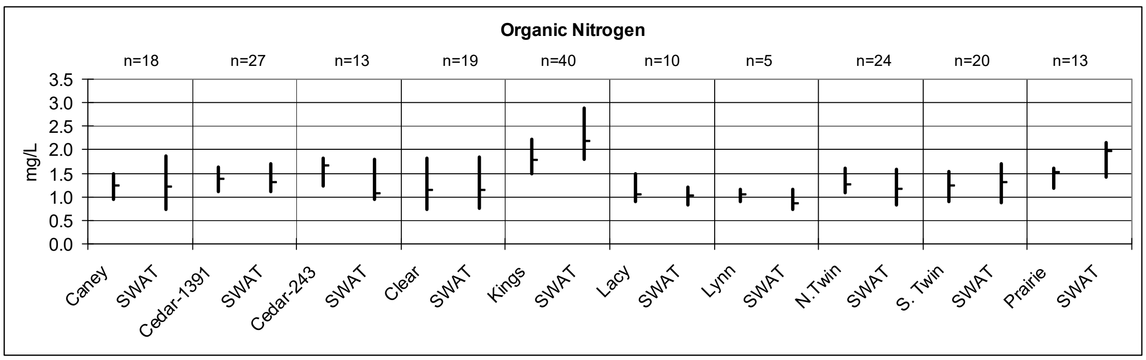


Figure 29. Measured and predicted organic nitrogen (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

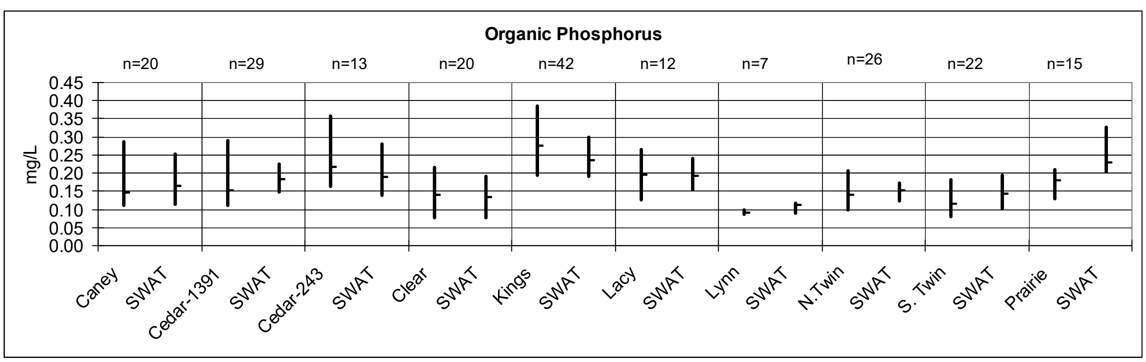


Figure 30. Measured and predicted organic phosphorus (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

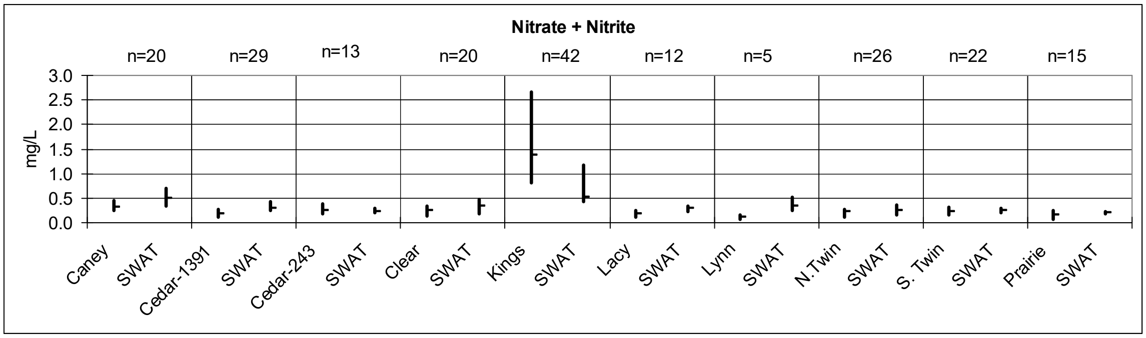


Figure 31. Measured and predicted nitrate + nitrite (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

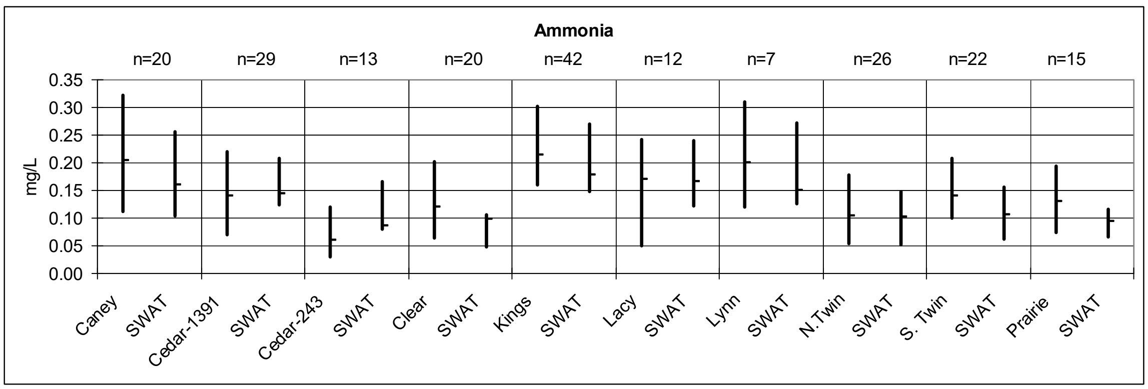


Figure 32. Measured and predicted ammonia (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

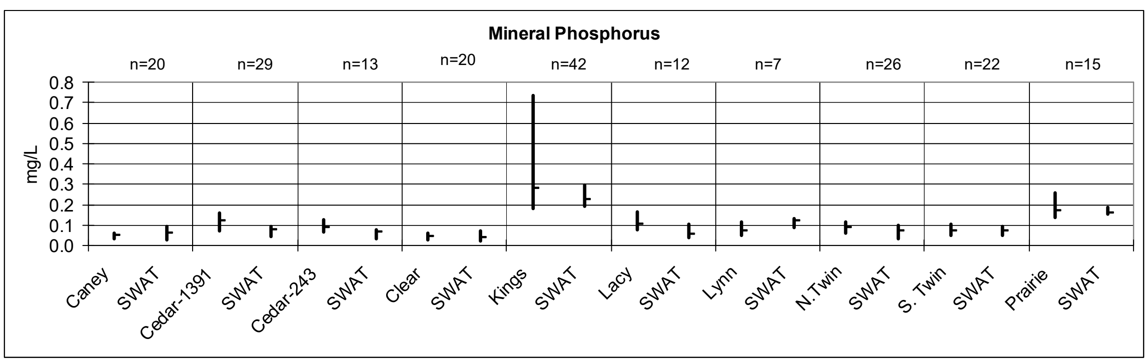


Figure 33. Measured and predicted mineral phosphorus (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

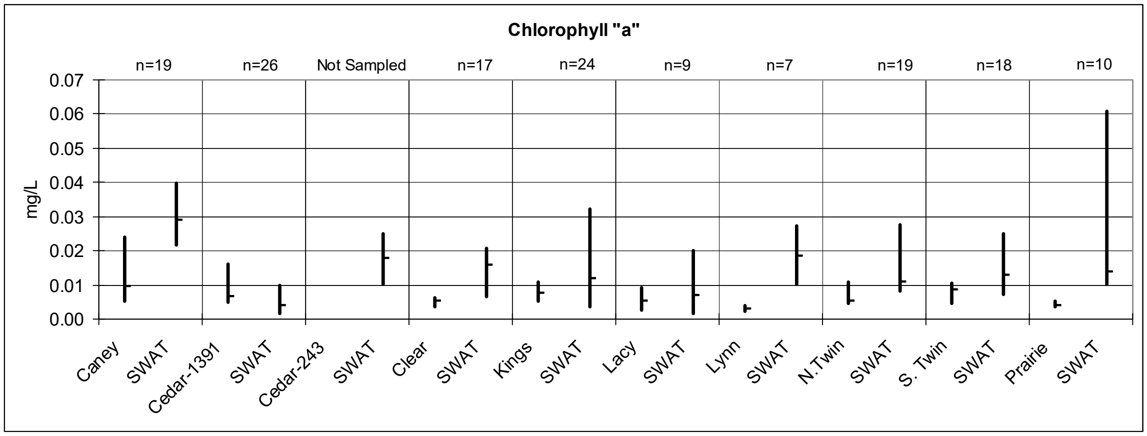


Figure 34. Measured and predicted chlorophyll ‘a’ (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

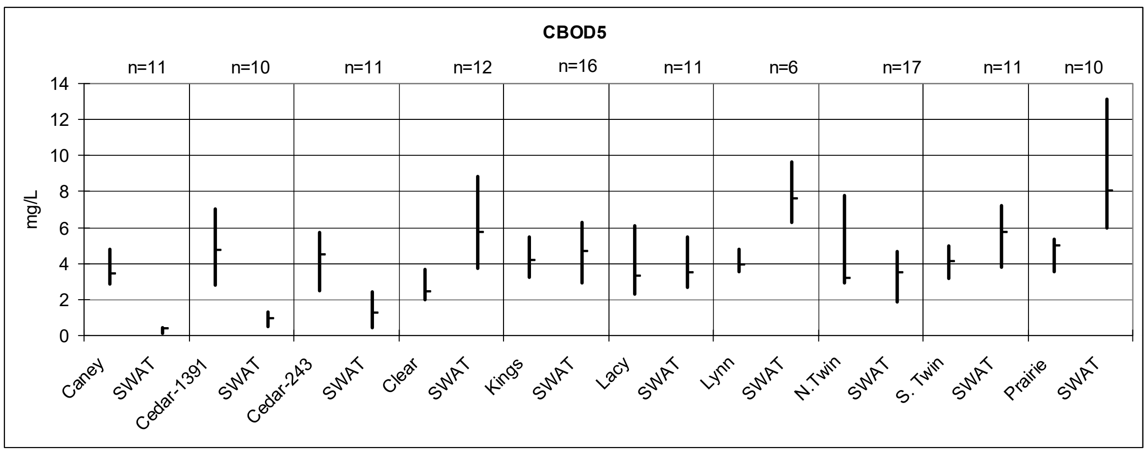


Figure 35. Measured and predicted CBOD5 (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

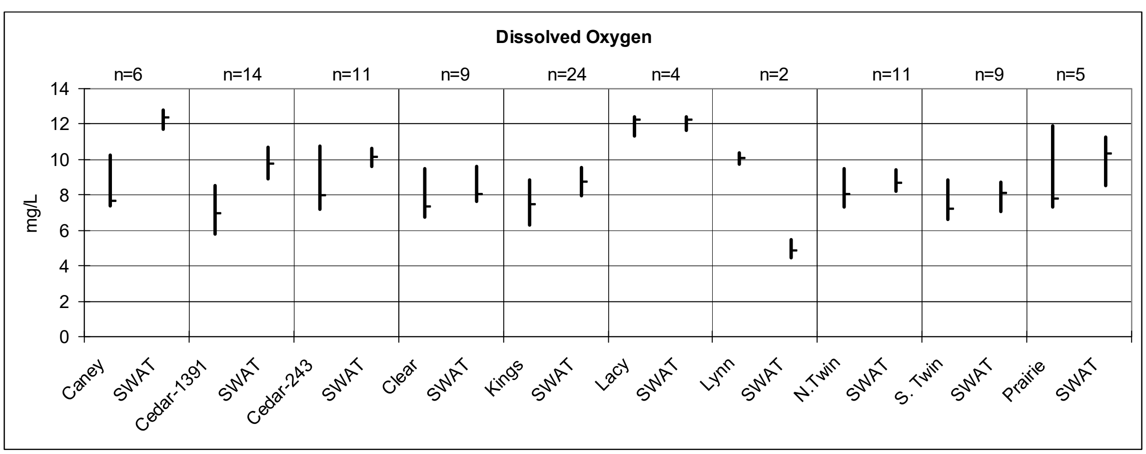


Figure 36. Measured and predicted dissolved oxygen (median, 25th, and 75th percentile), 1989 to 2002 Tributary Study.

Table 7. Statistical comparison of observed tributary median concentrations from 1989 to 2002 (as shown in Figures 26 to 36) to SWAT flow weighted predictions for the same period

| Parameter | $R^2$ |
|---|---|
| TSS | 0.177 |
| NH3 | 0.775 |
| NOX | 0.498 |
| ON | 0.536 |
| OrgP | 0.745 |
| OPO4 | 0.804 |
| TOTAL N | 0.697 |
| TOTAL P | 0.835 |
| CHLA | 0.069 |
| CBOD5 | 0.002 |
| DO | 0.011 |

*$R^2$ values highlighted in Red are significant at p = 0.05

## SWAT OUTPUT TO WASP INPUT

After calibration was completed, SWAT output from 1989 to 2002 was converted to a WASP nonpoint source (.nps) input file. Output from SWAT is given in *basins.rch* (stream flow and mass loadings) and *basins.bsb* (overland flow and loadings per unit area). The conversion was accomplished by writing a program to automatically read SWAT output files and convert them to a WASP non-point source (.nps) input file.

Each WASP segment in Cedar Creek Reservoir corresponds to a SWAT subbasin. For reservoir segments with tributary inflow, output from the basins.rch file was used to load the segment. For reservoir segments that do not receive direct tributary flow, output from basins.bsb was used to represent loadings from land areas surrounding the segment. Figure 37 shows the WASP segments for Cedar Creek Reservoir in relation to SWAT subbasins. Table 8 lists WASP reservoir segments and the corresponding SWAT subbasin and output file. SWAT output for the 11-year period from 1991 to 2001 were converted to .nps files, and provided to TRWD and Espey Consultants for WASP calibration, validation and load reduction scenario analysis.

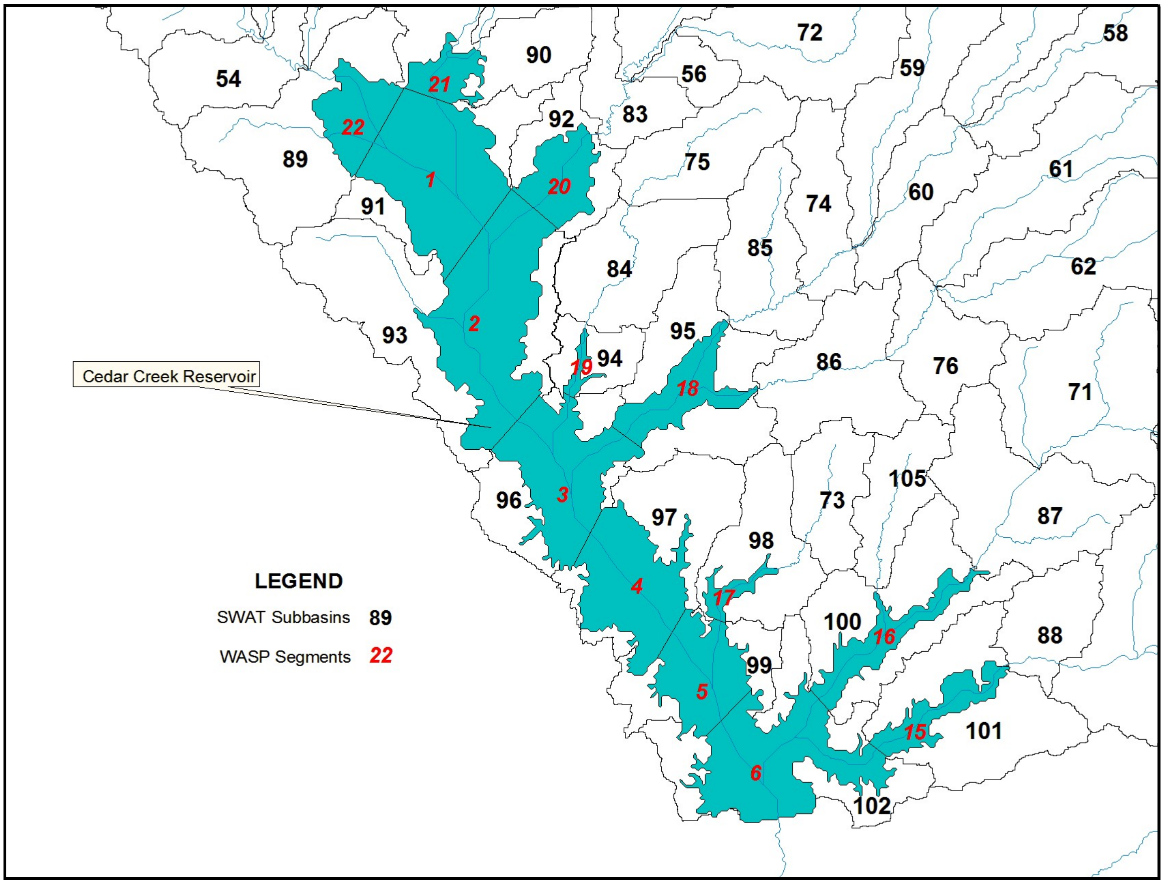

Figure 37. WASP segments and corresponding SWAT subbasins for Cedar Creek Reservoir.

Table 8. WASP segments, corresponding SWAT subbasins, and SWAT output files for Cedar Creek Reservoir.

| WASP Segment | SWAT Subbasin | SWAT Output File |
|---|---|---|
| 1 | 91 | .bsb |
| 2 | 93 | .bsb |
| 3 | 96 | .bsb |
| 4 | 97 | .bsb |
| 5 | 99 | .bsb |
| 6 | 102 | .bsb |
| 15 | 101 | .rch |
| 16 | 100 | .rch |
| 17 | 98 | .rch |
| 18 | 95 | .rch |
| 19 | 94 | .rch |
| 20 | 92 | .rch |
| 21 | 90 | .rch |
| 22 | 89 | .rch |

## AVERAGE ANNUAL LOAD BY LANDUSE

Figures 40 to 46 show the sediment and nutrient load contribution from various landuse and tributaries of the watershed

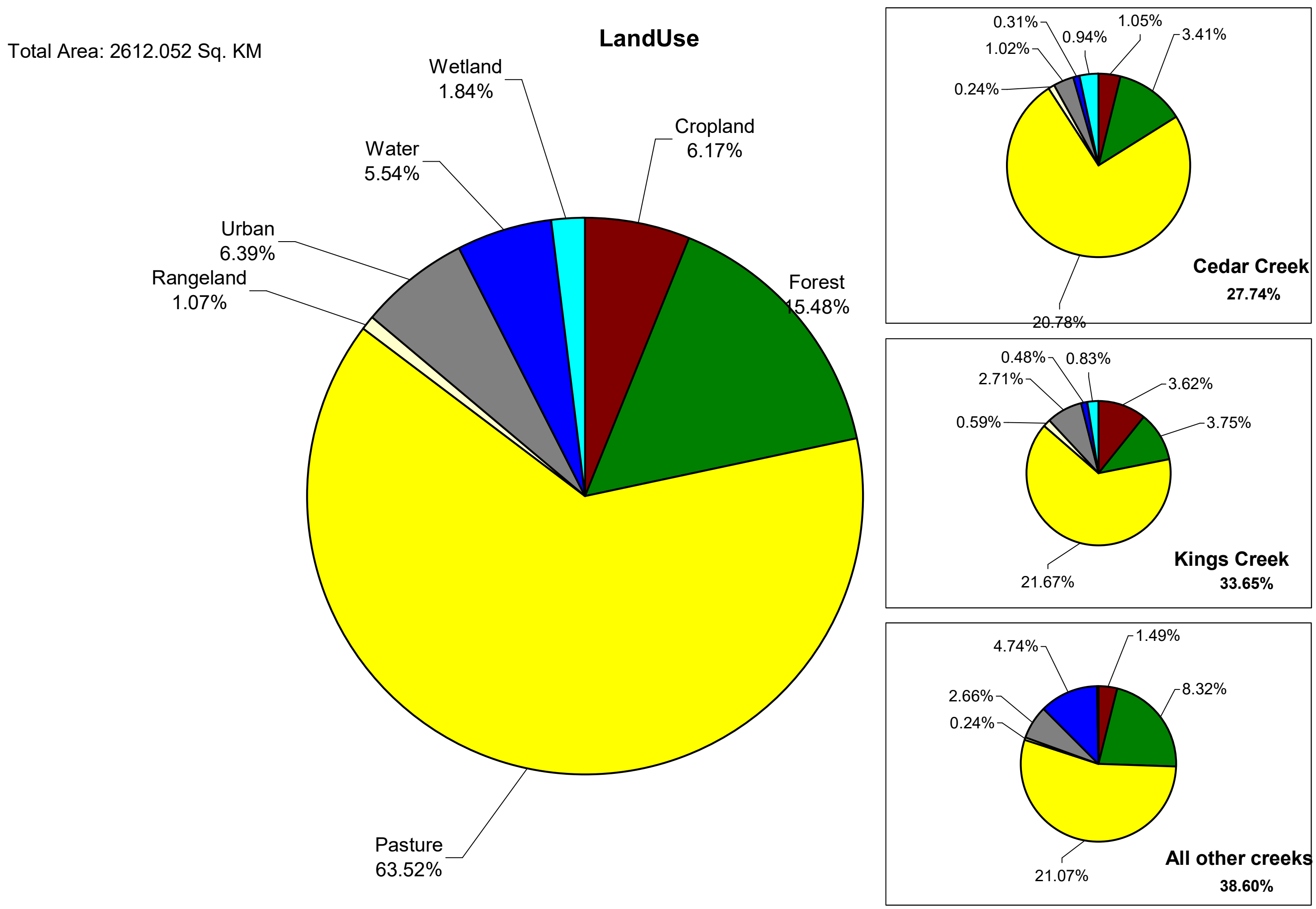


Figure 38. Landuse distribution by major creeks.

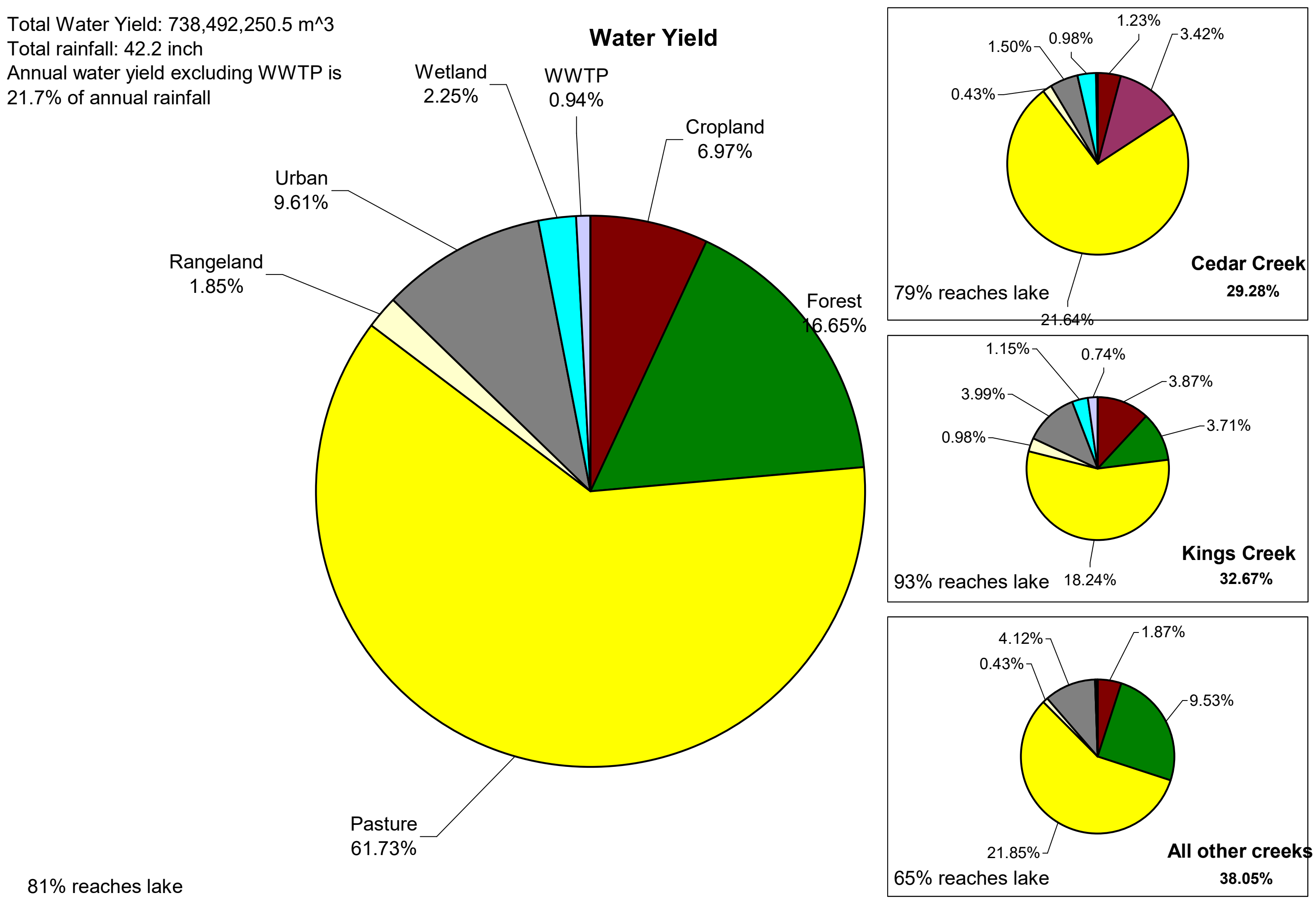


Figure 39. Water Yield by landuse and major creeks.

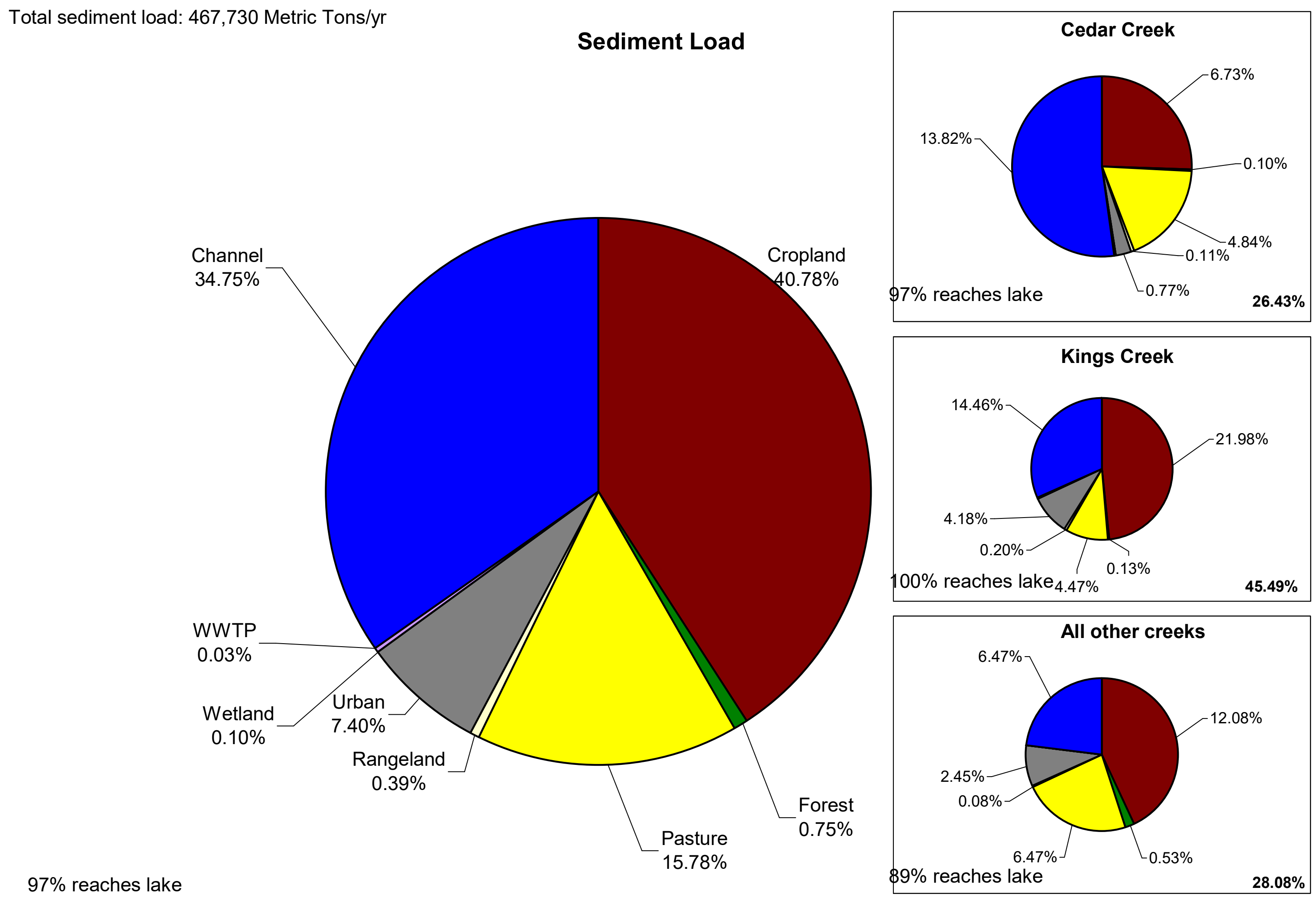


Figure 40.  Sediment load by landuse and major creeks.

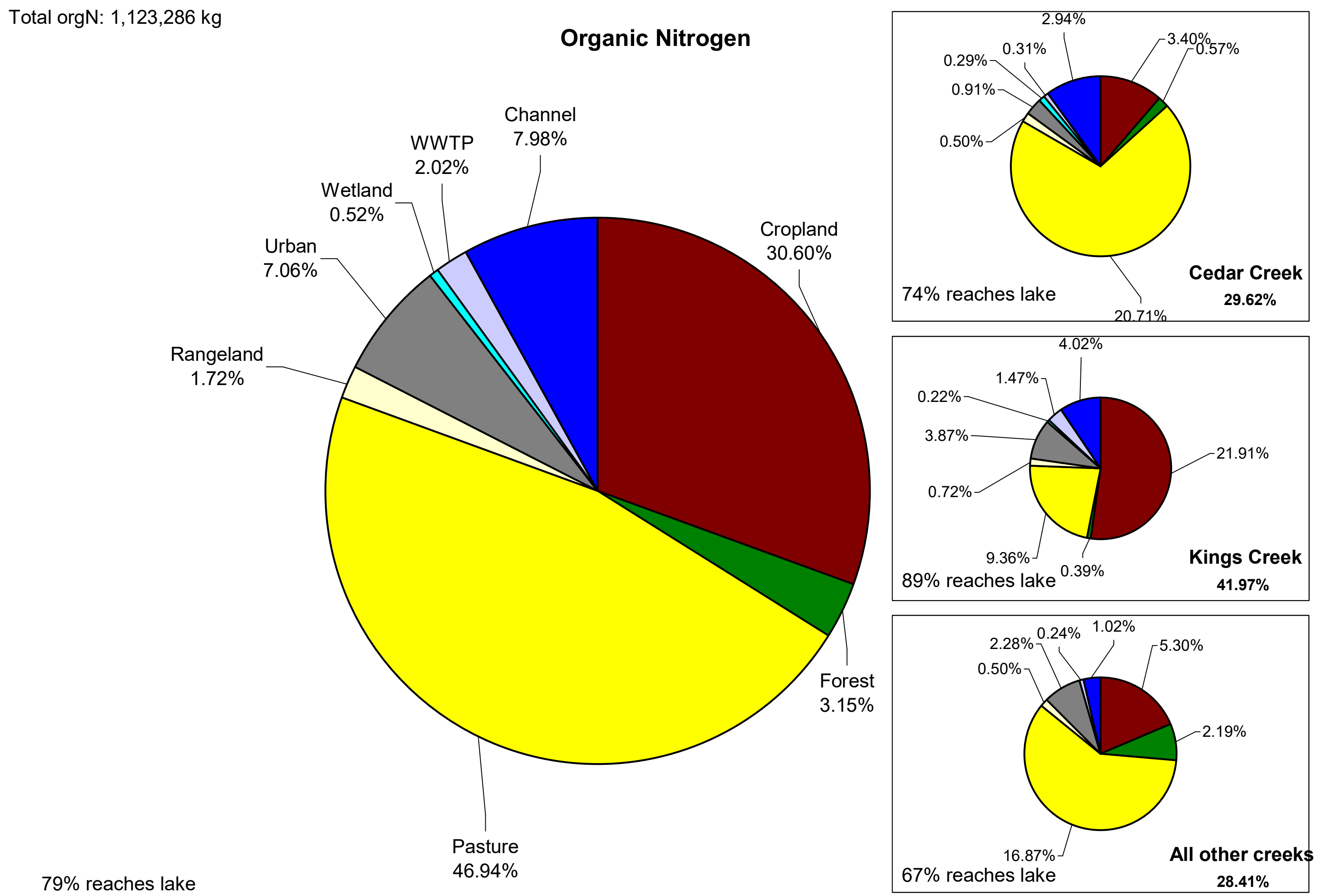


Figure 41. Organic Nitrogen load by landuse and major creeks.

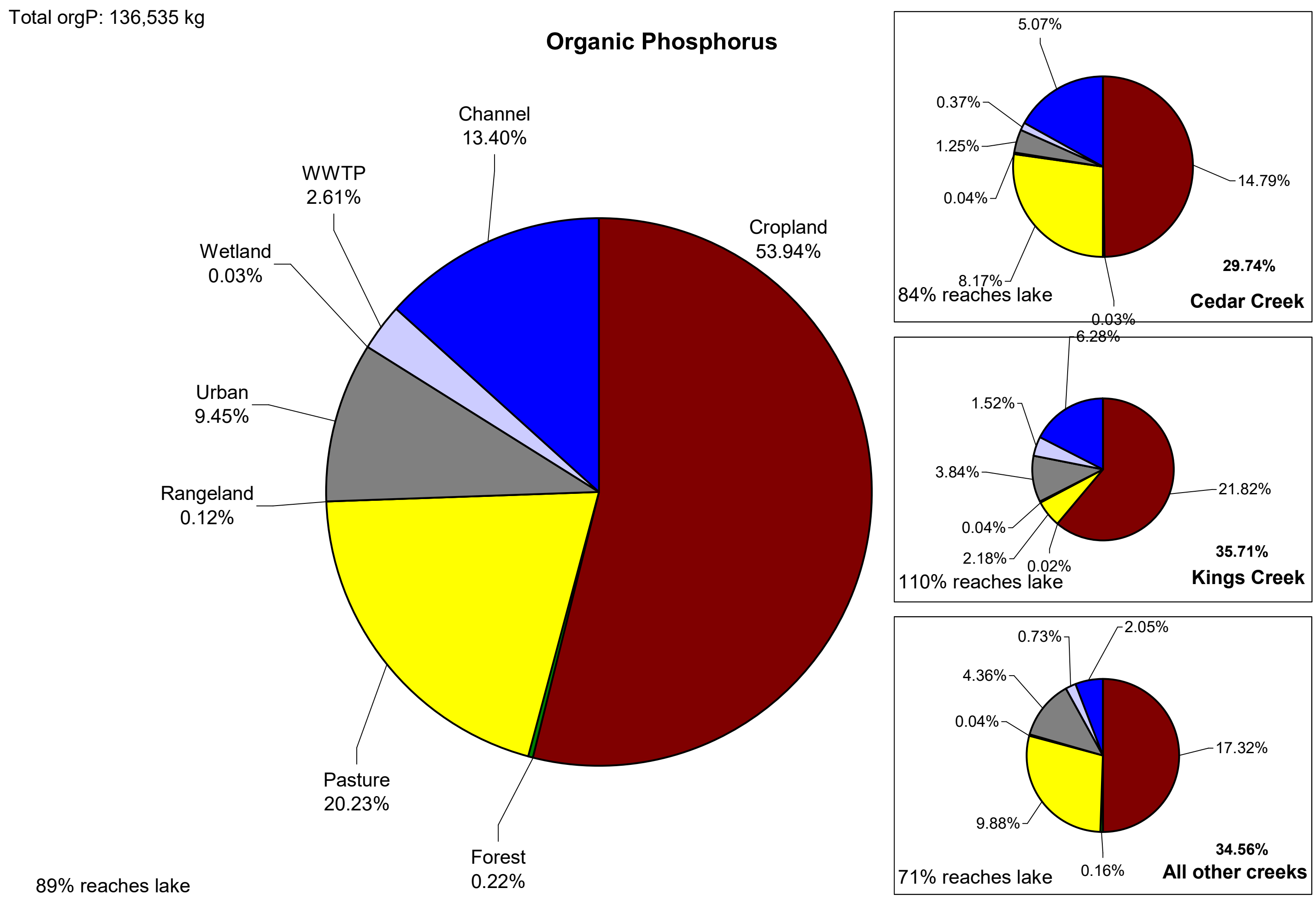


Figure 42. Organic Phosphorus load by landuse and major creeks.

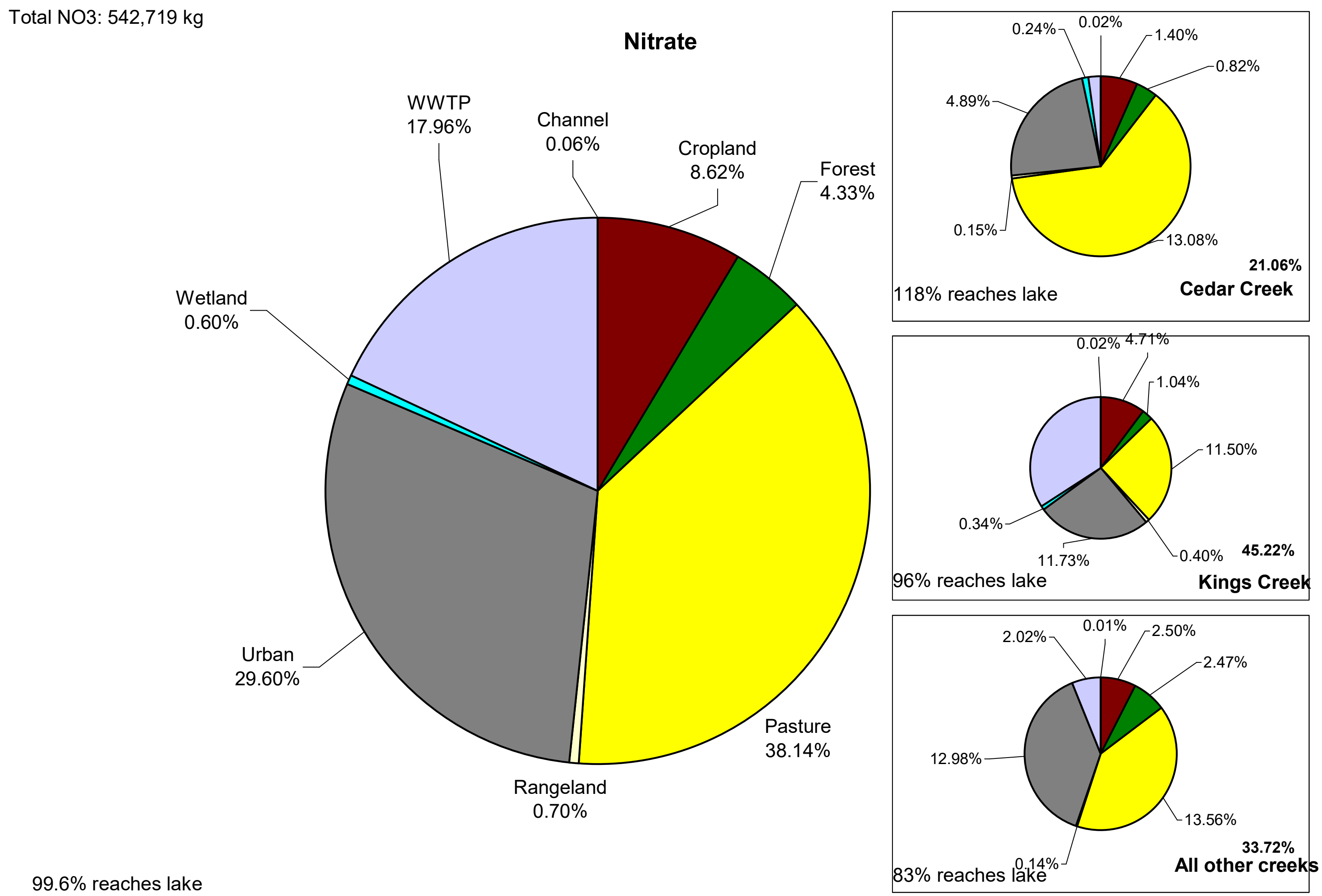


Figure 43. Nitrate load by landuse and major creeks.

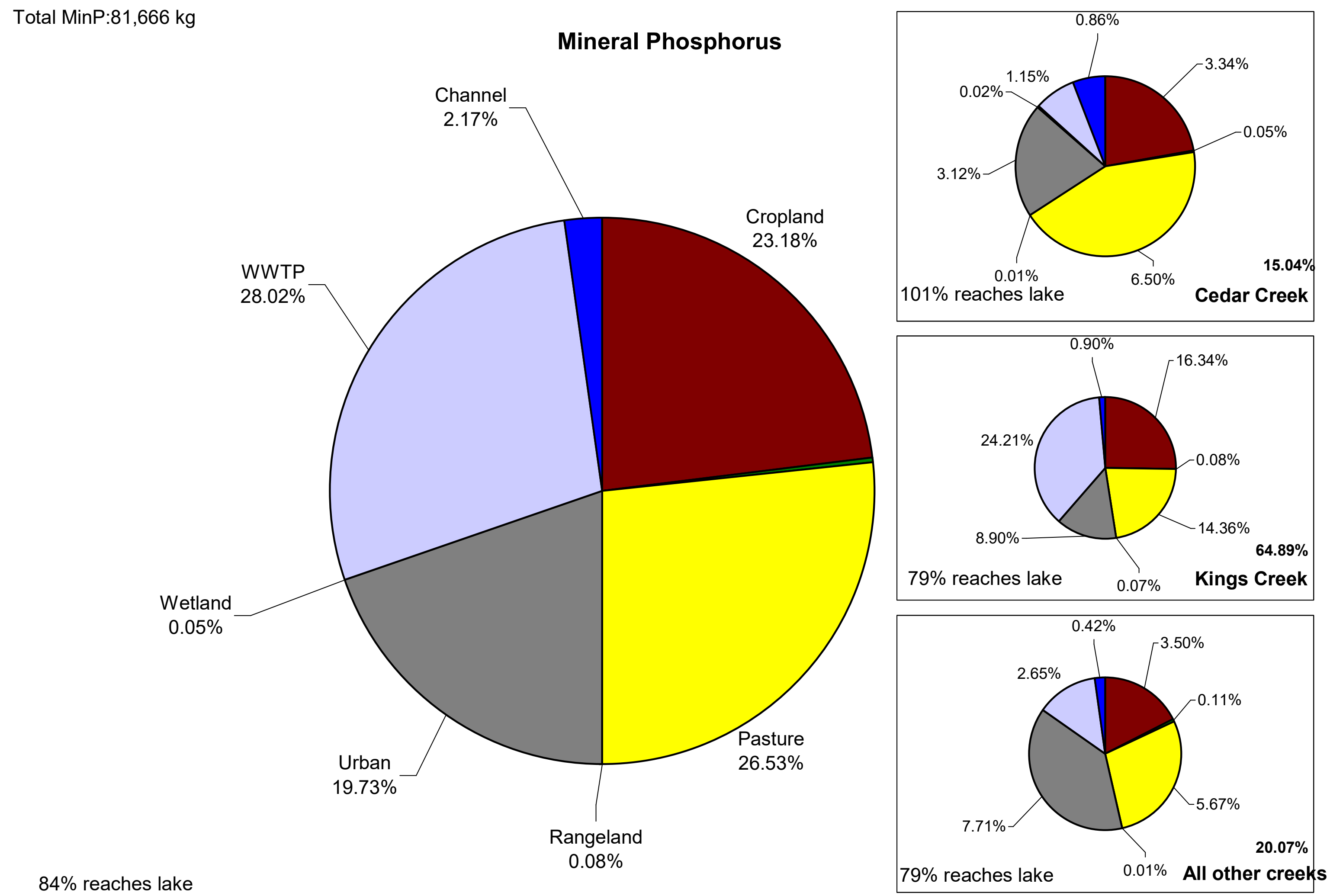


Figure 44. Mineral Phosphorus load by landuse and major creeks.

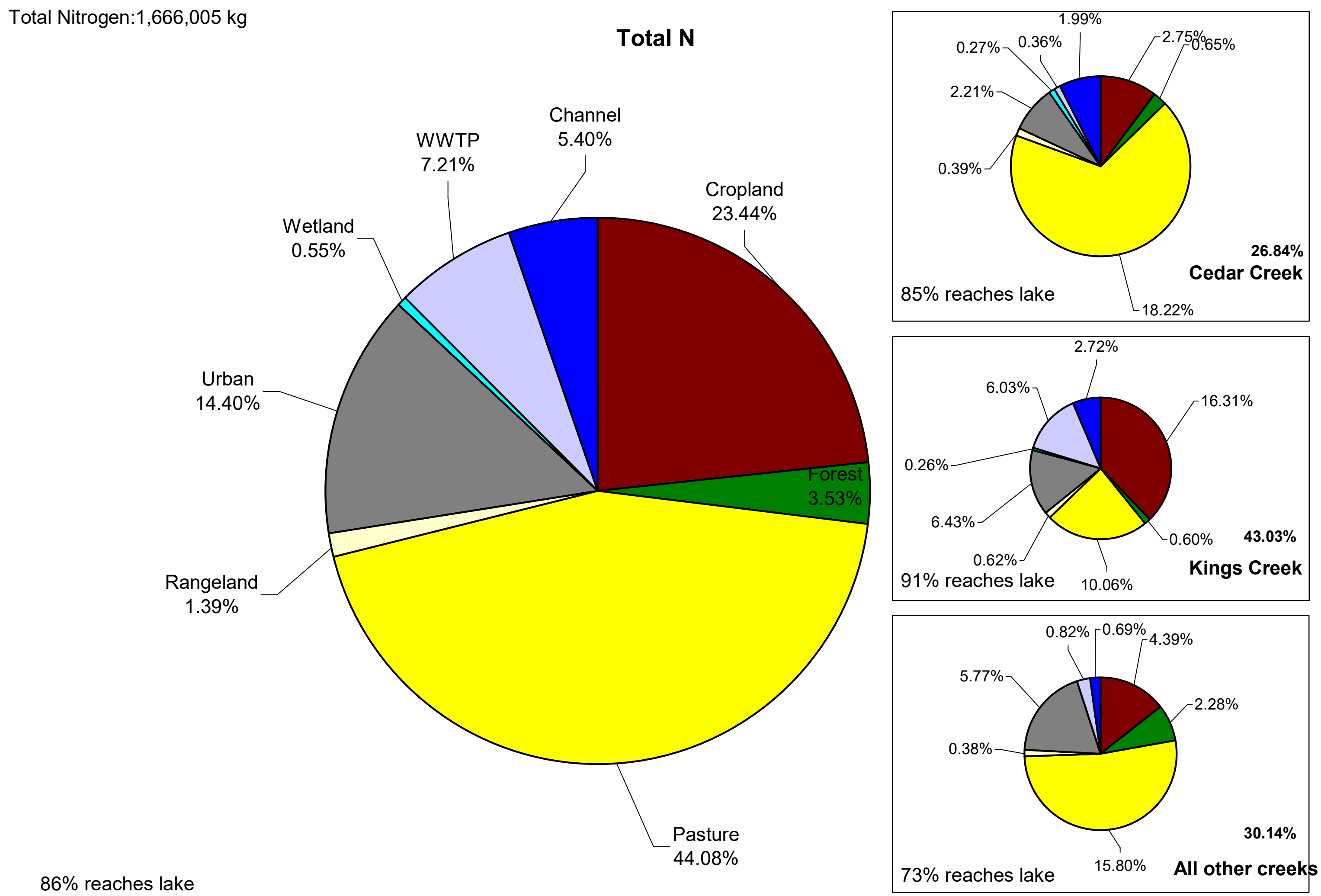


Figure 45. Total Nitrogen load by landuse and major creeks.

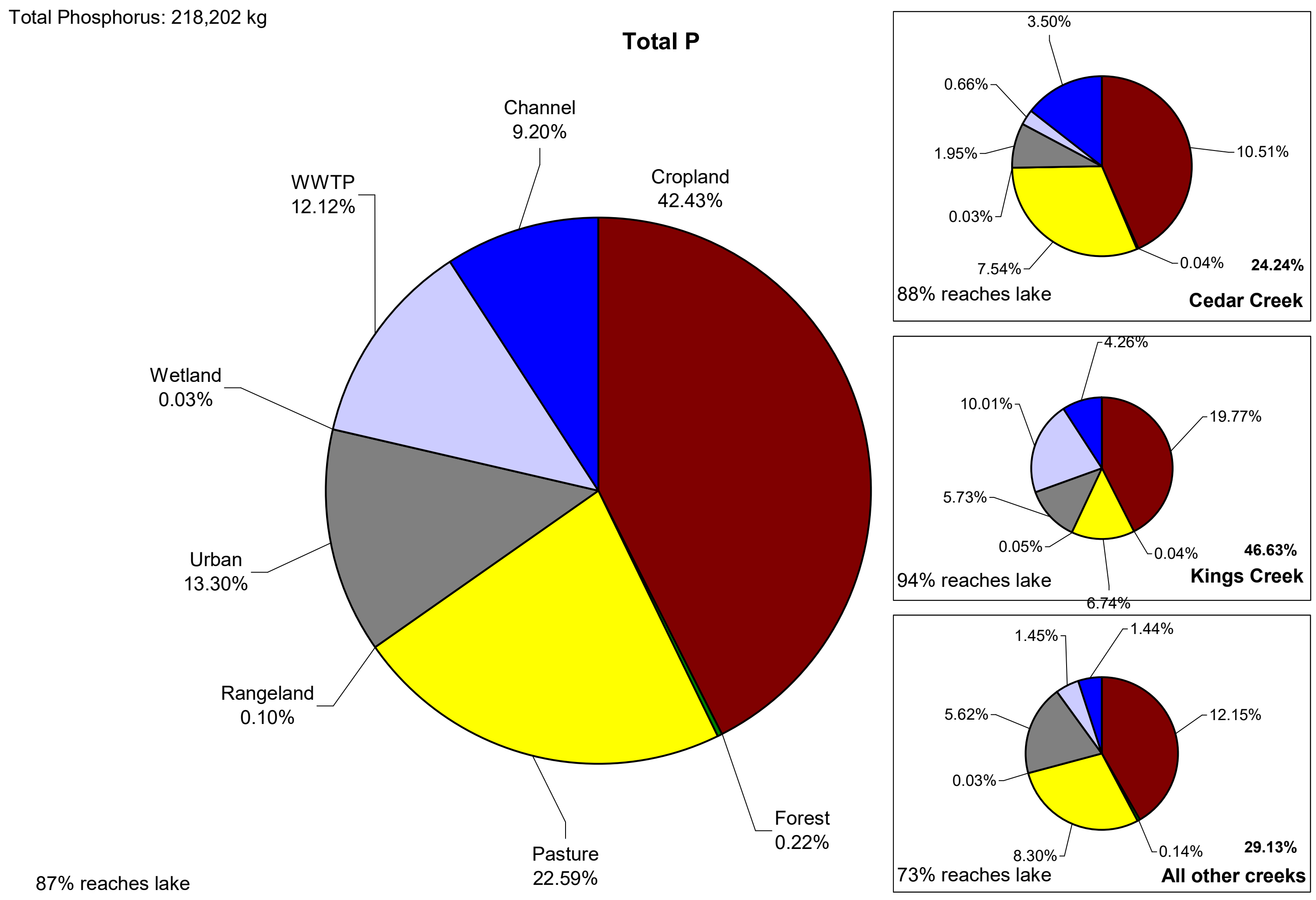


Figure 46. Total Phosphorus load by landuse and major creeks.

## AVERAGE ANNUAL LOAD BY SUBBASIN

Figures 47 to 55 show the spatial distribution of sediment and nutrient loads from various subbasins.

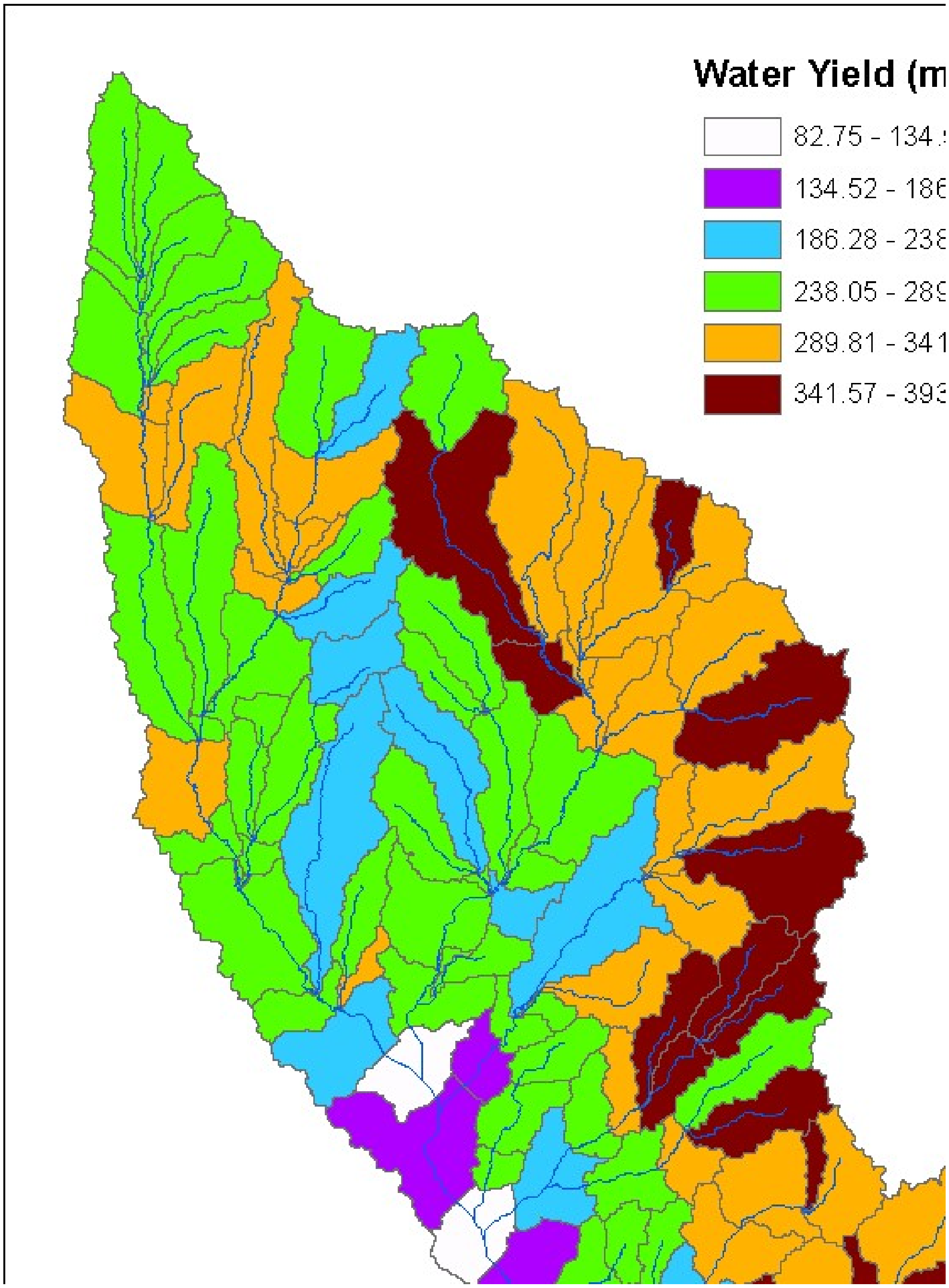

Figure 47. Annual average water yield.

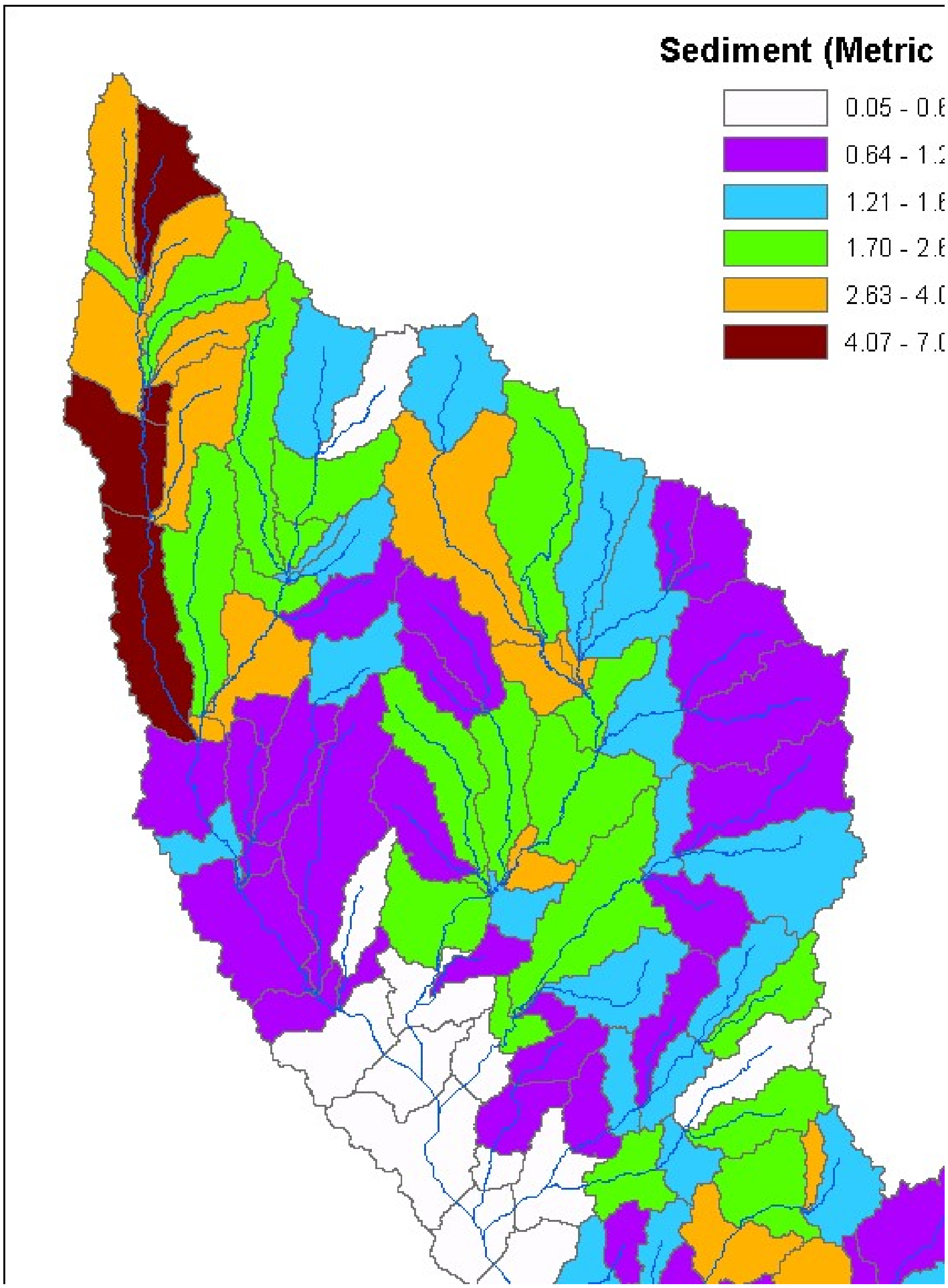

Figure 48. Annual average erosion rate (overland + channel).

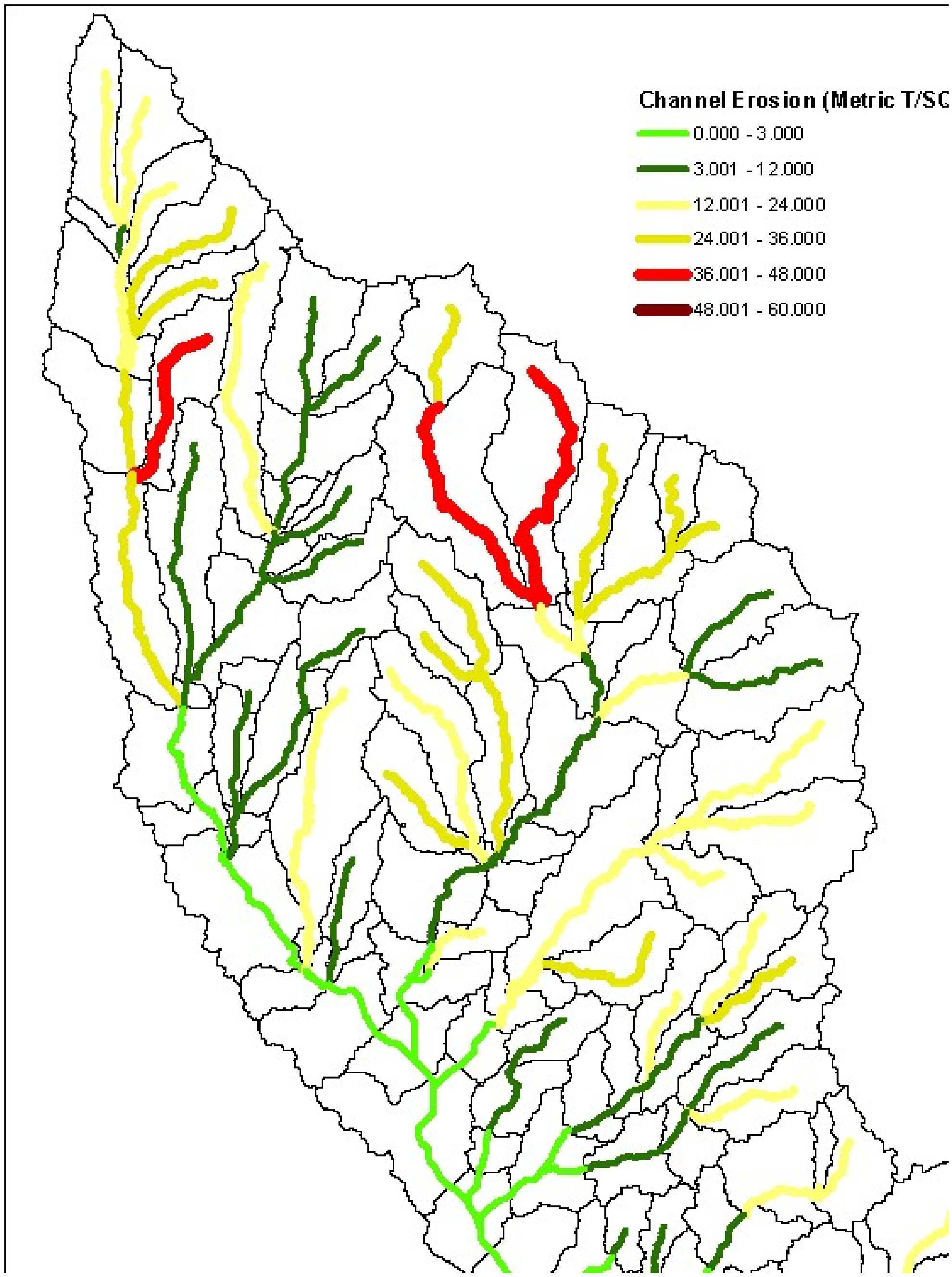

Figure 49. Annual average channel erosion rate.

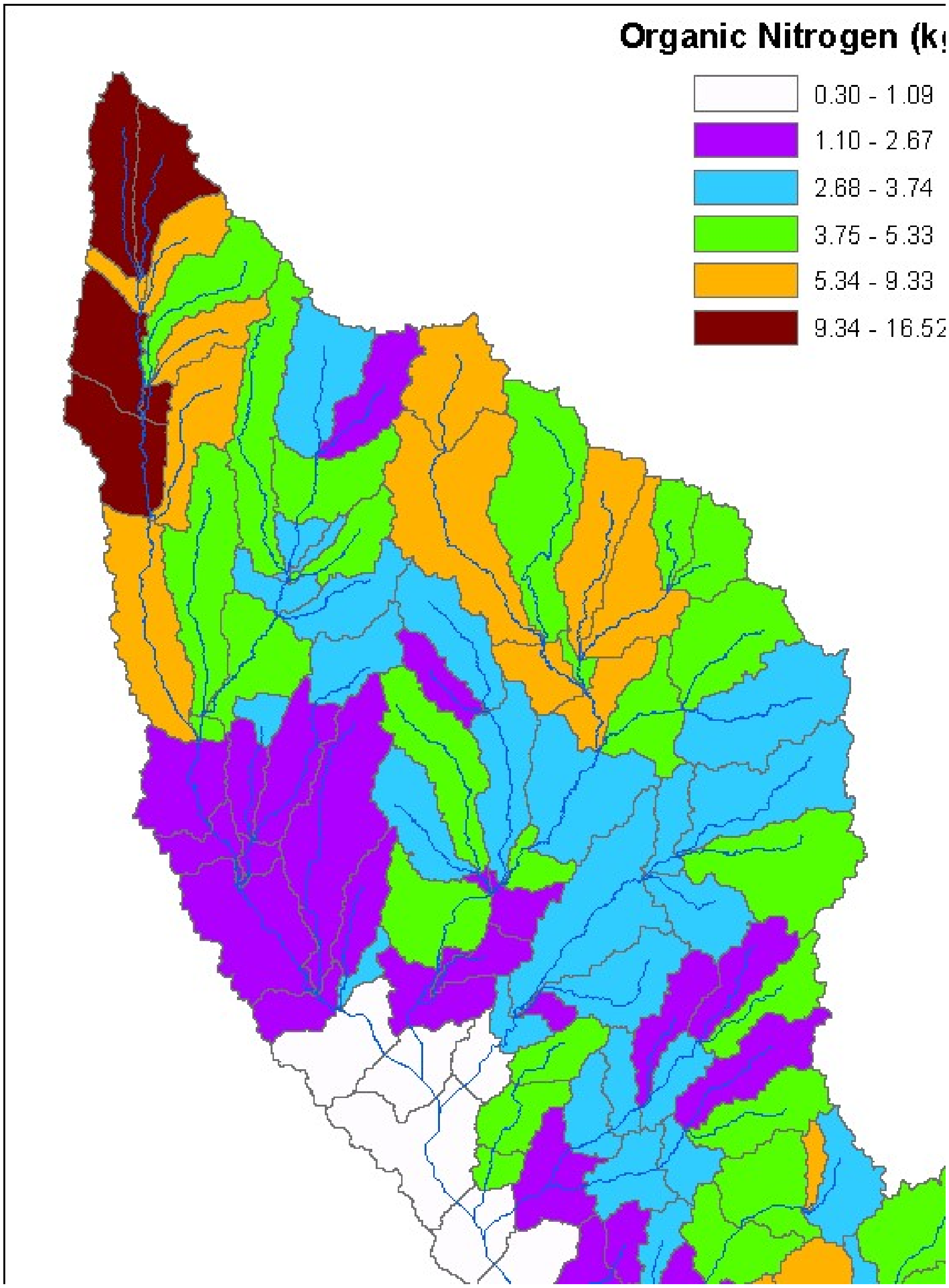

Figure 50. Annual average Organic Nitrogen load.

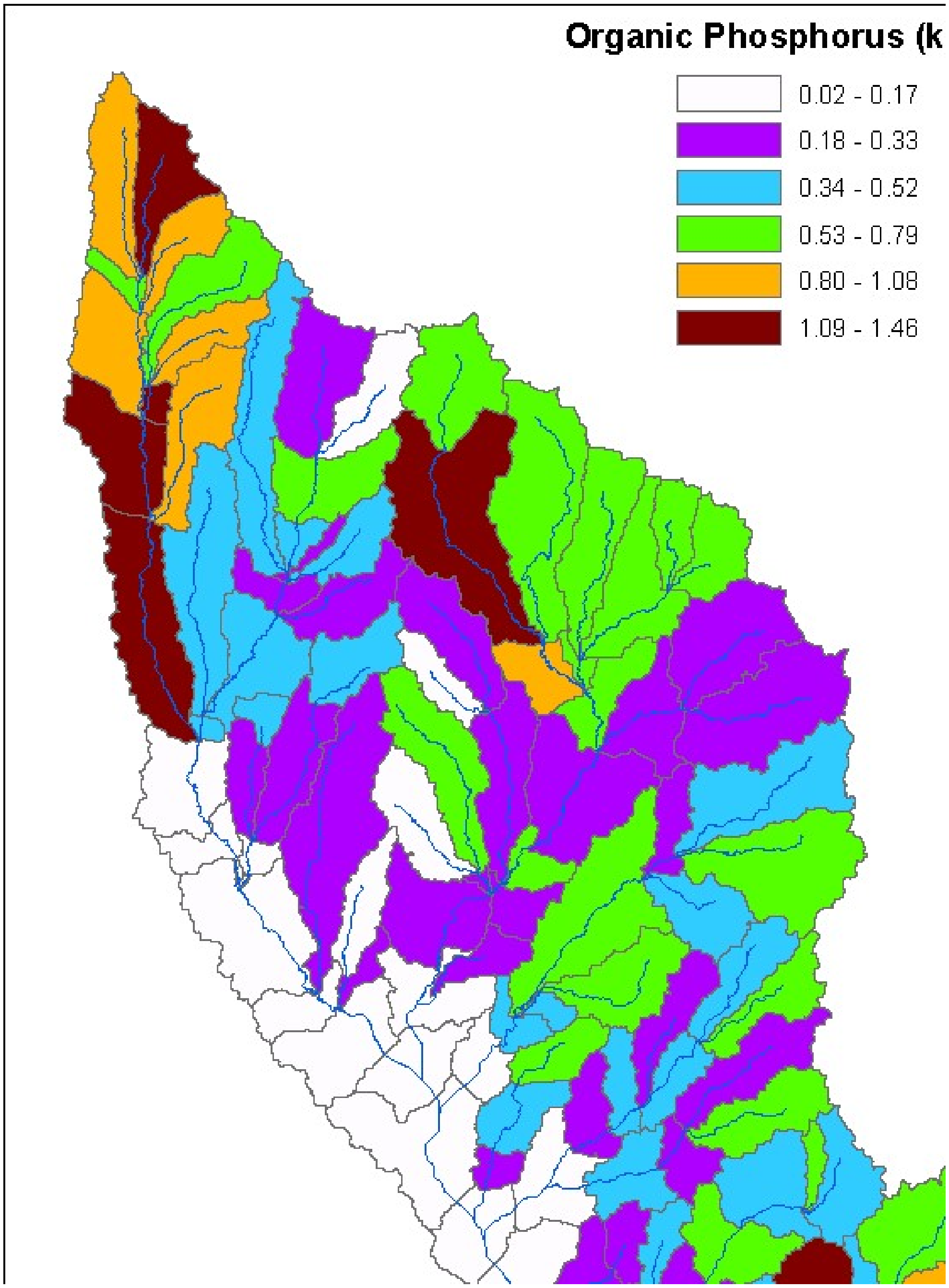

Figure 51. Annual average Organic Phosphorus load.

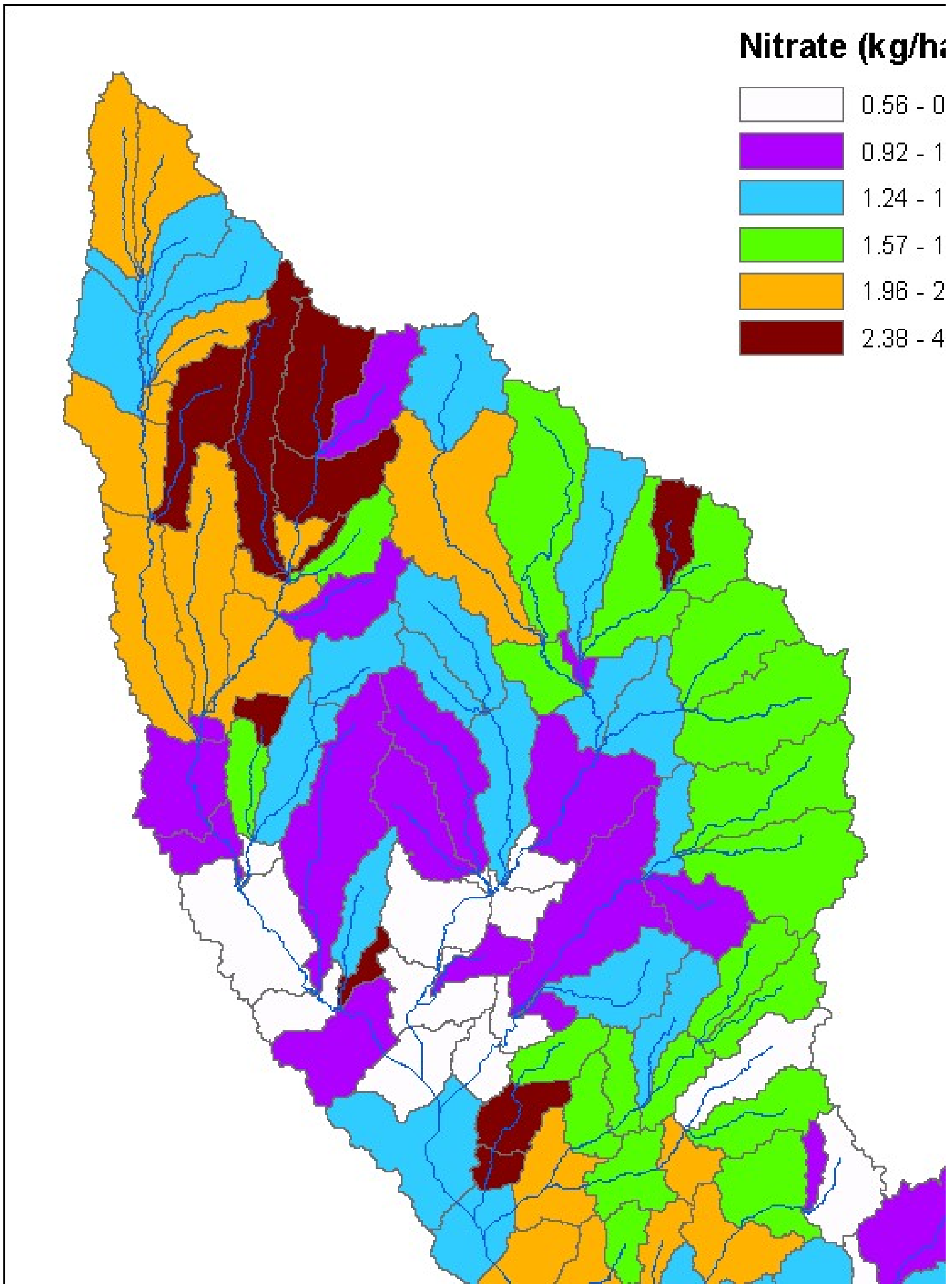

Figure 52. Annual average Nitrate load.

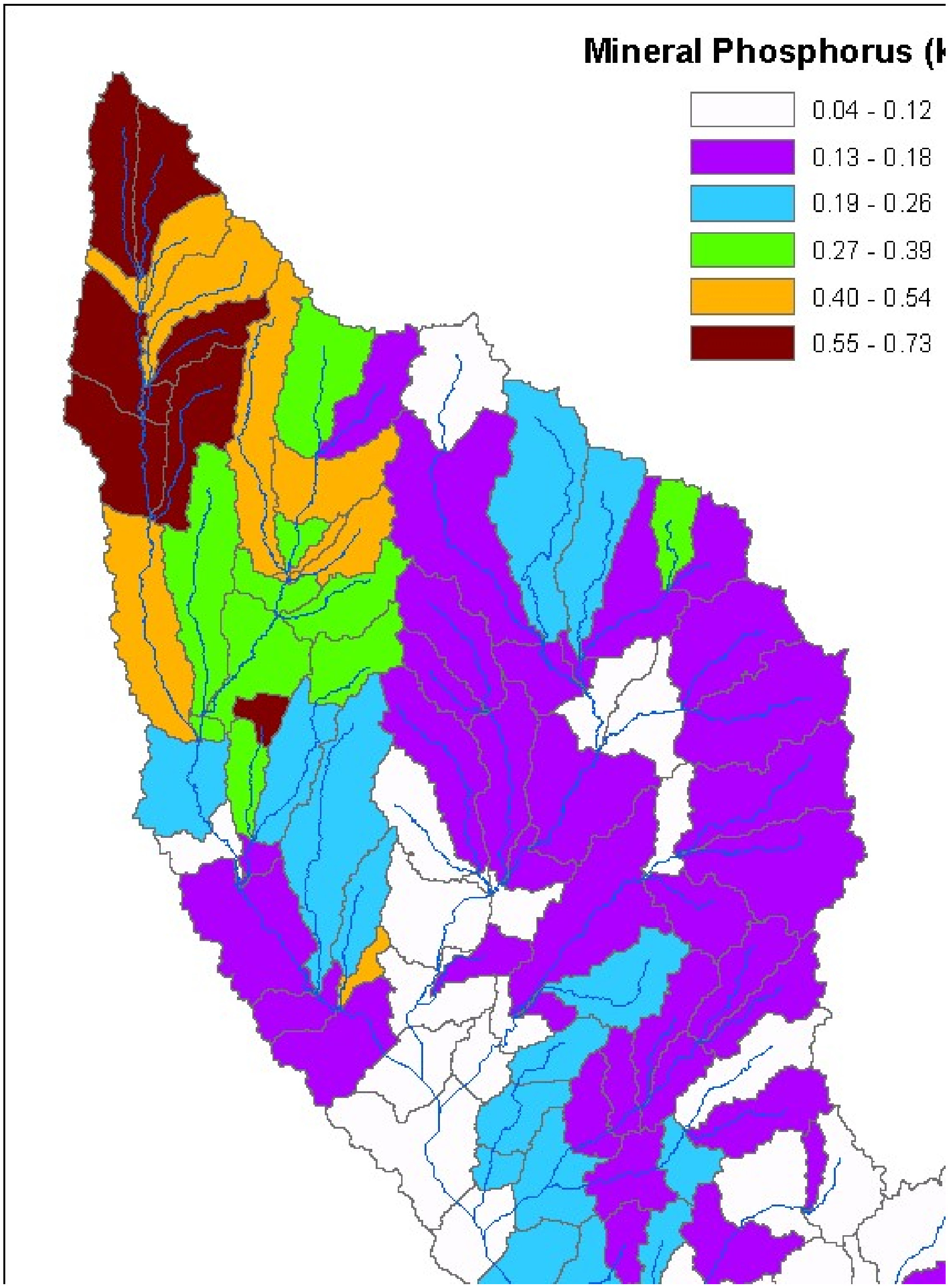


Figure 53. Annual average Mineral Phosphorus load.

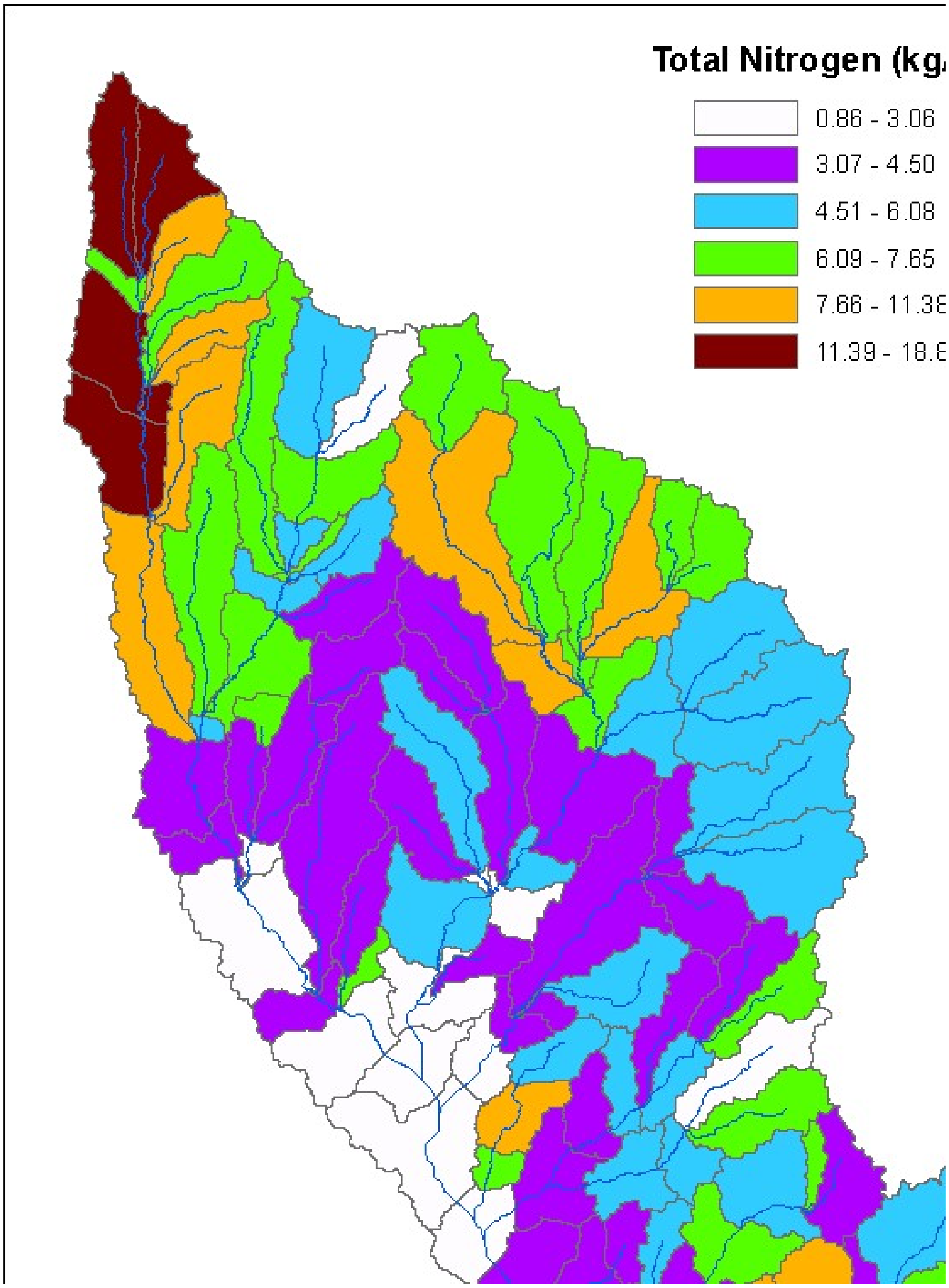

Figure 54. Annual average Total Nitrogen load.

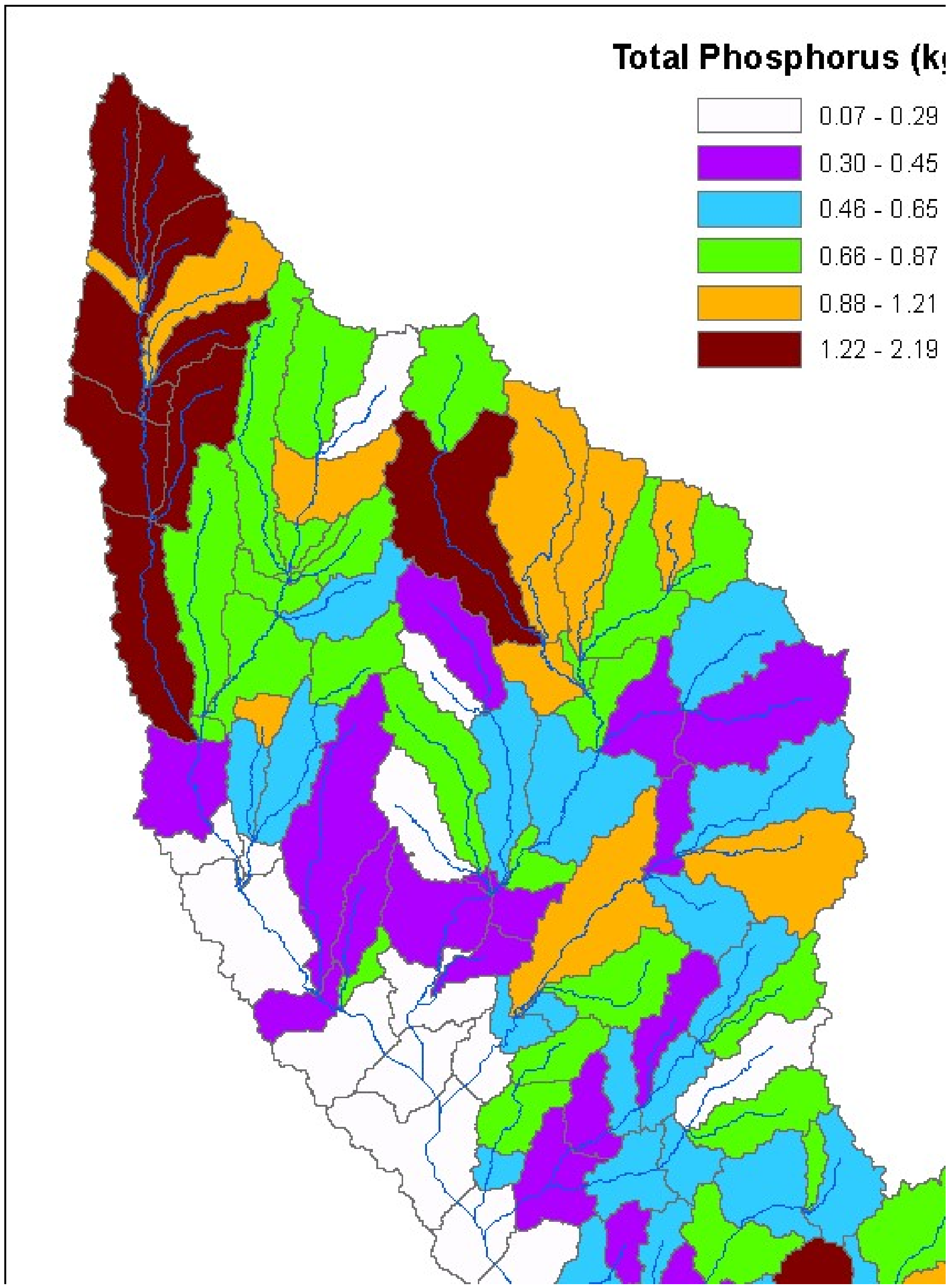

Figure 55. Annual average Total Phosphorus load.

## BEST MANAGEMENT PRACTICE SCENARIOS

Several best management practice (BMP) scenarios will be simulated that reduce non-point source pollution load to the lake by 15 to 30% based on the WASP load reduction scenarios. Some of the BMP's that will be simulated with SWAT are:

Cropland BMPs:
- Terraces
- Contour Farming
- Crop Residue Management
- Conversion of Cropland to Grass
- Nutrient Management
- Grass Waterways
- Buffer Strips

Pastureland BMPs:
- Grazing Management
- Fertilizer/Nutrient Management
- Pasture Planting/Range Seeding
- Grass Waterways
- Buffer Strips

Urban BMPs:
- Nutrient Management
- Soil Testing
- Street Sweeping
- Grass Waterways
- Buffer Strips

Channel BMPs:
- On or off channel sedimentation ponds
- Channel stabilization
- Channel cover

PL565 structures

Three point source BMP scenarios were run with SWAT from 1989 to 2002:
1. Baseline (calibration)
2. Waste water treatment plant (WWTP) nutrient loadings were reduced by 50%, but flow from the WWTP remained at 100%.
3. WWTP nutrient loadings were removed entirely, but flow remained at 100%.

SWAT output from these three scenarios was converted to .nps files, and provided to TRWD and Espey Consultants for reservoir water quality simulation with WASP. Similar to this other BMP scenarios will be simulated with SWAT and the NPS load will be used to simulate the effect on Chl'a' using WASP. Economic models will be used to identify best scenarios that result in better water quality with least overall expense.

**REFERENCES**


Allen, P.M., J. A. Dunbar, S. Prochnow, and L. Zygo. 2006. Cedar Creek: Stream Erosion and Reservoir Volume Evaluation. Baylor University and SDI Inc. April 2006.

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management. Texas A&M Univ. Press, College Station.

Arnold, J.G., P.M. Allen, R.S. Muttiah, G. Bernhardt. 1995a. Automated Base Flow Separation and Recession Analysis Techniques. GROUND WATER, Vol. 33, No. 6, November-December.

Arnold, J.G., J.R. Williams, D.R. Maidment. 1995b. A Continuous Water and Sediment Routing Model for Large Basins. American Society of Civil Engineers Journal of Hydraulic Engineering. 121(2): 171-183.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large Area Hydrologic Modeling and Assessment, Part1: Model Development. Journal of American Water Resources Association. 34(1): 73-89.

Di Luzio, M., R. Srinivasan, and J.G. Arnold, 1998. Watershed Oriented Non-point Pollution Assessment Tool. In Proceedings of the 7th International Conference on Computers in Agriculture. October 26-30, 1998. Orlando, Florida.

Di Luzio, M., R. Srinivasan, and J.G. Arnold, (Accepted for Publication). Integration of Watershed Tools and SWAT Model into BASINS. J. American Water Resources Association.

Knisel, W.G. 1980. CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems. United States Department of Agriculture Conservation Research Report No. 26.

Leopold, L. B., and T. Maddock, Jr., 1953. The Hydraulic Geometry of Stream Channels and some Physiographic Implications. U. S. Geological Survey, Prof. Paper, 252, 1953.

Narasimhan, B., P. M. Allen, R. Srinivasan, S. T. Bednarz, J. G. Arnold, and J. A. Dunbar. 2007. Streambank Erosion and Best Management Practice Simulation Using SWAT. Fourth Conference on Watershed Management to Meet Water Quality Standards and Emerging TMDL, ASABE, March 11-13, 2007, San Antonio, Texas.

Nichols, J.D. 1975. Characteristics of Computerized Soil Maps. Soil Science Society of America Proceedings. Volume 39, No. 5.

Rewerts, C.C. and B.A. Engel. 1991. Answers on GRASS: Integrating a watershed simulation with a GIS. ASAE Paper No. 91-2621, American Society of Agricultural Engineers, St. Joseph, MI.

Srinivasan, R. and B.A. Engel. 1991. A Knowledge Based Approach to Exact Input data From GIS. ASAE Paper No. 91-7045, American Society of Agricultural Engineers, St. Joseph, MI.

Srinivasan, R. and J.G. Arnold. 1994. Integration of a Basin Scale Water Quality Model With GIS. Water Resources Bulletin, Vol. 30, No. 3, June.

Texas Water Development Board, 1995. Volumetric Survey of Cedar Creek Reservoir. Prepared for Tarrant County Water Control and Improvement District Number One, July 31, 1995.

Texas Water Development Board, 2006. Volumetric Survey of Cedar Creek Reservoir. Prepared for Tarrant Regional Water District, February 2006.

U.S. Army. 1988. GRASS Reference Manual. USA CERL, Champaign, IL.

U.S. Geological Survey, 2002. Multi-Resolution Land Characteristics (MRLC). Available at http://edc.usgs.gov/glis/hyper/guide/mrlc. [Accessed Friday, August 9, 2002].

U.S. Geological Survey, 1987. Digital elevation models, US GeoData Users. Reston, Va., U.S. Geological Survey.

U.S. Department of Agriculture, Soil Conservation Service, 1972. National Engineering Handbook, Section 4-Hydrology, Chapters 4-10.

Williams, J.R., A.D. Nicks, and J.G. Arnold. 1985. Simulator for Water Resources in Rural Basins. J. Hydraulic Eng., ASCE, 111(6): 970-986.