# Modeling Phosphorous Loading for the Lake Eucha Basin

**FINAL REPORT**

**Submitted to:**
**Tulsa Metropolitan Utility Authority**


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# Introduction

Lake Eucha water quality is being degraded from excess algal growth. This excess growth is the result of an overabundance of nutrients in the lake, assumed to be primarily phosphorous. Most phosphorus in the lake comes from two sources, internal and external. The sediments in the lake itself release phosphorus to the water column, i.e. internal loading. Phosphorous coming into the lake from the watershed is external loading. External loading originates from either point-sources, such as the City of Decatur municipal waste water treatment plant, or from nonpoint sources like pastures. The majority of the phosphorous loading has been attributed to nonpoint sources.[1] Pastures in the Lake Eucha basin have received phosphorus from poultry litter applications for many years. Poultry litter is often applied to meet the crop's nitrogen requirements. When phosphorous in excess of what the crop can use is applied, phosphorous builds up in the soil. Runoff extracts soluble phosphorus from the soil and litter, and carries sediments containing phosphorous to the lake.

The SWAT (Soil and Water Assessment Tool)[2] model was used to predict how external loadings are affected by management changes. A range of soil test phosphorous levels and litter application rates were simulated. Long-term simulations project how soil test phosphorus likely changes over the next 30 years.

# Results Summary

Observed data were used to estimate phosphorous loads in the basin and to calibrate the SWAT model. A variety of Best Management Practice (BMP) scenarios were evaluated through SWAT model simulations. The effects of soil test phosphorous, litter application rates, cattle grazing rates, and the City of Decatur point source were each evaluated through model simulations. The stochastic variability associated with rainfall was quantified, and used to estimate confidence intervals. The following is a summary of the findings from this study:

- The observed average total phosphorous loading to Lake Eucha is estimated to be 47,600 kg per year.
- Some areas contribute a disproportionate amount of phosphorous.
- The City of Decatur wastewater treatment plant accounts for approximately 24% of the estimated total phosphorous load to Lake Eucha.
- Anthropogenic nonpoint sources account for 73% of the total phosphorous loading to Lake Eucha.
- Eastern portions of the basin have a higher pasture soil test phosphorous.

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1

Wagner, K., Woodruff, S., "Phase I Clean Lakes Project, Diagnostic and Feasibility Study of Lake Eucha", Oklahoma Conservation Commission, 1997.

2

Arnold, J.G., R. Srinivasin, R.S. Muttiah, and J. R. Williams. 1998. Large Area Hydrologic Modeling and Assessment: Part I. Model Development. JAWRA 34(1):73-89.

- Phosphorous load per unit pasture area, as estimated from monitoring data, is higher in the eastern portion of the basin.

- The SWAT model predicts a positive correlation between phosphorous loading to Lake Eucha and poultry litter application rate.

- The SWAT model predicts that increases in STP will result in increased loading to Lake Eucha.

- Dramatic increases in soil test phosphorous are predicted by the SWAT model with continued application of poultry litter.

- There are some discrepancies with phosphorous loadings between our estimates and the 1997 Phase 1 Oklahoma Conservation Commission study.

## Results

**Loadings**
Observed water quality data collected by the City of Tulsa and stream flow records from the U.S. Geographic Survey (USGS) were used to estimate nitrate and phosphorous loads in the Lake Eucha basin. Load estimates for the period August 1998 to April 2000 were used to calibrate the SWAT model. In addition, these loads were compared with those calculated by the Oklahoma Conservation Commission in 1997 for the period March 1993 to February 1994 (Figure 1, Table 1). The 1997 Oklahoma Conservation Commission study reported that Beaty Creek contributed a disproportionate phosphorous load for its size. Our estimates of phosphorous load vary significantly with the OCC estimates for Beaty Creek and Spavinaw Creek. This discrepancy is likely the period of record used to calculate nutrient loading. Our estimates are likely more accurate, since we were able to use more data.

External loading to Lake Eucha has three sources; point sources, anthropogenic non-point source, and background. Figure 2 contains a breakdown of nitrate and total phosphorous by source. Background loading was estimated using the SWAT model by assuming the entire basin was forest, and using the hydrologic calibration from Black Hollow. Background total phosphorous and nitrate were estimated to be 1,440 and 113,000 kg/yr, respectively. Monitoring data from November 1997 to August 2000 show the average annual total phosphorous and nitrate loading from point sources to be11,600 kg/year and 5,440 kg/yr, respectively. The Decatur municipal waste water treatment plant was the only significant point source identified.

Table 2 shows phosphorous loading per unit area at each City of Tulsa water quality station. The location of each water quality station is given in Figure 3. GIS landcover data were used to estimate the fraction of pasture and forest in the contributing area at each water quality station. Forested areas were assumed to contribute 0.05 kg P/ha/yr. Higher phosphorous loading per unit pasture area are estimated in the eastern portions of the basin at stations EUC08, EUC09, EUC10, and EUC11. SPAV06 also indicates a high loading per unit pasture area. However, because there is only a small fraction of pasture in this area, it is very sensitive to loading estimates of forested areas.

Relationships between nutrient concentration and flow were developed for ten water quality stations using the available nutrient data. Using three flow gages, daily flow was estimated at ungaged stations using flow from the closest gaged station and assuming flow was proportional to drainage area. Gaging records ranged from approximately two to ten years and high flow nutrient data were limited. The uncertainty of these relationships can be very high where the gaging record is short because the record typically lacks the full range of flow from low to high flow events.

Nutrient loads were estimated for each station by applying the concentration-flow relationships to daily flow data from August 1998 through April 2000. This period of record was selected because it is the period in which flow data were available for all stations and quality assurance protocols for nutrient data were implemented. It should be noted that the nutrient component of the SWAT model was calibrated using these loading estimates.

**Table 1** Total phosphorous and nitrate loadings to Lake Eucha estimated from monitoring data for the period August 1998 to April 2000, and March 1993 to February 1994 by subbasin compared to Oklahoma Conservation Commission study[1] for the period March 1993 to February 1994. A similar subbasin configuration was used for both loading estimates (Figure 1).

| | Estimates for period (8-98 to 4-00) | | Estimates for period (3-93 to 2-94) | | OCC study (3-93 to 2-94) | |
|---|---|---|---|---|---|---|
| SITE | Total P (kg/yr) | Nitrate (kg/yr) | Total P (kg/yr) | Nitrate (kg/yr) | Total P (kg/yr) | Nitrate (kg/yr) |
| Rattlesnake | 329 | 10,000 | 267 | 9,440 | 324 | 7,640 |
| Brush | 3,700 | 28,300 | 2,370 | 39,100 | 1,570 | 39,100 |
| Beaty | 6,620 | 117,000 | 6,080 | 162,000 | 11,600 | 157,000 |
| Dry | 404 | 16,100 | 605 | 24,200 | 1,040 | 24,800 |
| Spavinaw | 33,700 | 486,000 | 35,100 | 797,000 | 13,700 | 549,000 |
| Eucha Laterals | 2,840 | 21,800 | 1,820 | 30,000 | | |
| Misc. area | | | | | 1,570 | 39,100 |
| Entire basin | 47,600 | 680,000 | 46,200 | 1,060,000 | 29,800 | 816,000 |

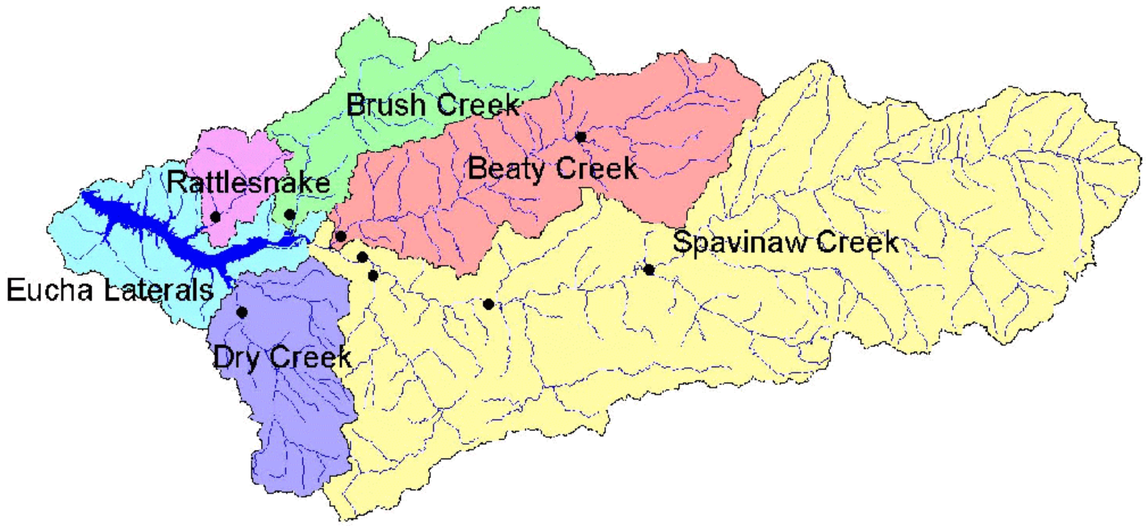


**Figure 1** Lake Eucha subbasin layout used to calculate nutrient loads in Table 1. Dots indicate City of Tulsa water quality stations.

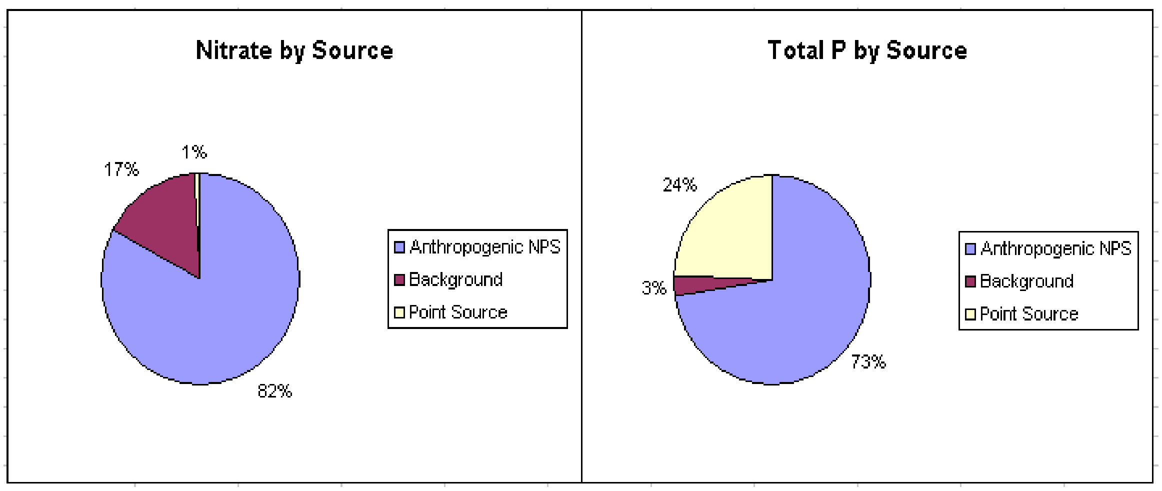


**Figure 2** Lake Eucha total phosphorous and nitrate loading by source. Point source loading based on monitoring data from November 1997 to August 2000. Background Nonpoint Source (NPS) loading based on SWAT simulations of Lake Eucha basin as all forest. Anthropogenic NPS loading estimated by difference compared to observed loading.

**Table 2** Estimated Lake Eucha observed phosphorous loading per unit pasture area in the contributing area above each water quality station. Forests are assumed to contribute 0.05 kg P/ha/yr.

| Tributary | SITE | Total Area (km^2) | Pasture Area (km^2) | Forest Area (km^2) | Total P (kg/yr) | Estimated Total P from Forest (kg/yr) | Total P from Pastures (kg/ha/yr) |
|---|---|---|---|---|---|---|---|
| Rattlesnake Creek | EUC04 | 20.9 | 5.4 | 15.5 | 295 | 78 | 0.40 |
| Brush Creek | EUC05 | 87.0 | 43.1 | 43.9 | 3,610 | 220 | 0.79 |
| Beaty Creek | EUC06 | 153.0 | 89.9 | 62.9 | 6,550 | 315 | 0.69 |
| Dry Creek | EUC07 | 50.6 | 15.5 | 35.1 | 283 | 175 | 0.07 |
| Spavinaw Creek | EUC08 | 517 | 253 | 264 | 33,300 | 1,320 | 1.26 |
| Spavinaw Creek | EUC09 | 424 | 216 | 207 | 40,900 | 1,040 | 1.84 |
| Spavinaw Creek | EUC10 | 269 | 152 | 117 | 15,800 | 586 | 1.00 |
| Beaty Creek | EUC11 | 65.9 | 47.3 | 18.6 | 7,580 | 93 | 1.58 |
| Cloud Creek | EUC12 | 64.3 | 27.5 | 36.8 | 712 | 184 | 0.19 |
| Black Hollow | SPAV06 | 15.6 | 0.8 | 14.9 | 173 | 74 | 1.32 |
| Total | | 1,670 | 851 | 816 | 109,000 | 4,080 | |
| | | | | | | Average | 0.92 |

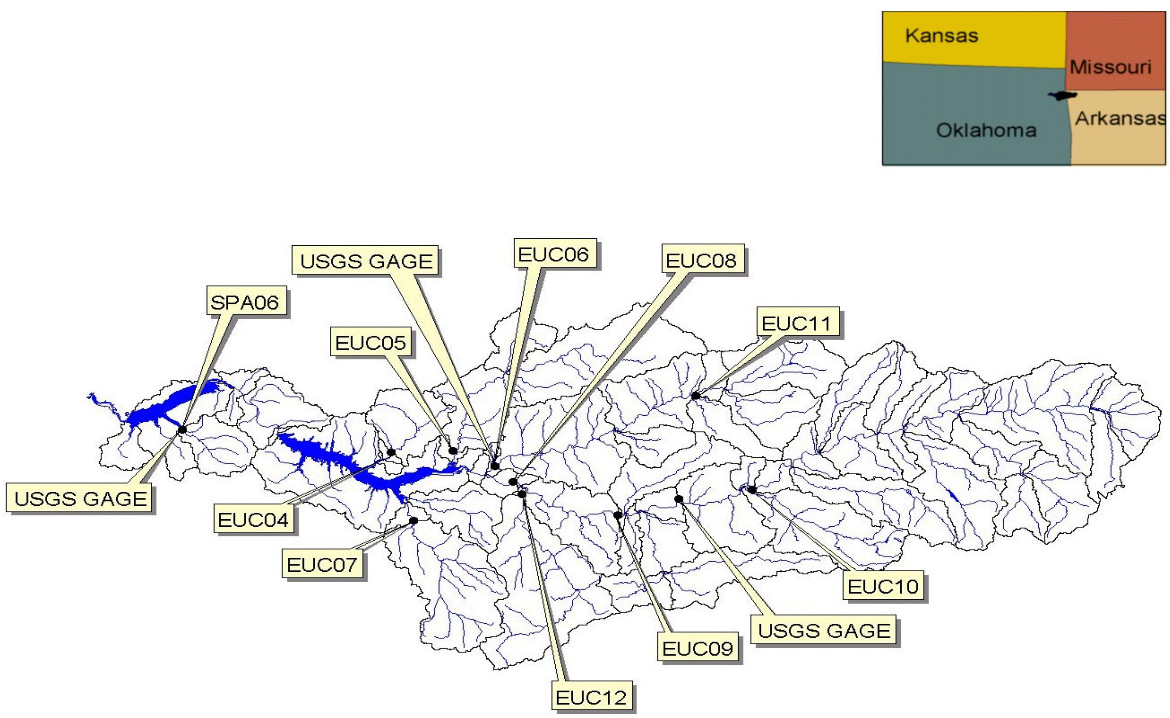


**Figure 3** City of Tulsa water quality stations and USGS stream flow gage locations for the Lake Eucha and Lake Spavinaw basin.

**Management and STP**

The current application rate of poultry litter was calculated from the number of animals located in each subbasin (Figure 4). All litter generated in a subbasin was assumed to be applied in that subbasin. Because field specific data were not available, a cattle grazing operation was assumed for all pastures in the basin.

Marshall (1998)[3] developed a nonparametric method to determine the number of samples required, within a 90% confidence interval, to estimate subbasin soil test phosphorous by land use for hydrologic/water quality modeling. This method was applied to the Eucha Basin, and a soil sampling plan was developed for pastures and forested areas. The Oklahoma Conservation Commission was contracted to collect these soil samples for the Oklahoma portion of the basin. A summary of the soil test data is given in Figure 5

For the Arkansas portion of the basin, soil test phosphorous data for the period 1994 to 1997 were obtained from the Arkansas Soil and Water Conservation Commission for Benton County (Figure 6). Observed soil test phosphorous for pastures was used in the SWAT model. Forested areas use a SWAT model based estimate, based on simulations of an undisturbed forested watershed in north-central Arkansas. A summary of the STP data used in the SWAT model is given in Figure 7.

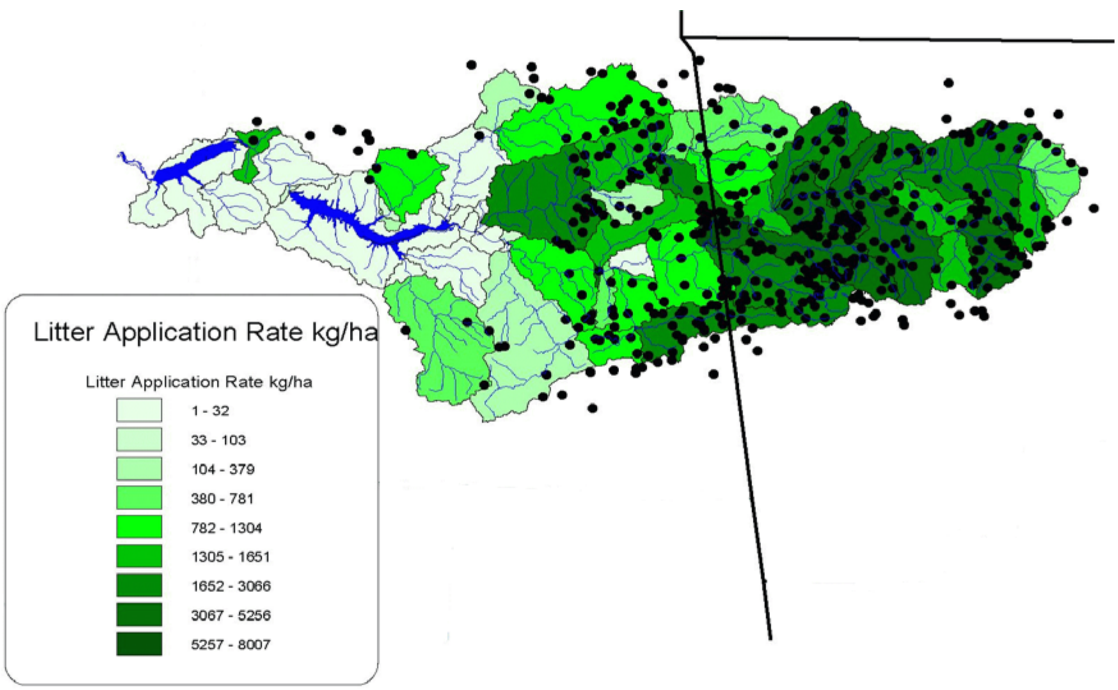


**Figure 4** Lake Eucha and Lake Spavinaw poultry litter application rate by subbasin used in the SWAT model and poultry house locations (black dots).

3 Marshall, W., "A Nonparametric Approach to Determine the Number of Observations Required for Estimating Basin-Scale Soil Test Phosphorous." Masters Thesis, Oklahoma State University, 1998

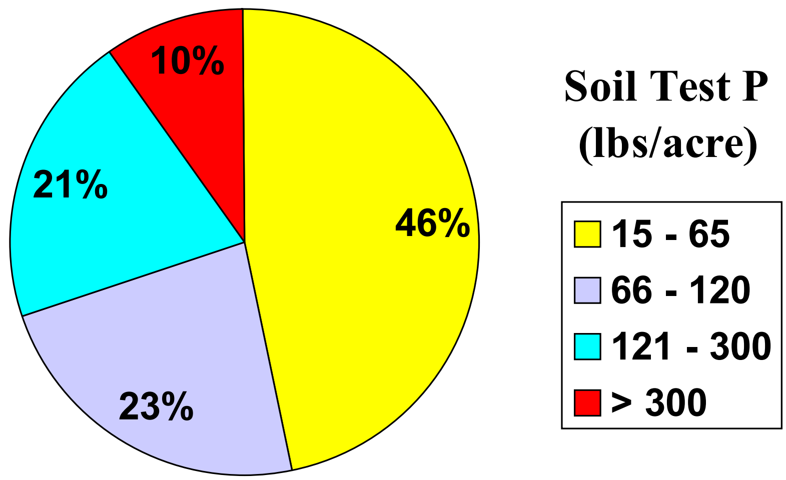


**Figure 5** Soil test phosphorous summary for the Oklahoma portion of the Eucha/Spavinaw Basin. Soil samples collected by the Oklahoma Conservation Commission from August 1998 to May 1999.

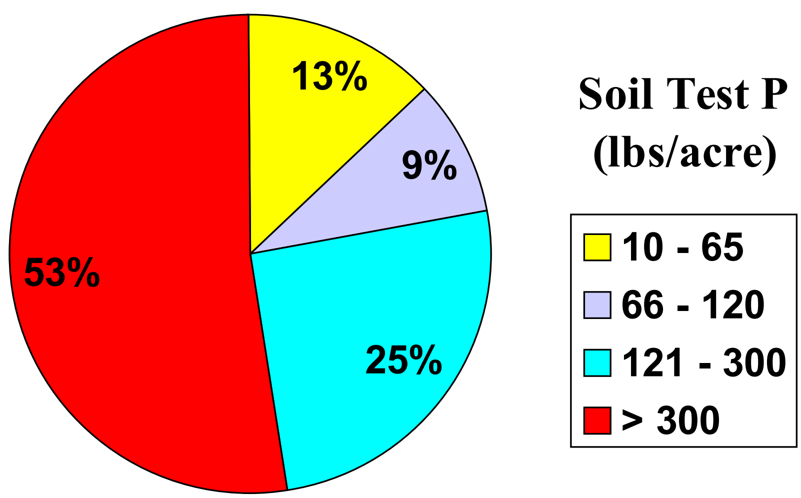


**Figure 6** Soil test phosphorous summary for the Lake Eucha Basin, Benton County, Arkansas. Data provide by the Arkansas Soil and Water Conservation Commission, based on samples taken from 1994 to 1997.

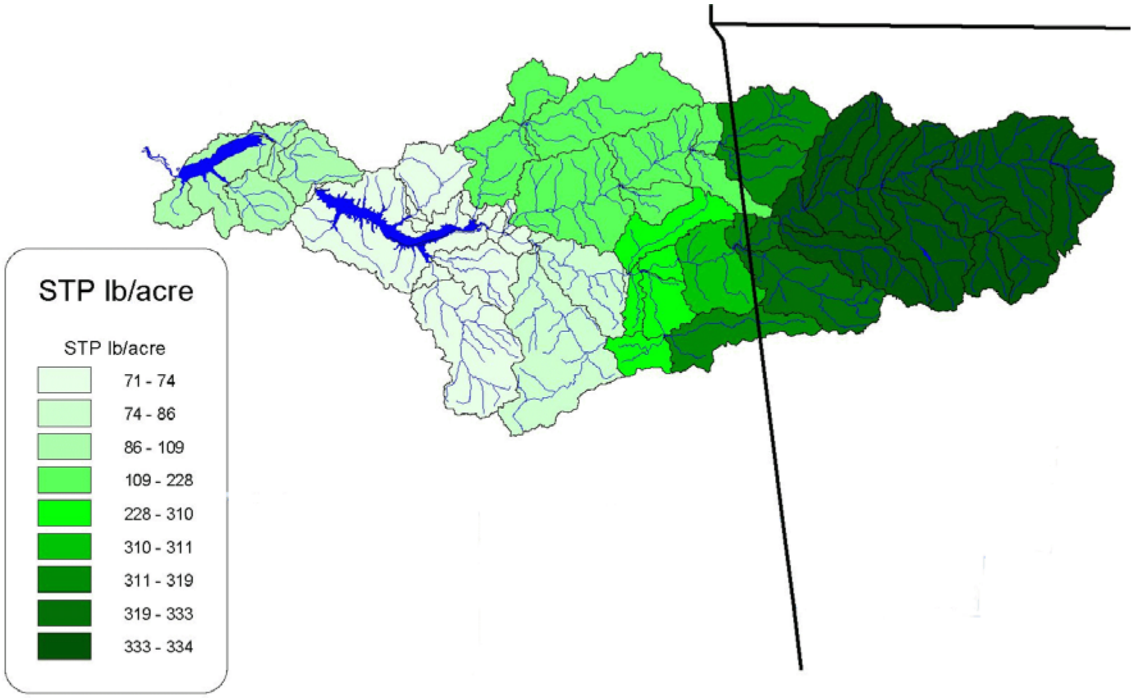


**Figure 7** Average Lake Eucha and Lake Spavinaw Mehlich III soil test phosphorous (STP) for pastures by subbasin. Used in SWAT model simulations.

**SWAT Model Calibration**

GIS data for topography, soils, landcover, and streams were used in the SWAT model. The most current GIS data at the time of compilation were used. Observed daily rainfall and temperature data from 27 stations were utilized. The basin was broken into 58 subbasins based on topography, and further divided into combinations of soil and landcover called HRUs (Hydraulic Response Units). A total of 351 HRUs were utilized.

The SWAT model version 99.2 was calibrated using observed stream and nutrient data. Three USGS stream gage stations and ten City of Tulsa water quality stations were used in the calibration (Figure 3). Loadings were calculated at each station by developing a relationship between flow and observed nutrient concentration. Loadings were developed for soluble phosphorous, total phosphorous, and nitrate. The SWAT model was first calibrated on surface runoff and baseflow at each of the three gages. After hydrologic calibration, the model was calibrated for nutrients.

**Stochastic Rainfall Simulations**

The effect of soil test phosphorous, litter application, grazing, and point sources were each evaluated through SWAT model simulations. The stochastic uncertainty associated with rainfall was quantified by performing multiple simulations using differing periods in the observed rainfall record. Thirty simulations were performed to estimate confidence intervals.

**Sediment-Bound Phosphorous Adjustments**

Sediment-bound phosphorous was under predicted in all SWAT simulations (Table 3). We assume this is the result of phosphorous being deposited with sediment in the stream, but not being re-entrained during high flow periods due to an error or limitation of the SWAT model. In addition, sediment that is re-entrained does not appear to contain phosphorous. To adjust for this, a correction factor was employed using the calibrated SWAT model and observed loadings. Sediment-bound phosphorous was underestimated by a factor of approximately 24 in the calibrated model. This fraction was assumed to be constant for all scenarios. Total phosphorous predictions calculated using this adjustment are labeled as (ADJ.).

**Table 3** Observed and SWAT predicted loading to Lake Eucha. Predicted average annual refers to average loading of 30 years of stochastic rainfall simulations. (ADJ.) indicates sediment-bound phosphorous loading was adjusted.

| Parameter | Observed 8-98 to 4-00 | Predicted 8-98 to 4-00 | Predicted 8-98 to 4-00 (ADJ.) | Predicted Average Annual | Predicted Average Annual (ADJ.) |
|---|---|---|---|---|---|
| Flow (m^3/sec) | 9.80 | 9.80 | 9.80 | 9.13 | 9.13 |
| Soluble P (kg/yr) | 32,800 | 34,500 | 34,500 | 31,200 | 31,200 |
| Sediment P (kg/yr) | 14,800 | 613 | 14,712 | 665 | 15,960 |
| Total P (kg/yr) | 47,600 | 35,100 | 49,212 | 31,865 | 47,160 |
| Nitrates (kg/yr) | 680,000 | 644,000 | 644,000 | 507,000 | 507,000 |

**Decatur Point Source**

Based on monitoring data from November 1997 to August 2000, the total annual phosphorous point source loading from the City of Decatur was 11,600 kg/year (Table 4). On a long-term basis, almost all phosphorous entering the stream will eventually end up in the lake, providing there is no net long-term deposition of sediment or significant removal by wildlife. We performed SWAT simulations considering various levels of point source loading from the City of Decatur. However, these simulations have limited utility if you assume that all the phosphorous entering the stream reaches the lake.

**Table 4** Current nutrient loading for the City of Decatur. Estimated from Permit Compliance System data from the Environmental Protection Agency for the period November 1997 to August 2000.

| Parameter | Total P | Nitrates | Flow | Ammonia |
|---|---|---|---|---|
| Load | 11,600 kg/yr | 5,470 kg/yr | 4,900 m^3/day | 11,300 kg/yr |
| Concentration | 6.53 mg/l | 3.06 mg/l | | 6.33 mg/l |

**Litter Application Scenarios**

The calibrated SWAT model was altered to depict nine different litter application/export scenarios. Litter application rates were adjusted by a fraction of the current estimated rate. An average of 0.77 ton/acre (1,747 kg/ha) were applied to pastures in the basin. All litter generated in a subbasin was assumed to be applied to pastures in that subbasin. In actuality, litter is moved between subbasins, into, and out of the Lake Eucha basin. However, data are not available to determine the actual application rate for each subbasin.

Predicted soluble and total phosphorous loading to Lake Eucha increased with increasing litter application (Figure 8). However, the effect of litter application is compounded by the effect of soil test phosphorous, since litter applications increase soil test phosphorous on a long-term basis. At reduced litter application rates, commercial nitrogen fertilizer was added to maintain a reasonable forage production. For this reason, the model predicted no significant reduction in nitrate loading at litter rates less than the current rate (Table 5).

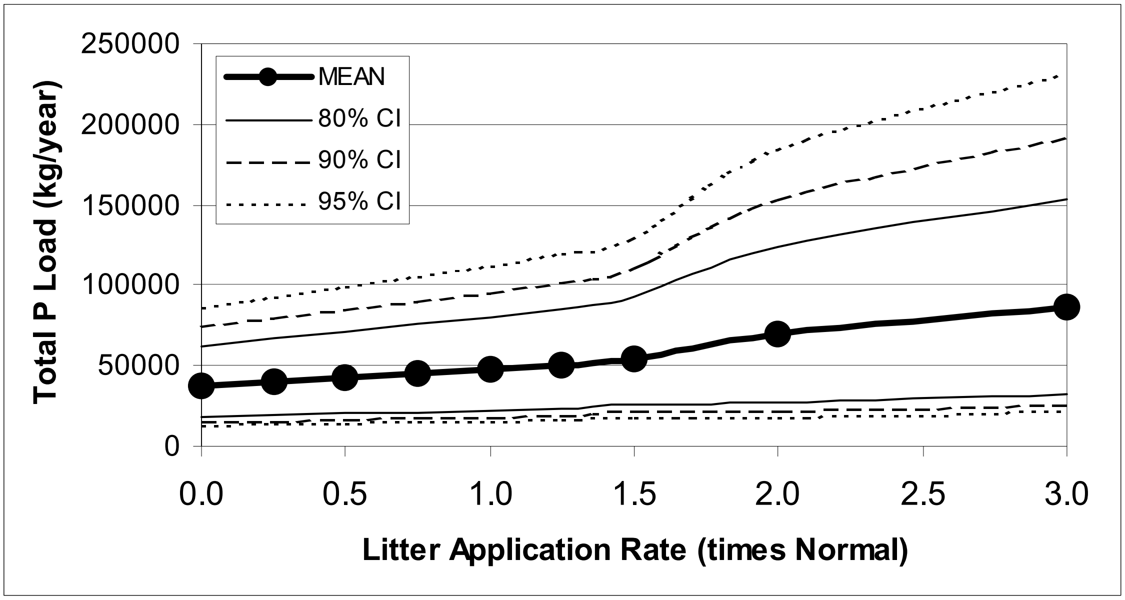


**Figure 8** SWAT estimated total phosphorous loading to Lake Eucha as a function of litter application rate. Nitrogen is supplemented at rates less than the current poultry litter rate. Adjusted sediment-bound phosphorous used to calculate total phosphorous. Confidence intervals reflect only the variability associated with rainfall.

**Table 5** Effect of litter application rate on the calibrated SWAT model. Adjusted sediment-bound P used to calculate Total P (ADJ.).

| X Current Litter Application Rate | Flow (m^3/s) | Soluble P (kg/yr) | Sediment P (kg/yr) | Total P (kg/yr) | Total P (ADJ.) (kg/yr) | Nitrate (kg/yr) |
|---|---|---|---|---|---|---|
| 0.00 | 9.13 | 22,500 | 630 | 23,100 | 37,600 | 508,000 |
| 0.25 | 9.13 | 24,600 | 640 | 25,200 | 40,000 | 508,000 |
| 0.50 | 9.13 | 26,900 | 649 | 27,500 | 42,500 | 508,000 |
| 0.75 | 9.13 | 29,000 | 660 | 29,700 | 44,900 | 507,000 |
| 1.00 | 9.13 | 31,200 | 665 | 31,900 | 47,100 | 507,000 |
| 1.25 | 9.23 | 34,800 | 657 | 35,500 | 50,500 | 598,000 |
| 1.50 | 9.31 | 38,300 | 680 | 39,000 | 54,600 | 688,000 |
| 2.00 | 9.42 | 44,800 | 1,040 | 45,800 | 69,600 | 866,000 |
| 3.00 | 9.51 | 56,600 | 1,230 | 57,800 | 86,000 | 1,180,000 |

**Soil Test Phosphorous Scenarios**
Simulations were performed at six levels of basin wide pasture soil test phosphorous ranging from 35 to 1000 lb phosphorous/acre. These six simulations were performed at three differing litter application rates, two are shown in Tables 6 and 7. At litter application rates less than current, nitrogen was supplemented to make up for the reduced nitrogen applied in litter. With increases in STP, SWAT predicts an increase in total phosphorous loading (Figure 9). STP had little or no effect on nitrates and water yield (Table 6).

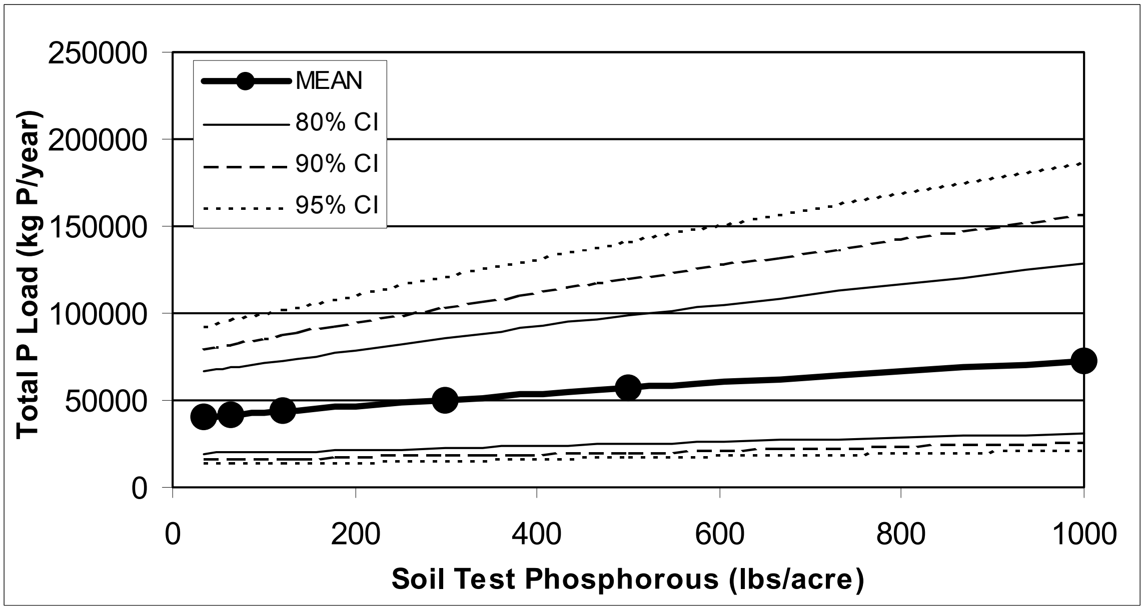


**Figure 9** SWAT predicted total phosphorous loading to Lake Eucha at pasture soil test phosphorous ranging from 35 to 1000 lb/acre. Adjusted sediment-bound P used to calculate total P. Confidence intervals reflect only the variability associated with rainfall. These SWAT simulations used the current litter application rate**.**

**Table 6** SWAT predicted mean annual loading to Lake Eucha at differing levels of pasture soil test phosphorous based on the current litter application rate. Adjusted sediment-bound P used to calculate total P (ADJ.).

| Soil Test P (lb/acre) | Flow (m^3/s) | Soluble P (kg/yr) | Sediment P (kg/yr) | Total P (kg/yr) | Total P (ADJ.) (kg/yr) | Nitrate (kg/yr) |
|---|---|---|---|---|---|---|
| 35 | 9.13 | 25,400 | 626 | 26,000 | 40,400 | 508,000 |
| 65 | 9.13 | 26,100 | 640 | 26,800 | 41,500 | 508,000 |
| 120 | 9.13 | 27,500 | 666 | 28,200 | 43,500 | 507,000 |
| 300 | 9.13 | 32,100 | 746 | 32,900 | 50,100 | 507,000 |
| 500 | 9.13 | 37,300 | 814 | 38,100 | 56,800 | 507,000 |
| 1000 | 9.13 | 50,000 | 946 | 50,900 | 72,700 | 506,000 |

**Table 7** SWAT predicted mean annual loading to Lake Eucha at differing levels of pasture soil test phosphorous. No litter was applied, only commercial nitrogen. Total nitrogen applied is the same as the 1X litter application rate. Adjusted sediment-bound phosphorous used to calculate total phosphorous (ADJ.).

| Soil Test P (lb/acre) | Flow (m^3/s) | Soluble P (kg/yr) | Sediment P (kg/yr) | Total P (kg/yr) | Total P (ADJ.) (kg/yr) | Nitrate (kg/yr) |
|---|---|---|---|---|---|---|
| 35 | 9.13 | 16,800 | 576 | 17,400 | 30,600 | 509,000 |
| 65 | 9.13 | 17,500 | 593 | 18,100 | 31,800 | 509,000 |
| 120 | 9.13 | 18,900 | 622 | 19,500 | 33,800 | 509,000 |
| 300 | 9.13 | 23,500 | 711 | 24,200 | 40,600 | 508,000 |
| 500 | 9.13 | 28,600 | 785 | 29,400 | 47,400 | 508,000 |
| 1000 | 9.13 | 40,800 | 923 | 41,700 | 63,000 | 507,000 |

**Long term simulations**

Long term simulations were performed to estimate how average soil test phosphorous (STP) may change under different litter application rates. The current basin-wide STP for pastures was estimated at 250 lb/acre, based on actual soil test data. At the current litter application rate, the SWAT model predicted that the average pasture soil test phosphorous will increase by 50 lb/acre in 5 years and by 250 lb/acre in 24 years (Figure 10). A reduction of 18 lb/acre STP was predicted if no litter was applied for 30 years. The removal of phosphorus from the soil is dependant on management. For instance exporting hay from the basin will remove more phosphorous than grazing. The majority of the phosphorous consumed by cattle from grass is redeposited as manure. In addition, chemical reactions in the soil may alter the long-term STP as well.

To check the SWAT model, time required to build up STP based on SWAT simulations was compared with poultry production history in the area. The poultry industry came to Delaware County, Oklahoma about 25 years ago and about 40 years ago to Benton County, Arkansas (personal communication Jason Hollenback OSU Extension). At poultry litter application rates of 0.5 and 0.75 of the current rate, it would take 42 and 28 years for STP to increase from background to the current level of 250 lb/acre, respectively . Litter applications would have steadily increased from very little when there were few houses, to the current rate. Therefore, a fraction of the current rate between 0.5 and 0.75 is reasonable, and provides a reasonable verification of the method.

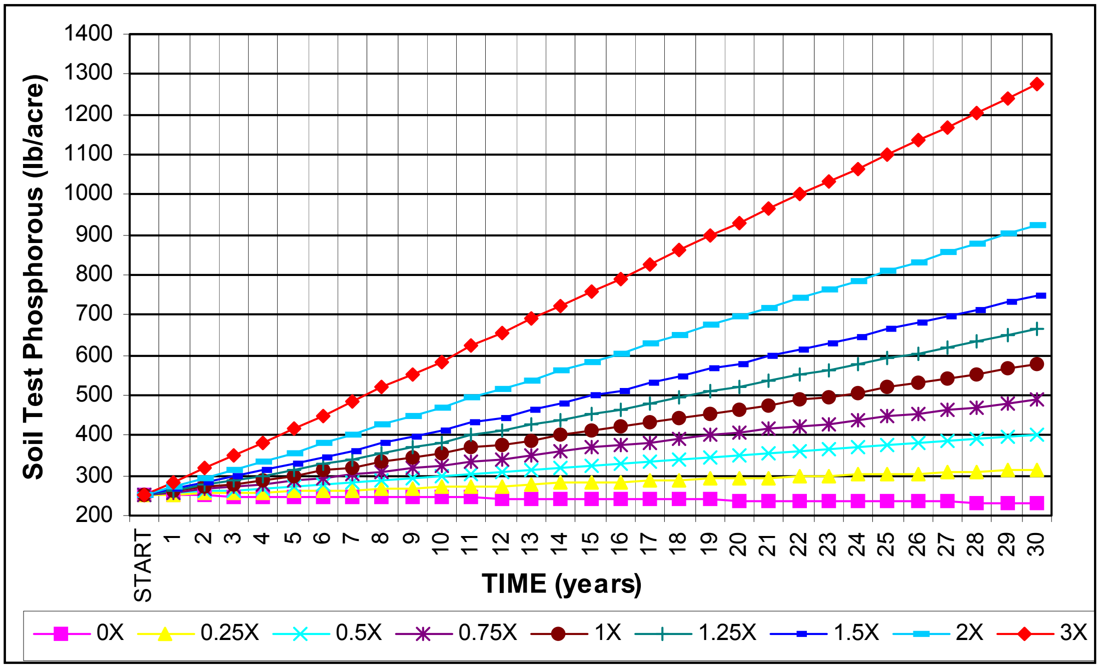


**Figure 10** Predicted soil test phosphorous as a function of litter application rate (fraction of current rate) over a 30-year period for the Lake Eucha Basin.

## SWAT Model Limitations

A model is a system of equations that represent a simplification of real world processes. The greater our understanding of these processes the better our models. Modeling requires many assumptions. Assumptions are made by the modeler, the model creator, and those who develop the relationships and define the process on which the model is based. There is a great deal of uncertainty associated with modeling. The nutrient loading for next year is every bit as unpredictable as next year's weather. We have quantified a portion of this uncertainty associated with rainfall variability. We know there are errors in the GIS data, water quality, and stream flow on which our calibration was based, but methods are currently not available to quantify the uncertainty from sources other than weather.[4]

Weather is the driving force for any hydrologic model. Great care was taken to include as much accurate observed weather data as possible. Unfortunately, weather data collected at a few points must be applied to the entire basin. Rainfall can be quite variable, especially in the spring when convective thunderstorms produce the majority of precipitation, and produce rainfall with a high degree of spatial variability.

An important limitation is that SWAT simulates poultry litter applications as simple nutrient additions applied uniformly to the top 10 mm of the soil surface. In reality poultry litter lies on the soil surface until rainfall moves it into the soil. In the first few rainfall events after

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Hession, W.C., D.E. Storm, "Watershed-Level Uncertainties: Implications for Phosphorous Management and Eutrophication" Journal of Environmental Quality" 29:1172-1179 (2000) application the litter interacts more closely with surface runoff than simulated by SWAT. In the field we expect high phosphorous concentrations in surface runoff immediately following litter application. In the SWAT model, simulated phosphorous concentrations do not increase so dramatically when litter is applied. These limitations caution us against using SWAT predictions on daily or even monthly basis. On an average annual basis, these loading errors are less pronounced due to calibration.

Another source of error was differences in soil test phosphorus (STP) data between Oklahoma and Arkansas. Oklahoma soil samples were analyzed by the Oklahoma State University (OSU) Soil, Water & Forage Analytical Laboratory and Arkansas soil samples were analyzed by the University of Arkansas (UA) Soil Testing and Research Laboratory. OSU and UA use extraction ratios of 1:10 and 1:7, respectively, and use different instrumentation for analysis. OSU uses a colorimetric method and UA uses inductively coupled argon plasma spectrometry (ICAP). Dr. Nathan Slaton with the UA provided the following relationships for different extraction ratios ($n \approx 500$):

$$\mathit{ICAP\,Mehlich\,III\,P}(1{:}10) = 1.27\ \mathit{ICAP\,Mehlich\,III\,P}(1{:}7) + 14.9$$

where Mehlich III is in mg/l. Dr. Hailin Zhang with OSU provided the following relationship between ICAP and the colorimetric method (n=3577, $R^2$=0.98):

$$\mathit{ICAP\,Mehlich\,III\,P}(1{:}10) = 1.11\ \mathit{Colormetic\,Mehlich\,III\,P}(1{:}10) + 26.7$$

where Mehlich III is in mg/l. The average pasture STP level used for the Arkansas portion of the Lake Eucha basin was 334 lbs/ac. Based on these regression equations, an Arkansas STP of 334 lbs/ac corresponds to an OSU value of 372 lbs/ac. In the context of this study, this 10 percent difference in STP is negligible.

Scenarios involving radical changes to the basin result in greater uncertainty. The model was calibrated using estimates of what is presently occurring in the basin. Large departures from calibration conditions raise the level of uncertainty.

SWAT models in-stream processes based, in large part, on unvalidated assumptions of channel and stream-bank properties. These in-stream processes are the primary cause of the low sediment-bound phosphorous prediction by the calibrated model.

Long-term simulations of soil test phosphorous assume SWAT`s soil phosphorous model is correct. The steady-state partitioning of phosphorous into SWAT`s various soil phosphorous pools was used to estimate soil test phosphorous. In reality this partitioning varies by soil type and cultural practices.

# SWAT Input Data

GIS data for topography, soils, landcover, and streams were used in the SWAT model. The data used were the most current at the time of compilation. Observed daily rainfall and temperature data were used in all modeling.

## SWAT Overview

SWAT (Soil and Water Assessment Tool) is a distributed hydrologic model. Distributed hydrologic models allow a basin to be broken into many smaller subbasins to incorporate spatial detail. Water yield and loadings are calculated for each subbasin, and then routed through a stream network to the basin outlet. SWAT goes a step further with the concept of HRUs (Hydraulic Response Units). A single subbasin can be further divided into areas with the same soil and land use, these are HRUs. Processes within an HRU are calculated independently. The total yield for a subbasin is the sum of all the HRUs within it. HRUs allow more spatial detail to be included by allowing more land use and soil classifications to be represented for any given number of subbasins.

SWAT is a physically based continuous simulation model that operates on a daily time step. Long-term simulations can be performed using simulated or observed weather data. The relative impact of different management scenarios can be quantified. Management is set as a series of individual operations (e.g. planting, tillage, harvesting, or fertilization).

SWAT is the combination of ROTO (Routing Outputs to Outlets) (Arnold et al., 1995) and SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990). SWAT was created to overcome maximum area limitations of SWRRB, which can only be used on watersheds a few hundred square kilometers in area and less than10 subbasins. SWAT can be used for much larger areas. Several models contributed to SWRRB and SWAT: CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980), GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al.,1987), and EPIC (Erosion-Productivity and Impact Calculator) (Williams et al.,1984).

## SWAT Input Data

An ArcView GIS interface is available to generate model inputs from commonly available GIS data. These GIS data are summarized by the interface and converted to a form usable by the model. GIS data layers of elevation, soils, and land use are used to generate the input files. Observed temperature and precipitation can be incorporated. If no observed weather data are available, weather can be stochastically simulated.

## Topography

Topography was defined by a DEM (Digital Elevation Model). DEMs for the United States are available for download via the Internet.[5] The DEM was used to calculate subbasin parameters such as slope, slope length, and to define the stream network. The resulting stream network was used to define the layout and number of subbasins. Characteristics of the stream network, such as channel slope, length, and width, were all derived from the DEM.

Individual 1:24,000 thirty meter DEMS were stitched together to construct a DEM for the entire basin. When tiled, 1:24,000 DEMS often have missing data at the seams. These missing data must be replaced. A 3x3 convolution filter was applied to the DEM to produce a seamless filtered DEM. Any missing data at the seams of the original DEM were replaced with data from the filtered DEM. The resulting seamless DEM retains as much non-filtered data as possible (Figure 11). Filtering tends to remove both peaks and valleys from a DEM thereby reducing the perceived slope. For this reason the use of filtered data were kept to a minimum.

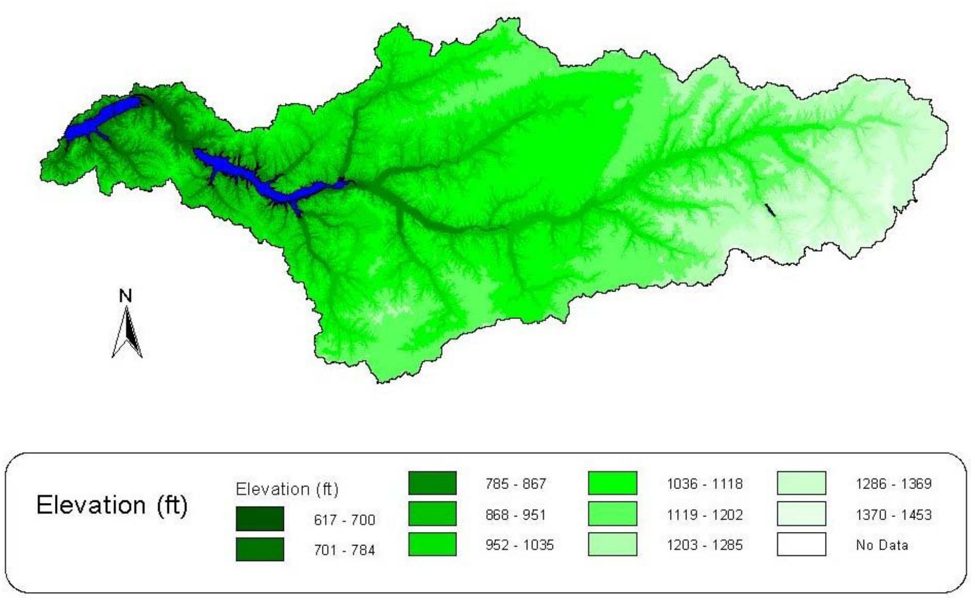


**Figure 11** Seamless Digital Elevation Model (DEM) of the Eucha/Spavinaw Basin constructed from U.S. Geographic Survey 1:24,000 DEMs.

[5] USGS DEMs are available via the web at http://edc.usgs.gov/doc/edchome/ndcdb/ndcdb.html

## Soils

Soil GIS data are required by SWAT to define soil types. SWAT uses STATSGO (State Soil Geographic Database) data to define soil attributes for any given soil. The GIS data must contain the S5ID (Soils5id number for USDA soil series), or STMUID (State STATSGO polygon number) to link an area to the STATSGO database.

The soils layer was derived from two separate GIS coverages. The Oklahoma portion is 200-meter resolution MIADS (Map Information Assembly and Display System) data from the Oklahoma NRCS.[1] The Arkansas portion is a 1:20,000 order II soil survey digitized by the University of Arkansas.[2] Basic properties of soils used by SWAT are listed in Appendix A.

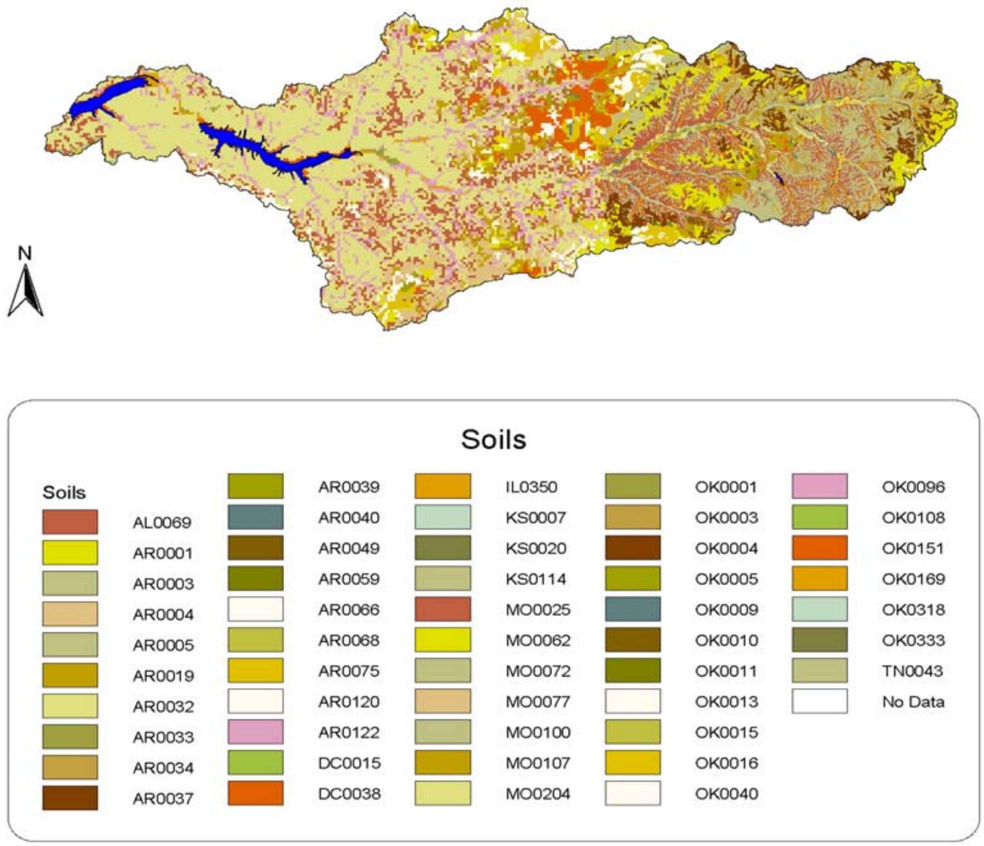


**Figure 12** Soils of the Eucha/Spavinaw basin by 5 digit identification.

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1 MIADS metadata available form the Oklahoma NRCS via the web at: http://ok.nrcs.usda.gov/gis/text/041_lu.htm

2 Benton County order II soil survey information available online at: http://www.cast.uark.edu/local/catalog/arkansas/pages/gif/phys21.gif

## Land Cover

Land cover is perhaps the most important GIS data used in the model. The land cover theme affects the amount and distribution of pastures and forest in the basin. These two land covers are radically different. Forested areas contribute little to the nutrient loading, while pastures are thought to be the primary source of the nutrient loading. It is important that these data be based on the most current data available, since land cover changes over time. Topography and soils cannot be changed so easily or rapidly by man.

Land cover was derived from Oklahoma and Arkansas GAP (Gap Analysis Program) data.[3] The GAP project mapped vegetation based on 30 meter Landsat Thematic Mapper satellite imagery. The primary purpose of this information was to predict the range of native vertebrate species. GAP land cover defines many native vegetation categories, but very few agricultural categories. We simplified GAP categories to pasture, forest, urban, and water. The basin is composed of 43.2% pasture, 55.0% forest, 1.7% water, and 0.1% urban. These data were then combined to produce a seamless coverage of the entire area (Figure 13).

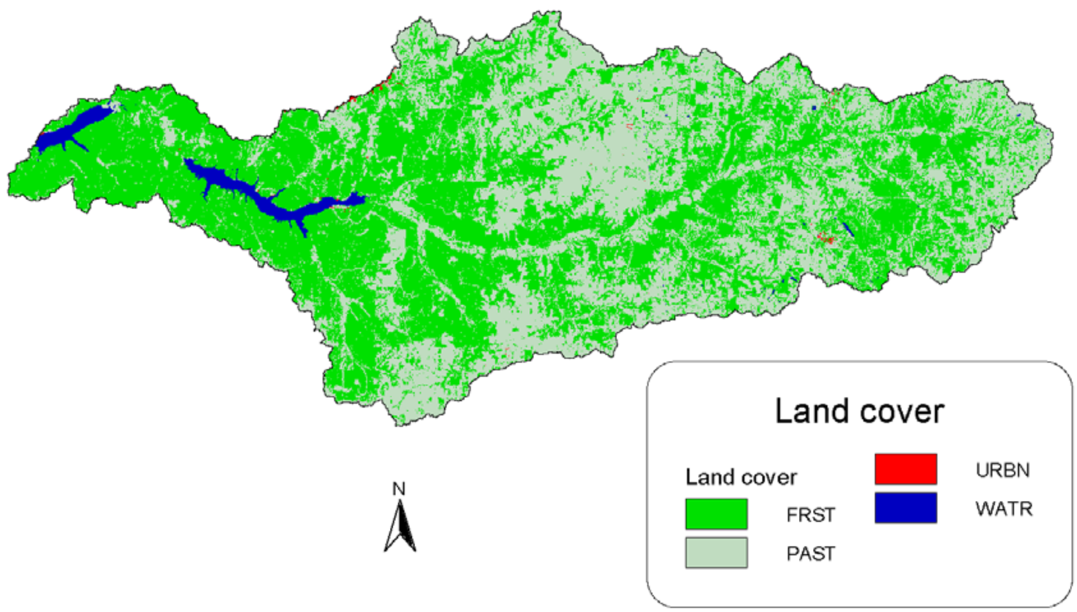


**Figure 13** 1:100,000 Gap Analysis Project derived land cover for the Eucha/Spavinaw basin.

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3 A more detailed description of GAP data is available online: http://www.gap.uidaho.edu/About/Overview/GapDescription/default.htm

## Weather

SWAT can use observed weather data or simulate it using a database of weather statistics from stations across the US. Observed daily precipitation and minimum and maximum temperature were used in the Eucha/Spavinaw model. National Weather Service COOP (Cooperative Observing Network) station data from 27 stations from 1/1/1950 to 4/30/00 were used to in the SWAT model (Figure 14). The location of each station is listed in Appendix B. COOP data are available from the NOAA (National Oceanic and Atmospheric Administration).

COOP data are seldom continuous for long periods of time. Missing days and even months are common. The period of record at stations are inconsistent, so the number of active stations changes with time. When SWAT detects missing data at a station, it generates simulated weather. Gaps in a station's record were filled using interpolated data from surrounding stations. Shepherd's weighted interpolation was used, because it is computationally efficient.

Shepherd's method uses weighting factors derived from the distance to nearby stations within a fixed radius:

$$Z_0 = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=1}^{n} W_i}$$

where $Z_0$ is the precipitation at the station of interest in mm, $Z_i$ is the precipitation at station *i* in mm, and $W_i$ is the weighting factor at station *i*.

Weighting factors are calculated using the distance between stations:

$$W_i = (1 - \frac{d_i}{R})^2 \text{ for } \frac{d_i}{R} < 1 \text{ And } W_i = 0 \text{ for } \frac{d_i}{R} \geq 1$$

where $R$ is the radius of influence in meters, and $d_i$ is the distance from station of interest to station *i* in meters.

Because of the large amount of data associated with these weather files, all processing and formatting was done using custom programs written in VBA (Visual Basic for Applications) and Microsoft Excel. SWAT assigns each subbasin to the closest gage station to the subbasin centroid, so many of the original 27 stations were not used by SWAT. The purpose of these extra stations was to fill gaps in records for the stations that were used by SWAT.

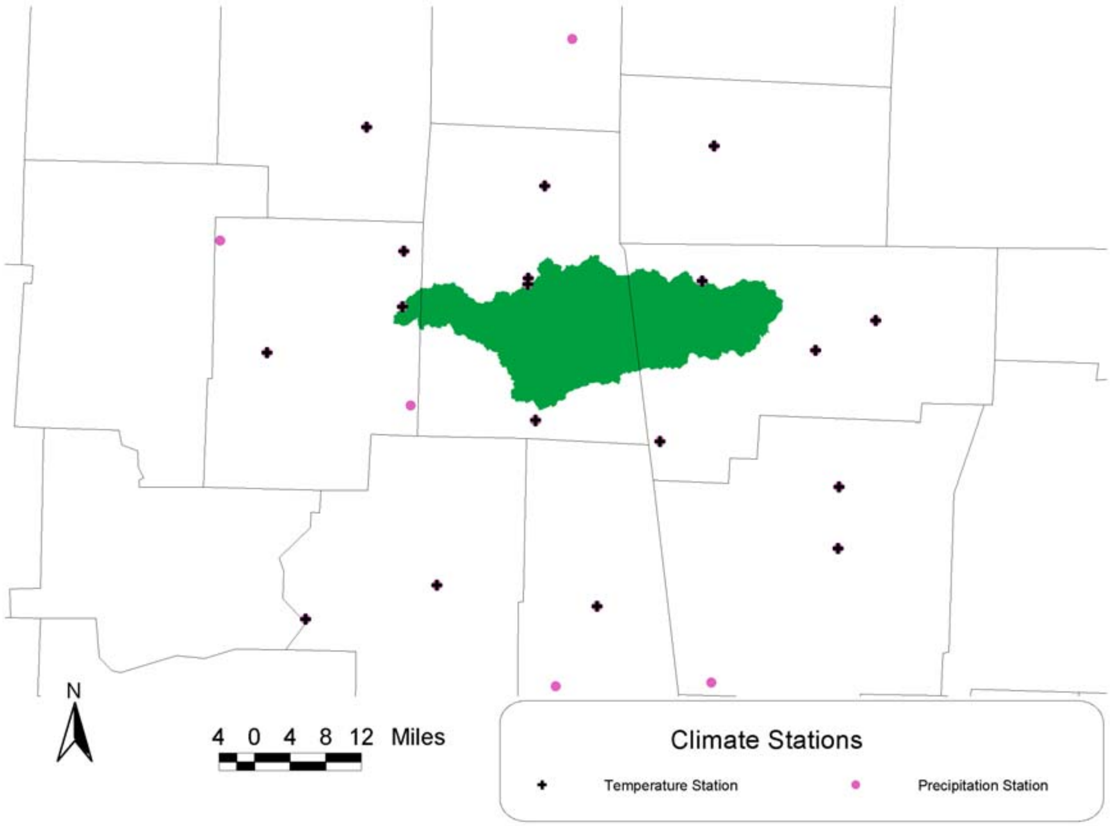



**Figure 14** National Weather Service Cooperative Observation network precipitation and temperature station locations near the Eucha/Spavinaw Basin.

### Subbasin delineation

The subbasin layout was defined by SWAT using the DEM, a stream burn in theme, and a table of additional outlets. The stream burn in theme consists of digitized streams. Its purpose is to help SWAT define stream locations correctly in flat topography. A modified reach3 file from the Environmental Protections Agency's BASINS (Better Assessment Science Integrating Point and Non-point Sources) model was used. The theme was modified to remove the outline of both lakes, which the model confused with a stream path.

Model output is only available at subbasin outlets, so additional outlets were added at points of interest such as gage stations, water quality stations, or lake boundaries (Appendix C). A stream threshold value of 1000 ha was used to delineate subbasins. Threshold area is the minimum contributing upland area required to define a single stream. The result is 58 subbasins (Figure 15). Fewer subbasins would simplify the modeling process, but this level of detail was needed to adequately represent the basin[4]. Selected properties of each subbasin are given in Appendix D.

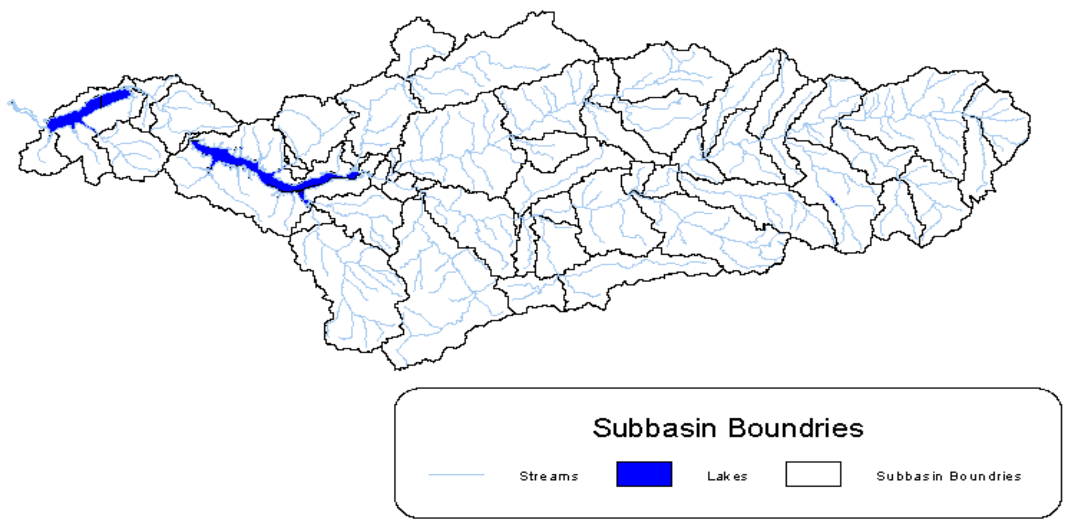



**Figure 15** Subbasin layout used in SWAT model. The Eucha/Spavinaw basin is simulated as 58 subbasins.

### HRU Distribution

Each of the 58 subbasins was split into HRUs (Hydraulic Response Units) by SWAT. The *land use [%] over subbasin area threshold* was changed from the default 20% to 10%. This threshold determines the minimum percentage of any land cover in a subbasin that will become an HRU. The *soil class [%] over subbasin area* was also reduced from its default value of 20% to 10%. By reducing these thresholds, the number of HRUs was increased to 351, allowing more spatial detail to be incorporated into the SWAT model.

4 Bingner, R.L., Garbrecht, J., Arnold, J.G., and Srinivasan, R., 1997, "Effect of Watershed Subdivision on Simulation Runoff and Fine Sediment Yield."

## Ponds

Ponds affect the hydrology by impounding water and trapping nutrients. Water in ponds is subject to evaporation and seepage into the shallow aquifer. Nutrients and sediment settle out and are trapped. Test runs using the SWAT model indicate ponds significantly reduced nutrient and sediment concentrations.

Because of the difficulty associated with counting ponds in each subbasin, ponds were assumed uniformly distributed in agricultural portions of the basin. Heavily forested areas were assumed to have no ponds (Figure 16). All ponds in a single Beaty Creek subbasin were counted and summarized. These estimates were applied to all subbasins considered to have ponds. Other subbasins with similar landcover appeared visually similar, indicating that ponds are somewhat uniformly distributed throughout pasture areas of the basin. These ponds were defined from 1:24,000 USGS DRG (Digital Raster Graphic). This level of detail was required to define the majority of ponds. The 1:100,000 GAP land cover displayed far fewer ponds than visual inspection of the same area.

Of the total area in each subbasin, 20% was routed through ponds. Total surface area of all ponds in a subbasin was estimated as 0.32% of the total area of that subbasin. Each pond was assumed to have an average depth of 1.5 meters. The ArcView interface was not used to create pond (.pnd) files for linguistic reasons. Pond files were generated for each subbasin using a custom VBA program.

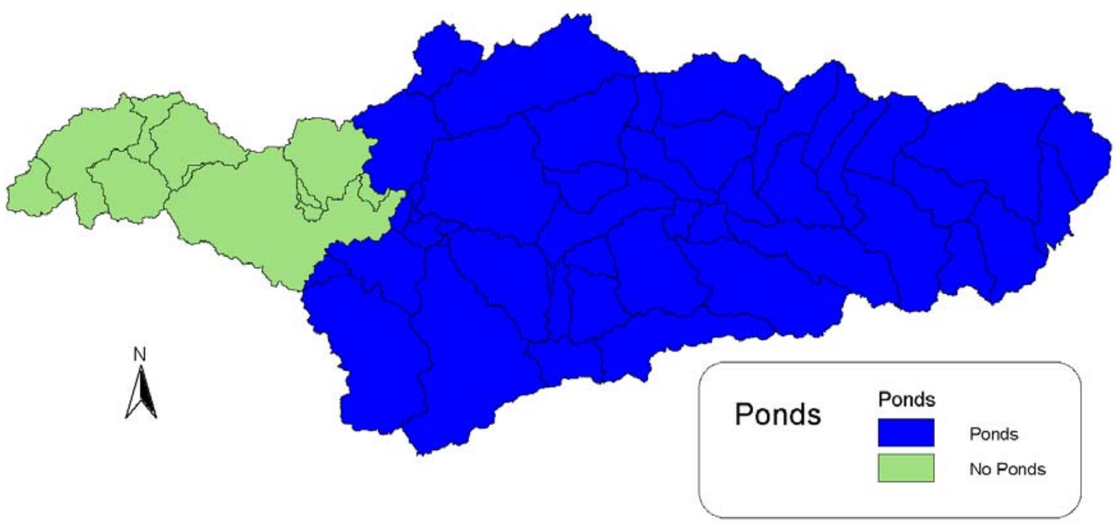



**Figure 16** Subbasins in the Eucha/Spavinaw basin assumed to have a significant number of ponds.

## Soil Phosphorous Content

Two distinctly different methods were used to estimate soil phosphorus content. Pasture soil phosphorous content was estimated using observed soil test data. Soil phosphorous content for forested areas was based on SWAT computer simulations.

### Forest - Soil Phosphorous Content

Soil test phosphorous observations were unexpectedly high in forested portions of the basin. These forested portions have no history of litter application. We think the soil test phosphorous was bias due to the high organic matter content of these soils. Much of the organic phosphorous is digested during a Mehlich III extraction, and reported in the measurement. The SWAT model has separate inputs for mineral and organic phosphorous. Mineral phosphorous estimates should not include organic phosphorous, because this fraction is estimated from the soil organic matter content by the model. If the forest soil test phosphorous data were used, soil mineral phosphorous content would be overestimated.

Soil phosphorous estimates for forested areas were based on SWAT computer simulations of an undisturbed forested area in north central Arkansas (Figure 17). North Sylamore Creek (Station 07060710) is a HBN (Hydrologic Benchmark Network) station. Separate simulations were performed to back calculate soil test phosphorous from observed water quality data (Appendix E). GIS data for elevation, land cover, soils, and streams were compiled for the North Sylamore Creek watershed (Figure 18). Observed precipitation and simulated temperature data were used for each SWAT simulation. Modifications to soil phosphorous were made using the SWAT input parameter Sol_labp (Labile [soluble] phosphorous concentration in the surface layer, mg/kg). This parameter also sets the amount of phosphorous in SWAT's various phosphorous pools. Sol_labp was assumed to be related to soil test phosphorous by (Appendix F):

**Mehlich III Soil test P (lb/acre) = 5 sol_labp (mg/kg)**

Sol_labp was adjusted until the results of the simulation closely matched observed data. Model results for the period 10-79 to 9-90 were compared to observed data of the same period. The model was allowed to "warm up" for a period of 5 years before any data were compared (Table 8). The model was not calibrated on flow or sediment, therefore soluble phosphorous was considered to be more important than total phosphorous. Sediment yield is highly uncertain in an uncalibrated model, and sediment-bound phosphorous is closely linked with sediment yield. Comparisons of observed and simulated soluble phosphorous were favorable at a soil test value of 35 lb/acre (sol_labp value of 7 mg/kg). A value of 35 lb/acre was used for all forested areas of the Eucha/Spavinaw basin.

**Table 8** Observed and SWAT simulated phosphorous comparisons at an soil test phosphorous value of 35 lb/acre in the North Slaymore Creek watershed.

| Parameter | Observed | Predicted | Relative Error % |
|---|---|---|---|
| Average soluble P concentration (mg/L) | 0.0082 | 0.0082 | -1% |
| Flow weighted soluble P concentration (mg/L) | 0.01 | 0.0079 | 21% |
| Average total P concentration (mg/L) | 0.0151 | 0.0096 | 36% |
| Flow weighted total P concentration (mg/L) | 0.04 | 0.0103 | 74% |


**Figure 17** North Sylamore Creek near Fifty Six, Arkansas (Station 07060710).

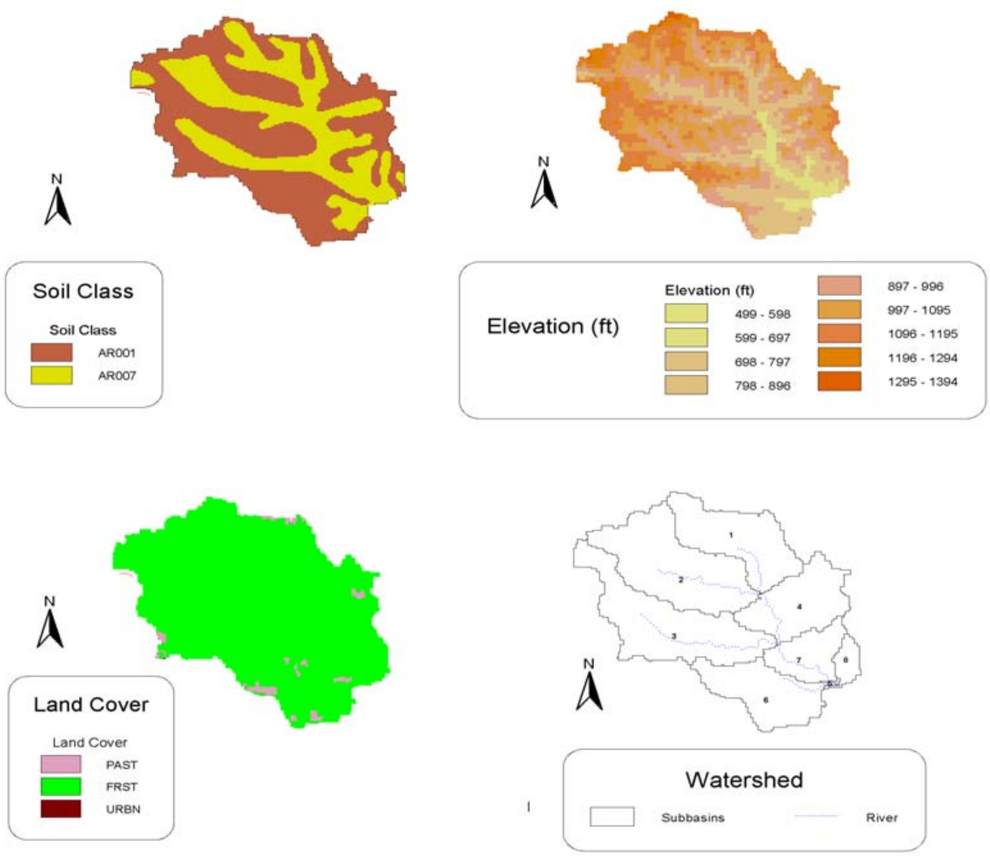



**Figure 18** GIS data used in SWAT for the North Sylamore Creek watershed.

**Pasture - Soil Phosphorous Content**

Observed soil test data were used to determine the soil phosphorous content for the pasture portions of each subbasin. Soil samples collected by the Oklahoma Conservation Commission (OCC) were used for the Oklahoma portion of the watershed (Appendix G). A mean of 334 lb P/acre was derived from 261 soil samples of Benton County pasture, and was used for the Arkansas portion of the basin (Appendix G).

Marshall (1998) developed a nonparametric method to determine the number of samples required, within a 90% confidence interval, to estimate subbasin soil test phosphorous by land use for hydrologic/water quality modeling. This method was applied to the Eucha Basin, and a soil sampling plan was developed for pastures and forested areas. The Oklahoma Conservation Commission was contracted to collect these soil samples for the Oklahoma portion of the basin. A summary of the soil test data is given in Figure 5

Soil samples from the OCC were double checked to ensure that their locations were within the indicated subbasin. Some 14 samples fell outside the Lake Eucha watershed or were unusable for other reasons. Samples less than 400 meters outside the basin were reassigned to the nearest subbasin (Table 9). Because SWAT defines its own subbasins, an approximation of Marshall 's (1998) original subbasin theme was used to determine where the samples were taken (Figure 19). An area weighted soil test phosphorous was calculated for each of SWAT`s 58 subbasins (Figure 20).

We used a specially compiled version of the SWAT model. At our request, Susan Neitsch (SWAT team, user assistance) modified SWAT 99.2 such that the entire soil profile was set to the same soluble phosphorous as the surface layer. The original SWAT 99.2 allows only the soluble phosphorous in the top 10 mm of soil to be set by the user, and the remainder of the soil profile is set to a value of 20 mg P/kg soil. The original SWAT was not very sensitive to changes in soil phosphorous. Adjustments to the phosphorous content of the top 10 mm make little difference to the total amount of phosphorous in the soil profile. Mixing between layers make the phosphorous content of the top 10 mm approach the default value of the layer beneath in a few years.

**Table 9** Number of soil samples from each major subbasin used to calculate average soil test phosphorous used in SWAT.

| | PASTURE total | FOREST total |
|---|---|---|
| Eucha | 5 | 3 |
| Dry | 25 | 11 |
| Brush | 29 | 5 |
| Beaty | 46 | 3 |
| Cloud | 33 | 4 |
| Cherokee | 41 | 5 |
| Black Hollow | 33 | 0 |

**Table 10** Soil test averages by subbasin (lb-nutrient/acre, Oklahoma portion only).

| Subbasin | PH | Buffer Index | N | Melich III P | K |
|---|---|---|---|---|---|
| Eucha | 6 | 7 | 17 | 91 | 323 |
| Dry | 6 | 7 | 14 | 69 | 306 |
| Brush | 6 | 7 | 11 | 150 | 268 |
| Beaty | 6 | 5 | 24 | 202 | 337 |
| Cloud | 5 | 7 | 9 | 120 | 291 |
| Cherokee | 6 | 6 | 26 | 297 | 363 |
| Black Hollow | 5 | 7 | 53 | 112 | 267 |

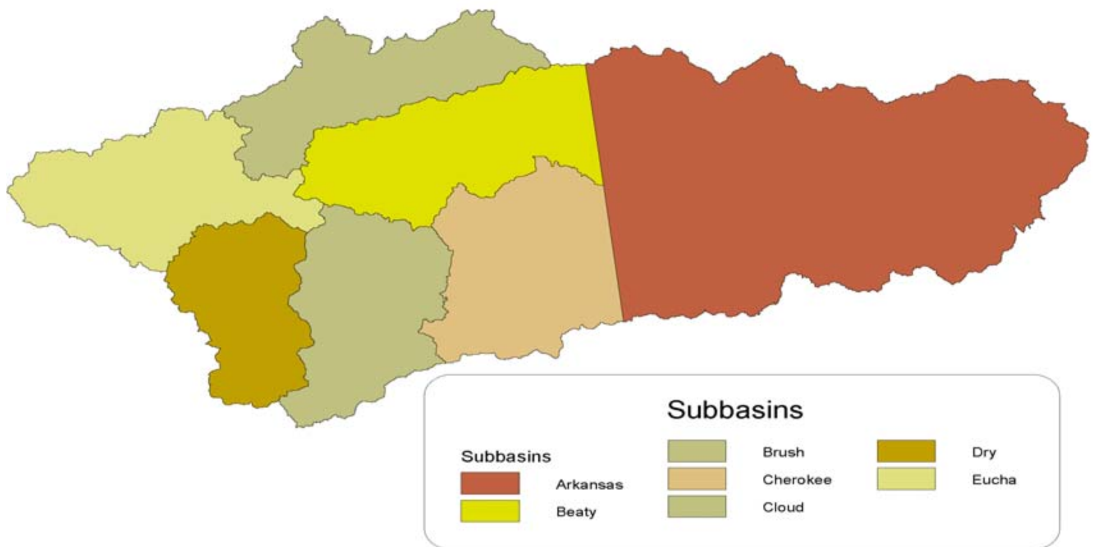



**Figure 19** Approximation of Marshall (1998) original subbasins.

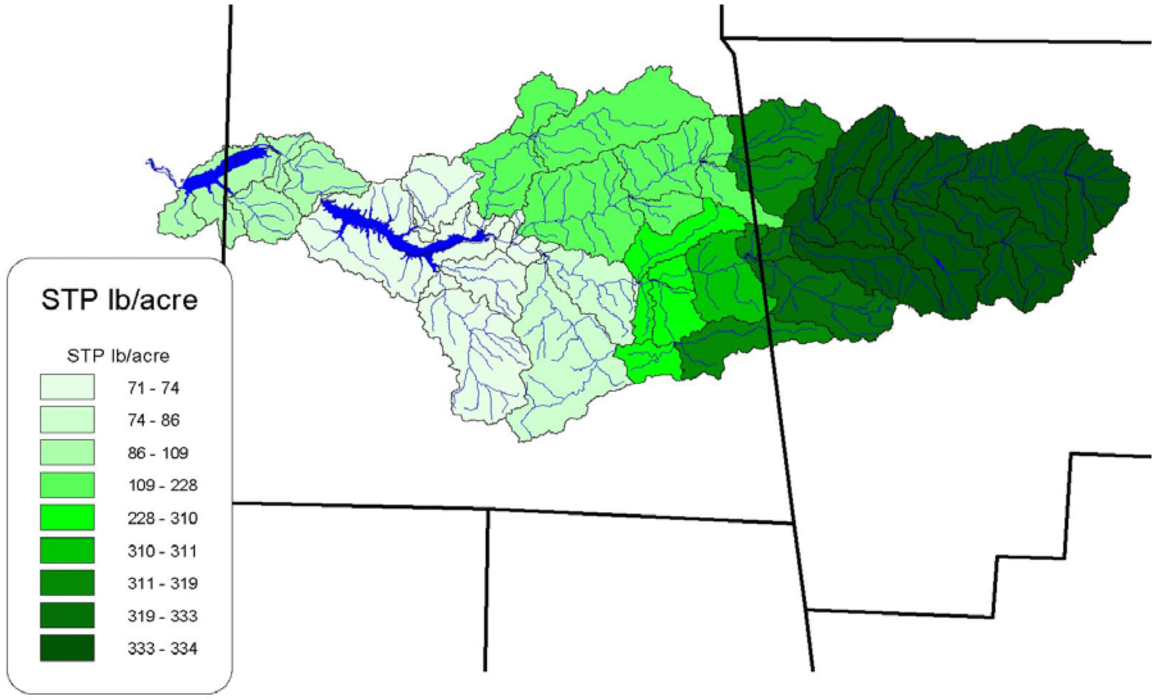



**Figure 20** Average Lake Eucha and Lake Spavinaw Mehlich III soil test phosphorous (STP) for pastures by subbasin.

**Nutrient Inputs --- Litter Application Rate**

The number of poultry houses and the pasture area in each subbasin were used to determine litter application rates. All litter produced in a subbasin was assumed to be uniformly applied to pastures in that subbasin.

Broiler, layer, and turkey production all contribute to the total litter production. Each type of operation produces a different amount of litter, and litter of a different composition (Table 11). The amount of litter contributed basin-wide by each type of operation is summarized in Table 12. The average litter composition was determined by using the relative amount of each litter applied in the basin and it's composition (Table 13).

A minimum of one ton was applied in each subbasin, to prevent technical difficulties associated with zero application rates. This amount is negligible when spread over the area the size of a subbasin. The average amount of litter applied to pastures was 1750 kg/ha (0.77 ton/acre). The maximum litter rate was assigned to subbasin 27, 8007 kg/ha (3.53 ton/acre), reflects the high number of poultry operations located in a small subbasin (Figure 21). A complete list of application rates by subbasin is available in Appendix H. A total of 83,800 tons of litter was estimated to be applied in the Eucha/Spavinaw Basin each year. This litter contained approximately 1,140,000 kg phosphorous (1260 ton) and 3,800,000 kg nitrogen (4190 ton).

**Table 11** Litter production in the Eucha/Spavinaw Basin and fractional composition by operation type.

| Operation | Litter per 20,000 animals | Mineral N | Mineral P | Organic N | Organic P | Source |
|---|---|---|---|---|---|---|
| Broiler | 100 ton/yr | 0.01000 | 0.00400 | 0.04000 | 0.01000 | Storm et al. (1999) and SWAT Database |
| Layer, Breeder | 200 ton/yr | 0.01300 | 0.00600 | 0.04000 | 0.01300 | Finley (1994) and SWAT Database |
| Turkey | 310 ton/yr | 0.00700 | 0.00300 | 0.04500 | 0.01600 | Vest (1994) and SWAT Database |

**Table 12** Relative litter production in the Eucha/Spavinaw Basin by operation type.

| Type | Animals | Houses | Litter production (t) | % of total litter |
|---|---|---|---|---|
| Broilers | 17937700 | 957 | 89689 | 88.6% |
| Layers | 720800 | 82 | 7208 | 7.1% |
| Turkeys | 282650 | 65 | 4381 | 4.3% |

**Table 13** Average fraction nutrient concentration of litter produced in Eucha/Spavinaw Basin.

| Operation | Relative amount | Mineral N | Mineral P | Organic N | Organic P |
|---|---|---|---|---|---|
| Broiler | 89% | 0.010 | 0.004 | 0.040 | 0.0100 |
| Layer, Breeder | 7% | 0.013 | 0.006 | 0.040 | 0.0130 |
| Turkey | 4% | 0.007 | 0.003 | 0.045 | 0.0160 |
| Average | | 0.010 | 0.0041 | 0.040 | 0.0105 |
| Used in model | | 0.01 | 0.0045 | 0.04 | 0.0105 |

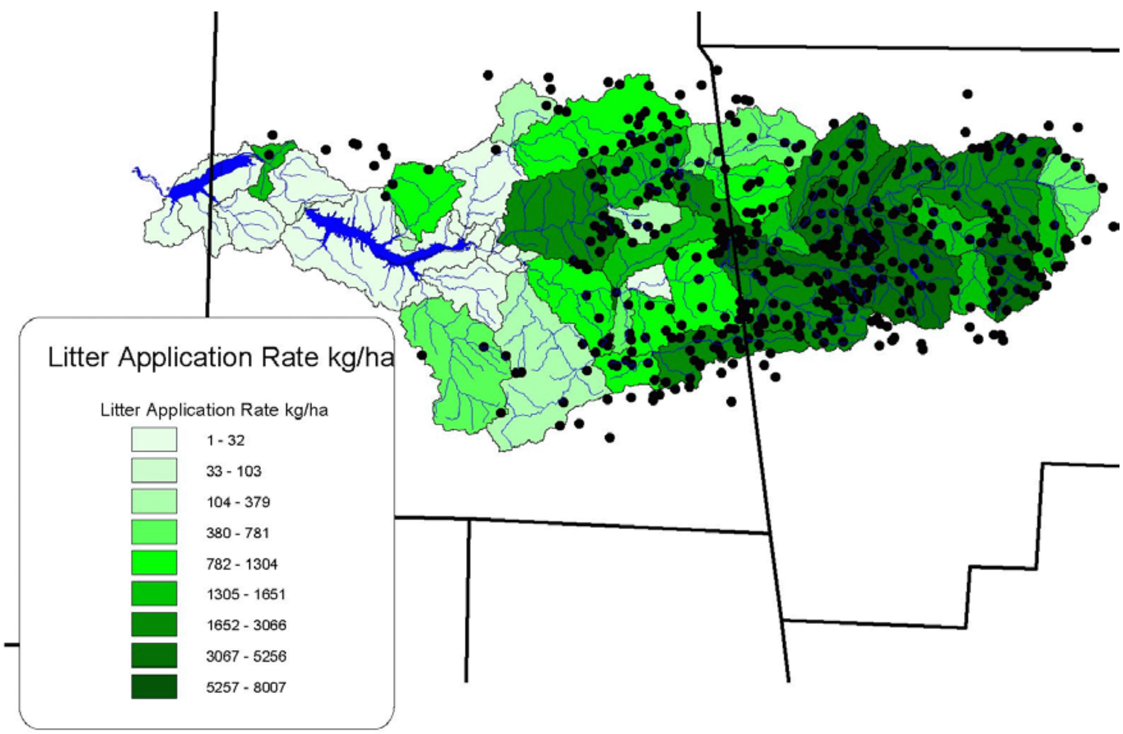



**Figure 21** Litter applied by subbasin and poultry house locations (black dots).

### Nutrient Inputs --- Commercial fertilizer applications

Commercial fertilizer sales in 1998 and 1999 for Delaware and Benton Counties were assumed to be uniformly applied to pastures in each county. The amount of pasture in each county was determined by USGS LULC (Land Use Land Cover) GIS data. LULC data were used because these data are readily available by county. Yearly rates for both counties were area weighed to estimate a single yearly application rate for the basin (4.8 kg/ha nitrogen and 0.1 kg/ha phosphorous). Appendix I contains additional information and calculations.

### Observed Stream Flow

The Eucha/Spavinaw Basin contains three USGS stream gages (Figure 22). These gages were used to calibrate the hydrologic portion of the model. Each gage station has a different period of record (Table 14.)

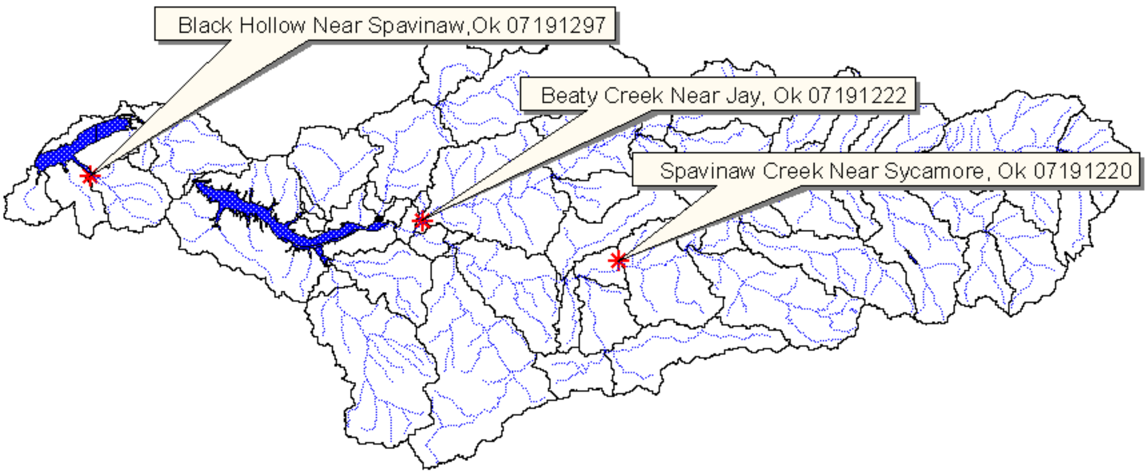



**Figure 22** Active U.S. Geographic Survey stream gage stations used to calibrate the SWAT model.

**Table 14** Perod of record at U.S. Geographic Survey stream gage stations used to calibrate the SWAT model.

| Gage Station | Start Date | End Date |
|---|---|---|
| Spavinaw Creek Near Sycamore | 10/1/61 | Current |
| Beaty Creek Near Jay | 7/31/98 | Current |
| Black Hollow Near Spavinaw | 7/24/98 | Current |

### Baseflow Separation

Stream flow has two primary sources, surface runoff and ground water. Ground water contributions to streamflow are known as baseflow. The SWAT model was calibrated separately against observed surface and baseflow. Baseflow was separated from the total observed stream flow using the USGS HYSEP[5] sliding interval method. The method works as follows:
The duration of surface runoff is calculated from the empirical relationship:

$$N=A^{0.2}$$

where N is the number of days after which surface runoff ceases and A is the drainage area in square miles. The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. We adjusted the interval to provide a range of acceptable

5 Sloto, R. A., Crouse, M. Y., HYSEP: "A Computer Program for Streamflow Hydrograph Separation and Analysis, U.S. Geological Survey

baseflow values. The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated (Figure 23).

Baseflow fractions were higher than expected throughout the basin, likely the result of the karst topography of the area. Karst features allow significant interaction between stream flow and ground water (Wagner and Woodruff 1997).

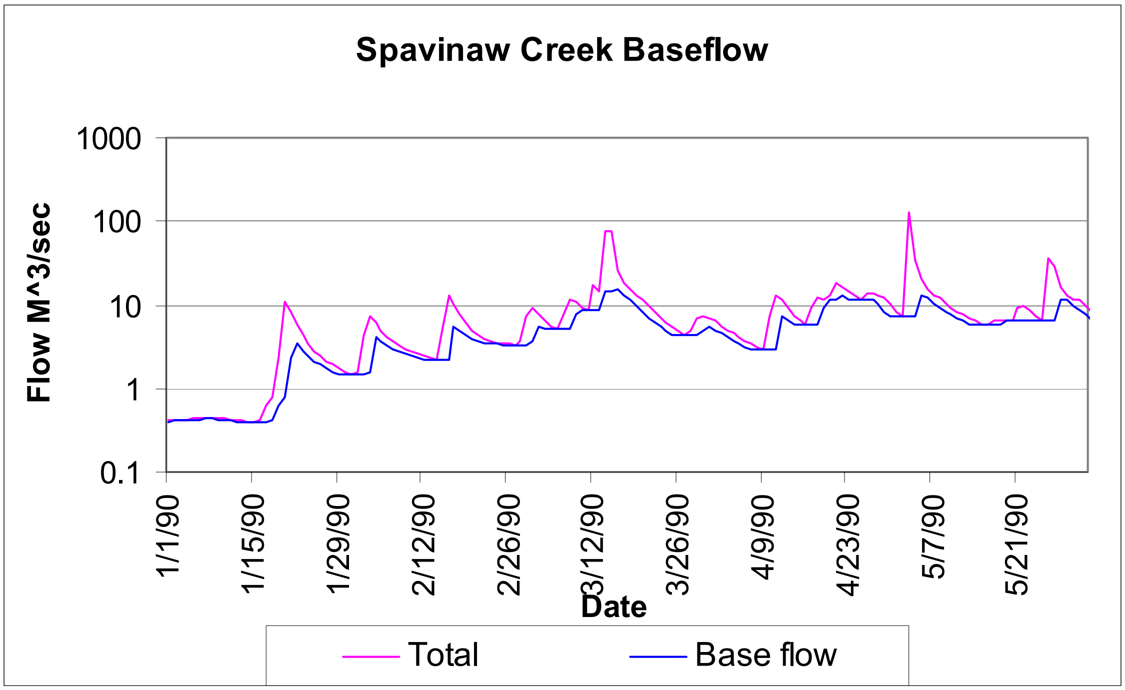



**Figure 23** Spavinaw Creek baseflow separation example.

**Table 15** Observed average flow and baseflow fractions as determined by the HYSEP sliding interval method.

| Gage Station | Average Flow (M^3/sec) | Period used | Baseflow | Surface runoff |
|---|---|---|---|---|
| Spavinaw Creek Near Sycamore | 3.8 | 1/90 to 4/00 | 66% - 60% | 34% - 40% |
| Beaty Creek Near Jay | 1.78 | 8/98 to 4/00 | 51% - 44% | 49% - 56% |
| Black Hollow Near Spavinaw | 0.12 | 8/98 to 4/00 | 79% | 21% |

**Observed Loading Development**

Water quality data were available for 10 suitable locations in the basin (Appendix J). Soluble phosphorous and total phosphorous loadings were estimated at each of these stations (Figure 24). Originally we only considered phosphorous, later it was deemed necessary to estimate nitrate loadings before calibrating SWAT for nutrients. Nitrate and phosphorous loadings were estimated separately. SWAT was calibrated for nutrients after the hydrologic calibration was completed.

Flow was estimated at each water quality station, because the observed water quality data have no associated flow information. We estimated daily flow from the closest stream gage and assumed flow was proportional to drainage area. Flow data before 8/1998 were estimated from the Spavinaw station only, because Spavinaw was the only active station before 8/1998. Daily flow was estimated for the period 1/1990 to 4/2000 at each water quality station. The stream gage used at each water quality station are listed in Appendix K, Table K1. If more that one USGS station was used to estimate flow, the flow per unit area from all stations was averaged.

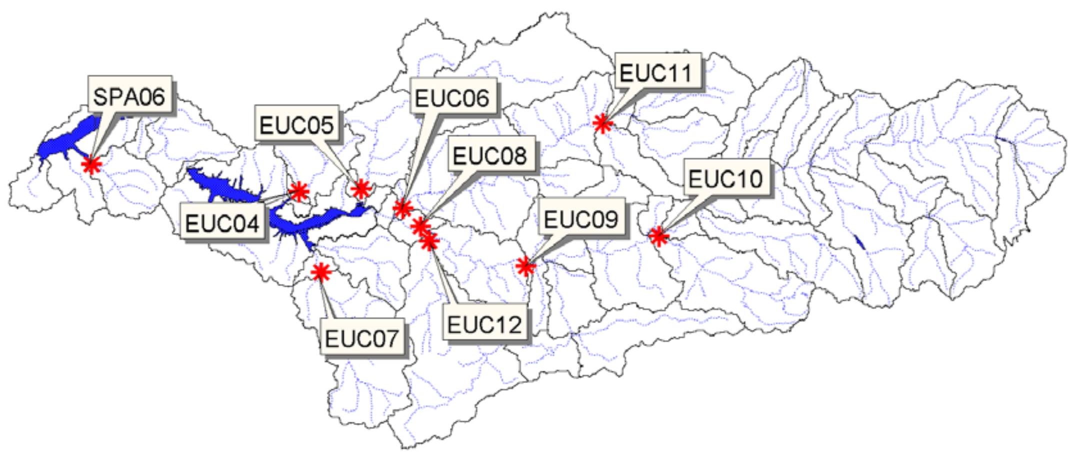



**Figure 24** City of Tulsa water quality station locations used to calibrate the SWAT model.

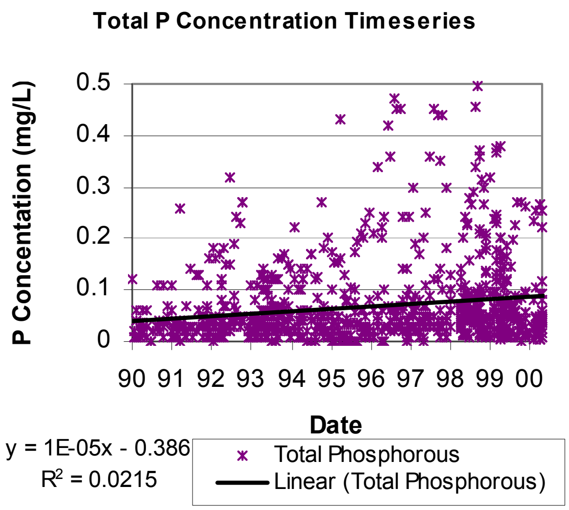
**Phosphorous Loading**

Estimated flow was graphed against concentration to detect any significant relationship. If a significant ($\alpha$=0.05) relationship was found, loading was determined using this relationship. If there was no significant ($\alpha$=0.05) relationship the average concentration was used to calculate load. Water quality data were divided into pre-1998 and post-1998 groupings. Data collected after 1998 had quality assurance information and higher frequency sampling. Charts were generated for all available data and post 1998 only. The group of data that exhibited the best relationship was favored to estimate loading. Other considerations included the number of available data points and the possibility of loading increases in recent years. Increases in nitrate and phosphorous concentrations in the basin were apparent (Figure 25). All of these considerations were judged at each location to select the most appropriate data set. No water quality observations before 1990 were used to help minimize these errors. A summary of calculations at each station is located in Appendix K.

If the regression was significant, the residuals were examined for seasonality. Where seasonality was apparent, separate regressions were developed for spring/summer and fall/winter. Separate regressions were necessary at only one station, EUC06 (Lower Beaty Creek) and only for soluble phosphorous. Estimated daily flow was used with any significant relationship or average concentration to determine a daily load. Table 16 contains average concentrations and total estimated load for the period 8-98 to 4-00. The following equation was used to estimate loads:

$$L = \sum_{i=1}^{n} 86.4 Q_i C$$

where $L$ is load in kg, $Q_i$ is flow in $m^3$/sec, $n$ is the number of days, and $C$ is concentration in mg/l.



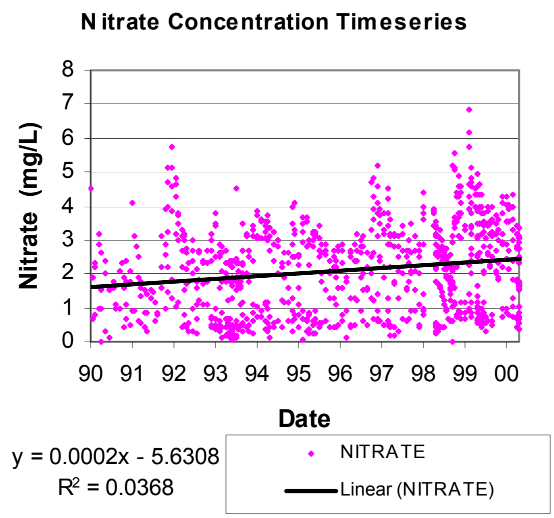




**Figure 25** Observed nutrient concentrations over time. All City of Tulsa water quality stations combined.

**Table 16** Estimated observed phosphorous loading, summary by station.

| SITE | Average flow (m^3/sec) | Average ORTHO P (MG/L) | Average TOTAL P (MG/L) | Average Monthly ORTHO (KG/Month) | Average Monthly TOTAL (KG/Month) | AREA (km^2) |
|---|---|---|---|---|---|---|
| EUC04 | 0.24 | 0.0100 | 0.0143 | 6 | 25 | 20.9 |
| EUC05 | 1.01 | 0.0117 | 0.0206 | 142 | 301 | 87 |
| EUC06 | 1.78 | 0.041 | 0.057 | 521 | 546 | 152.8 |
| EUC07 | 0.54 | 0.009 | 0.017 | 13 | 24 | 50.6 |
| EUC08 | 5.07 | 0.045 | 0.062 | 1898 | 2774 | 516.9 |
| EUC09 | 4.15 | 0.096 | 0.119 | 3146 | 3405 | 423.5 |
| EUC10 | 2.64 | 0.231 | 0.249 | 1137 | 1313 | 268.9 |
| EUC11 | 0.77 | 0.063 | 0.080 | 491 | 632 | 65.9 |
| EUC12 | 0.69 | 0.017 | 0.033 | 75 | 59 | 64.3 |
| SPA06 | 0.12 | 0.012 | 0.033 | 5 | 14 | 15.6 |

## Nitrate Loading

Nitrate loading was estimated in a similar manner. Average nitrate concentration for post 1998 data was greater than average concentration of all data at the majority of stations. For this reason only post 1998 data were considered. Otherwise, the methods used were identical. Additional information is available for each location in appendix L.

These loads were compared to loads calculated by the OCC for the period March 1993 to February 1994[1]. Table 18 contains average annual nutrient loadings during the calibration period August 1998 to March 2000 compared to the previous OCC study. Note the reduction in nitrate loading in the period even though average nitrate concentration was higher than in 1993-1994. This is the result of differing stream flow. Table 19 displays loading calculated using flow data from 1993-1994 and the current regression equations.

**Table 17** Estimated observed nitrate loading summary by station.

| SITE | Average flow (M^3/s) | Average Nitrates (MG/L) | Average Monthly Nitrate (KG) |
|---|---|---|---|
| EUC04 | 0.24 | 0.6016 | 752 |
| EUC05 | 1.01 | 0.8674 | 2305 |
| EUC06 | 1.78 | 2.072 | 9678 |
| EUC07 | 0.54 | 0.661 | 942 |
| EUC08 | 5.07 | 3.005 | 40024 |
| EUC09 | 4.15 | 3.467 | 37801 |
| EUC10 | 2.64 | 3.839 | 26597 |
| EUC11 | 0.77 | 3.162 | 6364 |
| EUC12 | 0.69 | 1.539 | 2787 |

**Table 18** Calibration period estimated loadings compared to 1997 OCC study.

| | Calibration period (8-98 to 4-00) | | | | OCC study (3-93 to 2-94) | | Relative diffrences | |
|---|---|---|---|---|---|---|---|---|
| SITE | Flow (m^3/sec | Ortho (kg/yr) | Total P (kg/yr) | Nitrate (kg/yr) | Total P (kg/yr) | Nitrate (kg/yr) | Total P | Nitrate |
| Rattlesnake | 0.27 | 86 | 329 | 10068 | 324 | 7643 | 2% | 24% |
| Brush | 1.04 | 1743 | 3699 | 28315 | 1566 | 39087 | 58% | -38% |
| Beaty | 1.80 | 6323 | 6624 | 117386 | 11602 | 156671 | -75% | -33% |
| Dry | 0.78 | 218 | 404 | 16137 | 1043 | 24805 | -158% | -54% |
| Spavinaw | 5.14 | 23061 | 33708 | 486393 | 13690 | 548817 | 59% | -13% |
| Eucha Laterals | 0.80 | 1339 | 2842 | 21755 | | | | |
| MISC areas | | | | | 1566 | 39087 | | |
| Entire basin | 9.82 | 32769 | 47606 | 680054 | 29791 | 816110 | 37% | -20% |

**Table 19** Loading calculated using 93-94 hydrologic data compared to OCC Study.

| | Estimates for (3-93 to 2-94) | | | | OCC study (3-93 to 2-94) | | Relative diffrences | |
|---|---|---|---|---|---|---|---|---|
| SITE | Flow (M^3/sec) | Ortho (kg/yr) | Total P (kg/yr) | Nitrate (kg/yr) | Total P (kg/yr) | Nitrate (kg/yr) | Total P | Nitrate |
| Rattlesnake | 0.4 | 118 | 267 | 9444 | 324 | 7643 | -21% | 19% |
| Brush | 1.4 | 1174 | 2366 | 39096 | 1566 | 39087 | 34% | 0% |
| Beaty | 2.5 | 5170 | 6081 | 162082 | 11602 | 156671 | -91% | 3% |
| Dry | 1.2 | 327 | 605 | 24179 | 1043 | 24805 | -72% | -3% |
| Spavinaw | 8.4 | 24467 | 35106 | 796705 | 13690 | 548817 | 61% | 31% |
| Eucha Laterals | 1.1 | 902 | 1818 | 30039 | | | | |
| MISC areas | | | | | 1566 | 39087 | | |
| Entire basin | 15.0 | 32159 | 46243 | 1061546 | 29791 | 816110 | 36% | 23% |

**Point Source Loadings**

Although most of the nutrient loading was attributed to non-point source pollution, one significant point source is located in the Eucha/Spavinaw Basin at the City of Decatur. A poultry processing plant is located in Decatur, with waste from the plant processed by the City of Decatur waste water treatment plant. The treatment plant discharges to Colombia Hollow in subbasin 20. The US Environmental Protection Agency PCS (Permit Compliance System) contains estimated monthly loading from Decatur (NPDES ID AR0022292); these data are available in appendix M. Only the average daily load for the period November 1997 to August 2000 was used in the model (Table 20). The 1997 OCC study also estimated the loading from the City of Decatur for the period March 93 to February 94 and October 95 to September 96 (Table 14). Monthly loading data indicate a slight reduction in both nitrates and phosphorous over the period observed (Figure 26).

**Table 20** Decatur point source daily load for the period 11-97 to 8-00.

| Parameter | total P | NITRATES | FLOW | AMMONIA |
|---|---|---|---|---|
| Units | KG/day | KG/day | M^3/day | KG/day |
| Value | 32 | 15 | 4894 | 31 |

**Table 21** Ave annual City of Decatur nutrient loadings. Derived from the US Environmental Protection Agency's Permit Compliance System.

| | 93-94 OCC Estimate | 95-96 OCC Estimate | 97-00 Updated Estimate |
|---|---|---|---|
| Total Phosporous (kg/yr) | 8153 | 15923 | 11680 |
| Total Nitrogen (kg/yr) | 19567 | 38214 | 16790 |

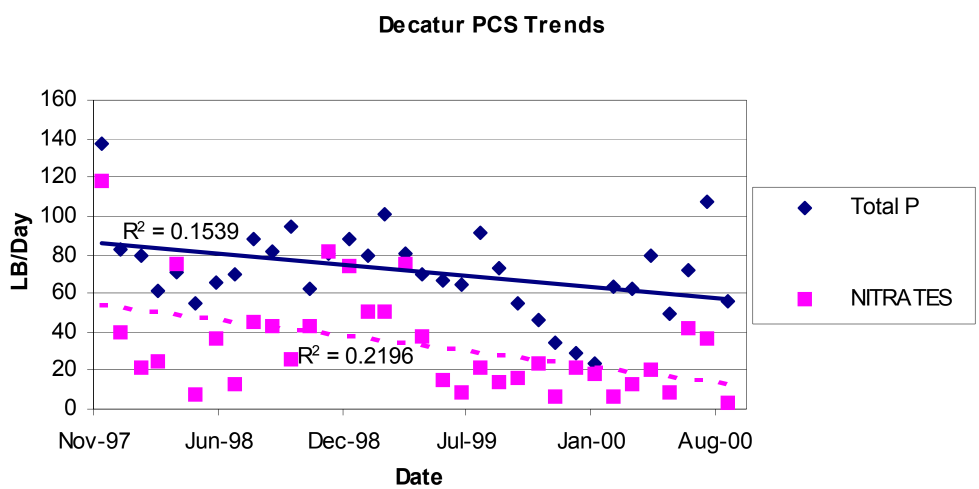



**Figure 26** Decatur point source loading trends. Derived from the Environmental Protection Agency's Permit Compliance System.

## Management

SWAT defines management as a series of individual operations. The timing of these operations may be defined by a date, or as a fraction of the total heat units required by the crop. Heat unit scheduling is the default. All forested HRUs use the default management generated by the ArcView SWAT interface. Pasture management was set up as a cattle grazing operation. Table 22 contains the individual operation and the aproximate timing of each. The default management generated by the interface was modified to include several additional operations. “Plant Pasture” and “Harvest/Kill“ are default operations that were not modified.

Heat units are accumulated when the average daily temperature exceeds the base temperature of the crop. The base temperature is the minimum temperature required by the plant to grow. The amount of heat units accumulated each day is equal to the average daily temperature minus the base temperature of the plant. When no plant is growing the model uses a base temperature of $0^{o}$ C and keeps a separate running total. This base $0^{o}$ running total is used to schedule planting dates because no heat units can be accumulated until plant growth begins.

Grazing was simulated at approximately 0.33 animal units per acre (Oklahoma State University Extension Facts 2855), with 9.35 kg of dry biomass consumed and 2.92 kg of dry manure deposited per hectare (ASAE D384.1). The grazing occurs for a maximum of 200 days. Any time there is less than 600 kg (dry weight) of biomass per hectare grazing is suspended. Some areas are quite sensitive to lower values of the parameter *Minimum biomass required for grazing*. This indicates that the grazing rate may be excessive in these areas.

When the fraction of the crop’s required heat units reaches 0.25, litter and commercial fertilizers were applied. Litter was applied in two identical applications, both occurring the same day. It was necessary to make two applications because the maximum fertilizer application rate allowed by the model is less than that required in some areas.

Pasture management is not uniform across the basin. The amount of litter applied in each subbasin is different. We did not use the SWAT interface to generate these management files (.mgt), because that would have required us to manually modify each file. There is one management file for each of the 351 HRUs. With multiple management changes, the task would be daunting. A program was written to create files identical in format to those generated by the interface.

**Table 22** Pasture management operations used in the SWAT model and their timing.

| Description | Heat unit fraction | Approximate date |
|---|---|---|
| Plant Pasture | 0.150 | 04/18 |
| Graze 0.33 AU/acre | 0.200 | 05/20 |
| Litter application | 0.250 | 05/27 |
| Litter application | 0.250 | 05/27 |
| Commercial Fertilization | 0.250 | 05/27 |
| Harvest/Kill 1.2HU | 1.200 | 08/25 |

# Calibration

The SWAT model was calibrated using observed stream and nutrient data. Three stream gage stations and ten water quality stations were used in the calibration. The model was calibrated for total flow, surface flow, baseflow, soluble phosphorous, total phosphorous, and nitrate.

The model was first calibrated on streamflow at each of the three gages. Observed streamflow was split into surface runoff and baseflow. After hydrologic calibration the model was calibrated for nutrients. Predicted loadings were compared to observed loadings at 10 water quality stations, and relative error was calculated at each station. An area weighted relative error was determined by weighting the error at each station by the watershed area above that station, and was used to guide the nutrient calibration.

### Hydrologic calibration

Three gage stations, shown in Figure 27, were used in the calibration of total flow, surface runoff, and base flow. The period of available data from the three stations is not the same, Beaty Creek and Black Hollow have less flow data. Spavinaw Creek has much more observed data and would therefore be considered a more accurate calibration.

We split the basin into three areas, each with a different set of calibration parameters. Subbasins not upstream of a gage were lumped with the most similar adjacent calibrated area. Land use, topography, and distances were used to determine how to lump each subbasin.

Preliminary calibration baseflow fractions were far lower than estimates from observed stream flow. We modified the soils database to allow increased crack infiltration, by setting crack potential for each soil to 0.75. This modification increased aquifer recharge and baseflow contributions to help compensate for the karst topography.

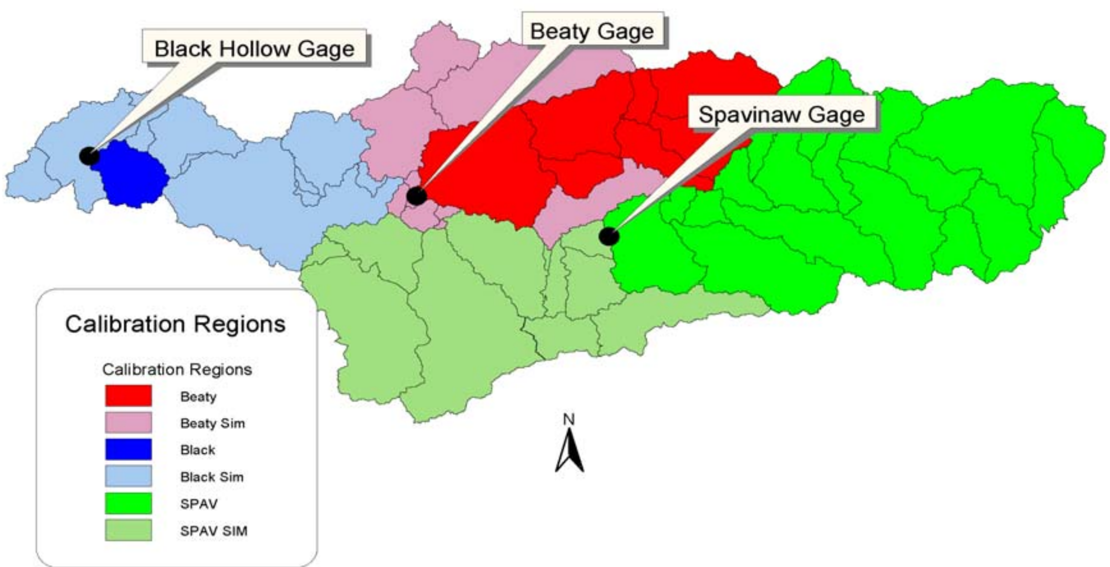



**Figure 27** Calibration regions (SIM denotes an area that is not upstream a gage station).

### Time Dependant Model Output

Runoff chariteristics of forested areas changed with time during the first calibration. The runoff characteristics were dependant on how long the model was allowed to "warm up". The period of avaliable streamflow record at each streamgage station dictated the calibration period at each station. When the individual calibrations were combined into the final model, the model was ran for 15 years, 8 years longer than during the calibration at some stations. The flow at these stations became inconsistant with the calibration. The longer the simulation ran, the greater the average annual water yield. We assumed this was the result of residue accumulation in these forested areas. The default SWAT management was used for all forested areas.

In our experiance SWAT's plant growth model is not well suited for unmanaged forests. We think that residue built up to unreasonable levels during the simulation. To prevent this accumulation, some of the forest was harvested. The plant portion considered yield and harvested is called the harvest index, and can be set by the user. Figure 28 demonstrates the effect of harvest index on average yearly flow for a 50 year simulation on Black Hollow. The average observed flow at the Black Hollow station was 0.12 $m^3$/sec. A harvest index of 0.75 reduced the time dependancy of flow. The harvest index for all forest was set to 0.75. To ensure that no nutrients were removed from the forest, the fraction of nitrogen and phosphorous in the yield was set to 0. After these changes the entire calibration was updated.

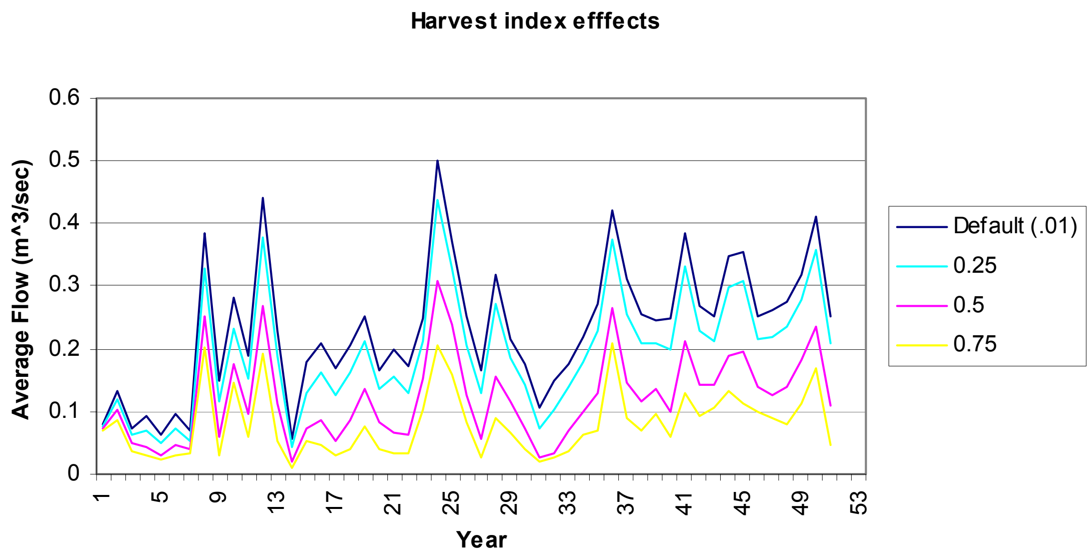



**Figure 28** Effect of harvest index on flow over a 50 year period, as simulated by the SWAT model.

## Beaty Creek

Beaty Creek contains a higher fraction of pasture than the other two calibration areas. The nutrient loadings developed by the OCC for 1993-1994 indicated that Beaty Creek contributed disproportionate phosphorous load for its size. The updated loadings do not reflect this (Table 18).

USGS gage data for the period August 1998 to April 2000 were used to calibrate Beaty Creek and portions of Brush Creek. Adjustments to several parameters were necessary to calibrate Beaty Creek. Curve numbers were increased by 2.08. ESCO (Soil Evaporation Compensation Factor) was increased from 0.95 (default) to 1. Parameters pertaining to ground water were adjusted to provide increased baseflow. These ground water parameters determine how the shallow aquifer interacts with surface flow. Relative error was used to compare observed and predicted data and to guide the calibration process.

**Relative Error (%) = (Observed - Predicted)/Observed * 100 %**

A 6.5% relative error was obtained for the average total flow. Baseflow fell near the center of the estimated baseflow range. Surface runoff was sightly over predicted. Additional data are available in Appendix N.

**Table 23** Beaty Creek (US Geographic Survey stream gage 07191222) calibration average flow and relative differences. (all units are $m^3/s$) Upper and lower values of surface and baseflow are provided by adjusting the interval used during baseflow seperation.

| | Observed | | | | | Predicted | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Flow | Baseflow (upper) | Baseflow (lower) | Surface (upper) | Surface (lower) | Flow | Surface | Base | Misc |
| AVE | 1.78 | 0.90 | 0.78 | 1.00 | 0.88 | 1.666 | 0.823 | 0.834 | 0.009 |
| Rel. Error | 6.5% | 7.4% | -7.2% | 17.9% | 6.4% | | | | |

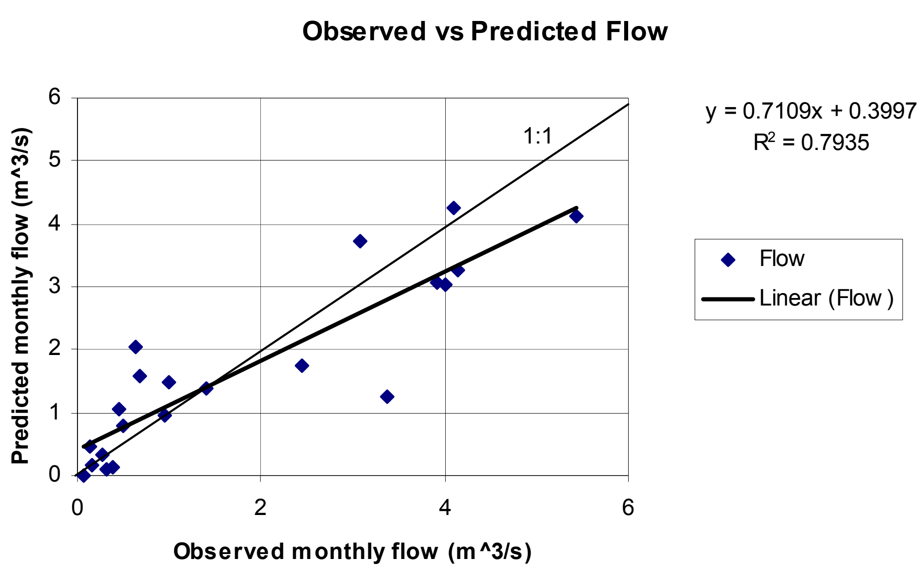



**Figure 29** Beaty Creek (US Geographic Survey stream gage 07191222) monitoring vs SWAT predicted total stream flow (8-1998 to 4-2000).

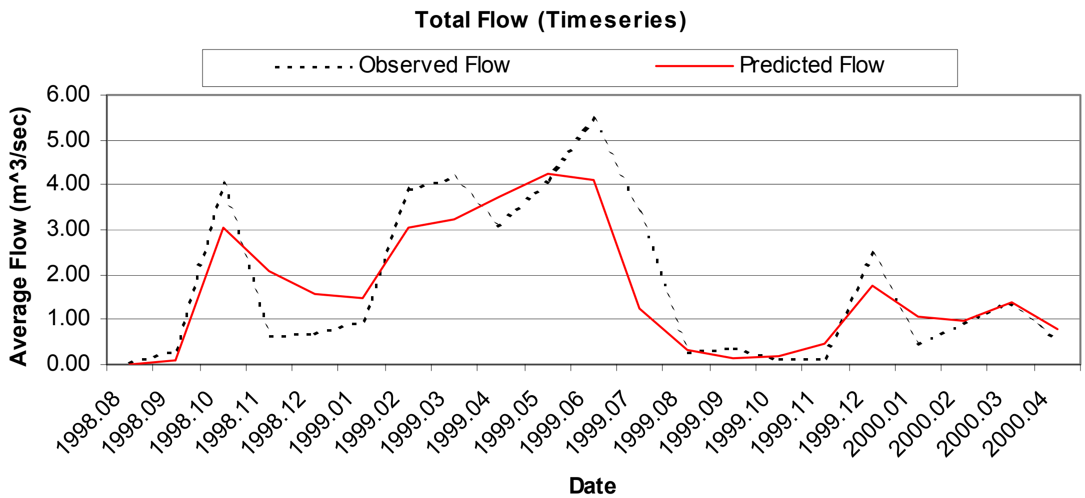



**Figure 30** Beaty Creek (US Geographic Survey stream gage 07191222) observed and SWAT predicted total streamflow (time-series).

**Spavinaw Calibration**

The Spavinaw gage station has more available data than any other gage. In addition, the drainage area at the Spavinaw gage station is greater than any other gage, therefore the calibration at Spavinaw should be considered more accurate than that at any other gage. Data from January 1990 to April 2000 were used for calibration.

Parameter adjustments are listed in appendix O. Average monthly flow was predicted within 2.5% after calibration, but baseflow was underestimated by 15.7% (Table 24). The under prediction of baseflow is of little concern, considering the uncertainty associated with estimating baseflow from observed data.

Good agreement was found between observed and predicted average monthly flow (Figure 31). This was the best fit seen at any gage station. Visual inspection of observed and predicted flows over time (Figure 32) suggest the source of the under prediction was baseflow, particulaly during dry periods. Additional data for Spavinaw are available in Appendix O.

**Table 24** Spavinaw (US Geographic Survey stream gage 07191220) calibration average annual flow and relative differences. (all units are $m^3/s$) Upper and lower values of surface and baseflow are provided by adjusting the interval used during baseflow seperation.

| | Observed | | | | | Predicted | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Baseflow (upper) | Baseflow (lower) | Surface (lower) | Surface (upper) | Total | Surface | Baseflow | Misc |
| AVE | 3.80 | 2.51 | 2.29 | 1.29 | 1.51 | 3.90 | 1.75 | 2.06 | 0.09 |
| Rel Error | -2.5% | 18.1% | 10.2% | -35.5% | -15.7% | | | | |

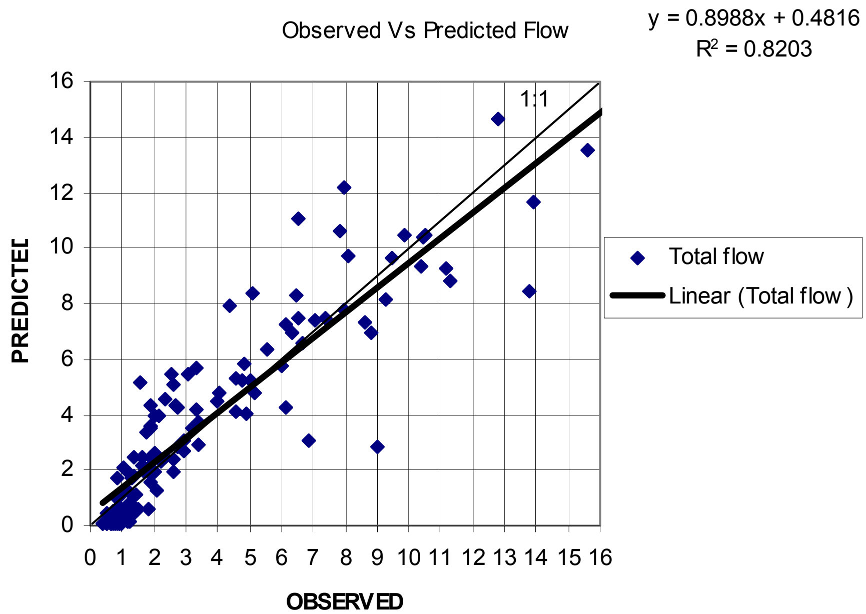



**Figure 31** Spavinaw Creek (US Geographic Survey stream gage 07191220) observed vs SWAT predicted stream flow (1-1990 to 4-2000).

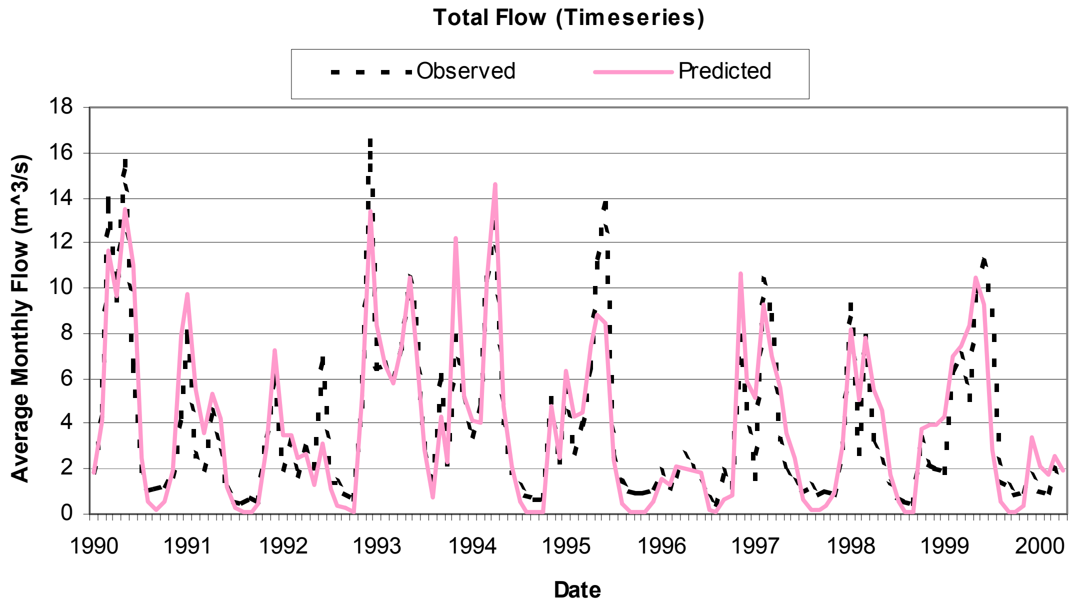



**Figure 32** Spavinaw Creek (US Geographic Survey stream gage 07191220) observed flow vs SWAT predicted flow (time-series).

## Black Hollow Calibration

The Black Hollow gage has the smallest contributing area of any gage in the basin, only 1559 ha. This area was composed of only one subbasin in the model. Almost the entire area is forested as determined from the GAP land cover; therefore, the entire basin was simulated as forest by the SWAT model.

No baseflow range was estimated for Black Hollow because of its small size, only a single interval was used to seperate baseflow. Total flow comparisons were good with a relative error of -4.2% (Table 25). Again the fraction of baseflow was underestimated, but it is much less important than total flow.

The relationship between observed and predicted flow indicates over prediction at low flows (Figure 33). This over prediction was also apparent when flow was graphed against time (Figure 34). The observed gage data indicated no flow for long periods of time. The large error in November 1998 is thought to be the result of weather differences between the subbasin and the rain gage location. This area is more sensitive to weather because it consits of a single subbasin, any uses the observed data from only one weather station. Tabular data are located in Appendix P.

**Table 25** Black Hollow (US Geographic Survey Gage 07191297) average flow and relative differences. (all units are $M^3/s$)

| | Observed | | | Predicted | | |
|---|---|---|---|---|---|---|
| | Total | Baseflow | Surface | Total | Baseflow | Surface |
| AVE | 0.1176 | 0.0930 | 0.0247 | 0.1226 | 0.0811 | 0.0318 |
| Rel Error | -4.2% | 12.8% | -29.2% | | | |

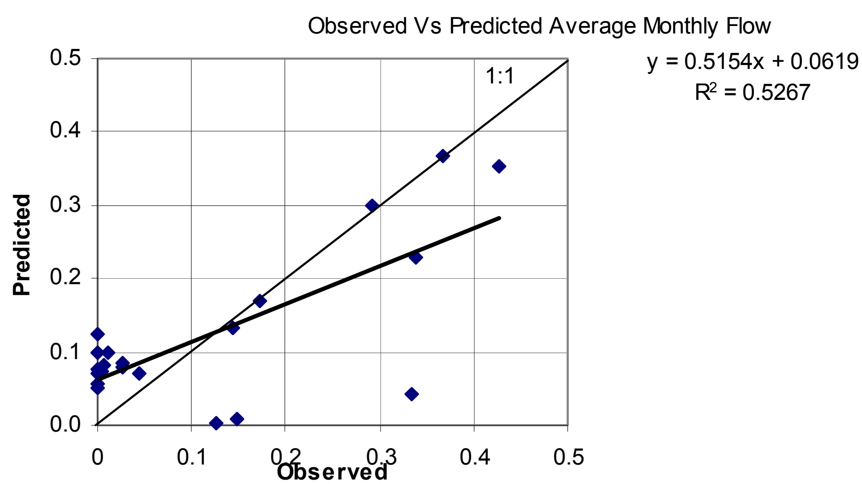
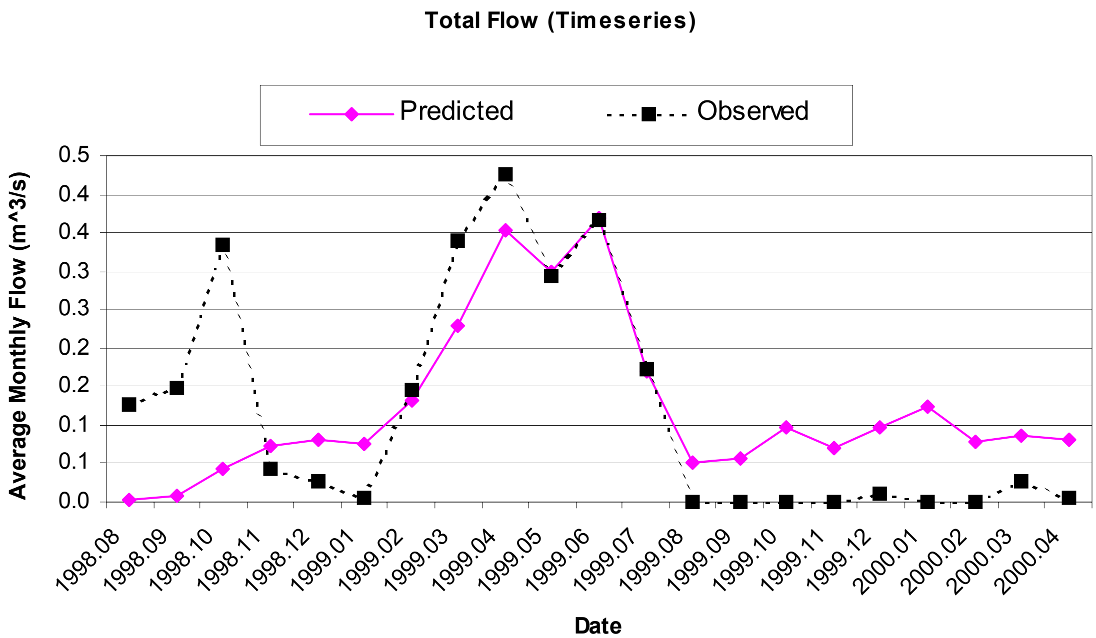



**Figure 33** Black Hollow (US Geographic Survey Gage 07191297) observed vs SWAT predicted stream flow (8-1998 to 4-2000).

**Figure 34** Black Hollow (US Geographic Survey Gage 07191297) observed flow vs




SWAT predicted flow (time-series).

**Nutrient Calibration**

The nutrient calibration was performed in a different manner than the hydrologic calibration, because many nutrient parameters are basin wide. The entire basin was calibrated as a whole using comparisons at all stations simultaneously. Sediment is included because it has a large impact on nutrients and was adjusted only to reasonable levels for these land covers.

**Sediment**

No recent sediment data were available for the Eucha/Spavinaw Basin, so the calibration was stopped when sediment yields were reasonable based on literature values. SWAT uses the Modified Universal Soil Loss Equation (MUSLE) to calculate sediment yield[6]. The MUSLE C factor is calculated internally from the total of surface residue and biomass and a minimum C factor. This minimum C factor can be related to the average annual C by the following set of equations:

$$MC = EXP(1.463 \ln(CVA) + 0.1034)$$

where ***MC*** is the minimum C factor and ***CVA*** is the average annual C factor.

A minimum C factor of 0.0003 was used for forest and 0.0009 for pastures. These minimum C factors correspond to average annual C factors of 0.0036 and 0.0077, respectively.

6

Neitsch, S.L., J.G. Arnold, J.R. Williams, "Soil and Water Assessment Tool User's Manual Version 99.2" Blackland Research Center, 1999.

Average annual sediment yields for the period January 1990 to April 2000 are 62.7 kg/ha for pasture and 25.9 kg/ha for forest.

**Nutrients**

Observed and predicted loadings at each of the 10 stations were compared. Relative error was calculated at each station for nitrate, sediment-bound phosphorous, and total phosphorous. These relative errors were area weighted according to the contributing area at each water quality station, the result was used to guide the calibration. The result of the nutrient calibration is shown in Table 26.

Relative error at any given station may be off by a substantial amount. Because the parameters are not distributed, there is no way to make an adjustment at one station without affecting all other stations. The results of the calibration are displayed in Table 26. The parameters recomended in the model documentation were used for nutrient calibration. The following parameters were adjusted in the basin input file (.bsn):

NPERCO (Nitrogen Percolation Coefficient) = 1
PPERCO (Phosphorous Percolation Coefficient) = 12
PHOSKD (Phosphorous Soil Partitioning Coefficient) = 400
BMIX (Biological Mixing Efficiency) = 0.3

Additional modifications were made uniformly to each Main Channel Input File (.rte). These modifications allow increased stream bank errosion, but did not significantly impact nutrient loading in the model.

CH_COV (Channel Cover Factor) = 0.2
CH_EROD (Channel Erodibility Factor) = 0.2

**Table 26** Observed and SWAT predicted average annual nutrient loading for the period August 1998 to April 2000.

| Predicted | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | kg | | | | mg/L | | | | |
| Station | AREA (km^2) | Flow (m^3/s) | Sediment P | Soluble P | Total P | Nitrate | Sediment P | Soluble P | Total P | Nitrate |
| EUC04 | 20.9 | 0.17 | 6 | 210 | 217 | 6446 | 0.001 | 0.040 | 0.041 | 1.225 |
| EUC05 | 87 | 0.99 | 173 | 2511 | 2684 | 52720 | 0.006 | 0.081 | 0.087 | 1.710 |
| EUC06 | 152.8 | 1.67 | 29 | 7189 | 7218 | 162299 | 0.001 | 0.139 | 0.139 | 3.133 |
| EUC07 | 50.6 | 0.46 | 3 | 420 | 423 | 12739 | 0.000 | 0.030 | 0.030 | 0.899 |
| EUC08 | 516.9 | 5.06 | 375 | 25817 | 26192 | 423221 | 0.002 | 0.164 | 0.166 | 2.689 |
| EUC09 | 423.5 | 4.29 | 609 | 25195 | 25804 | 403359 | 0.005 | 0.189 | 0.193 | 3.024 |
| EUC10 | 268.9 | 2.86 | 2538 | 19248 | 21785 | 283655 | 0.029 | 0.217 | 0.245 | 3.194 |
| EUC11 | 65.9 | 0.53 | 1 | 2482 | 2483 | 45062 | 0.000 | 0.150 | 0.150 | 2.723 |
| EUC12 | 64.3 | 0.47 | 2 | 392 | 394 | 9712 | 0.000 | 0.027 | 0.027 | 0.658 |
| SPA06 | 15.6 | 0.12 | 22 | 24 | 46 | 2903 | 0.006 | 0.006 | 0.012 | 0.761 |
| USGS | | 3.54 | 1560 | 22192 | 23752 | 345604 | 0.014 | 0.202 | 0.216 | 3.139 |
| Observed | | | | | | | | | | | |
| | | | kg | | | | mg/L | | | | |
| Station | AREA (km^2) | Flow (m^3/s) | Sediment P | Soluble P | Total P | Nitrate | Sediment P | Soluble P | Total P | Nitrate |
| EUC04 | 20.9 | 0.24 | 218 | 77 | 295 | 9019 | 0.03 | 0.0101 | 0.039 | 1.190 |
| EUC05 | 87 | 1.01 | 1911 | 1702 | 3614 | 27663 | 0.06 | 0.0540 | 0.115 | 0.878 |
| EUC06 | 152.8 | 1.78 | 298 | 6256 | 6553 | 116132 | 0.01 | 0.1129 | 0.118 | 2.097 |
| EUC07 | 50.6 | 0.54 | 130 | 153 | 283 | 11307 | 0.01 | 0.0091 | 0.017 | 0.669 |
| EUC08 | 516.9 | 5.07 | 10514 | 22772 | 33285 | 480292 | 0.07 | 0.1443 | 0.211 | 3.044 |
| EUC09 | 423.5 | 4.15 | 3107 | 37749 | 40857 | 453606 | 0.02 | 0.2923 | 0.316 | 3.512 |
| EUC10 | 268.9 | 2.64 | 2121 | 13639 | 15761 | 319163 | 0.03 | 0.1662 | 0.192 | 3.889 |
| EUC11 | 65.9 | 0.77 | 1687 | 5896 | 7583 | 76366 | 0.07 | 0.2470 | 0.318 | 3.199 |
| EUC12 | 64.3 | 0.69 | | 905 | 712 | 33443 | | 0.0422 | 0.033 | 1.558 |
| SPA06 | 15.6 | 0.12 | 110 | 63 | 173 | 2648 | 0.03 | 0.0172 | 0.047 | 0.724 |
| USGS | | 3.41 | | | | | | | | |

**Table 27** SWAT nutrient calibration relative error at City of Tulsa water quality stations.

| Station | AREA (km^2) | Sediment P | Nitrate | Soluble P | Total P |
|---|---|---|---|---|---|
| EUC04 | 20.9 | 97.1% | 28.5% | -174.1% | 26.6% |
| EUC05 | 87 | 91.0% | -90.6% | -47.5% | 25.7% |
| EUC06 | 152.8 | | -39.8% | -14.9% | -10.1% |
| EUC07 | 50.6 | 97.4% | -12.7% | -174.4% | -49.6% |
| EUC08 | 516.9 | 96.4% | 11.9% | -13.4% | 21.3% |
| EUC09 | 423.5 | 80.4% | 11.1% | 33.3% | 36.8% |
| EUC10 | 268.9 | -19.6% | 11.1% | -41.1% | -38.2% |
| EUC11 | 65.9 | 99.9% | 41.0% | 57.9% | 67.3% |
| EUC12 | 64.3 | | 71.0% | 56.7% | 44.7% |

# Model Output and Analysis

## Simulated nutrient loading

Nutrient loadings were simulated at important locations throughout the basin. The nutrient load to Spavinaw Lake cannot be directly predicted since SWAT cannot fully simulate the process that occur in Lake Eucha. However, a loading estimate for the area between Spavinaw and Eucha was required to determine if this area is a significant source of nutrients. The simulated outflow from Lake Eucha subtracted from the simulated loading to Spavinaw Lake from Spavinaw Creek was initially used to provide the estimate. Some loads to Spavinaw Lake were negative, indicating that more nutrients were assimilated by the stream than were being added. To eliminate the negative loadings, stream processes were ignored in the Spavinaw laterals portion of the basin (Figure 35).

Loading from the small portion of the basin between the Lake Eucha dam and Spavinaw Lake was insignificant when compared to the loading to Eucha Lake. The sediment-bound phosphorous for the Spavinaw portion does not entirely account for stream losses, and is much higher than in other portions of the basin. Nutrients associated with sediment from this portion of the basin should not be directly compared the Eucha portion. Charts and tables in the body of this report feature the Eucha portion. Additional data for both areas are included in the appendix for that section.

Average annual loadings to Lake Eucha over the period August 1998 to April 2000 were near observed values for both nitrates and soluble phosphorous (Table 29). Sediment-bound phosphorous was under-predicted leading to an under-prediction of total phosphorous. Many attempts were made to increase sediment-bound phosphorous, but agreement was not possible without making unreasonable modifications to the model. We think that two issues contribute to this problem. The first is the stream erosion routines of the SWAT model. Sediment eroded in the channels did not appear to significantly impact sediment-bound phosphorous. Sediment resulting from channel degradation was increased two orders of magnitude and had little effect. We think that this was the major factor. The second issue was types of land cover not simulated by the model. Some very small land covers contribute comparatively vast amount of sediment. These very small areas were either not included in the GAP land cover or were too small to be simulated by the model. This problem is discussed further in model limitations.

An adjustment factor was used to correct for low sediment-bound phosphorous. The adjustment factor was calculated by dividing the observed estimate of sediment-bound phosphorous loading (14800 kg/year) by the predicted loading (612 kg/year). The adjustment factor, 24, was multiplied by the results from the SWAT model to correct the predicted loading of sediment-bound phosphorous. Tables and figures using the adjustment note its use.

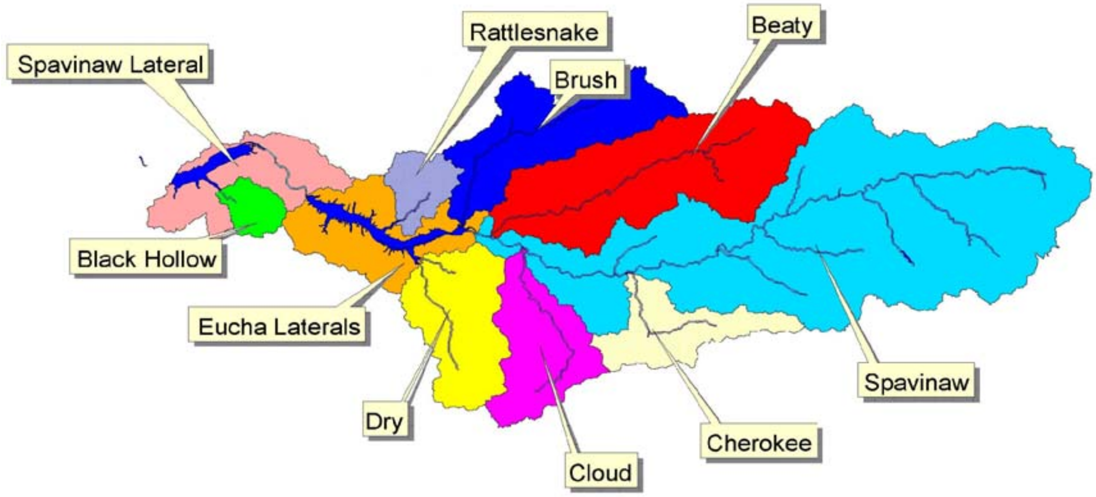



**Figure 35** Contributing areas at each location where model output is generated. The contributing area for Spavinaw includes Beaty, Cloud, and Cherokee.

**Table 28** SWAT simulated average annual nutrient loading August 1998 to April 2000. Spavinaw includes Beaty, Cloud, and Cherokee. Sediment-bound phosphorous and total phosphorous are unmodified.

| Subbasin | Flow | Sediment P (mt) | Soluble P (kg) | Total P (kg) | NO3 (kg) |
|---|---|---|---|---|---|
| Cherokee | 0.42 | 2 | 1859 | 1861 | 34338 |
| Cloud | 0.48 | 1 | 396 | 398 | 9819 |
| Dry | 0.65 | 19 | 504 | 523 | 16577 |
| Beaty | 1.68 | 45 | 7155 | 7200 | 162602 |
| Spavinaw | 6.81 | 389 | 32748 | 33137 | 585802 |
| Brush | 1.01 | 119 | 2506 | 2625 | 52953 |
| Rattlesnake | 0.19 | 3 | 213 | 217 | 6895 |
| Eucha Laterals | 0.55 | 47 | 160 | 207 | 7225 |
| Eucha Total | 9.81 | 613 | 34485 | 35097 | 643936 |
| Spavinaw Lateral | 0.49 | 232 | 168 | 400 | 2867 |
| Blackhollow | 0.12 | 17 | 24 | 41 | 2908 |
| Spavinaw Total - Eucha Outflow | 0.61 | 248.66 | 191.87 | 440.53 | 621.0 |

**Table 29** Observed and model estimated loading to Lake Eucha. No adjustment was made to account for sediment-bound phosphorous under predictions in this table.

| Observed estimates for calibration period (8-98 to 4-00) | | | | Simulation (8-98 to 4-00) | | | |
|---|---|---|---|---|---|---|---|
| Flow | Soluble P (KG) | Total P (KG) | Nitrate (KG) | Flow | Soluble P (KG) | Total P (KG) | Nitrate (KG) |
| 9.8 | 32769 | 47606 | 680054 | 9.8 | 34485 | 35097 | 643936 |

**Background loading estimates**

Background loading was estimated by simulating the entire basin as forest, using the calibration from Black Hollow. Black Hollow was used because it contains a higher fraction of forest than the other two calibration areas.

The anthropogenic effects appear to be large, soluble phosphorous was estimated to increase by 21 fold. The increase is a result of many factors, the Decatur point source and litter application appear to be the largest contributors, but changing forests to pastures and increases in STP are also important factors.

**Table 30** SWAT simulated background and calibrated model loading to Lake Eucha (January 1990 to April 2000).

| | Flow (m^3/s) | Sediment P (kg/yr) | NO3 (kg/yr) | Soluble P (kg/yr) |
|---|---|---|---|---|
| Background Estimate | 8.22 | 223 | 154578 | 1808 |
| Calibrated Model | 9.81 | 711 | 747798 | 40046 |
| Percentage Increase | 19% | 220% | 384% | 2115% |

**Uncertainty Analysis**

The uncertainty associated with water quality models is difficult to quantify. According to MacIntosh et al. (1984), there are two major types of uncertainty, knowledge uncertainty and stochastic uncertainty. Knowledge uncertainly stems from measurement errors and the inability of the model to accurately simulate the physical, chemical, and biological processes. Stochastic uncertainty is due to the random nature of natural systems, like rainfall. Rainfall is the driving force behind nutrient transport. Because rainfall is so important, it represents a major source of uncertainty. One method to quantify this uncertainty is to perform many simulations of the same scenario using different rainfall records. In this manner we can quantify the stochastic uncertainty associated with natural temporal variations in rainfall. We generated statistics from many simulations to estimate confidence intervals. This procedure accounts for only stochastic uncertainty associated with rainfall.

A total of 30 simulations were performed for each scenario. Observed rainfall records for the period 1/1/65 to 12/31/99 were used in these simulations. Each simulation covered a total of 6 years, the first 5 years allow the model to “warm-up” so that initial conditions are less important (Figure 36). Only data from the last year of the simulation were used. Custom software was written specifically to perform these simulations. The computational requirements to perform such simulations are enormous. In excess of 36 hours of processing time were often required to perform a single set of simulations.

A distribution was assumed and tested before confidence intervals were estimated. The results from 30 simulations of the calibrated model were analyzed to determine an acceptable distribution for each output parameter (appendix R). The distribution type for each output parameter was assumed to be constant(Table 31). More detail and statistical tests are shown in appendix Q. Log-normal distributions are common for streamflow applications.[7] By assuming a distribution, we can determine the probability that loading will be in a particular range (Figure 37 and 38).

The effect of rainfall variations on the system is dramatic, thus the confidence intervals are quite large. Rainfall has such a major effect that it could mask the effect of any BMP for a particular year. For example, there is approximately a 10% chance that the loading for any given year could be 60% greater than the average annual predicted loading.

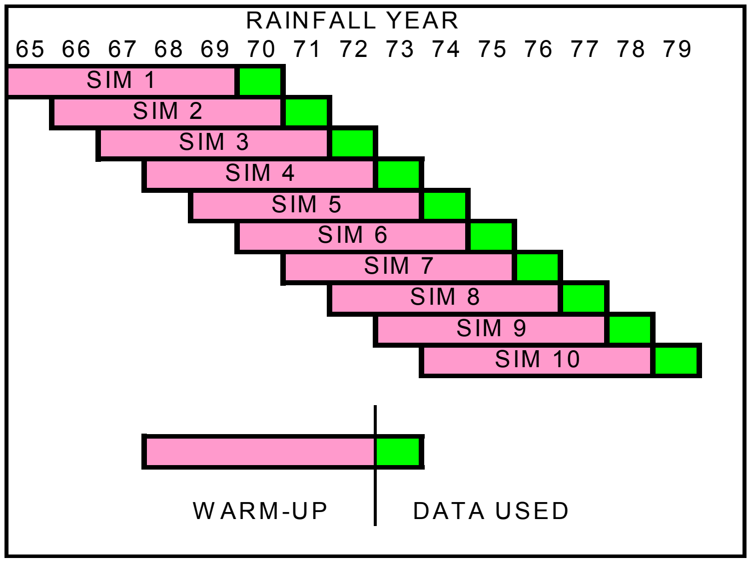



**Figure 36** Simulation timing for the rainfall uncertainty analysis.

**Table 31** Assigned distribution used to determine confidence intervals.

| Output Parameter | Distribution |
|---|---|
| Flow | LogNormal |
| Soluble P | LogNormal |
| Sediment Bound P | LogNormal |
| Nitrate | Normal |

**Table 32** Calibrated SWAT model output statistics. Derived from 30 simulations of the calibrated SWAT model.

| Area | Flow (m^3/sec) | | Soluble P (kg/yr) | | Sediment P (kg/yr) | | Nitrate (kg/yr) | |
|---|---|---|---|---|---|---|---|---|
| | MEAN | STD | MEAN | STD | MEAN | STD | MEAN | STD |
| Spavinaw | 0.403 | 0.267 | 128 | 102 | 83 | 141 | 7557 | 4846 |
| Eucha | 9.13 | 4.62 | 31174 | 13604 | 665 | 620 | 507045 | 246838 |

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Haan, C.T., B.J. Barfield, J.C. Hayes, "Design Hydrology and Sedimentation for Small Catchments", Academic Press INC., 1994, p 17

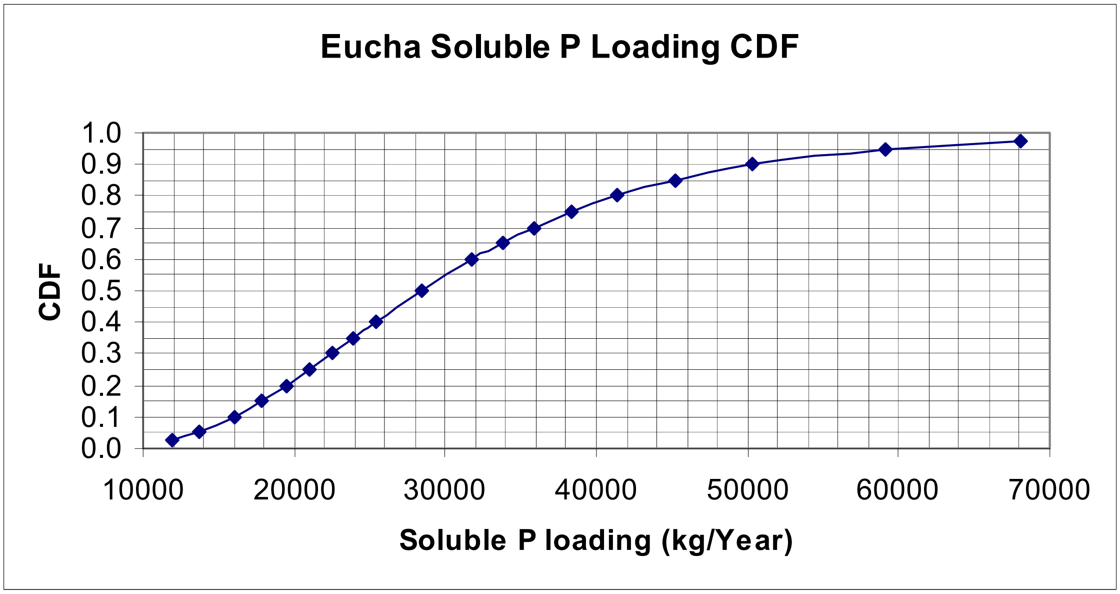



**Figure 37** Cumulative Distribution Function (CDF) of soluble phosphorous loading to Lake Eucha under calibrated conditions as predicted by SWAT.

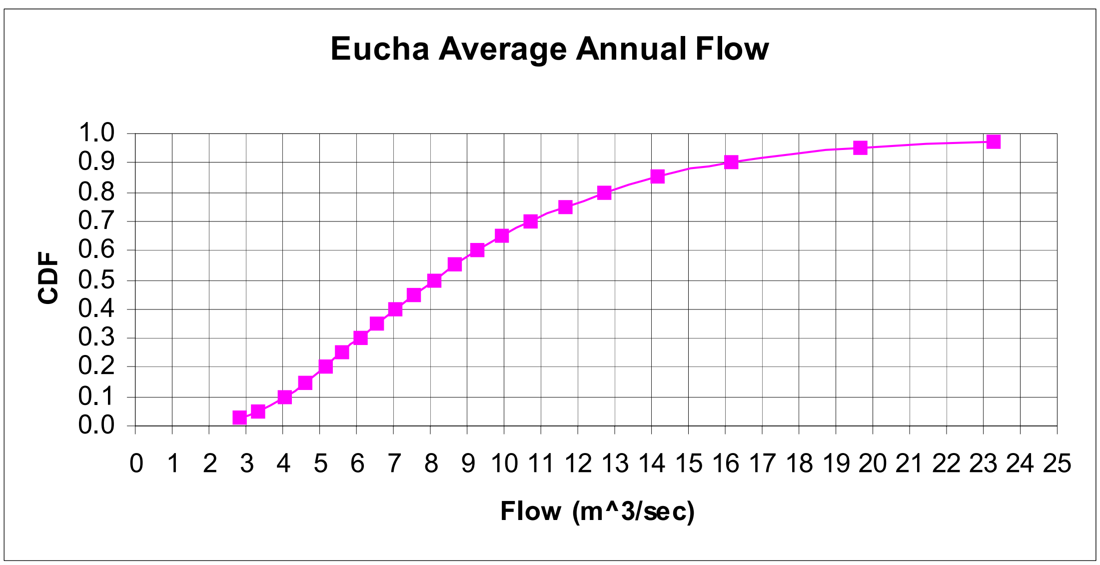



**Figure 38** Cumulative Distribution Function (CDF) of predicted average annual streamflow to Lake Eucha, as predicted by SWAT. Derived from 30 simulations of the calibrated SWAT model.

**Table 33** Confidence intervals at calibrated conditions. Derived from 30 simulations of the calibrated SWAT model.

| Parameter | 95%(Low) | 90%(Low) | 80%(Low) | MEAN | 80%(High) | 90%(High) | 95%(High) |
|---|---|---|---|---|---|---|---|
| Flow (m^3/sec) | 2.81 | 3.33 | 4.05 | 9.13 | 16.00 | 19.47 | 23.05 |
| Soluble P (kg/yr) | 11868 | 13657 | 16070 | 31174 | 50301 | 59188 | 68110 |
| Sediment P (kg/yr) | 144 | 177 | 225 | 665 | 1210 | 1539 | 1893 |
| Nitrate (kg/yr) | 23243 | 100997 | 191093 | 507045 | 822998 | 913094 | 990848 |

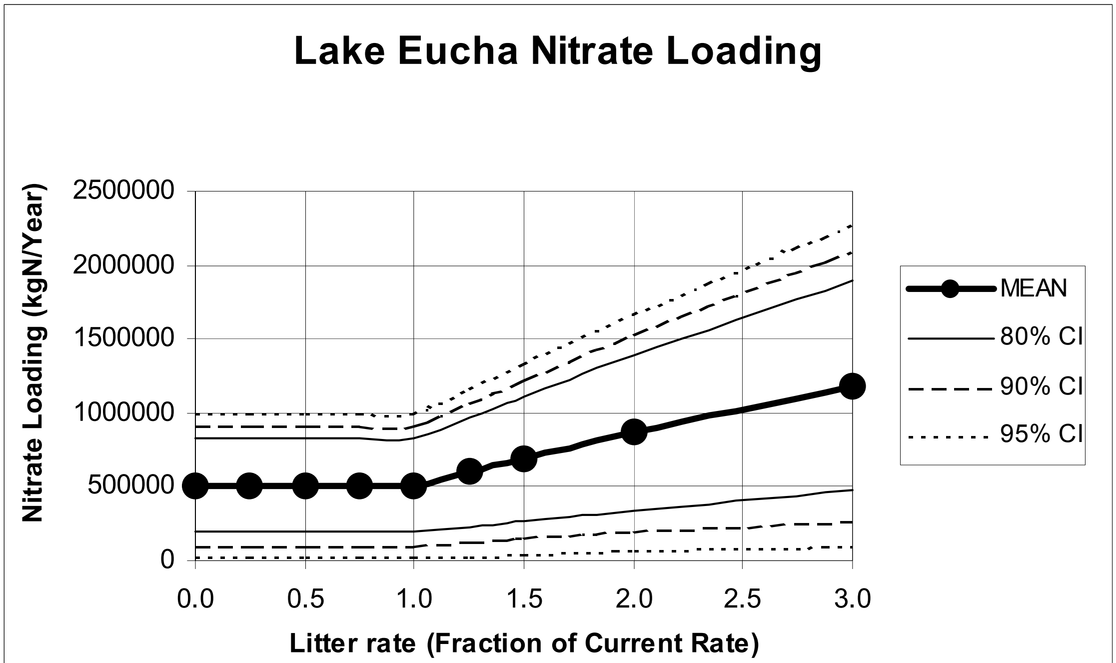
## BMP Scenarios

The calibrated model was modified to simulate a variety of BMPs. Litter application rate, soil test phosphorus, and grazing rate were each modified. An additional simulation was performed excluding the Decatur point source from the calibrated model. Each scenario is evaluated using the method detailed in the previous section. Additional charts and tables are located in Appendix S.

### Litter Application Scenarios

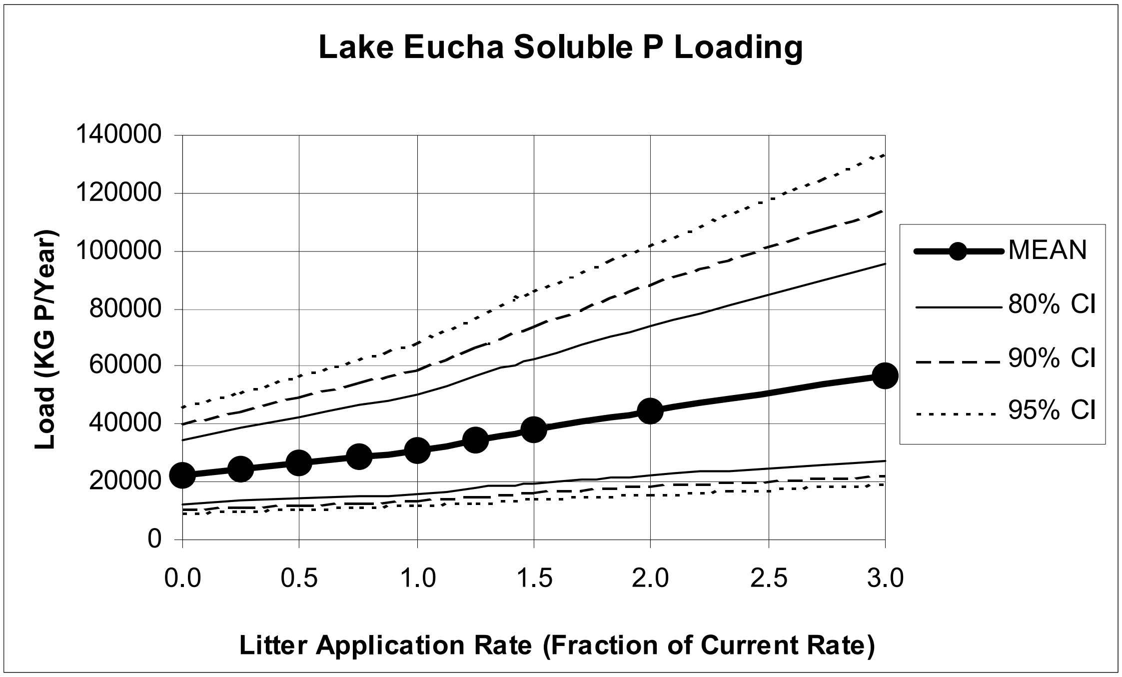
Litter application rates from 0 to 3 times the current rate were modeled. Commercial nitrogen was supplemented at litter application rates less than the current rate to maintain the current total nitrogen rate. Nitrate loading to Lake Eucha was nearly constant over this range (Figure 39). The model simulated a positive correlation between litter application rate and phosphorous loading (Figures 40 and 41). Litter application rates primarily affect nutrients, but do have some effect on the hydrology. Litter applications influence plant growth which in turn effects surface residue and evapo-transpiration.

Litter was assumed to be applied only to pastures, and the application rate varies by subbasin. The average amount of phosphorous applied in litter was 26.4 kg/ha. The average litter application rate was 1747 kg/ha (0.77 t/acre). The amount of litter applied in each subbasin was assumed to be equal to the estimated litter production in that subbasin. All litter produced in a subbasin was assumed to be applied uniformly to pastures in that subbasin. SWAT does not directly simulate the surface application of litter; it is treated as simple addition of nutrients to the surface soil layer. Litter application rate had a larger impact on nutrients than any other BMP simulated.



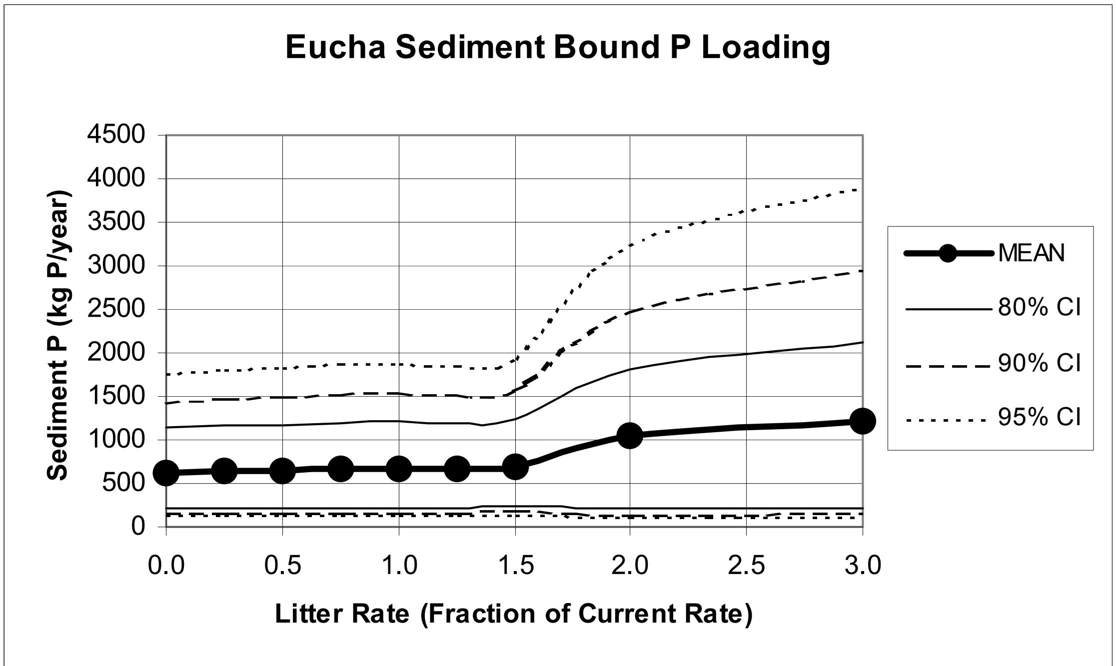

| Litter Rate (X Current) | 95%(Low) | 90%(Low) | 80%(Low) | MEAN | 80%(High) | 90%(High) | 95%(High) |
|---|---|---|---|---|---|---|---|
| 0.00 | 23299 | 101209 | 191486 | 508073 | 824660 | 914937 | 992847 |
| 0.25 | 23428 | 101268 | 191464 | 507766 | 824068 | 914264 | 992104 |
| 0.50 | 23488 | 101281 | 191422 | 507532 | 823643 | 913784 | 991577 |
| 0.75 | 23451 | 101186 | 191261 | 507139 | 823018 | 913092 | 990828 |
| 1.00 | 23243 | 100997 | 191093 | 507045 | 822998 | 913094 | 990848 |
| 1.25 | 32147 | 123011 | 228297 | 597520 | 966742 | 1072029 | 1162892 |
| 1.50 | 44621 | 148018 | 267827 | 687978 | 1108128 | 1227937 | 1331334 |
| 2.00 | 64417 | 193168 | 342356 | 865535 | 1388715 | 1537902 | 1666654 |
| 3.00 | 96273 | 271234 | 473966 | 1184918 | 1895870 | 2098602 | 2273563 |

**Figure 39** SWAT predicted average nitrate load to Lake Eucha as a function of applied litter.




| Litter Rate (X Current) | 95%(Low) | 90%(Low) | 80%(Low) | MEAN | 80%(High) | 90%(High) | 95%(High) |
|---|---|---|---|---|---|---|---|
| 0.00 | 9563 | 10843 | 12541 | 22525 | 34800 | 40251 | 45636 |
| 0.25 | 10139 | 11545 | 13419 | 24635 | 38540 | 44796 | 51005 |
| 0.50 | 10742 | 12282 | 14345 | 26914 | 42627 | 49788 | 56927 |
| 0.75 | 11308 | 12973 | 15212 | 29048 | 46463 | 54481 | 62505 |
| 1.00 | 11868 | 13657 | 16070 | 31174 | 50301 | 59188 | 68110 |
| 1.25 | 12943 | 14938 | 17638 | 34758 | 56566 | 66790 | 77088 |
| 1.50 | 14019 | 16217 | 19199 | 38280 | 62719 | 74251 | 85894 |
| 2.00 | 15976 | 18546 | 22046 | 44773 | 74115 | 88101 | 102277 |
| 3.00 | 19286 | 22530 | 26976 | 56612 | 95413 | 114243 | 133455 |

**Figure 40** SWAT simulated soluble phosphorous load to Lake Eucha as a function of litter application rate.




| Litter Rate (X Current) | 95%(Low ) | 90%(Low ) | 80%(Low ) | MEAN | 80%(High) | 90%(High) | 95%(High) |
|---|---|---|---|---|---|---|---|
| 0.00 | 138 | 170 | 215 | 630 | 1133 | 1437 | 1763 |
| 0.25 | 140 | 172 | 218 | 640 | 1156 | 1466 | 1800 |
| 0.50 | 141 | 174 | 220 | 649 | 1177 | 1494 | 1836 |
| 0.75 | 142 | 174 | 222 | 660 | 1201 | 1528 | 1881 |
| 1.00 | 144 | 177 | 225 | 665 | 1210 | 1539 | 1893 |
| 1.25 | 145 | 177 | 225 | 657 | 1194 | 1514 | 1859 |
| 1.50 | 149 | 184 | 233 | 680 | 1241 | 1575 | 1935 |
| 2.00 | 113 | 149 | 203 | 1036 | 1805 | 2466 | 3227 |
| 3.00 | 117 | 155 | 215 | 1226 | 2127 | 2948 | 3908 |

**Figure 41** SWAT simulated sediment-bound phosphorous loading to Lake Eucha as a function of litter application rate. Sediment-bound phosphorous is not adjusted in this figure.

**Table 34** SWAT simulated effect of litter applications rate on loadings to Lake Eucha.

| Scenario (litter rate) | FLOW | FLOW | SOLP | SOLP | SEDP | SEDP | NITR | NITR |
|---|---|---|---|---|---|---|---|---|
| X normal | MEAN | STD | MEAN | STD | MEAN | STD | MEAN | STD |
| 0.00 | 9.13 | 4.62 | 22525 | 9031 | 630 | 609 | 508073 | 247334 |
| 0.25 | 9.13 | 4.62 | 24635 | 10138 | 640 | 612 | 507766 | 247111 |
| 0.50 | 9.13 | 4.62 | 26914 | 11337 | 649 | 615 | 507532 | 246962 |
| 0.75 | 9.13 | 4.62 | 29048 | 12470 | 660 | 623 | 507139 | 246780 |
| 1.00 | 9.13 | 4.62 | 31174 | 13604 | 665 | 620 | 507045 | 246838 |
| 1.25 | 9.23 | 4.65 | 34758 | 15436 | 657 | 594 | 597520 | 288455 |
| 1.50 | 9.31 | 4.66 | 38280 | 17163 | 680 | 610 | 687978 | 328243 |
| 2.00 | 9.42 | 4.68 | 44773 | 20428 | 1036 | 1958 | 865535 | 408734 |
| 3.00 | 9.51 | 4.70 | 56612 | 26585 | 1226 | 2489 | 1184918 | 555431 |

**Soil Test Phosphorous Scenarios**

To determine the relationship between STP and phosphorous loading, an additional set of model runs was made. The STP for all pastures was set to a single value and varied, but forest STP was not modified. To single out the effect of STP, no litter was applied in one set of these simulations. Two additional sets were performed that do include litter applications. Additional tables and figures are located in Appendix T.

Soil test phosphorous mainly effect soluble and sediment-bound phosphorous loadings. STP has little effect on flow and nitrates. Sediment-bound phosphorous was greater when no litter or supplemental nitrogen was applied. Plant growth depends on the litter as a source of nitrogen; without it there is much less growth and residue. With reduced residue and plant growth the soil surface is more exposed and subject to additional soil erosion. All simulations in this report at reduced litter application rates use enough supplemental commercial nitrogen to maintain the current total nitrogen application rate. It is also likely that producers will use more commercial fertilizer if they reduced their litter application rates.

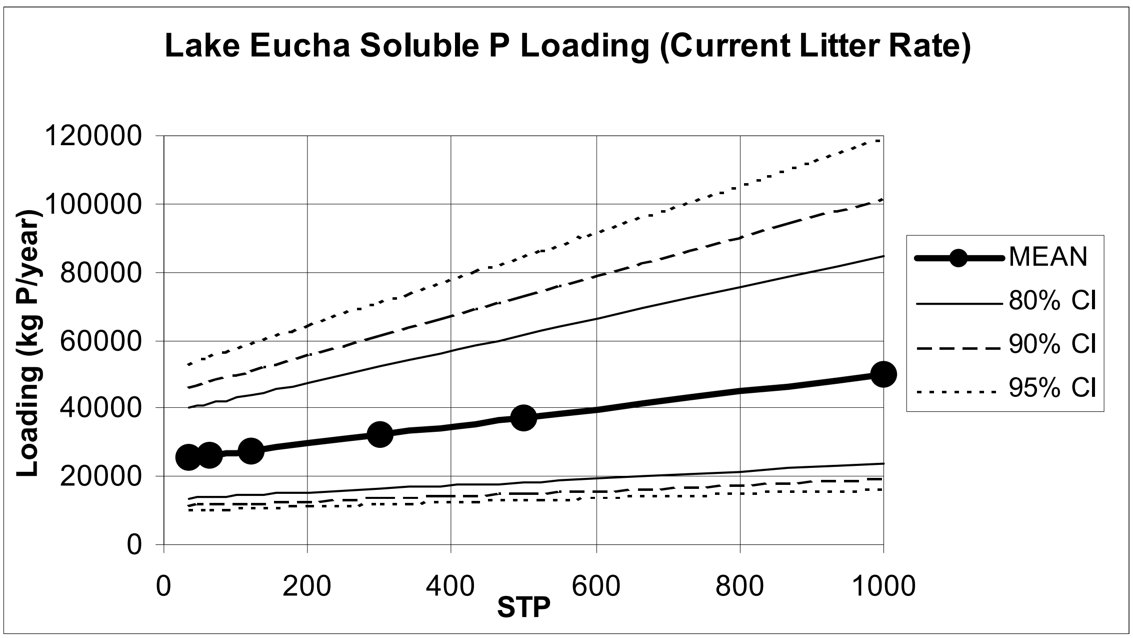



**Figure 42** The effect of STP on soluble phosphorous loading to Lake Eucha as simulated by the SWAT model using the current litter application rate.

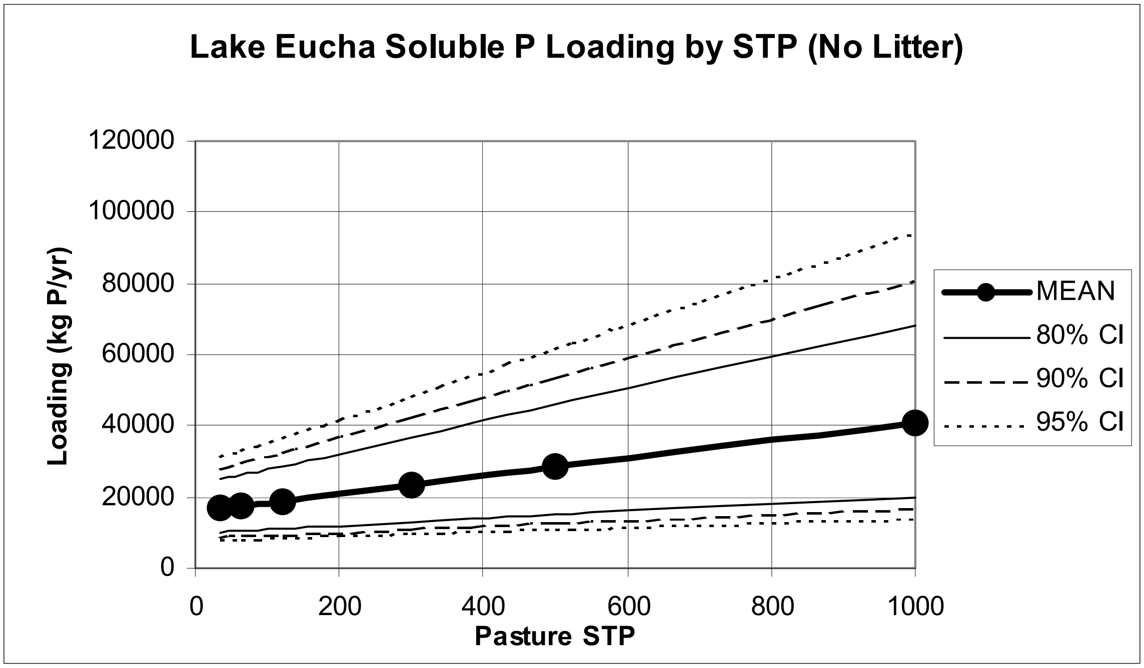



**Figure 43** Soluble phosphorous loading to Lake Eucha, as simulated by SWAT. No applied litter, commercial nitrogen equivalent to current litter application rate is applied.

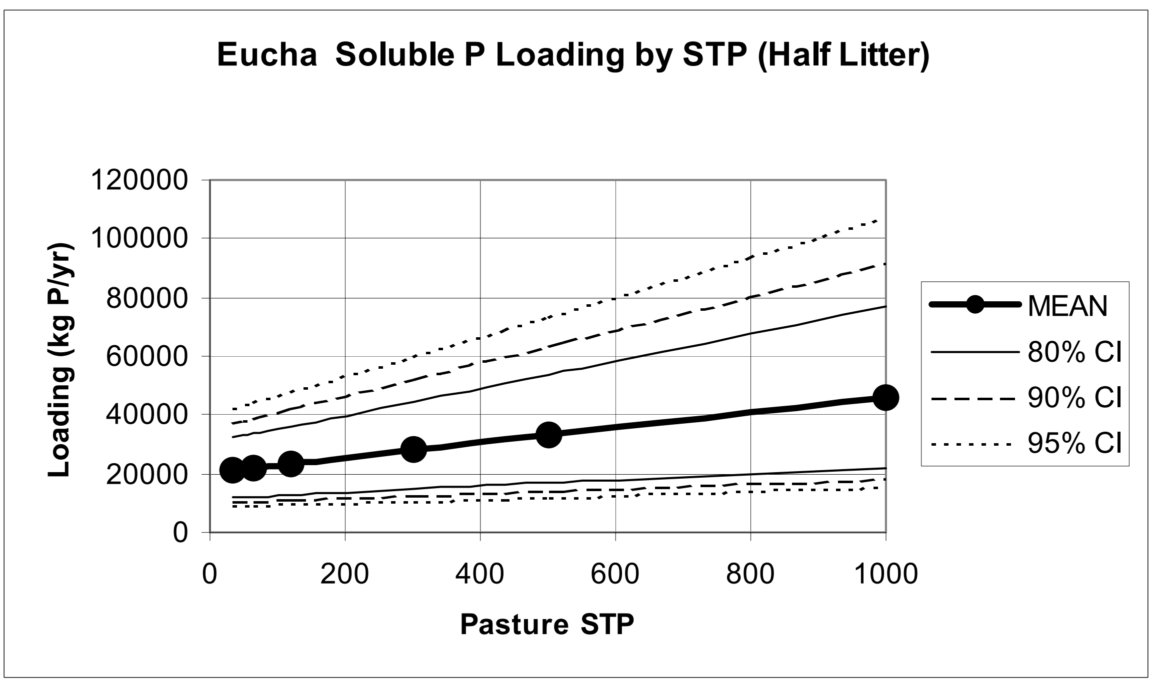



**Figure 44** Soluble phosphorous loading to Lake Eucha as simulated by SWAT, half of the current litter rate is applied. Commercial nitrogen applied to maintain the total nitrogen application rate.

**Table 35** The effect of soil test phosphorous on the loadings to Lake Eucha as predicted by SWAT (no litter, nitrogen supplemented)

| SCEN | Flow m^3/s | | Soluble P kg/yr | | Sediment P kg/yr | | Nitrate kg/yr | |
|---|---|---|---|---|---|---|---|---|
| STP | MEAN | STD | MEAN | STD | MEAN | STD | MEAN | STD |
| 35 | 9.1303 | 4.62 | 16812 | 6030 | 576 | 590 | 509066 | 247573 |
| 65 | 9.1303 | 4.62 | 17535 | 6411 | 593 | 596 | 508923 | 247542 |
| 120 | 9.1303 | 4.62 | 18918 | 7166 | 622 | 608 | 508713 | 247529 |
| 300 | 9.1303 | 4.62 | 23496 | 9659 | 711 | 656 | 508114 | 247260 |
| 500 | 9.1303 | 4.62 | 28587 | 12439 | 785 | 676 | 507524 | 246989 |
| 1000 | 9.1303 | 4.62 | 40839 | 19111 | 923 | 729 | 506583 | 246511 |

**Table 36** The effect of soil test phosphorous on the model loadings to Lake Eucha as predicted by SWAT(half of current litter rate, nitrogen supplemented).

| SCEN | Flow m^3/s | | Soluble P kg/yr | | Sediment P kg/yr | | Nitrate kg/yr | |
|---|---|---|---|---|---|---|---|---|
| STP | MEAN | STD | MEAN | STD | MEAN | STD | MEAN | STD |
| 35 | 9.13 | 4.62 | 21137 | 8306 | 606 | 597 | 508213 | 247306 |
| 65 | 9.13 | 4.62 | 21872 | 8707 | 620 | 603 | 508142 | 247223 |
| 120 | 9.13 | 4.62 | 23278 | 9466 | 647 | 615 | 507932 | 247205 |
| 300 | 9.13 | 4.62 | 27886 | 11975 | 731 | 663 | 507501 | 247026 |
| 500 | 9.13 | 4.62 | 33018 | 14771 | 801 | 682 | 506991 | 246864 |
| 1000 | 9.13 | 4.62 | 45605 | 21640 | 935 | 734 | 506333 | 246438 |

**Table 37** The effect of soil test phosphorous on the model loadings to Lake Eucha as predicted by SWAT(at current litter rate).

| SCEN | Flow m^3/s | | Soluble P kg/yr | | Sediment P kg/yr | | Nitrate kg/yr | |
|---|---|---|---|---|---|---|---|---|
| STP | MEAN | STD | MEAN | STD | MEAN | STD | MEAN | STD |
| 35 | 9.13 | 4.62 | 25353 | 10553 | 626 | 603 | 507636 | 247021 |
| 65 | 9.13 | 4.62 | 26126 | 10964 | 640 | 609 | 507565 | 247029 |
| 120 | 9.13 | 4.62 | 27528 | 11724 | 666 | 621 | 507492 | 246977 |
| 300 | 9.13 | 4.62 | 32146 | 14238 | 746 | 669 | 507031 | 246843 |
| 500 | 9.13 | 4.62 | 37283 | 17029 | 814 | 688 | 506741 | 246604 |
| 1000 | 9.13 | 4.62 | 50003 | 23980 | 946 | 739 | 506167 | 246239 |

## Grazing Rate Scenarios

Grazing rate was modified to determine its effect on nutrient loading. Based on the SWAT model, results indicate that alterations to the current estimated grazing rate do not significantly reduce nutrient loadings. Grazing rate does not have a major impact on soluble phosphorous loading to Lake Eucha (Figure 45). However, doubling the grazing rate used in the calibration does have a significant effect of sediment-bound phosphorous (Figure 46).

Grazing or stocking rate scenarios may require changes to other model parameters, for instance curve number. Over-grazed pastures have a higher curve number because of reduced surface vegetation and increased soil compaction[7]. Likewise, under-grazing simulations have a lower curve number indicating more surface vegetation. Simulations at the 2X level have curve numbers increased for all pastures by 4. The minimum biomass at which grazing is allowed was reduced from 600 kg/ha to 300 kg/ha, so that overgrazing would be properly simulated. Simulations at the 0.5X level and no grazing scenario have curve numbers reduced by 4. At the 2X rate the amount of phosphorous loading increases dramatically. Areas that are over-grazed could be contributing far more than the same area would if the stocking rate were reduced.

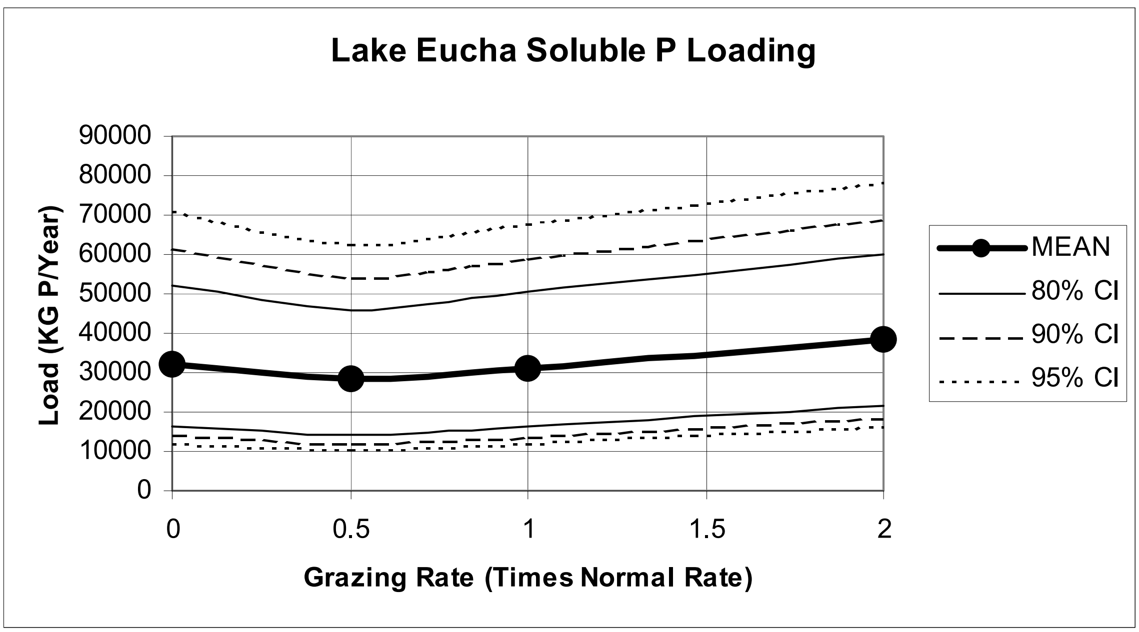



**Figure 45** SWAT predicted soluble phosphorous loading to Lake Eucha as a function of grazing rate.

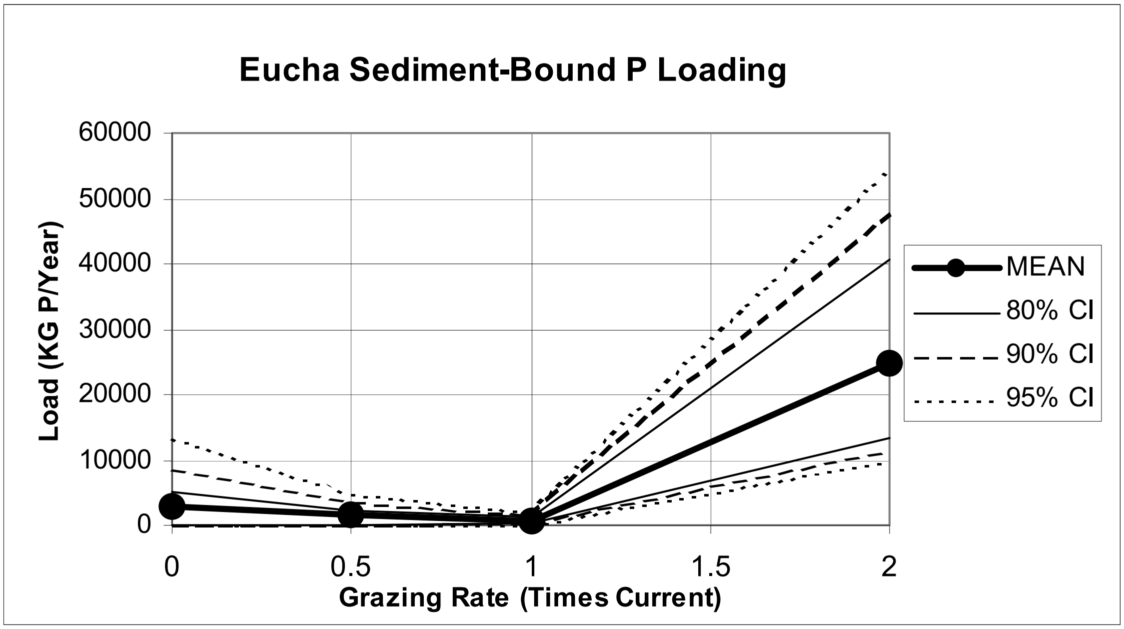



**Figure 46** SWAT predicted sediment-bound phosphorous loading to Lake Eucha as a function of grazing rate.

**Table 38** The effect of grazing rate on water yield and nutrient loading to Lake Eucha, as predicted by SWAT.

| SCEN (grazing rate) | Flow m^3/s | | Soluble P kg/yr | | Sediment P kg/yr | | Nitrate kg/yr | |
|---|---|---|---|---|---|---|---|---|
| X normal | MEAN | STD | MEAN | STD | MEAN | STD | MEAN | STD |
| 0 | 9.51 | 4.75 | 32334 | 14428 | 2975 | 6213 | 638659 | 315624 |
| 0.5 | 9.31 | 4.69 | 28257 | 12806 | 1438 | 3498 | 484828 | 252219 |
| 1 | 9.13 | 4.62 | 31174 | 13604 | 665 | 620 | 507045 | 246838 |
| 2 | 9.99 | 4.73 | 38629 | 14787 | 24891 | 7580 | 504688 | 214823 |

## Decatur Point Source Control

Simulations were performed with a reduced Decatur point source contribution at 50% and 0% of the current load. Litter application and STP were not modified from the calibrated model. The contribution of the point source to the lake was estimated (Table 40). The observed total annual phosphorous point source loading is estimated to be 11,600 kg/year. The model indicates that 78% of the phosphorous added by the point source reaches the lake. Although SWAT does predict assimilation, on a long-term basis, almost all phosphorous entering the stream will eventually end up in the lake. Tabular model outputs are listed in Appendix V.

**Table 39** Current nutrient loading of the Decatur point source. Estimated from Permit Compliance System data from the US Environmental Protection Agency for the period November 1997 to August 2000.

| Parameter | Total P | Nitrates | Flow | Ammonia |
|---|---|---|---|---|
| Load | 11,600 kg/yr | 5,470 kg/yr | 4,900 m^3/day | 11,300 kg/yr |
| Concentration | 6.53 mg/l | 3.06 mg/l | | 6.33 mg/l |

**Table 40** Loading reduction to Lake Eucha at 50% and 0% of the current Decatur point source contribution as predicted by SWAT. Adjusted sediment-bound phosphorous used to calculate total phosphorous.

| Point Source Loading | SOLUBLE P (kg/yr) | SEDIMENT P (kg/yr) | NITRATE (kg/yr) | Total P(adj) (kg/yr) |
|---|---|---|---|---|
| 100% of Current | 31174 | 665 | 507045 | 47134 |
| 0% of Current | 25301 | 531 | 501762 | 38045 |
| 50% of Current | 28229 | 598 | 504385 | 42581 |
| REDUCTION | | | | |
| 0% of Current | 5872 | 134 | 5283 | 9088 |
| 50% of Current | 2944 | 67 | 2660 | 4552 |

## Long-term Simulations

A series of long-term simulations were performed to estimate long-term soil test phosphorous at different litter application rates. When phosphorous is applied in excess of what the crop can use, it builds up in the soil (Figure 48). When poultry litter is applied to meet the nitrogen requirements of the crop, phosphorous is over applied.

The default grazing rate was used for these simulations. Management operations, such as cutting hay, remove more nutrients from the pasture than grazing cattle, and may have a small impact on long-term Soil Test Phosphorous (STP). However, if the hay is fed inside the basin, the effect would be similar to grazing. Appendix W contains the calculations for STP at the current litter application rate.

STP was estimated by calculating an area weighted phosphorous balance for all pastures. Soil mineral phosphorous content and STP are quite different. STP is a measure of active and labile phosphorous. Soil mineral phosphorous includes active phosphorous and relative insoluble phosphorous compounds. These less soluble compounds represent the bulk of soil mineral phosphorous. Figure 47 depicts the steady-state partitioning of mineral phosphorus in the SWAT model.

The initial observed area weighted STP for pastures in the Lake Eucha Basin was estimated to be 250 lb/acre. The initial mineral phosphorous content, as estimated by SWAT's partitioning scheme (Figure 47), was 761 kg/ha (667 lb/acre). The net change was assumed to apply to only the top 6 inches of soil, the rest of the profile is assumed to have a constant STP. Organic phosphorous content was also assumed constant for all layers. The net change was added to the soil mineral phosphorous content from the previous year. STP was calculated from soil total mineral phosphorous each year using the same steady state partitioning as SWAT.

To check the SWAT model, the local history of the poultry industry was compared to SWAT simulations of STP. The poultry industry came to Delaware County about 25 years ago and about 40 years ago to Benton County (personal communication Jason Hollenback OSU Extension). At application rates of 0.5 and 0.75 of the current rate it would take 42 and 28 years for STP to increase from background to the current level of 250 lb/acre, respectively. Litter applications would have steadily increased from very little when there were few houses, to the current rate. Therefore, a fraction of the current rate between 0.5 and 0.75 is reasonable, and provides a reasonable verification of the method.

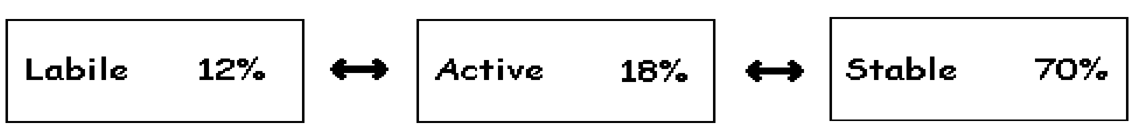



**Figure 47** Steady state partitioning of mineral soil phosphorous in SWAT.

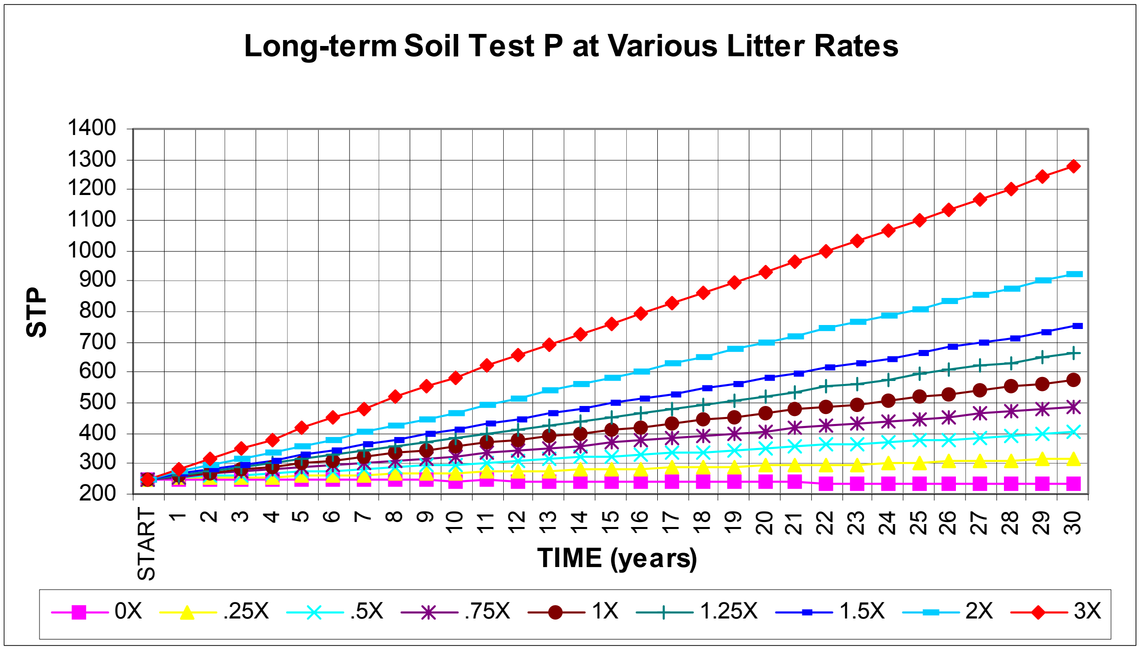



**Figure 48** Model predicted STP as a function of litter rate (fraction of current rate) over a 30 year period.

**Table 41** SWAT model predicted STP as a function of litter application rate over a 30-year period.

| | Litter Rate (Times Normal Rate) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| YEARS | 0X | .25X | .5X | .75X | 1X | 1.25X | 1.5X | 2X | 3X |
| START | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| 1 | 250 | 252 | 255 | 258 | 261 | 264 | 266 | 272 | 283 |
| 2 | 249 | 254 | 260 | 265 | 271 | 277 | 282 | 294 | 317 |
| 3 | 249 | 256 | 264 | 272 | 280 | 288 | 297 | 313 | 348 |
| 4 | 247 | 257 | 268 | 279 | 290 | 301 | 312 | 335 | 381 |
| 5 | 247 | 260 | 273 | 287 | 301 | 315 | 329 | 358 | 415 |
| 6 | 246 | 262 | 278 | 295 | 311 | 328 | 346 | 380 | 449 |
| 7 | 246 | 263 | 282 | 302 | 321 | 341 | 361 | 401 | 482 |
| 8 | 246 | 267 | 289 | 311 | 334 | 357 | 380 | 426 | 519 |
| 9 | 245 | 269 | 293 | 319 | 344 | 370 | 396 | 448 | 552 |
| 10 | 244 | 270 | 297 | 325 | 353 | 382 | 411 | 468 | 584 |
| 11 | 245 | 274 | 305 | 337 | 368 | 400 | 432 | 495 | 623 |
| 12 | 244 | 275 | 308 | 341 | 376 | 410 | 445 | 514 | 654 |
| 13 | 243 | 278 | 314 | 351 | 388 | 426 | 463 | 539 | 689 |
| 14 | 243 | 280 | 320 | 360 | 400 | 440 | 480 | 561 | 724 |
| 15 | 242 | 282 | 325 | 368 | 412 | 455 | 498 | 585 | 760 |
| 16 | 241 | 284 | 329 | 374 | 420 | 466 | 512 | 605 | 791 |
| 17 | 240 | 286 | 334 | 383 | 432 | 481 | 530 | 628 | 826 |
| 18 | 240 | 288 | 340 | 391 | 443 | 495 | 547 | 651 | 861 |
| 19 | 239 | 291 | 345 | 400 | 455 | 510 | 565 | 675 | 896 |
| 20 | 238 | 292 | 349 | 406 | 463 | 521 | 579 | 695 | 928 |
| 21 | 238 | 295 | 355 | 416 | 476 | 537 | 598 | 720 | 964 |
| 22 | 237 | 298 | 361 | 425 | 488 | 552 | 616 | 743 | 999 |
| 23 | 236 | 299 | 364 | 430 | 496 | 563 | 629 | 763 | 1030 |
| 24 | 236 | 301 | 369 | 438 | 507 | 577 | 646 | 786 | 1065 |
| 25 | 235 | 304 | 375 | 447 | 520 | 592 | 665 | 810 | 1101 |
| 26 | 234 | 306 | 380 | 455 | 531 | 606 | 681 | 832 | 1135 |
| 27 | 234 | 308 | 386 | 464 | 542 | 620 | 699 | 855 | 1170 |
| 28 | 233 | 310 | 390 | 470 | 551 | 633 | 714 | 876 | 1202 |
| 29 | 232 | 313 | 397 | 480 | 565 | 649 | 733 | 902 | 1240 |
| 30 | 232 | 315 | 402 | 489 | 576 | 663 | 750 | 924 | 1274 |

**Sensitivity Analysis**

A sensitivity analysis was performed using may of the more easily modifiable parameters. It is not feasible to perform such analysis on all parameters due to the number of parameters and the difficulty associated with modifying each one. The parameters selected include the more important parameters that are often used during the calibration of the SWAT model. To simplify calculations, loadings were calculated where Spavinaw Creek meets Lake Eucha (Figure 49), which contains the majority of the basin. The average annual outputs for a 20 year period was used to calculate sensitivity. A five year warmup period was used as in all previous simulations, and the model was run for the period 1/1/1975 to 12/31/1999.

Five observations were used to calculate relative sensitivity for each parameter. One observation was the calibrated model. Charts associated with each parameter and output are located in Appendix X. Relative sensitivity was calculated for the interval between each of the five data points. The average of these four values is reported as the relative sensitivity.

One of the two equations below was used to calculate relative sensitivity. The equation used depends on how the parameter was modified. Input parameters may be modified by a percentage, by a fixed amount, or by directly setting the parameter value. A relative sensitivity calculation may in some cases require the use of an area weighted average, since SWAT is a distributed model.

$$S_r = \frac{(O_1 - O_2)/O_b}{(P_1 - P_2)/100}$$

Where:
$S_r$ = Relative sensitivity (non-dimensional)
$O_b$ = Selected model output for baseline (calibrated) conditions
$P_1$ = Parameter adjustment %
$P_2$ = Parameter adjustment %
$O_1$ = Selected model output @ $P_1$
$O_2$ = Selected model output @ $P_2$

$$S_r = \frac{P_b}{O_b} * \frac{O_2 - O_1}{P_2 - P_1}$$

Where:
$S_r$ = Relative sensitivity (non-dimensional)
$P_b$ = Parameter investigated baseline (calibrated) value
$O_b$ = Selected model output for baseline (calibrated) conditions
$P_1$ = Parameter value adjusted less than $P_b$
$P_2$ = Parameter value adjusted greater than $P_b$
$O_1$ = Selected model output @ $P_1$
$O_2$ = Selected model output @ $P_2$

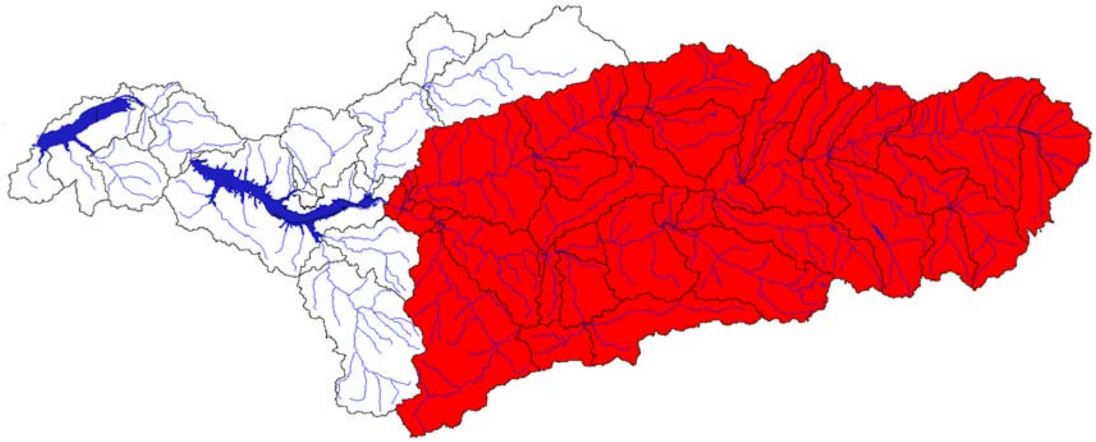


**Figure 49** Portion of Lake Eucha Basin used in the sensitivity analysis.

**Table 42** Relative sensitivity for 18 commonly used SWAT input parameters.

| Parameter | Flow(m^3/sec) | SED(Metric T) | Organic N (kg) | Sed P (kg) | NO3 (kg) | SOL P (kg) |
|---|---|---|---|---|---|---|
| Alpha Baseflow Factor | 0.0029 | 0.0144 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Soil Available Water Content | -0.8172 | -1.0933 | -1.9175 | -2.4415 | -0.7077 | -0.4593 |
| Biological Mixing Efficiency | -0.0425 | 0.0538 | 0.2220 | 0.1306 | -0.2633 | -0.6332 |
| MUSLE "Minimum Crop Factor" | 0.0000 | 0.1671 | 0.3633 | 0.4351 | 0.0000 | 0.0057 |
| Channel Cover Factor | 0.0000 | 0.5146 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Channel Erodibility Factor | -0.0001 | 0.4098 | -0.0533 | -0.0404 | 0.0021 | 0.0044 |
| Channel K Factor | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Curve Number | 0.1971 | 1.6481 | 3.0951 | 3.3867 | 2.7688 | 2.2436 |
| ESCO | 2.2138 | 1.6162 | 1.0213 | 0.9917 | 0.8425 | 0.8682 |
| Min. Depth in Shallow Aquifer for Baseflow | -0.0061 | -0.0024 | 0.0002 | 0.0001 | 0.0000 | 0.0000 |
| Nitrogen Percolation Coff. | -0.0035 | 0.0623 | 0.2631 | 0.3375 | 0.6846 | -0.0328 |
| PHOSKD | 0.0000 | 0.0000 | -0.0586 | -0.0446 | 0.0025 | -0.9138 |
| Phosphorous Percolation Coff. | 0.0000 | 0.0000 | 0.0159 | 0.0764 | -0.0005 | 0.2239 |
| Min. Depth in Shallow Aquifer for Revap | 0.0061 | 0.0024 | -0.0002 | -0.0001 | 0.0000 | 0.0000 |
| Revap Factor | -0.0190 | -0.0069 | 0.0005 | 0.0005 | 0.0000 | 0.0000 |
| Slope Length | -0.0011 | 0.0793 | 0.3396 | 0.3864 | -0.0051 | 0.0118 |
| Slope | 0.0007 | 0.3373 | 1.0252 | 1.2298 | 0.0038 | 0.0055 |
| Soil Labile P (1 year warmup) | 0.0000 | 0.0000 | 0.0258 | 0.1059 | -0.0009 | 0.1980 |
| Soil Labile P (5 year warmup) | 0.0000 | 0.0000 | 0.0144 | 0.1763 | -0.0006 | 0.1897 |

## Model limitations

There are several model limitations that should be noted. Model limitation may be the result of data used in the model, inadequacies in the model, or using the model to simulate situations for which it was not designed. Hydrologic models will always have limitations, because the science behind the model is not perfect nor complete. A model by definition is a simplification of the real world.

Weather is the driving force for any hydrologic model. Great care was taken to include as much accurate observed weather data as possible. The only weather information available was collected at weather stations. Data collected at a few points must be applied to an area of 1000 $km^2$. Rainfall can be quite variable, especially in the spring when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a weather station, but be dry a short distance away. On an average annual or average monthly basis, these errors have less influence. This limitation among others caution us against using model output on a daily basis or monthly basis.

Scenarios involving radical changes to the basin result in greater uncertainty. The model was calibrated using estimates of what is presently occurring in the basin. Large departures from calibration conditions raise the level of uncertainty.

Only a single point source was included in the model. There are many point sources in the basin; these could be significant. Other potential point sources include household septic systems, CAFOs other than poultry, and municipalities other than Decatur.

Land uses that cover only a small areas were not represented in the model. Land uses that occupy limited areas such as unpaved roads, bare areas, construction sites, and row crops were not simulated. Most of these features were not depicted in the available GAP land cover. Some of these very small areas may contribute a thousand times more sediment than a pasture of the same area. Although significant, they cannot be simulated with the currently available data.

Each HRU in a subbasin was assumed to have the same characteristics by the model. For instance, the same slope was used for all pastures and forest HRUs in a single subbasin. Pastures are generally located in valleys or other flat areas. Forests generally occupy land that is steeper than pastures. This problem is more important in a watershed of this type, where each land cover has such different topographical characteristics.

Long-term simulations of soil test phosphorous assume SWAT`s soil phosphorous model is correct. The steady-state partitioning of phosphorous into SWAT`s various soil phosphorous pools was used to estimate soil test phosphorous. In reality this partitioning varies by soil type and cultural practices.

There is a great deal of uncertainty associated with management. A single management scenario was applied uniformly to each particular land cover. These simulations assume all pastures are grazed, but not over-grazed. In the real world, management varies dramatically. Pastures may be cut for hay, over-grazed, under-grazed, planted with a particular forage, or not managed at all. It is not possible to easily determine what is happening where, or to simulate all these activities in the model. Therefore, a single reasonable management was selected and applied basin-wide.

An important limitation is that SWAT simulates poultry litter applications as simple nutrient additions applied uniformly to the top 10 mm of the soil surface. In reality poultry litter lies on the soil surface until rainfall moves it into the soil. In the first few rainfall events after application the litter interacts more closely with surface runoff than simulated by SWAT. In the field we expect high phosphorous concentrations in surface runoff immediately following litter application. In the SWAT model, simulated phosphorous concentrations do not increase so dramatically when litter is applied. These limitations caution us against using SWAT predictions on daily or even monthly basis. On an average annual basis, these loading errors are less pronounced due to calibration.

Another source of error was differences in soil test P (STP) data between Oklahoma and Arkansas. The Oklahoma samples were analyzed by the Oklahoma State University (OSU) Soil, Water & Forage Analytical Laboratory and the Arkansas samples were analyzed by the University of Arkansas (UA) Soil Testing and Research Laboratory. OSU and UA use extraction ratios of 1:10 and 1:7, respectively. In addition, the two labs use different instrumentation for analysis. OSU uses a colorimetric method and UA uses inductively coupled argon plasma spectrometry (ICAP). Dr. Nathan Slaton with the UA provided the following relationships for different extraction ratios ($n \approx 500$):

$$ICAP\,Mehlich\,III\,P(1{:}10) = 1.27\ ICAP\,Mehlich\,III\,P(1{:}7) + 14.9$$

where Mehlich III is in mg/l. Dr. Hailin Zhang with OSU provided the following relationship between ICAP and colorimetric methods ($n=3577$, $R^2=0.98$):

$$ICAP\,Mehlich\,III\,P(1{:}10) = 1.11\ Colormetic\,Mehlich\,III\,P(1{:}10) + 26.7$$

where Mehlich III is in mg/l. The average pasture STP level used for the Arkansas portion of the Lake Eucha basin was 334 lbs/ac. Based on these regression equations, an Arkansas STP of 334 lbs/ac corresponds to an OSU value of 372 lbs/ac. In the context of this study, this 10 percent difference in STP is negligible.

As a check of the model the fraction of soluble phosphorous from each source was estimated from the model results (Figures 50 and 51). This is done to determine if the fraction attributed to each source is reasonable. The intent is not to claim that this is the actual breakdown. There are many assumptions that must be made in addition to those made in the model to perform this type of analysis. The assumptions made for this analysis were marginal and could not be used for all model outputs. These results are presented to reflect on the model accuracy only, and should be treated accordingly. The fraction of loading associated with each change to the model was isolated. For instance the contribution of the load due to the application of poultry litter was estimated as the difference in the predicted load between the 1x application rate and the 0x rate. The fraction associated with litter applications is a conservative estimate, due to model limitations at racially different management conditions. The other constituents were similarly calculated. The contribution of STP was estimated as the difference between the 300 lb/acre STP and 35 lb/acre scenarios. Sources were determined for soluble phosphorous and nitrates. Total phosphorous is linked with sediment, and there was too much interaction between the sources for this method to produce a reasonable breakdown for total phosphorous.

The fraction associated with deforestation was calculated by modeling background conditions with pastures and forest and subtracting the background loading. Background estimates were made assuming an all forest watershed. The additional loading associated with the conversion of forest to pastures is the result. Other sources were calculated such that the total loading from all sources matches the calibrated model loading. It should also be noted that these estimates assume there is no interaction between the sources. The relative percentages for each source were calculated using only the average annual model output. Rainfall uncertainty could cause a dramatic shift in the percentages from any given year.

SWAT models in-stream processes based, in large part, on unvalidated assumptions of channel and stream-bank properties. These in-stream processes are the primary cause of the low sediment-bound phosphorous prediction by the calibrated model. Sediment-bound phosphorous was under predicted in all simulations. We think this is the result of phosphorous being deposited with sediment in the stream, but not being reintrained during high flow periods. In the SWAT model, sediment that was re-entrained did not appear to contain phosphorous. Sediment from stream degradation was increased by 2 orders of magnitude, and there was little change in sediment-bound phosphorous. Sediment-bound phosphorous was lost from the system as a result of the stream processes; this would not happen in the real world. Almost all nutrients entering the stream system would eventually reach the lake, provided there is no net deposition of sediment in the stream system. To adjust for this, a correction factor was estimated using the calibrated model and observed loadings. Sediment-bound phosphorous was underestimated by a factor of 24 in the calibrated model. This fraction was assumed to be constant for all scenarios, and applied only to the Lake Eucha Basin. This method produced reasonable estimates of total phosphorous for all BMPs simulated.

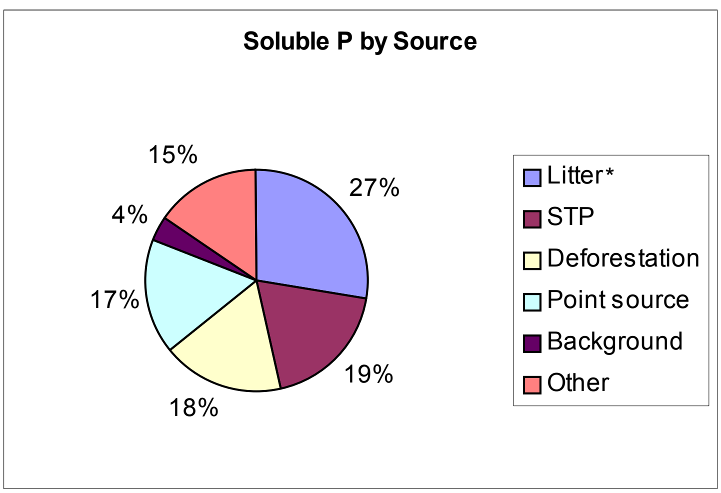



**Table 43** Soluble phosphorous breakdown (Kg P/year)

| Source | Soluble P (kg/yr) |
|---|---|
| Litter | 8649 |
| STP | 5821 |
| Deforestation | 5460 |
| Point source | 5278 |
| Background | 1147 |
| Other | 4819 |
| Total | 31174 |

**Figure 50** Soluble phosphorous loading to Lake Eucha breakdown by source, as predicted by SWAT. This analysis required many assumptions, these data are presented to illustrate model limitations, and should be used in that context. * Conservative estimate, litter applications should account for a greater percentage of the loading.

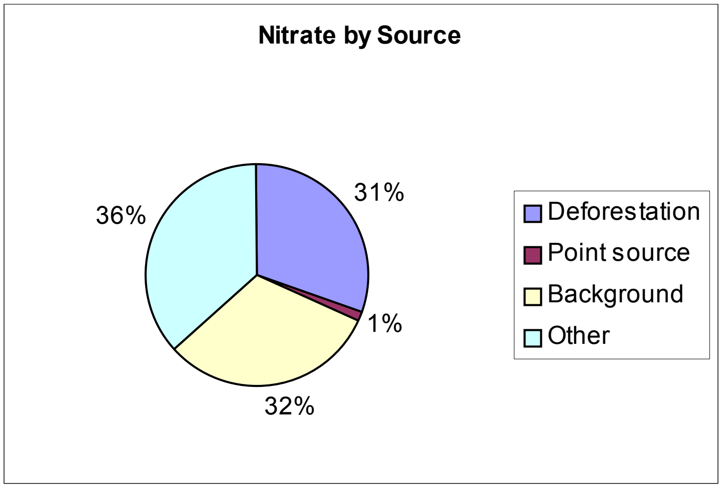



**Table 44** Nitrate Breakdown (kg N/yr)

| Source | Nitrates |
|---|---|
| Deforestation | 154915 |
| Point source | 5283 |
| Background | 159730 |
| Other | 187117 |
| Total | 507045 |

**Figure 51** Nitrate loading to Lake Eucha breakdown by source, as predicted by SWAT. This analysis required many assumptions, these data are presented to illustrate model limitations, and should be used in that context.

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