Pasture Phosphorus Management (PPM) Calculator

Technical Documentation Version 1.0

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Executive Summary

In December of 2001 the City of Tulsa and the Tulsa Metropolitan Utility Authority filed suit in Federal Court against Tyson Foods, Inc., Cobb-Vantress Inc., Peterson Farms, Inc., Simmons Foods, Inc., Cargill, Inc., George's, Inc., and the City of Decatur, Arkansas for damages and injunctive relief for one of the City of Tulsa's water supplies, the Lake Eucha/Spavinaw complex (United States District Court for the Northern District of Oklahoma, Case No. 01 CV 0900EA[C]). In July of 2003 a settlement agreement between the parties was reached. The settlement agreement requested that Oklahoma State University and the University of Arkansas work on a "Phosphorus Risk Index" to be submitted to the Court by January 1, 2004. The technical Phosphorus Index Team members of Oklahoma State University and the University of Arkansas were unable to agree on a common Phosphorus Index, and thus Oklahoma State University is submitting its own Phosphorus Index to the Court. The submitted Phosphorus Index meets the requirements of the settlement agreement and is specific to the Lake Eucha/Spavinaw basin. Presented is a technical document which describes the development, verification, sensitivity analysis, and validation of the submitted Phosphorus Index.

The Phosphorus Index submitted to the Court and documented in this report is called the Pasture Phosphorus Management (PPM) Calculator, which was developed at Oklahoma State University Division of Agricultural Sciences and Natural Resources by faculty and staff in the Biosystems and Agricultural Engineering and Plant and Soil Sciences Departments. The PPM Calculator is a quantitative tool developed to predict edge-of-field phosphorus loss from pasture systems in the Lake Eucha/Spavinaw basin. The PPM Calculator is a simple interface written in Visual Basic that uses the Soil and Water Assessment Tool (SWAT) 2000 model, which allows field personnel to take advantage of the predictive capacity of SWAT typically reserved for use by hydrologists and engineers. The PPM Calculator was designed to be simple to use by field personnel with readily available inputs, and thus insulates the user from the complexity of SWAT by formatting model inputs and interpreting model output. By using the physically based SWAT model, the PPM Calculator can accurately simulate a variety of management options under a variety of field conditions.

SWAT is a widely accepted model which has been used extensively by hydrologists and engineers since 1994 in the United States as well as a number of other countries around the world. SWAT's strength lies in the physical basis of the model, which gives it the ability to make accurate predications under a wide range of conditions and Best Management Practices (BMPs). The PPM Calculator only utilizes the "field" components of the SWAT model and does not use the channel routing and transformation routines that may be needed when applying the model at a basin scale.

The PPM Calculator was designed to prevent the model from being modified by a user and thereby produce incorrect results. The PPM Calculator requires several files to operate properly, and thus a modified or corrupt file may invalidate results generated by the model. Therefore, modification of any file required by the PPM Calculator deactivates the software, forcing the user to reinstall the software. The PPM Calculator also has smart input fields which help the user avoid mistakes. All values entered in the interface are checked to ensure that they are numeric, positive and in the acceptable range for that parameter. Moving the cursor slowly over an input field will produce a tag with information or guidance concerning that input. Various warnings and messages alert the user to possible mistakes. When possible, references tables or calculators are included to aid the user. Tools for estimating stocking rates in animal units, minimum available forage in dry weight, and fertilizer application rates are included.

To add to the reliability of the PPM Calculator, the model was verified for various parameters (or processes), a sensitivity analysis was performed, and the model was validated. Verification is a process that certifies that the model components are working correctly. A sensitivity analysis is a process of identifying parameters that have the greatest impact on model output, and validation is a process that assures that the model functions properly and produces reasonable results under specific conditions. The PPM Calculator was validated using 33 months of data on four fields just south of the Lake Eucha/Spavinaw basin using data presented by Edwards et al. (1994), Edwards et al. (1996a, 1996b), and Edwards et al. (1997). The validation process tests the PPM Calculator with observed data that is not used in calibration. The PPM Calculator was not directly calibrated; however the model made use of SWAT hydrologic parameters calibrated specifically for the Lake Eucha/Spavinaw basin (Storm et al., 2003). Using these basin specific parameters significantly increases the reliability of the PPM Calculator when applied to pastures in the Eucha/Spavinaw basin. The performance of the PPM Calculator on the validation data set was excellent, thus providing additional confidence in the model's accuracy and predictive capability.

The PPM Calculator predicts average monthly and annual phosphorus loads based on 15 years of observed weather data. The PPM Calculator utilizes existing and proven technology and can be used to determine the amount of litter that can be applied to a pasture to meet a specific water quality objective. The PPM Calculator also allows the agricultural producer to select from a number of management options that will minimize phosphorus loss from his/her field. Therefore, the PPM Calculator is an important component of an environmentally sound nutrient management plan. Another benefit of the PPM Calculator is that the nutrient management plan developer can work with the agricultural producer on site to evaluate multiple management options in a few minutes and develop a plan that minimizes phosphorus loss as well as optimizing agricultural productivity.

The PPM Calculator is a physically-based quantitative tool based on a widely tested and accepted model. A qualitative Phosphorus Index is less likely to accurately predict phosphorus loss especially for conditions outside the range used to develop the index, and therefore it is unlikely that one can accurately predict whether a specific water quality objective can be met. In order to accurately predict phosphorus loss from a pasture system, the effects of the amount and timing of grazing, haying, and fertilization must be accounted for in a physically based hydrologic model. It should be noted that both a quantitative and qualitative Phosphorus Index require the selection of a water quality endpoint (water quality objective). Although an endpoint is not required to run the PPM Calculator, the endpoint is required to determine the allowable phosphorus load allocation for pasture systems in the Lake Eucha/Spavinaw basin. A similar endpoint is required to set thresholds for a qualitative Phosphorus Index.

Introduction and Background

In December of 2001 the City of Tulsa and the Tulsa Metropolitan Utility Authority filed suit in Federal Court against Tyson Foods, Inc., Cobb-Vantress Inc., Peterson Farms, Inc., Simmons Foods, Inc., Cargill, Inc., George's, Inc., and the City of Decatur, Arkansas for damages and injunctive relief for one of the City of Tulsa's water supplies, the Lake Eucha/Spavinaw complex (United States District Court for the Northern District of Oklahoma, Case No. 01 CV 0900EA[C]). In July of 2003 a settlement agreement between the parties was reached. The following is an excerpt from the settlement agreement describing the intent of the settlement:

> *"C. STATEMENT OF INTENT....(2) to ensure that nutrient management protocols are used in the Watershed to reduce the risk of harm to Plaintiffs' Water Supply due to the Land Application of Nutrients and The City of Decatur's WWTP discharge, while at the same time recognizing the right of the Poultry Defendants and their Growers to continue to conduct poultry operations in the Watershed within such protocols and the importance of clean lakes, safe drinking water and a viable poultry industry to the economics of Northeast Oklahoma and Northwest Arkansas."*

The settlement agreement also requested that Oklahoma State University and the University of Arkansas work on a "Phosphorus Risk Index" to be submitted to the Court by January 1, 2004. Below are excerpts from the settlement that describe the requested Phosphorus Index:

> *"17. "PI" means the risk based Phosphorus Index developed to govern the terms and conditions under which Nutrients may be land applied in the Watershed, as further described in Section D of this Agreement, and includes the numerical index system represented thereby, the target objective or index necessary to limit the land application of Nutrients, as described therein, and any other associated requirements, limits or guidelines pertaining to the land application of Nutrients as prescribed by the PI developers. Page 2*
>
> *1. A new phosphorus risk-based index ("PI") shall be developed to govern the terms and conditions under which any Nutrients may be land applied in the Watershed. Although the PI, as developed or with modification, may have broader application or be of interest to other watersheds or parties not involved in the Watershed, the PI shall be developed particularly for the existing physical, geological and hydrological conditions and characteristics of the Watershed and the stated goals and intent of this Agreement.*
>
> *2. The PI shall be developed to achieve the least amount of total phosphorus reasonably attainable from each Application Site to the Water Supply from all sources of phosphorus on each such Application Site while still meeting the agronomic requirements for the growth of grasses, crops and other desirable plant life."*

As part of the Settlement agreement, there is a moratorium on litter application in the basin "*...until a Nutrient management Plan containing a PI number for each tract, field or pasture"* is developed. The technical Phosphorus Index team members of Oklahoma State University and the University of Arkansas were unable to agree on a common Phosphorus Index, and thus Oklahoma State University is submitting its own Phosphorus Index to the Court. Presented is a technical document which describes the development, verification, sensitivity analysis, and validation of the submitted index. In its current form this Phosphorus Index should only be applied to pastures in the Lake

Eucha/Spavinaw basin.

The Lake Eucha/Spavinaw basin (Figure 1) is located in northeast Oklahoma and northwest Arkansas, and covers approximately 265,000 acres of Delaware County, Oklahoma and Benton County, Arkansas. The basin is located in the Ozark Highlands and the Central Irregular Plains Ecoregion. The land cover is primarily pasture and forest. Forests are mostly deciduous, but pine trees are common. Pastures are used for hay and grazing cattle. There are approximately 85 million chickens and turkeys produced annually in over 1000 poultry houses in the basin, and thus poultry litter is often applied to these pastures to increase their productivity. The topography is Karst, with exposed limestone in some areas. Soils are mainly of the ultisol order, and are typically thin and highly permeable. Average annual precipitation is approximately 45 inches. Additional details on the basin are given in Storm et al. (2002).

Figure 1. Lake Eucha/Spavinaw basin.

The Phosphorus Index submitted to the Court and documented in this report is called the Pasture Phosphorus Management (PPM) Calculator, which was developed at the Oklahoma State University Division of Agricultural Sciences and Natural Resources by faculty and staff in the Biosystems and Agricultural Engineering and Plant and Soil Sciences Departments. The PPM Calculator was developed to predict phosphorus loss from pasture systems in the Lake Eucha/Spavinaw basin. The PPM Calculator is a simple interface written in Visual Basic that uses the Soil and Water Assessment Tool (SWAT) 2000 model, which allows field personnel to take advantage of the predictive capacity of SWAT typically reserved for use by hydrologists and engineers.

The PPM Calculator is a quantitative tool that predicts the edge-of-field average annual total phosphorus load from pastures under a variety of management options. The PPM Calculator was designed to be simple to use by field personnel, with readily available inputs. The PPM Calculator insulates the user from the complexity of SWAT by generating model inputs and interpreting model output. By using the physically based SWAT model, the PPM Calculator can accurately simulate a variety of management practices and field characteristics.

SWAT 2000 Background

SWAT is a distributed parameter basin-scale model developed by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas. SWAT is included in the Environmental Protection Agency's (EPA) latest release of Better Assessment Science Integrating Point and Nonpoint Sources (BASINS). The model has been used extensively under a variety of conditions in the United States as well as a number of other countries around the world. Additional documentation (Users Manual and Theoretical Documentation) for the SWAT model are located online at http://www.brc.tamus.edu/swat/swatdoc.html. A list of peer reviewed SWAT publications is given in Appendix A.

PPM Calculator Model Components

The PPM Calculator acts as an interface for the SWAT 2000 model while greatly simplifying its use for modeling pasture systems. SWAT is a widely accepted model which has been used extensively by hydrologists and engineers since 1994 in the United States as well as a number of other countries around the world. SWAT's strength lies in the physical basis of the model, which gives it the ability to make accurate predications under a wide variety of Best Management Practices (BMPs). The PPM Calculator interacts with SWAT as shown in Figure 2. SWAT input files are generated using input from the user via the PPM Calculator interface and then used during the execution of the model. The PPM Calculator summarizes the SWAT model output in a simple table that is easy to interpret. It should be noted that the PPM Calculator only utilizes the "field" components of the SWAT model and does not use the channel routing and transformation routines that may be needed when applying the model at a basin scale.

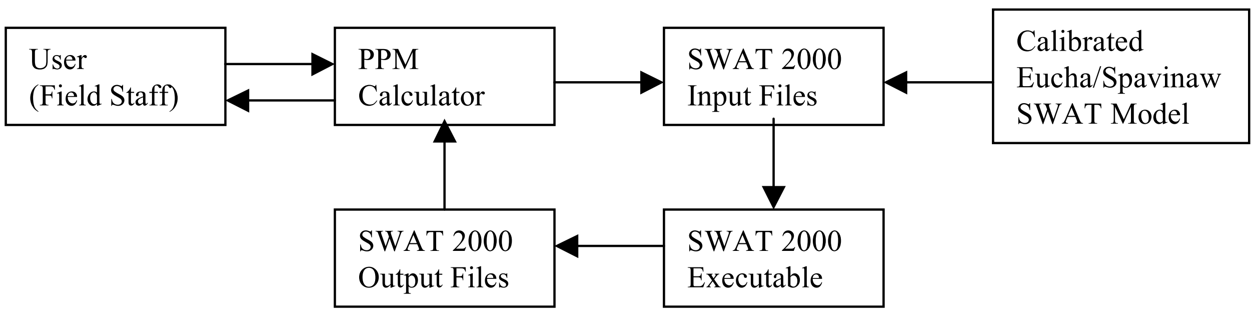

Figure 2. PPM Calculator block diagram.

PPM Calculator User Interface

The PPM Calculator user interface is the bridge between the user and the SWAT model. The user interface is the only portion that the user interacts with. It was designed to be easy to use, but we recommend that users read the SWAT users manual. The PPM Calculator includes critical reference tables and calculators to minimize the need for additional documents or software.

Input Parameters

The default PPM Calculator input parameters are given in Appendix B. The PPM Calculator interface (Figure 3) allows the user to specify the following parameters:

Field Owner - Owner or manager responsible for the property.

Plan Developer - Person who runs the PPM Calculator to develop a nutrient management plan for a particular field.

Field Description (optional) - Allows owners of multiple fields to add a description or name.

Date - Date plan is developed.

Field Area - Area of field not including buffer strips in acres.

Soil Type - The Interface contains data for 35 soils commonly found in the Eucha/Spavinaw basin.

Forage Type - Allows the user to select warm, cool, or mixed forages.

STP - Input for Mehlich III Soil Test Phosphorus. User must specify which lab performed the analysis. All Soil Test Phosphorus measurements are converted to an Oklahoma State University equivalent.

Minimum Dry Forage - The minimum dry forage present on the field at any time of the year. Grazing is suspended by the program when this level is reached.

Forage Yield Goal - Used to calculate maximum nitrogen recommendations based on OSU guidelines. The program will alert the user if the nitrogen amount is exceeded.

Field Slope - The average field slope in percent.

Slope Length - Revised Universal Soil Loss Equation Slope Length in feet.

Slope to Stream (Not active in Version 1.0) - Average slope of the area between the field and nearest stream or concentrated flow channel.

Distance to Stream (Not active in Version 1.0) - Distance from field to nearest stream or concentrated flow channel.

Alum Treated Litter (Not active in Version 1.0) - Used to indicate that litter is treated with alum before it is applied to a pasture, which may reduce soluble phosphorus loss.

Buffer Strip Width (Not active in Version 1.0) - Buffer strips are a BMP that may trap sediment and nutrients before they leave the field.

Field Center (UTM Coordinates) - Location of field being analyzed. These data are saved by PPM Calculator, but are not used in any calculations.

Hay - Used to indicate that a hay operation occurs this month. All operations are scheduled for the first day of the month selected.

Stocking Rate - Number of animal units per acre grazed each month. One animal unit is equivalent to a 1000 lb cow. The conversion table for other animal types is included in the PPM calculator.

Litter N - Total amount of nitrogen (as N) applied in litter this month.

Litter P - Total amount of phosphorus (as P_2O_5) applied in litter this month.

Commercial N - Amount of nitrogen (as N) applied in commercial fertilizers this month.

Commercial P - Amount of phosphorus (as P_2O_5) applied in commercial fertilizers this month.

Status and Warnings - This display shows the status of the program and displays warnings that may require corrective action by the user.

P Allocation - This is the maximum allowable phosphorus load permitted from pastures in the Eucha/Spavinaw basin to meet a specific water quality objective. This endpoint must be set by the parties and/or the Court if the risk of P loss from a particular field is desired. The default value is arbitrarily set to zero. This value is not required to run the PPM Calculator.

Buttons

The interface (Figure 4) allows the user to perform the following functions:

Save - Saves data to a .ppm file

Load - Loads data from a .ppm file

Help - Shows user manual.

RUN - Executes model run, may take 5-20 seconds depending on the speed of the CPU.

Fertilizer Calculator - A tool to calculate the amount of nutrients (N, P, and K) based on application rates and nutrient content of litter or commercial fertilizer.

About - Show information about PPM Calculator.

Calculator - Shows Microsoft Windows calculator.

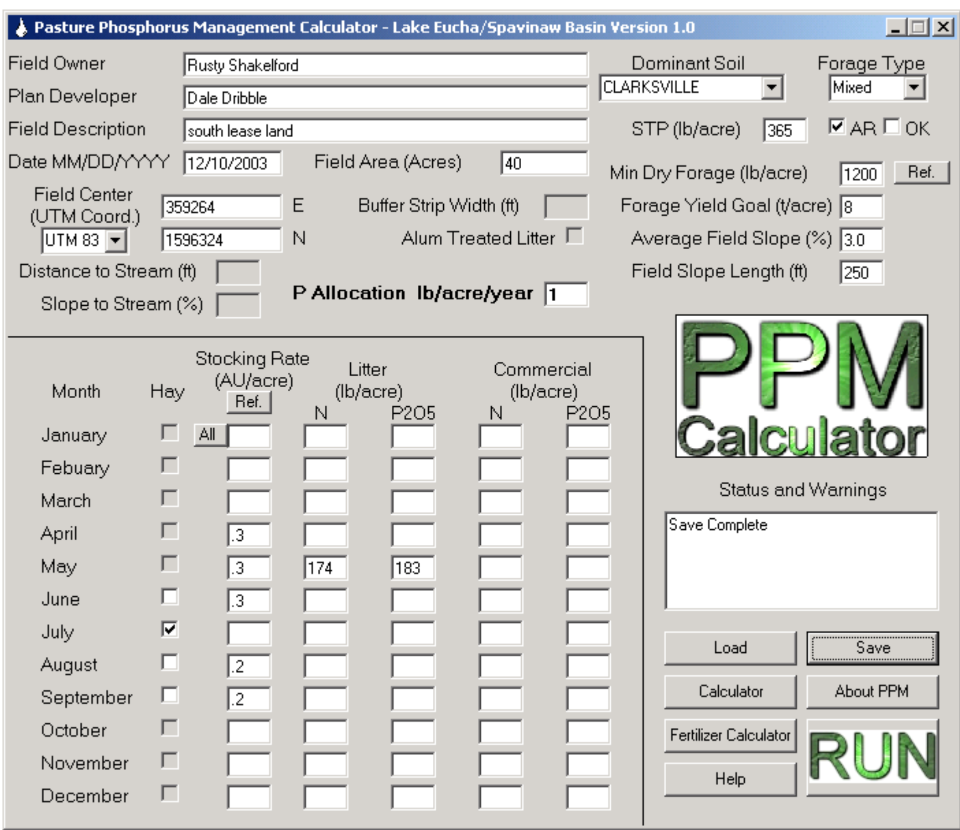

Figure 4. PPM Calculator User Interface Version 1.0. The *P Allocation* input parameter of 1.0 lb/ac/year is used ONLY for demonstration purposes and is not a proposed policy endpoint.

Output

Output from the PPM Calculator is a standard .txt file witch can be read by any word processor or text editor. All the information entered by the user is listed in the output, along with monthly and annual precipitation, runoff, sediment, total phosphorus, and estimated available forage. A message at the bottom of the output tells the user if this scenario is predicted to meet the Parties and/or Court specified *Phosphorus Allocation*.

```
Created 12/19/2003  1:36:43 PM  by PPM Calculator 1.0

Field Owner: Rusty Shakelford
Plan Developer: Dale Dribble
Field Description: south lease land
Plan Date: 12/10/2003
Field Area (acres): 40
Field Slope (%): 3.0
Soil Type: CLARKSVILLE  Hydrologic Group B
Curve Number: 56
Forage Type: Mixed
Arkansas STP (lb/acre): 365 (OK Equivalent):  407
Minimum Standing Forage (lb/acre): 1200
Forage Yield Goal (ton/acre): 8
UTM Coordinates: 359264E 1596324N UTM 83
Allowed P Allocation (lb/acre/year): 1
Hay Harvested (ton/acre/year): 2.2969


Month Hay Stocking  Litter  Commercial Precip Runoff Sediment   Total     Available
           Rate     N  P2O5   N  P2O5                         Phosphorus    Forage
          (AU/acre) ----(Lb/acre)----   (in)    (in)   (t/acre) (lb/acre) (Dry ton/acre)


Jan           0.0     0   0       0   0    1.56   0.21    0.000     0.08         0.16

Feb           0.0     0   0       0   0    2.19   0.44    0.000     0.16         0.22

Mar           0.0     0   0       0   0    3.88   0.55    0.000     0.19         0.39

Apr           0.3     0   0       0   0    3.87   0.63    0.000     0.22         0.48

May           0.3   174 183       0   0    4.65   0.35    0.000     0.14         1.18

Jun           0.3     0   0       0   0    4.37   0.43    0.000     0.19         2.28

Jly    X      0.0     0   0       0   0    2.64   0.04    0.000     0.02         1.02

Aug           0.2     0   0       0   0    3.77   0.07    0.000     0.03         1.90

Sep           0.2     0   0       0   0    3.34   0.18    0.000     0.08         2.68

Oct           0.0     0   0       0   0    3.67   0.20    0.000     0.09         3.30

Nov           0.0     0   0       0   0    3.87   0.33    0.000     0.14         0.17

Dec           0.0     0   0       0   0    2.45   0.37    0.000     0.16         0.17

------------------------------------------------------------------------------------
Annual Totals       174 183       0   0   40.26   3.80    0.002     1.48

WARNING: PPM Calculator predicts this management scenario will exceed
the allowable phosphorus load by   48.1%
```

NOTE: The *P Allocation* input parameter of 1.0 lb/ac/year is used ONLY for demonstration purposes and is not a proposed policy endpoint.

Quality Assurance and Quality Control Features

Smart Inputs
The PPM Calculator has smart input fields which help the user avoid mistakes. All values entered in the interface are checked to ensure that they are numeric, positive, and in the acceptable range for that parameter. Moving the cursor slowly over an input field will produce a tag with some information or guidance concerning that input. Various warnings and messages alert the user to possible mistakes. When possible, references tables or calculators are included to aid the user. Tools for estimating stocking rates in animal units, minimum available forage in dry weight, and fertilizer application rates are included.

Tamper Resistance
The PPM Calculator requires several files to operate properly, these files are accessible to the user for inspection only. A modified or corrupt file may invalidate results generated by the model. Therefore, modification of any file required by the PPM Calculator will deactivate the software, forcing the user to reinstall the program. The PPM Calculator was designed to prevent the model from being modified and produce erroneous results.

SWAT Input Parameters

The PPM Calculator generates several files needed to run SWAT using site specific data provided by the user. Data entered by the user is transformed into a suitable format to be used by the SWAT model. Files modified or created by the PPM Calculator are listed below:

HRU Properties (.HRU)
Soil Chemistry File (.CHM)
Soil Properties (.SOL)
Management Operations (.MGT)
Basin Configuration (.BSN)

The remaining SWAT files are not altered by the PPM Calculator. Parameters in these remaining files may be predefined SWAT defaults or taken directly from the SWAT model calibrated for the Lake Eucha basin (Storm et al., 2003). The hydrologic parameters from the Lake Eucha/Spavinaw SWAT model were used in the PPM Calculator (Storm et al., 2003). All files required to run SWAT are visible in the *\BIN* directory of the PPM Calculator installation. These can be inspected at any time by any user; however if any file is corrupted or modified the PPM Calculator will not run, and reinstallation will be required.

HRU Properties (.HRU)

Field Slope and *Slope Length* are contained in this file (shown in bold). Unit conversions are performed by the PPM Calculator.

```
0.0000273    | HRU_FR : Fraction of total watershed area contained in HRU
   18.293    | SLSUBBSN : Average slope length [m]
    0.087    | SLOPE : Average slope stepness [m/m]
    0.140    | OV_N : Manning's "n" value for overland flow
    0.000    | LAT_TTIME : Lateral flow travel time [days]
    0.000    | LAT_SED : Sediment concentration in lateral flow and groundwater
               flow [mg/l]
    0.000    | SLSOIL : Slope length for lateral subsurface flow [m]
    0.000    | CANMX : Maximum canopy storage [mm]
    0.450    | ESCO : Soil evaporation compensation factor
    0.000    | EPCO : Plant uptake compensation factor
    0.000    | RSDIN : Initial residue cover [kg/ha]
```

```
0.000    | ERORGN : Organic N enrichment ratio
0.000    | ERORGP : Organic P enrichment ratio
0.000    | FILTERW : Filter strip width
    0    | IURBAN : Urban simulation code
    0    | URBLU : Urban land type identification number
    0    | IRR : Irrigation code
    0    | IRRNO : Irrigation source location
0.000    | FLOWMIN : Minimum in-stream flow for irrigation
0.000    | DIVMAX : Maximum daily irrigation diversion from the reach [mm]
0.000    | FLOWFR : Fraction of available flow
0.000    | DDRAIN : Depth to surface drain [mm]
0.000    | TDRAIN : Time to drain soil to field capacity [hours]
0.000    | GDRAIN : Drain tile lag time [hours]
    0    | NPTOT : The total number of different type of pesticides
    0    | IPOT : Number of HRU
0.000    | POT_FR : Fraction of HRU are that drains into pothole
0.000    | POT_TILE : Average daily outflow to main channel from tile flow
           [m3/s]
0.000    | POT_VOLX : Maximum volume of water stored in the pothole [104m3]
0.000    | POT_VOL : Initial volume of water stored in pothole [104m3]
0.000    | POT_NSED : Normal sediment concentration in pothole [mg/l]
0.000    | POT_NO3L : Nitrate decay rate in pothole [1/day]
```

Soil Chemistry File (.CHM)

This file contains the Soil Test Phosphorus (STP) input (shown in bold) data. The Soil Labile P in the first three soil layers is defined by the PPM Calculator using STP which is input by the user. The STP value is corrected for differences in lab methods between the Oklahoma State University and University of Arkansas labs.

```
Soil Nutrient Data
 Soil Layer             :        1          2          3          4
 Soil NO3 [mg/kg]       :     0.00       0.00       0.00       0.00
 Soil organic N [mg/kg] :     0.00       0.00       0.00       0.00
 Soil labile P [mg/kg]  :    36.83      36.83      36.83       0.00
 Soil organic P [mg/kg] :     0.00       0.00       0.00       0.00


Soil Pesticide Data
 Pesticide  Pst on plant    Pst in 1st soil layer Pst enrichment
   #          [kg/ha]           [kg/ha]            [kg/ha]
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
   0             0.00              0.00               0.00
```

Correcting STP for Differences in Laboratory Methods

STP data for Oklahoma and Arkansas were analyzed in different labs using slightly different methods. Oklahoma soil samples were analyzed by the Oklahoma State University Soil, Water & Forage Analytical Laboratory and Arkansas soil samples were analyzed by the University of Arkansas Soil Testing and Research Laboratory. Oklahoma State University and University of Arkansas use extraction ratios of 1:10 and 1:7, respectively, and use different instrumentation for analysis. Oklahoma State University uses a colorimetric method and the University of Arkansas uses inductively coupled argon plasma spectrometry (ICAP). All data were converted to an Oklahoma State University equivalent using the following relationship established by testing the same set of soil samples by both labs ($R^2 = 0.98$, n=46, Appendix C):

Oklahoma State University *Mehlich III* = 1.05 * University of Arkansas *Mehlich III* + 8.4

where *Mehlich III* is in lb/ac.

Relating Soil Test Phosphorous to SWAT Soil Labile Phosphorus

SWAT contains three phosphorus pools: active pool, stable pool, and labile or soluble pool. STP is related to soil labile phosphorus by assuming that a Mehlich III extractant can dissolve phosphorus roughly equal to that contained in the Active and Liable pools as defined by the SWAT model.

STP = OSU Equivalent Mehlich III Soil Test Phosphorus value (lb/acre)
Sol_labp = Labile (soluble) P concentration in the surface layer (mg/kg)
Sol_actp = Amount of phosphorus stored in the active mineral phosphorus pool (mg/kg)

UNIT Conversions:

1 lb P/acre ≅ 0.5 ppm (Note: Assuming 6 inch soil layer.)

1 mg/kg = 1 ppm ≅ 2 lb/acre

The initial value of sol_actp is given in the SWAT source code as:

sol_actp = sol_labp* (1. - 0.4) / 0.4)

Simplified to:
sol_actp = 1.5 sol_labp

STP value represents the soil labile P pool + soil active P pool:

STP = sol_actp +sol_labp

Substitute and simplify:

STP = 1.5 sol_labp +sol_labp
STP= 2.5 sol_labp

Incorporate unit conversions:

STP (lb/acre) ≅ sol_labp (mg/kg) / 5

Soil Properties (.SOL)

SWAT requires extensive soil information to make accurate predictions. The Eucha Spavinaw basin contains many different soils; 35 of the most common soils in the basin are included with the PPM Calculator. The following soils are available in the interface:

BATES	ELSAH	MOKO	SECESH
BRITWATER	ENDERS	MOUNTAINBURG	SHIDLER
CAPTINA	FATIMA	NEWTONIA	SUMMIT
CARYTOWN	HEALING	NIXA	TAFT
CHEROKEE	HECTOR	NOARK	TALOKA
CLARKSVILLE	JAY	OKEMAH	TONTI
DENNIS	LINKER	PARSONS	VERDIGRIS
DONIPHAN	MACEDONIA	PERIDGE	WABE
ELDORADO	MAYES	RAZORT	

Below is an example soil file. Note that all soils will have different properties. These are derived from the SWAT State Soil Geographic STATSGO soil database. When a new soil is selected the entire .sol file is replaced.

```
 Soil Name: OKEMAH
 Soil Hydrologic Group: C
 Maximum rooting depth(m) : 2006.00
 Porosity fraction from which anions are excluded: 0.500
 Crack volume potential of soil: 0.500
 Texture 1               : SIL-SIC-SIC
 Depth                [mm]:      533.40     1092.20     2006.60
 Bulk Density Moist [g/cc]:        1.40        1.52        1.52
 Ave. AW Incl. Rock Frag  :        0.20        0.15        0.14
 Ksat. (est.)      [mm/hr]:        2.00        0.21        0.20
 Organic Carbon [weight %]:        1.16        0.39        0.13
 Clay           [weight %]:       23.50       45.00       45.00
 Silt           [weight %]:       52.04       47.63       47.63
 Sand           [weight %]:       24.46        7.37        7.37
 Rock Fragments   [vol. %]:        0.53        0.58        0.58
 Soil Albedo (Moist)      :        0.02        0.11        0.18
 Erosion K                :        0.43        0.43        0.43
 Salinity (EC, Form 5)    :        0.00        0.00        0.00
```

Management Operations (.MGT)

The management file is the most complex file generated by the PPM Calculator for SWAT. Each operation adds a line to the file. Due to the complexity and structure of this file we recommend that users consult the SWAT users manual for file structure information.

<u>*General Management Variables*</u>

General Management variables are parameters which do not change with time or management operations. These are specified on line 2 of the .MGT file.

Minimum Dry Biomass (BIOMIN)

This is the minimum dry above ground biomass at which grazing is permitted. The purpose of this variable is to prevent over gazing by basing day-to-day grazing on available forage. The user enters this variable as minimum dry forage in lb/acre.

Curve Number

Curve Number has a direct influence on runoff volume. We based Curve Number on grazing, Minimum Dry Biomass (BIOMIN), and hydrologic soil group. To eliminate discontinuities, Curve Numbers with grazing and a BIOMIN between 401-650 lb/ac and between 650-899 lb/ac are linearly interpolated.

Condition	Hydrologic Soil Group			
	A	B	C	D
With Grazing and BIOMIN < 400 kg/ha	68	79	86	89
With Grazing and BIOMIN = 650 kg/ha	49	69	79	84
With Grazing and BIOMIN > 900 kg/ha	39	61	74	80
No Grazing	30	58	71	78

General Management Default Variables

The following general management variables are static default SWAT values for the PPM Calculator:

0 IGRO Land cover status code.
1 NROT Number of years of rotation.
0 NCRP Land cover identification number.
0 ALAI Initial leaf area index.
0 BIO_MS Initial dry weight biomass (kg/ha).
0 PHU Total number of heat units or growing degree days needed to bring plant to maturity.
0 BIOMIX Biological mixing efficiency.
1 USLE_P USLE equation support practice factor.

<u>*Management Operations*</u>
The number and type of management operations scheduled depends on the user. The user can specify when operations such as haying, grazing, and fertilization take place. The PPM Calculator uses this information and a set of default operations to generate a set of management operations for use in the SWAT model.

Plant/Begin Growing Season
This operation starts the growing season with the forage type listed by the user. This operation is scheduled for January 1, but forage growth will not occur until temperatures are suitable. The temperature required for forage growth depends on the forage type. Cool season and mixed forage will generally have earlier growth than warm season. If cool season forage is selected by the user Tall Fescue is planted; if warm season forage is selected Bermuda is planted. Because SWAT cannot simulate more than one crop at a time, a new crop was created to simulate mixed forage. This crop is a mix of the parameters between Tall Fescue and Bermuda, which mimic the growth pattern of a mix of warm and cool season forages.

Fertilizer Application
If litter or commercial fertilizer is applied the operation is scheduled for the first day of the month. Litter nitrogen was assumed to be 80% organic and 20% mineral, and litter phosphorus was assumed to be 70% organic and 30% mineral (SWAT, 2002). Commercial fertilizers were treated as 100% mineral. All fertilizer operations are performed on the first day of the month.

Hay
Haying is allowed from June to September for warm and mixed forages and for June and July only for cool season grasses. Hay operations were assumed to cut 90% of the above ground forage, and 90% of that is removed from the field since hay rakes and bailers are not 100% efficient. Forage cut and not removed from the field is converted to residue. These harvest efficiency parameters are predefined by SWAT. Hay operations are performed on the first day of the month.

Grazing
SWAT simulates cattle grazing as the daily removal of biomass with a corresponding deposition of manure. The amount of forage consumed by an animal unit is 25 lb dry matter/day with an additional 6.25 lb dry matter/day being trampled (OSU Extension Pub. F-2871). Each animal unit produces 8 lb of manure daily (ASAE, 1995). If at any time the amount of available forage falls below the BIOMIN or Minimum Dry Forage, SWAT suspends grazing until more growth occurs.

Basin Configuration (.BSN)

The drainage area used in the MUSLE equation was assumed to be 40 acres. This assumption was required since it will be difficult for the nutrient management plan developers to accurately estimate. It should be noted that the drainage area is not the area of the field.

Eucha Calibration Parameters

Hydrologic parameters from the Lake Eucha calibration (Storm et al., 2003) were used in the PPM Calculator. Due to the changes in the way in which biological mixing was implemented and the lack of in-stream nutrient processes in the original Lake Eucha/Spavinaw model (Storm et al., 2003), we did not use the phosphorus parameters (PPERCO and PHOSKD) calibrated for the Lake Eucha/Spavinaw basin. We used the predefined phosphorus parameter values in SWAT.

The default PPM Calculator input parameters are given in Appendix B. Parameters/data taken from the calibrated Lake Eucha/Spavinaw model were (Storm et al., 2003):

Soil evaporation compensation factor = 0.45
Groundwater delay [days] = 1
Baseflow alpha factor [days] = 0.11
Threshold depth of water in shallow aquifer required for return flow to occur [mm] = 30
Groundwater "revap" coefficient = 0.02
Threshold depth of water in the shallow aquifer for "revap" to occur [mm] = 10
Deep aquifer percolation fraction = 0.2
Curve Number for moisture condition 2 = Adjusted by -5
Weather data from the Lake Spavinaw dam (1975-1990)

PPM Calculator Verification and Sensitivity Analysis

The PPM Calculator was verified for various parameters (or processes) accounted for in the model. The parameters considered were field slope, slope length, soil test P, litter and commercial P_2O_5 application rate, litter and commercial nitrogen application rate, minimum dry forage (biomass), forage type, maximum stocking rate, hay, soil type, grazing and application timing. Most of the parameters have five different levels (values). The verification was carried out by varying one parameter at a time from a default value, then running the model. Default values are shown in Figure 5. The levels of the variations used in the verifications are shown in Table 1. As an example, the levels of field slope factor were 0, 2, 3, 5, and 10%, with the default (median) value of 3%. The verification results for runoff, soluble phosphorus (Sol P), organic P (Org P), sediment bound P (Sed P) and total P (TP) were as expected for our default condition (Table 1 and Appendix E).

To answer the question about the relative importance of factors that influence phosphorus loss in runoff, the sensitivity of the PPM Calculator was tested for various parameters (or processes) accounted in the model. The parameters considered for sensitivity analysis were field slope, slope length, soil test P, litter P_2O_5, commercial P_2O_5, litter N, commercial N, minimum dry forage (biomass), and maximum stocking rate. The tabular summary of the sensitivity analysis for all the parameters is given in Table 2, and the graphical summaries are given in Appendix E. The relative sensitivity coefficient was calculated using the following equation:

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

where: Sr = Relative sensitivity (non-dimensional)
Pb = Parameter investigated baseline value
Ob = Selected model output for baseline conditions
P1 = Parameter value adjusted less than Pb
P2 = Parameter value adjusted greater than Pb

O1 = Selected model output @ P1
O2 = Selected model output @ P2

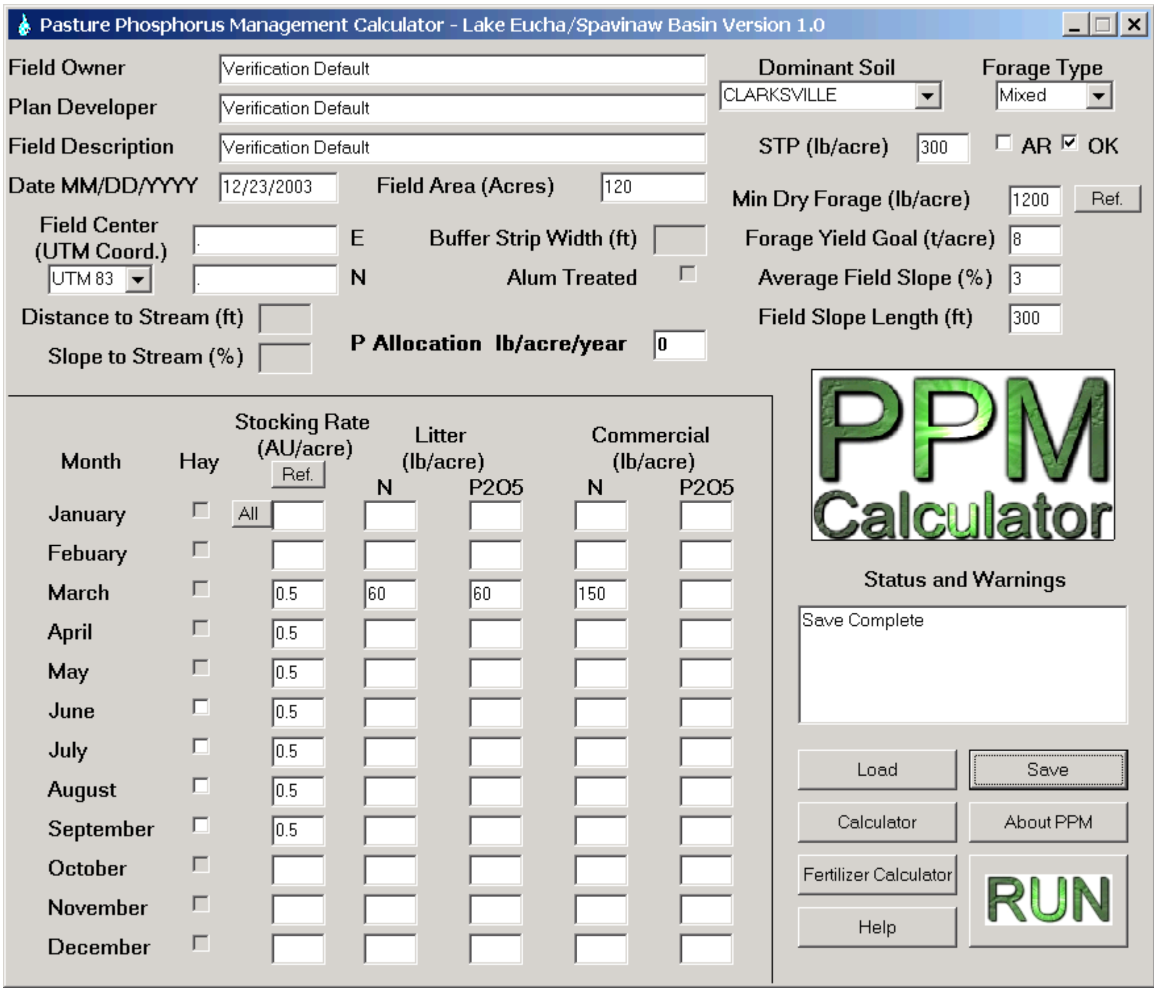

Figure 5 Default values used in verification and sensitivity analysis.

Table 1 Summary table for the effects of the parameters considered for verifying the Pasture Phosphorus Management Calculator.

Parameters	Output				
	Runoff (in)	Soluble P (lb/acre)	Organic P (lb/acre)	Sediment P (lb/acre)	Total P (lb/acre)
Field Slope (%)					
0	4.06	0.91	0.00	0.00	0.91
2	4.05	0.91	0.01	0.02	0.94
3	4.05	0.91	0.01	0.03	0.95
5	4.05	0.91	0.03	0.06	1.00
10	4.04	0.90	0.08	0.19	1.17
Slope Length (ft)					
100	4.04	0.91	0.01	0.02	0.94
200	4.05	0.91	0.01	0.03	0.95
300	4.05	0.91	0.01	0.03	0.95
400	4.05	0.91	0.01	0.03	0.96
500	4.05	0.91	0.01	0.03	0.96
STP (lb/acre)					
65	4.05	0.73	0.01	0.02	0.76
120	4.05	0.77	0.01	0.02	0.81
300	4.05	0.91	0.01	0.03	0.95
500	4.05	1.06	0.01	0.04	1.11
1000	4.05	1.44	0.01	0.06	1.51
Min Dry Forage (lb/acre)					
400	11.4	2.26	0.47	1.51	4.24
800	4.97	1.07	0.02	0.06	1.15
1200	4.05	0.91	0.01	0.03	0.95
1600	4.02	0.91	0.01	0.03	0.95
2000	4.01	0.91	0.01	0.03	0.96
Litter P_20_5 (lb/acre)					
0	4.05	0.55	0.01	0.02	0.57
60	4.05	0.91	0.01	0.03	0.95
120	4.05	1.27	0.02	0.04	1.33
180	4.05	1.63	0.03	0.05	1.7
240	4.05	1.99	0.03	0.06	2.08
Litter N (lb/acre)					
0	4.72	0.86	0.03	0.06	0.95
60	4.05	0.91	0.01	0.03	0.95
120	4.04	0.99	0.01	0.03	1.03
180	4.06	1.04	0.01	0.03	1.09
240	4.07	1.08	0.01	0.03	1.12
Commercial N (lb/acre)					
0	4.30	0.87	0.02	0.05	0.94
75	4.22	0.90	0.01	0.04	0.95
150	4.05	0.91	0.01	0.03	0.95
175	4.04	0.92	0.01	0.03	0.96
200	4.03	0.93	0.01	0.03	0.97

Table 1 (Continued) Summary table for the effects of the parameters considered for verifying the Pasture Phosphorus Management Calculator.

Parameters	Output				
	Runoff (in)	Soluble P (lb/acre)	Organic P (lb/acre)	Sediment P (lb/acre)	Total P (lb/acre)
Commercial $P_2 0_5$ (lb/acre)					
0	4.05	0.91	0.01	0.03	0.95
25	4.05	1.13	0.01	0.04	1.18
50	4.05	1.35	0.01	0.04	1.40
75	4.05	1.57	0.01	0.05	1.63
100	4.05	1.78	0.01	0.05	1.85
Max Stocking rate (AU/acre)					
0.00	3.74	0.85	0.01	0.03	0.89
0.25	4.13	0.94	0.01	0.03	0.98
0.50	4.05	0.91	0.01	0.03	0.95
0.75	4.90	1.04	0.04	0.12	1.20
1.00	4.90	1.11	0.04	0.13	1.28
Soil Type					
Okemah (HSG C)	3.40	0.73	0.09	0.19	1.01
Clarksville (HSG B)	4.05	0.91	0.01	0.03	0.95
Dennis (HSG C)	4.08	0.89	0.11	0.22	1.22
Captina (HSG C)	5.31	1.21	0.12	0.27	1.61
Cherokee (HSG D)	6.97	1.58	0.17	0.42	2.17
Carytown (HSG D)	7.03	1.62	0.17	0.39	2.18
Nixa (HSG C)	7.95	1.66	0.01	0.02	1.69
Forage Type					
Warm	4.62	0.96	0.02	0.05	1.03
Cool	4.40	0.94	0.01	0.04	1.00
Mixed	4.05	0.91	0.01	0.03	0.95
Hay					
No hay	4.05	0.91	0.01	0.03	0.95
June	4.78	0.92	0.03	0.09	1.04
July	4.92	0.95	0.03	0.09	1.07
Aug	4.63	0.92	0.03	0.09	1.04
Sept	4.51	0.92	0.01	0.03	0.95
Grazing					
No Grazing	3.74	0.85	0.01	0.03	0.89
May-July	4.04	0.92	0.01	0.03	0.96
Apr - Aug	4.07	0.91	0.01	0.03	0.95
Mar-Sep	4.05	0.91	0.01	0.03	0.95
All year	4.05	0.92	0.01	0.03	0.96
Application Timing					
Once (March)	4.05	0.91	0.01	0.03	0.95
Once(July)	4.24	0.88	0.01	0.03	0.92
Once(October)	4.39	0.84	0.02	0.06	0.92
Twice (Mar/Oct - Split)	4.28	0.91	0.01	0.04	0.96

Table 2 Summary of the sensitivity analysis of the parameters considered for the Pasture Phosphorus Management Calculator.

Parameter	Relative Sensitivity (dimensionless)				
	Runoff	Soluble P	Organic P	Sediment P	Total P
Field Slope (%)	-0.001	-0.003	2.400	1.900	0.082
Slope Length (ft)	0.002	0.000	0.000	0.250	0.016
STP (lb/acre)	0.000	0.250	0.000	0.428	0.253
Min Dry Forage (lb/acre)	-1.370	-1.113	-34.500	-37.000	-2.589
Litter P_2O_5 (lb/acre)	0.000	0.567	0.500	0.500	0.568
Litter N (lb/acre)	-0.080	0.111	-1.000	-0.500	0.083
Commercial N (lb/acre)	-0.050	0.049	-0.750	-0.500	0.024
Commercial P_2O_5 (lb/acre)	0.000	0.322	0.000	0.250	0.321
Max Stocking rate (lb/acre)	0.143	0.143	1.500	1.667	0.205

PPM Calculator Validation

Validation improves the reliability of the model predictions. The validation process tests the model with observed data that is not used in the calibration. The PPM Calculator was not directly calibrated; however the model makes use of SWAT parameters calibrated for the Lake Eucha Basin. The PPM Calculator was validated using 33 months of data on four fields 12 miles west of Fayetteville Arkansas. These data were presented in Edwards et al. (1994), Edwards et al. (1996a, 1996b), and Edwards et al. (1997) (Appendix D). This study monitored four fields under natural rainfall, with elevated STP due to the application of poultry litter. Two fields received additional litter during the study period and two received only commercial nitrogen. This data-set, known as the Moore's Creek Study, was ideal for validating the PPM Calculator.

The Moore's Creek study contains all data required by the PPM Calculator with the exception of minimum dry forage. Other site characteristics and management for the four fields are given in Tables (3-7). Precipitation data collected at each set of fields was included in the PPM Calculator for the validation. Personal communication with J. F. Murdoch (2003), who was responsible for field work associated with the Moore's Creek project, stated that to the best of his recollection there were a minimum of 2-3 inches of forage and the pastures were never over grazed. Excellent condition fertilized tall fescue contains 450-550 lbs dry forage/inch/acre (Barnhart, Stephen, "Estimating Available Forage, PM 1758"., Iowa State University Extension). We estimated minimum dry forage for all four fields to be 500 lbs dry forage/inch/acre * 3 inches = 1500 lb dry forage/acre. We also elected to include a table of validation results at a minimum dry forage of 1200 lb/acre (Table 10). The results were very similar.

The overall performance of the PPM Calculator on the validation data set was excellent (Tables 8 and 9). Relative errors for total and soluble P for fields RU and WU were less than 2% and -25%, respectively, and relative errors for RM and WM were higher. Relative error in predicted sediment yields ranged from 28% to -99%. It should be noted that erosion rates from these fields are very small and the maximum over prediction by the model was only 69 lb/ac.

The PPM calculator performed better on fields receiving litter than those which received only commercial nitrogen. The PPM calculator generally under predicted total phosphorous on fields RM and WM, which was likely due in part to the application of poultry litter on these fields in 1991 just prior to the study. Fields RM and WM experienced significant ($P < 0.02$) decreases in runoff soluble phosphorous concentration during the monitoring period (Edwards et al., 1996a). In addition, soil test phosphorus generally decreased for these two fields during the study period (Table 6). This under prediction by the PPM Calculator for total phosphorus on these two fields is expected because the PPM Calculator does not consider recent litter application.

Table 3 Moore's Creek site characteristics.

Field	Area (acre)	Soil	Slope (%)	Slope Length (ft)	STP (lb/acre)
RU	3.04	Captina	3.00	450	353
RM	1.41	Fayetteville	2.00	465	492
WU	2.62	Allegheny-Hector-Mountainburg	4.00	590	374
WM	3.61	Linker	4.00	635	727

Table 4 Moore's Creek average annual fertilizer and stocking rates.

Field	Equivalent Litter (t/acre/yr)	Commercial N (lb/acre/yr)	Ave Stocking Rate (AU/acre/yr)
RU	6	-	0.5
RM	-	85	0.5
WU	5.5	-	0.3
WM	-	75	0.1

Table 5 Moore's Creek average monthly stocking rate for the period 8-91 to 4-94.

Month	RU	RM	WU	WM
Jan	0.7	0.7	0.3	0.1
Feb	0.5	0.5	0.4	0.1
Mar	0.5	0.5	0.4	0.1
Apr	0.2	0.3	0.3	0.0
May	0.0	0.0	0.5	0.0
Jun	0.0	0.0	0.4	0.0
Jul	0.0	0.0	0.4	0.0
Aug	0.5	0.5	0.3	0.2
Sep	0.7	0.7	0.2	0.3
Oct	0.7	0.7	0.2	0.3
Nov	0.7	0.7	0.3	0.3
Dec	0.7	0.7	0.3	0.3
Average	0.5	0.5	0.3	0.1

Table 6 Moores Creek fields Soil Test Phosphorus (STP). Each observation is the average of five samples.

Date	RU STP (lb/ac)	RM STP (lb/ac)	WU STP (lb/ac)	WM STP (lb/ac)
09/91	362	615	-	-
12/91	388	614	425	1266
03/92	230	420	368	786
06/92	506	592	394	787
09/92	493	625	416	771
12/92	304	476	380	619
03/93	261	395	258	606
06/93	257	432	320	537
09/93	397	408	357	471
12/93	343	393	405	678
03/94	346	441	416	753
Average	353	492	374	727

Table 7 Moores Creek estimated annual runoff losses of analysis parameters**.**

Parameter	RU	RM	WU	WM
	------------------------- lb/ac/year ---------------------------			
NO_3-N	0.24	0.38	0.25	3.01
PO_4-P	3.87	0.59	1.40	2.41
TP	4.09	0.69	1.77	2.38
NH_3-N	0.36	0.18	0.88	1.13
TKN	4.97	1.41	3.49	5.46
COD	86.81	25.68	42.86	71.66
TSS	69.19	26.31	60.75	104.59

Table 8 The PPM Calculator validation results for average annual runoff volume and total phosphorus.

Field	Observed Runoff (in)	Predicted Runoff (in)	Runoff RE (%)	Observed Total P (lb/acre)	Predicted Total P (lb/acre)	Total P RE (%)
RU	8.2	6.7	19%	4.1	5.1	-25%
RM	1.8	3.1	-76%	0.69	0.49	29%
WU	2.8	3.3	-20%	1.8	2.0	-12%
WM	7.4	3.5	53%	2.4	0.81	66%

Table 9 PPM Calculator validation results for average soluble phosphorus and sediment.

Field	Observed Soluble P (lb/acre)	Predicted Soluble P (lb/acre)	Soluble P RE (%)	Observed TSS (lb/ac)	Predicted Sediment (lb/acre)	Sediment RE (%)
RU	3.9	3.8	2%	69	138	-99%
RM	0.59	0.35	41%	26	50	-90%
WU	1.4	1.6	-15%	61	44	28%
WM	2.4	0.45	81%	105	90	14%

Table 10 PPM Calculator validation using a minimum dry forage of 1200 lb/acre instead of 1500/lb/acre for total and soluble phosphorus.

Field	Observed Total P (lb/acre)	Predicted Total P (lb/acre)	Total P RE (%)	Observed Soluble P (lb/acre)	Predicted Soluble P (lb/acre)	Soluble P RE (%)
RU	4.1	5.3	-28%	3.9	3.9	0%
RM	0.69	0.57	17%	0.59	0.36	39%
WU	1.8	2.0	-12%	1.4	1.6	-15%
WM	2.4	0.76	68%	2.4	0.44	82%

Limitations

There are a few limitations of the PPM Calculator and SWAT models that should be noted. Limitations 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, and a model by definition is a simplification of the real world. Understanding the limitations helps assure that accurate inferences are drawn from model predictions.

Because the PPM Calculator uses SWAT, it is subject to the same limitations as SWAT for pasture systems. The selected management options are applied the same each year and do not varying with weather conditions for a particular year. Also, the PPM Calculator does not consider recent litter applications, which may alter the predicted phosphorus loads in the first couple of years of the simulation. Another limitation of the PPM calculator is the assumption of a 40 acre drainage area, which is used to predict erosion in the MUSLE equation. This assumption was required to simplify the implementation of the PPM Calculator by the nutrient management plan developers.

The PPM Calculator predicts average monthly values based on 15 years of observed weather data. The PPM Calculator is intended to predict long term average values and is not intended to predict phosphorus load for a specific year in the future. In addition, the PPM Calculator does not currently consider cultivated crops or small grains planted into pastures. One of SWAT's strengths is its ability to examine BMPs on cultivated fields. Unfortunately, there was not time to include this component in the current version of the PPM Calculator interface.

Proposed Future Work

Below is a list of features we will consider in release 2.0 or later versions to expand the utility of the PPM Calculator:

- Expanded simulation period with the addition of precipitation based statistical confidence intervals on loads. This will allow the PPM Calculator to predict a probability of exceeding a particular load allocation based on weather variability.

- Account for alum treated litter. Some producers may be able to apply alum treated litter who may not otherwise be allowed to apply untreated litter.

- Include buffer strips to allow the producer more options to meet the required phosphorus allocation.

- Activate the USLE algorithms in the SWAT model to predict erosion and eliminate the need to specify the drainage area for the field.

- Add a delivery function from field to stream to estimate the contribution of phosphorus delivered to the stream.

- Include other Best Management Practices (BMPs) as options. The effect of some BMPs can be scientifically quantified, many others however have little research with which to construct a quantitative algorithm to add to the model.

- Evaluate the accuracy of forage yields and output the number of days grazing takes place per month to allow the producer to use the PPM Calculator as an economic planning and management tool.

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Appendix

Appendix A Swat Peer Reviewed Publications

Appendix B Default PPM Calculator-SWAT Input Parameters

Appendix C Relationship between Oklahoma State University and University of Arkansas Soil Test Phosphorus

Appendix D Moore’s Creek Data

Appendix E Graphical Verification Results

Appendix A
SWAT Peer Reviewed Publications

Journal Publications and Book Chapters (as of August 21, 2003)
Available online at: http://www.brc.tamus.edu/swat/swat-peerreivewed-publications.htm

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Appendix B
Default PPM Calculator-SWAT Input Parameters

Pond Properties (.PND)
Ponds were not included

In-Stream Water Quality Parameters (.SWQ)
In-stream Processes are disabled.

Weather Generator (.WGN)
Observed rainfall and temperature from spavianw dam weather station included.
Other stats generated using default SWAT weather database for Siolam Springs.

Water Use (.WUS)
No consumptive usage

Stream Channel Properties (.RTE)

```
          10.111     | CHW2 : Main channel width [m]
           2.000     | CHD : Main channel depth [m]
           0.002     | CH_S2 : Main channel slope [m/m]
           2.5       | CH_L2 : Main channel length [km]
           0.014     | CH_N2 : Manning's nvalue for main channel
           0.000     | CH_K2 : Effective hydraulic conductivity [mm/hr]
           0.000     | CH_EROD: Channel erodibility factor
           0.000     | CH_COV : Channel cover factor
           5.000     | CH_WDR : Channel width:depth ratio [m/m]
           0.000     | ALPHA_BNK : Baseflow alpha factor for bank storage [days]
```

Subbasin Properties (.SUB)

```
               1     | HRUTOT : Total number of HRUs modeled in subbasin
       36.343544     | LATITUDE : Latitude of subbasin [degrees]
          316.69     | ELEV : Elevation of subbasin [m]
           0.000     | PLAPS : Precipitation lapse rate [mm/km]
           0.000     | TLAPS : Temperature lapse rate [˙C/km]
           0.000     | SNO_SUB : Initial snow water content [mm]
           1.000     | CH_L1 : Longest tributary channel length [km]
           0.002     | CH_S1 : Average slope of tributary channel [m/m]
          82.111     | CH_W1 : Average width of tributary channel [mm/km]
           0.500     | CH_K1 : Effective hydraulic conductivity in tributary channel
[mm/hr]
           0.014     | CH_N11 : Manning's "n" value for the tributary channels
| HRU data files
000010001.hru000010001.mgt000010001.sol000010001.chm000010001.gw
```

Ground Water Properties (.GW)

```
        100.0000     | SHALLST : Initial depth of water in the shallow aquifer [mm]
       1000.0000     | DEEPST : Initial depth of water in the deep aquifer [mm]
          1.0000     | GW_DELAY : Groundwater delay [days]
          0.1100     | ALPHA_BF : BAseflow alpha factor [days]
         30.0000     | GWQMN : Threshold depth of water in the shallow aquifer required
for return flow to occur [mm]
          0.0200     | GW_REVAP : Groundwater "revap" coefficient
         10.0000     | REVAPMN: Threshold depth of water in the shallow aquifer for
"revap" to occur [mm]
          0.2000     | RCHRG_DP : Deep aquifer percolation fraction
          1.0000     | GWHT : Initial groundwater height [m]
          0.0030     | GW_SPYLD : Specific yield of the shallow aquifer [m3/m3]
          0.0000     | GW_NO3 : Concentration of nitrate in groundwater contribution to
streamflow from subbasin [mg N/l]
          0.0000     | GWSOLP : Concentration of soluble phosphorus in groundwater
contribution to streamflow from subbasin [mg P/l]
```

Basin Configuration (.BSN)

```
           0.165       | DA_KM : Area of the watershed [km2]
           0.000     | DT : . Time step for infiltration and channel routing [hr]
           1.000     | SFTMP : Snowfall temperature [ºC]
           0.500     | SMTMP : Snow melt base temperature [ºC]
           4.500     | SMFMX : Melt factor for snow on June 21 [mm H2O/ºC-day]
           4.500     | SMFMN : Melt factor for snow on December 21 [mm H2O/ºC-day]
           1.000     | TIMP : Snow pack temperature lag factor
```

Appendix B

Default PPM Calculator-SWAT Input Parameters

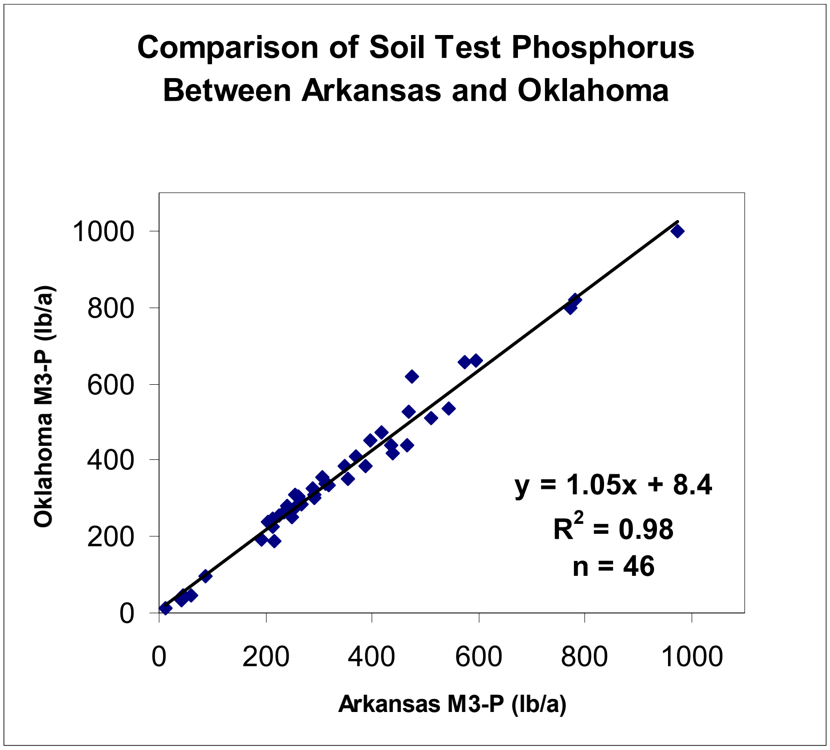
```
            1.000    | SNOCOVMX : Minimum snow water content that corresponds to 100%
snow cover [mm]
           0.500    | SNO50COV : Fraction of snow volume represented by SNOCOVMX that
corresponds to 50% snow cover
           1.000    | RCN : Concentration of nitrogen in rainfall [mg N/l]
           0.000    | SURLAG : Surface runoff lag time [days]
           1.000    | APM : Peak rate adjustment factor for sediment routing in the
subbasin (tributary channels)
           1.000    | PRF : Peak rate adjustment factor for sediment routing in the
main channel
           0.001    | SPCON : Linear parameter for calculating the maximum amount of
sediment that can be reentrained during channel sediment routing
           1.500    | SPEXP : Exponent parameter for calculating sediment reentrained
in channel sediment routing
           1.000    | EVRCH : Reach evaporation adjustment factor
           3.000    | EVLAI : Leaf area index at which no evaporation occurs from
water surface [m2/m2]
           0.000    | FFCB : Initial soil water storage expressed as a fraction of
field capacity water content
           0.003    | CMN : Rate factor for humus mineralization of active organic
nitrogen
          20.000    | UBN : Nitrogen uptake distribution parameter
          20.000    | UBP : Phosphorus uptake distribution parameter
           2.000    | NPERCO : Nitrogen percolation coefficient
           5.00     | PPERCO : Phosphorus percolation coefficient
         300.000    | PHOSKD : Phosphorus soil partitioning coefficient
           0.400    | PSP : Phosphorus sorption coefficient
           0.050    | RSDCO : Residue decomposition coefficient
           0.500    | PERCOP : Pesticide percolation coefficient
               0    | IRTPEST : Number of pesticide to be routed through the watershed
channel network
           0.000    | WDPQ : Die-off factor for persistent bacteria in soil solution.
[1/day]
           0.000    | WGPQ : Growth factor for persistent bacteria in soil solution
[1/day]
           0.000    | WDLPQ : Die-off factor for less persistent bacteria in soil
solution [1/day]
           0.000    | WGLPQ : Growth factor for less persistent bacteria in soil
solution. [1/day]
           0.000    | WDPS : Die-off factor for persistent bacteria adsorbed to soil
particles. [1/day]
           0.000    | WGPS : Growth factor for persistent bacteria adsorbed to soil
particles. [1/day]
           0.000    | WDLPS : Die-off factor for less persistent bacteria adsorbed to
soil particles. [1/day]
           0.000    | WGLPS : Growth factor for less persistent bacteria adsorbed to
soil particles. [1/day]
         175.000    | BACTKDQ : Bacteria partition coefficient
           1.070    | THBACT : Temperature adjustment factor for bacteria
die-off/growth
           0.000    | MSK_CO1 : Calibration coefficient used to control impact of the
storage time constant (Km) for normal flow
           3.500    | MSK_CO2 : Calibration coefficient used to control impact of the
storage time constant (Km) for low flow
           0.200    | MSK_X : Weighting factor controlling relative importance of
inflow rate and outflow rate in determining water storage in reach segment

Simulation Control File (.COD)
              20    | NBYR : Number of years simulated
            1970    | IYR : Beginning year of simulation
               1    | IDAF : Beginning julian day of simulation
             365    | IDAL : Ending julian day of simulation
               0    | IPD : Print code (month, day, year)
               5    | NYSKIP : Number of years to skip output printing/summarization
               1    | IPRN : Print code for .std file: 0=input summary is printed
               0    | ILOG : Stream flow print code: 1=print log of streamflow
               1    | IPRP : Print code for .pso file: 1=print pesticide output
               0    | IGN : Random number seed cycle code
```

Appendix B

Default PPM Calculator-SWAT Input Parameters

```
                1      | PCPSIM : Precipitation simulation code: 1=measured, 2=simulated
               30      | IDT : Rainfall data time step
                0      | IDIST : Rainfall distribution code 0 skewed, 1 exponential
             1.30      | REXP : Exponent for IDIST=1
                1      | TMPSIM : Precipitation simulation code: 1=measured, 2=simulated
                2      | SLRSIM : Solar radiation simulation code: 1=measured,
2=simulated
                2      | RHSIM : Relative humidity simulation code: 1=measured,
2=simulated
                2      | WINDSIM : Windspeed simulation code: 1=measured, 2=simulated
                0      | IPET : PET method: 0=priest-t, 1=pen-m, 2=har, 3=read into model
                0      | IEVENT : Rainfall//runoff code: 0=daily rainfall/CN
                0      | ICRK : Crack flow code: 1=model crack flow in soil
                0      | IRTE : Water routing method 0=variable travel time, 1 =
Muskingum
                0      | IDEG : Channel degradation code
                0      | IRESQ : Lake water quality: 1= model lake water quality
                0      | IWQ : In-stream water quality: 1= model in-stream water quality
                0      | ISPROJ : special project: 1=HUMUS, 2=Missouri River
Reach output variables
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
Subbasin output variables
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
HRU output variables
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

Appendix C
Relationship between Oklahoma State University and University of Arkansas Soil Test Phosphorus



Appendix D

Moores Creek Data

Table D1 Manure and commercial fertilizer application by field.

Field	Date	Fertilizer Type	Application Rate (lb/ac) N	P
RU	03/15/92	Poultry Manure	296	106
	07/13/93	Poultry Manure	402	186
RM	03/23/92	NH4NO3	60	0
	08/14/92	NH4NO3	60	0
	04/22/93	NH4NO3	103	0
	07/14/93	NH4NO3	121	0
WU	03/23/92	Poultry Litter	194	55
	08/13/92	Poultry Litter	128	53
	04/13/93	Poultry Litter	141	38
	07/20/93	Poultry Litter	173	63
	03/29/94	Poultry Litter	166	63
WM	03/23/92	NH4NO3	123	0
	04/13/93	NH4NO3	91	0
	07/20/93	NH4NO3	91	0
	03/24/94	NH4 NO3	90	0

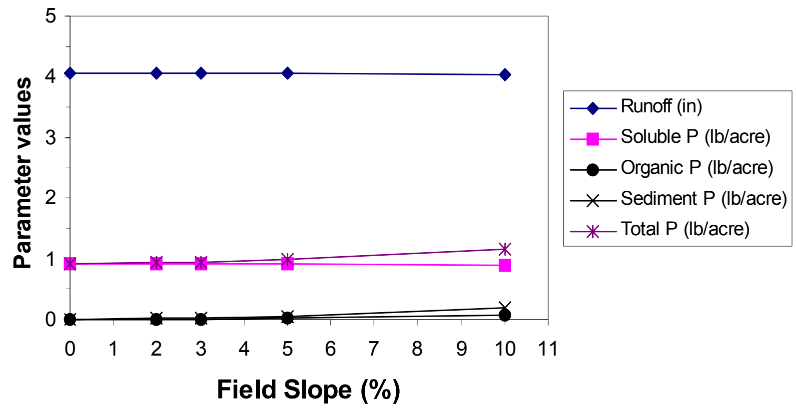
Appendix D
Moores Creek Data

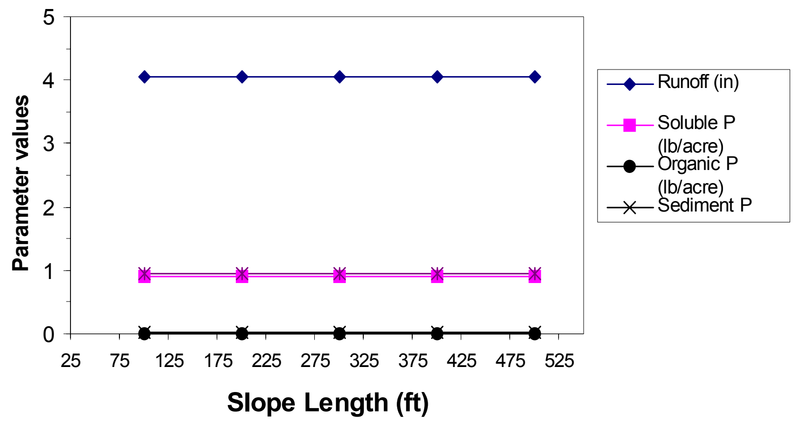
Table D2 Stocking rate by field.

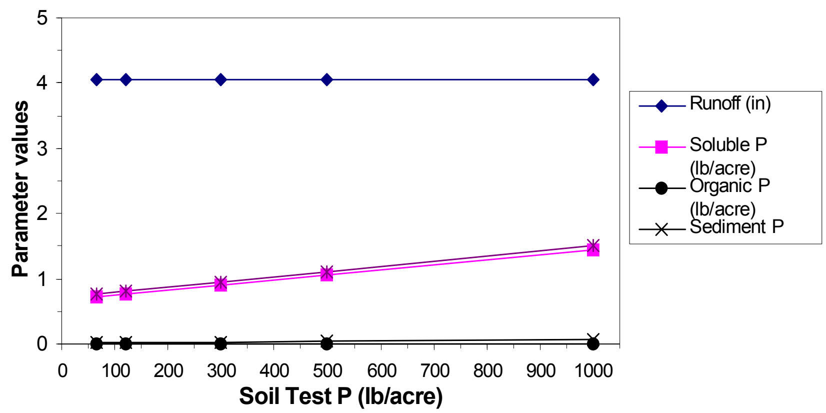
Month	Field			
	RU	RM	WU	WM
	-----------animal units/ha----------------			
08/91	2.0	2.0	0.3	0.3
09/91	2.0	2.0	0.3	0.3
10/91	2.0	2.0	0.3	0.3
11/91	2.0	2.0	0.3	0.3
12/91	2.0	2.0	0.3	0.3
01/92	2.0	2.0	0.3	0.3
02/92	2.0	2.0	1.0	0.0
03/92	2.0	2.0	1.0	0.0
04/92	0.0	0.0	1.0	0.0
05/92	0.0	0.0	1.0	0.0
06/92	0.0	0.0	1.0	0.0
07/92	0.0	0.0	1.7	0.0
08/92	0.0	0.0	1.7	0.0
09/92	1.5	1.5	1.1	1.1
10/92	1.5	1.5	1.1	1.1
11/92	1.5	1.5	1.1	1.1
12/92	1.5	1.5	1.1	1.1
01/93	1.5	1.5	1.5	0.0
02/93	1.5	1.5	1.5	0.0
03/93	1.5	1.5	1.5	0.0
04/93	1.5	1.5	1.5	0.0
05/93	0.0	0.0	1.5	0.0
06/93	0.0	0.0	0.9	0.0
07/93	0.0	0.0	0.0	0.0
08/93	1.4	1.4	0.0	1.0
09/93	1.4	1.4	0.0	1.0
10/93	1.4	1.4	0.0	1.0
11/93	1.4	1.4	0.5	0.5
12/93	1.4	1.4	0.5	0.5
01/94	1.4	1.4	0.5	0.5
02/94	0.0	0.0	0.5	0.5
03/94	0.0	0.0	0.5	0.5
04/94	0.0	1.0	0.0	0.0

Appendix E

Graphical Verification Results

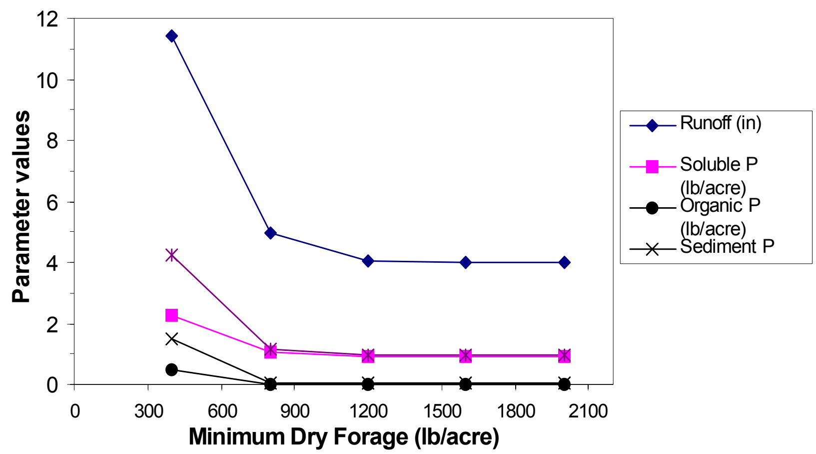


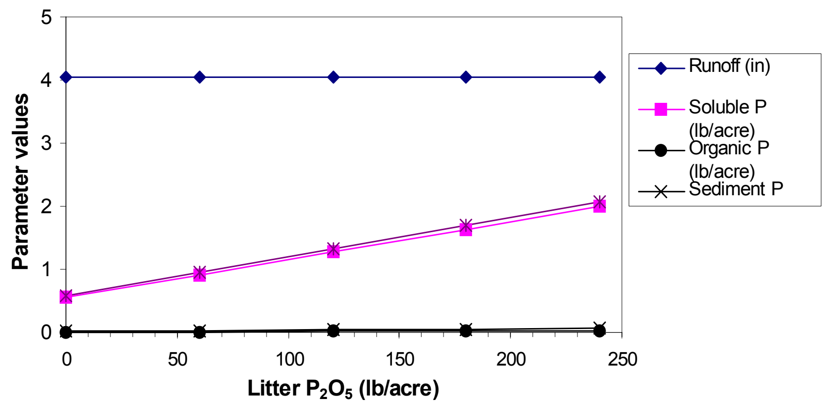


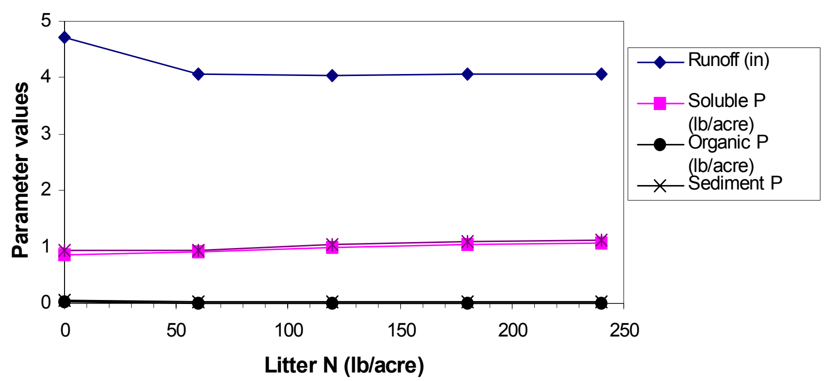


Appendix E

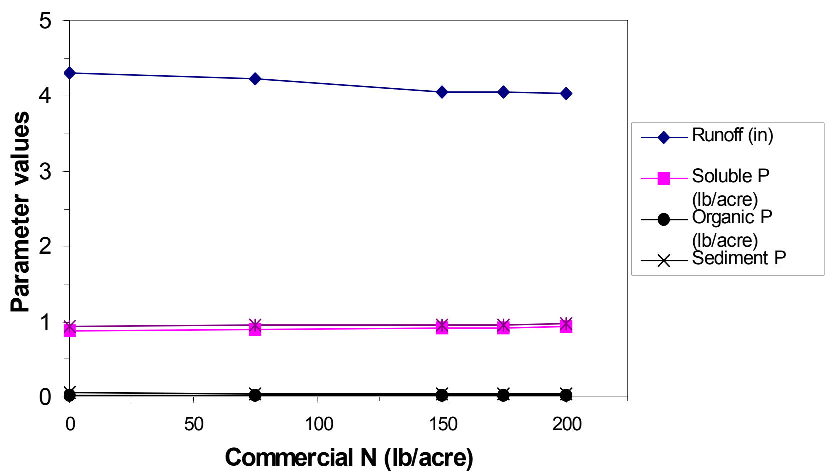
Graphical Verification Results (Continued)

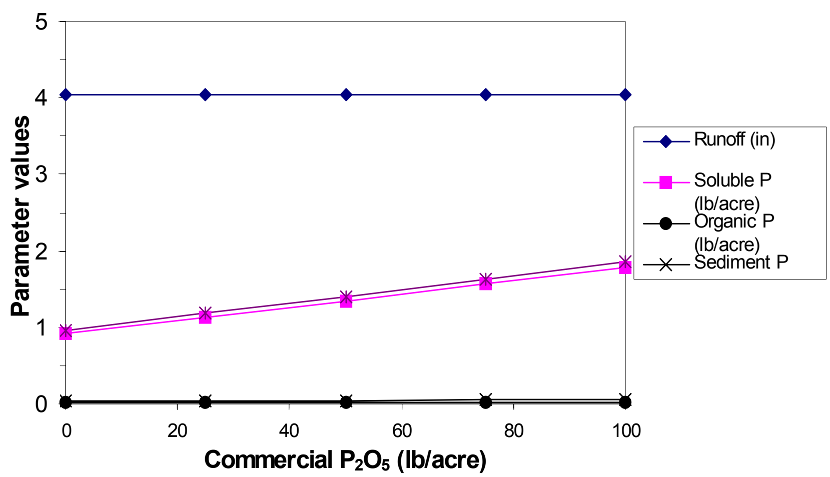


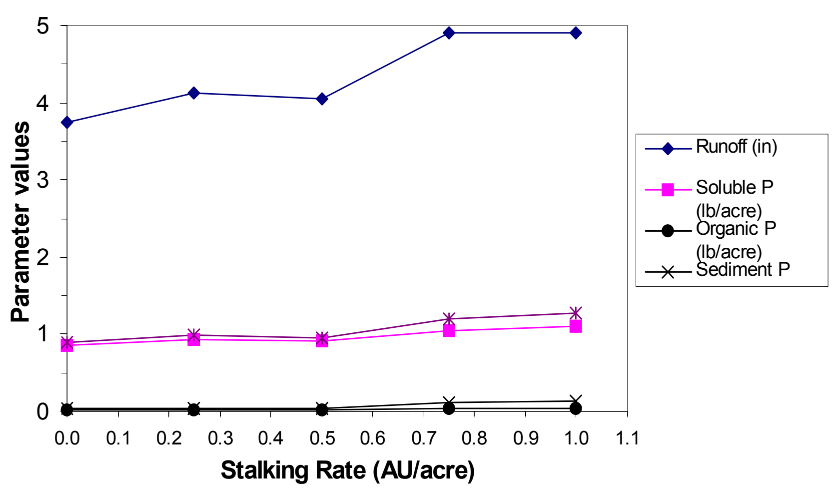




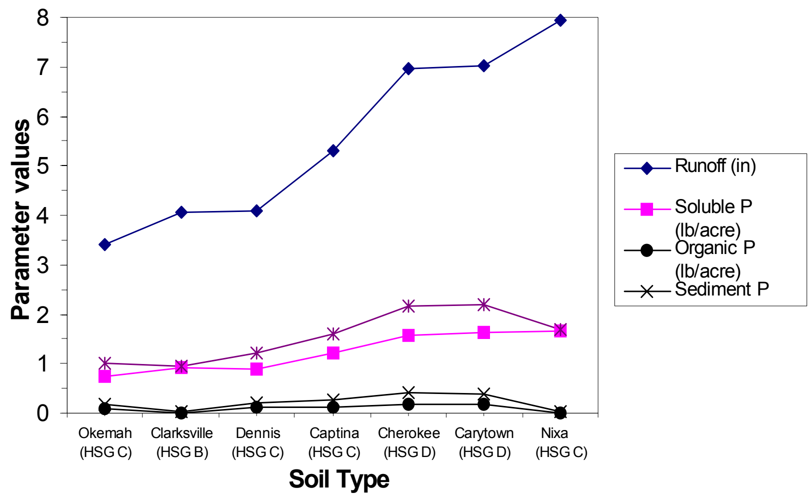
Appendix E
Graphical Verification Results (Continued)

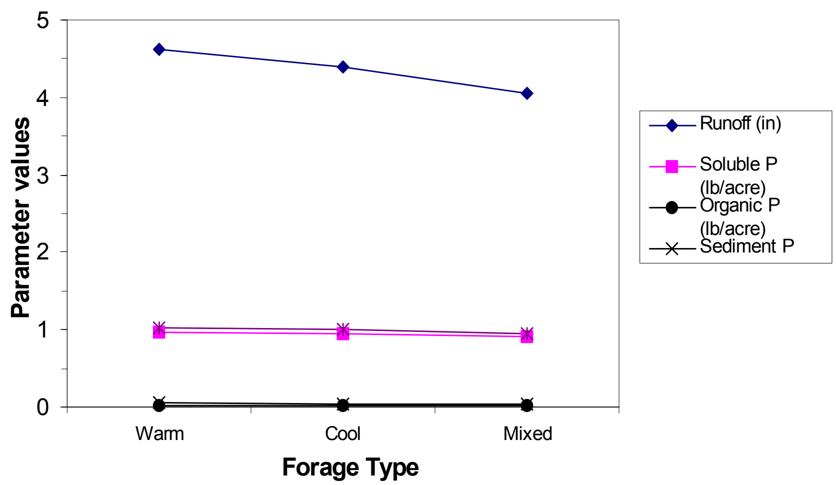


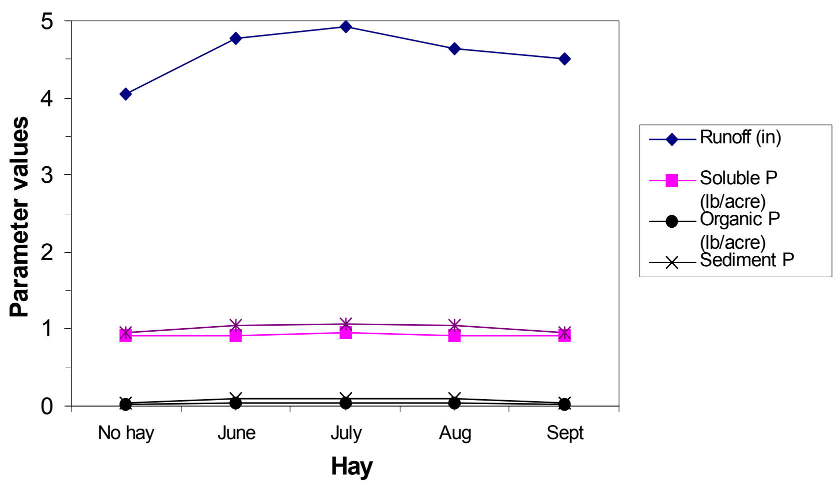




Appendix E
Graphical Verification Results (Continued)







Appendix E

Graphical Verification Results (Continued)